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A condensed succession at the Jurassic/Cretaceous transition in a shallowing basin on the eastern Russian Platform

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Abstract. The eastern periphery of the Russian Platform houses an exceptional record of the Jurassic/Cretaceous transition, which is represented by very thin sandstone beds. The presence of glaucony grains, phosphorite concretions and shark teeth indicates that the transitional sediments constitute a condensed succession, although the allochtonous origin of the glaucony grains in itself is not a reliable indicator. The combination with thin ammonite zones and a strongly diminished sedimentation rate, as low as ~0.05 cm/ka are, however, convincing evidence. The Jurassic/Cretaceous transitional deposits accumulated in a basin the depth of which decreased simultaneously with a global eustatic sea-level fall. This coincidence suggests that condensed successions may form in shallowing environments, which contradicts the sequence-stratigraphic concept. Considering the character of the sediments under study, it appears that both stratigraphic and taphonomic condensation patterns occur in this part of the eastern Russian Platform.

Key words: condensed succession, shallowing, ammonite zones, Jurassic, Cretaceous, Russian Platform.

Апстракт. Источни обод Руске Платформе показује изузетан податак о јурско-кредном прелазу, који је представљен веома танким слојевима пешчара. Присуство глауконитских зрна, фосфорних конкреција и зуби ајкула указују да прелазни седименти изграђују кондензовану сукцесију и ако алохтоно порекло глауконитских зрна није увек поуздан показатељ. Комбинација уских амонитских зона и јако смањење брзине седиментације од ~0.05 cm/ka су свакако убедљив доказ. Прелазни јурско-кредни седименти депоновани су у басен чија се дубина истовремено повећава са падом еустатичког нивоа светског мора. Ова коинциденција указује да се кондензоване сукцесије могу формирати у плитким срединама, а која је у супротности са концептом секвентне стратиграфије. Разматрајући проучавани карактер седимената, произилази да су се и стратиграфска и тафономска кондензација дешавале у овом делу источне Руске Платформе.

Кључне речи: кондензована сукцесија, оплићавање, амонитске зоне, јура, креда, Руска Платформа.

Introduction

Condensed successions result from an exceptionally low sedimentation rate. Although Heim (1934) was the first to study this phenomenon, its present-day concept is rooted in sequence stratigraphy (Loutit *et al.* 1988). Sequence stratigraphy establishes links between condensed sections and maximum flooding surfaces, which separate transgressive systems tracts and highstand systems tracts (Loutit *et al.* 1988, Catuneanu 2006).

Another significant contribution to the understanding of condensed successions comes from theoretical investigations of fossil concentrations (e.g., Kidwell *et al.* 1986, Kidwell 1993, Kondo *et al.* 1998). The most comprehensive characteristics of this phenomenon were provided by Gómez & Fernández-López (1994) and Fernández-López (2000), who distinguished between sedimentary, stratigraphic, and taphonomic condensation and who also emphasized the possible occurrence of condensed successions in a variety of sedimentary environments. Kitamura (1998) and Amorosi (2003) showed that the presence of glaucony grains is not always a reliable indicator of condensed successions, which is in disagreement with the sequence-stratigraphic concept (Loutit *et al.* 1988).

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In the present contribution, an example of intense condensation in a shallowing sedimentary succession, is provided, *viz*. that at the Jurassic/Cretaceous transition on the eastern Russian Platform (Fig. 1). Previous studies (ZORINA 2005, ZORINA & RUBAN 2007) documented a concentration of several ammonite zones within thin siliciclastic beds of this succession, as well as a general basin shallowing. The linking of these two phenomena represents an example of an unusual condensation mechanism.

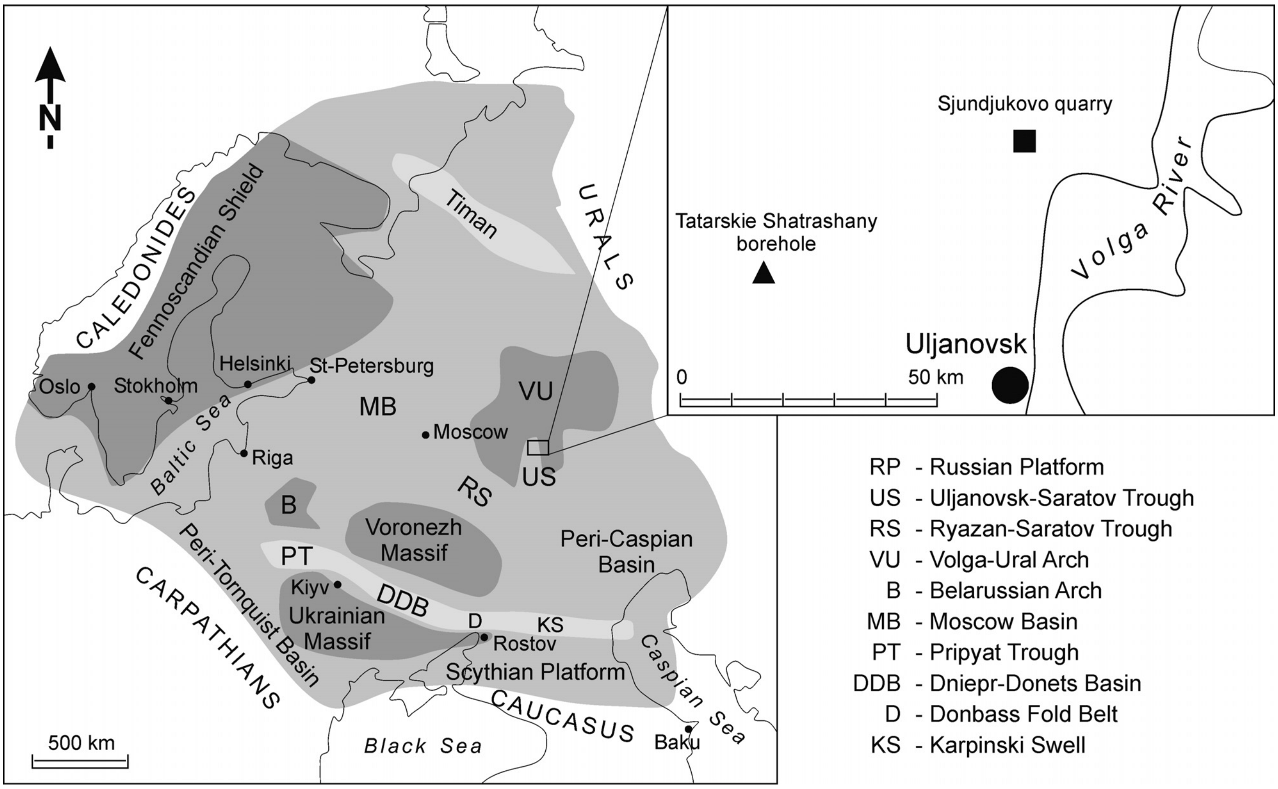

Fig. 1. Location of the study area. Sketch of the Russian Platform adapted from NIKISHIN *et al.* (1996), SAHAGIAN *et al.* (1996) and ZORINA & RUBAN (2007).

Geological setting

The eastern periphery of the Russian Platform is surrounded by the large watershed of the Volga River and its main tributaries. The study area is the north-eastern part of the Uljanovsk–Saratov Basin (Fig. 2), which is a trough incised in the southern periphery of the Volga–Ural Arch (SAHAGIAN *et al.* 1996). This basin is filled up with Middle Jurassic-Paleogene deposits with a total thickness of about 450 m (ZORINA 2005). The Jurassic/Cretaceous transition in this region was reviewed comprehensively by ZORINA (2005) and ZORINA & RUBAN (2007). Detailed palaeoenvironmental reconstructions were presented by RIBOULLEAU *et al.* (1998, 2003).

Formation names for the rocks in this area have been proposed by JAKOVLEVA (1993) but their definition is not clear. Therefore, ZORINA & RUBAN (2007) suggested alternative lithostratigraphic units that are related to the local ammonite-based biozones and that can be fitted in a chronostratigraphical context (Fig. 3). The transitional Jurassic/Cretaceous strata are represented in the north-eastern part of the Uljanovsk–Saratov Basin by green and greenish-grey sandstones with a total thickness of up to 2.5 m. These deposits contain the ammonites: *Virgatites pallasianus* (ORBIGNY), *V. sosia* (VISHNIAKOFF), *Virgatites* cf. *gerassimovi* MITTA, *V. pussilus* MICHALSKY, *Epivirgatites nikitini* (MICHALSKY), *E.* sp., *Kachpurites fulgens* (TRAUTSCHOLD), *Craspedites okensis* (ORBIGNY), and *C.* cf. *okensis* (ORGBIGNY). This combination of taxa indicates a stratigraphic interval

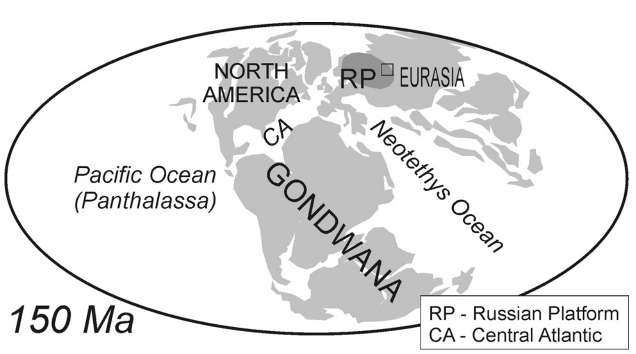

Fig. 2. Palaeotectonic position of the study area (simplified from SCOTESE, 2004).

ranging from the *Virgatites virgatus* Zone to the *Craspedites subditus* Zone. In addition to the ammonites, bivalves and belemnites are found in the deposits under study. The transitional Jurassic/Cretaceous strata overlie sometimes conformably, sometimes disconformably, the organic-rich clays of the *Dorsoplanites panderi* Zone. A significant hiatus follows and the *Dorsoplanites panderi* Zone is overlain by Hauterivian deposits.

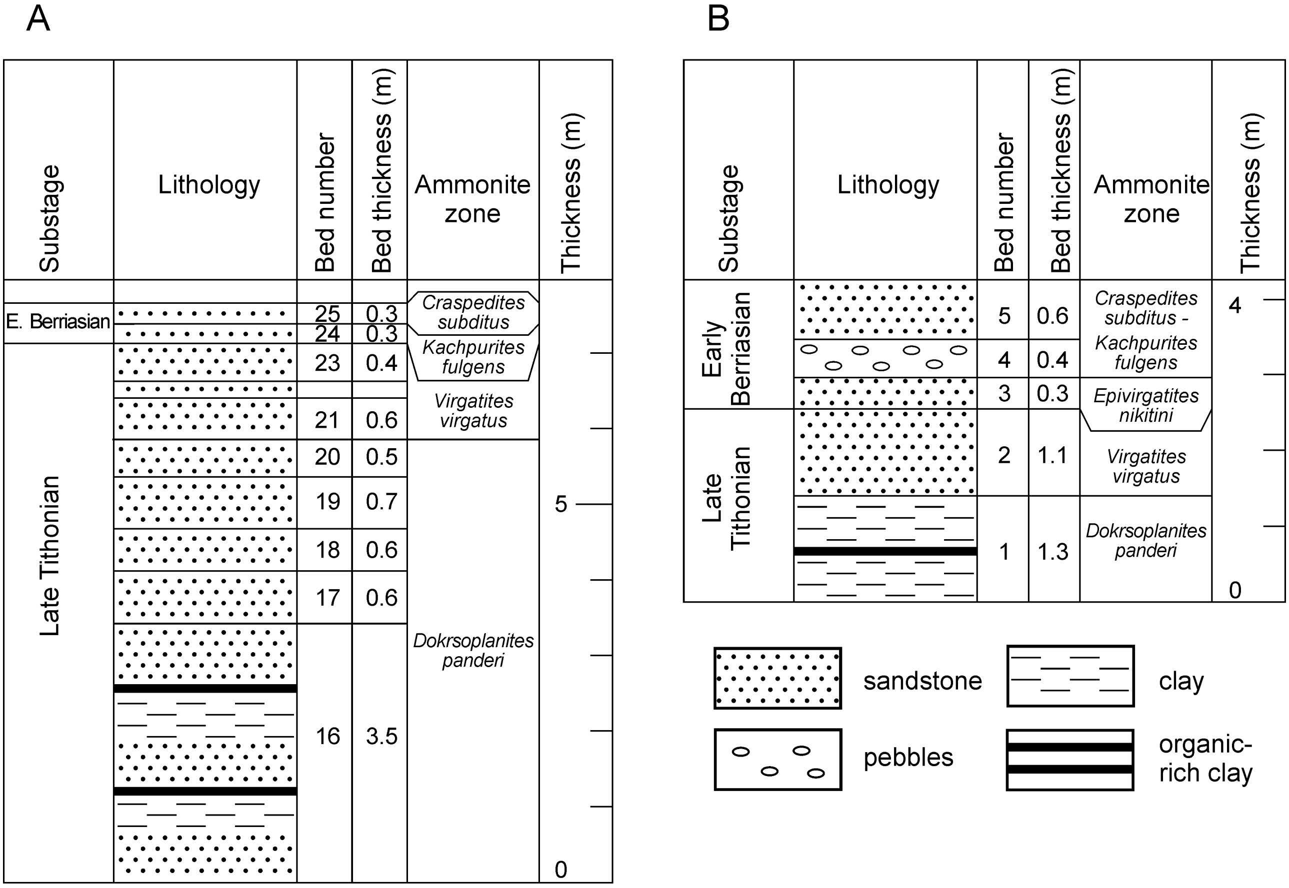

Fig. 3. Schematic chrono-, litho- and biostratigraphy of the two sections under study.

In general, the study territory is situated between the Tethyan and Boreal Regions, in the middle of western Eurasia (Fig. 2). The transitional Jurassic/Cretaceous deposits accumulated in the shallow Interior Russian Sea (JASAMANOV 1978), which had a strongly fluctuating sea level (SAHAGIAN *et al.* 1996, ZORINA & RUBAN 2007). This sea had wide connections with Boreal water masses but its connections with the Caucasian Sea to the South were intermittent (BARABOSHKIN *et al.* 2003, ROGOV *et al.* 2006). The sea water was warm, with a normal salinity (JASAMANOV 1978, RIBOULLEAU *et al.* 1998). Analysis of the clay mineralogy indicates an arid climate (RIBOULLEAU *et al.* 2003). Wave activity along the shore, in combination with bottom currents, frequently resulted in erosion, commonly followed by resedimentation of the particles (ZORINA & RUBAN 2007).

Materials and methods

A representative section from the eastern Russian Platform, in the form of cores from the Tatarskie Shatrashany borehole, was investigated (Fig. 1). Analysis of the lithological characteristics and the fossil assemblages in each bed of the Jurassic/Cretaceous transitional interval resulted in a detailed stratigraphic framework for the site. The emphasis of the analyses was on the transitional Beds 21–25 (Fig. 3A). The data thus obtained were compared with those from the nearby Sjundjukovo Quarry.

The analyses were aimed at finding lithological evidence for the presence of a condensed succession based on the sedimentological criteria proposed by LOUTIT *et al.* (1988) and CATUNEANU (2006). These include the occurrence of glaucony grains, phosphorite concretions and shark teeth. However, it must be emphasized, in this context, that none of these criteria is sufficient in itself to recognize a condensed succession (GÓMEZ & FERNÁNDEZ-LÓPEZ 1994, KITAMURA 1998, AMOROSI 2003). On the other hand, intraformational disconformities seem to be reliable indicators of a decreased sedimentation rate (*cf.* GÓMEZ & FERNÁNDEZ-LÓPEZ 1994). The possible occurrence of a condensed succession was, therefore, investigated by analysis of the local sedimentation rate (*sensu* GÓMEZ & FERNÁNDEZ-LÓPEZ 1994). This sedimentation rate (*SR*) is defined here as $SR = T_{lu}/t_{lu}$, with T_{lu} being the thickness of the entire lithological unit and t_{lu} being the total duration of the deposition of the unit involved (including minor hiatuses).

A decrease in the sedimentation rate can be caused by: (1) a longer time interval between the accumulation of individual sedimentary particles (or thin successions, for instance laminae, formed by them); (2) interruptions in sedimentation or (3) a combination of these two factors. A condensed character cannot be established if only one single unit is considered, as the sedimentation rate is always relative (GÓMEZ & FERNÁNDEZ-LÓPEZ 1994). In the present study, the sedimentation rate of the potentially condensed interval was compared with that of the likely uncondensed underlying strata. It is possible to measure the sedimentation rate semi-quantitatively using ammonite zones, or quantitatively by obtaining absolute ages. Both types of analysis were performed for the present study; the applied chronostratigraphic framework was taken from the work of GRADSTEIN *et al.* (2004).

Condensation patterns

The transitional Jurassic/Cretaceous strata in the Tatarskie Shatrashany borehole (= Beds 21–25) consist of very fine-grained sandstones with a total thickness of 1.75 m (Fig. 3A). The size of individual grains varies little (from 0.05 to 0.12 mm) but their roundness shows large variations. The sandstones consist of glaucony grains (36–74 %), quartz grains (3–16 %) and rare feldspar grains; the sement consists of carbonates, clay particles and collophane, whereas the matrix is constituted of mineral clasts and glaucony. The joint amount of cement and matrix amounts to 35–68 %. The sandstones contain abundant phosphorite concretions and grains. In the Sjundjukovo Quarry, the size of the phosphorite concretions varies between 2 and 5 cm. The total content of P_2O_5 varies from 2.7 to 16.4 %. The total amount of P_2O_5 increases upwards in the succession (ZORINA & VALITOV 2007). The collophane constitutes up to 35 % of the sandstone and it is present in both concretions and cement. Phosphorite-bearing matter also encrusts some invertebrate remains, which are present both as clasts and as part of the matrix. Shark teeth are abundant within the transitional Jurassic/Cretaceous sandstones of both the borehole and the quarry. Their total amount attains a maximum of 3 % in the sandstones of Bed 24 of the Tatarskie Shatrashany borehole, where also numerous intraformational disconformities are present (as in the entire section under study). These features are typical of condensed successions (LOUTIT *et al.* 1988, CATUNEANU 2006). However, the glaucony grains seem to be allochtonous and, therefore, cannot be used as a proper indicator of a condensed succession (*cf.* AMOROSI 2003).

Beds 21–23 in the Tatarskie Shatrashany borehole belong to the *Virgatites virgatus* Zone, whereas Beds 24–25 are attributed to the interval of the *Kachpurites fulgens - Craspedites subditus* Zones (Fig. 3A); the *Epivirgatites nikitini* Zone is absent in this succession, which must be ascribed to a hiatus. The deposition of the section with the transitional beds thus corresponds to four ammonite zones (including the lacking *Epivirgatites nikitini* Zone). In comparison, the five underlying beds (Beds 16–20) with a combined total thickness of 5.9 m were deposited during a time span representing only one ammonite zone (the *Dorsoplanites panderi* Zone). This is clear evidence that the transitional beds (21–25) form a condensed succession.

A preliminary correlation of the local biostratigraphic units with the global chronostratigraphy (ZORINA 2007) indicates that Beds 21–25 were deposited during ~3.5 Ma, which implies a sedimentation rate of ~0.05 cm/ka. In comparison, the sedimentation rate during the deposition of the underlying *Dorsoplanites panderi* Zone was 0.8 cm/ka. These simple calculations, although being only approximate, also strongly support condensation at the Jurassic/Cretaceous transition in the study area.

In the Sjundjukovo Quarry, beds 2–4 belong to the interval of the *Virgatites virgatus* and the *Craspedites subditus* Zones (Fig. 3B). In this section, the *Epivirgatites nikitini* Zone is present in the sedimentary record. The total thickness of beds 2–4 is 1.8 m, hence the sedimentation rate can be calculated to be also ~0.05 cm/ka, which implies a similar degree of condensation as found for the transitional beds in the Tatarskie Shatrashany borehole.

Relationship between condensation rate and basin depth

The depth of the sea around the north-eastern part of the Uljanovsk–Saratov Basin can be reconstructed accurately with the criteria proposed by SAHAGIAN *et al.* (1996), as already discussed by ZORINA & RUBAN (2007). The presence of phosphorites in the very fine sands indicates that the depth was less than 20 m and, thus, most commonly, above the storm wave base. This is supported by the presence of phosphorite gravels and pebbles (ZORINA & RUBAN 2007). Although autochthonous glaucony indicates a depth of 50–500 m, allochtonous grains tend to accumulate close to the shoreline when in a regressive setting (AMOROSI 2003). In this case, the grains were reworked by waves and bottom currents. In comparison, the deposits of the *Dorsoplanites panderi* Zone were deposited at a depth of over 40–50 m, as suggested by the dominance of organic-rich clays and sulphides (SAHAGIAN *et al.* 1996, ZORINA & RUBAN 2007).

The above-mentioned changes in basin depth reflect a significant shallowing trend (Fig. 4). The sea retreated from the study area for a long time already in the earliest Cretaceous, as indicated by the middle Berriasian to early Hauterivian hiatus (ZORINA 2005). It must, consequently, be deduced that the strong condensation coincided with a basin shallowing during an accentuated regressive episode. The regional sea-level changes coincided with the global eustatic drop documented by HAQ *et al.* (1987) and HAQ & AL-QAHTANI (2005) (Fig. 4).

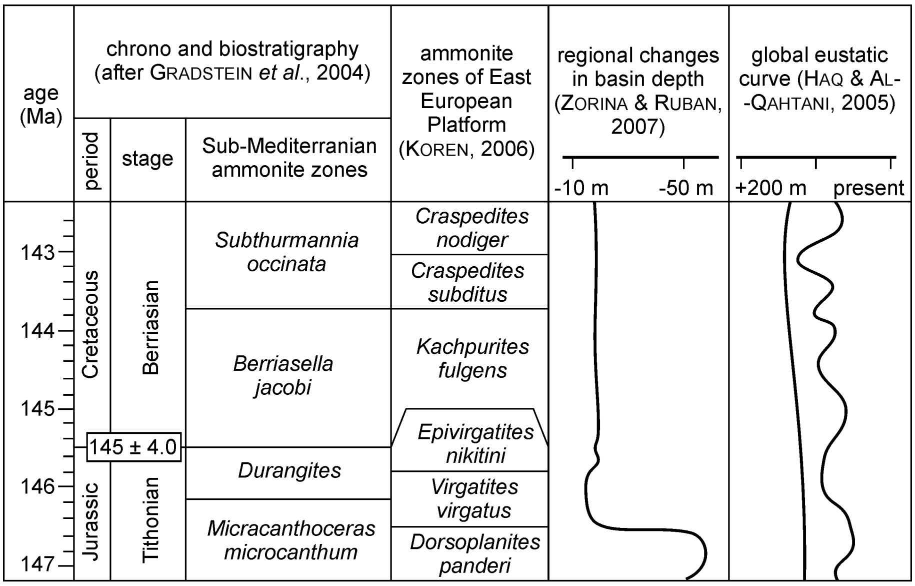

Fig. 4. Changes in basin depth and global eustatic sea-level fluctuations.

ZORINA & RUBAN (2007), following an assumption by HALLAM (2001), hypothesized that the end-Jurassic shallowing and the regression were tectonically-controlled and coincided with similar phenomena documented just occasionally in other regions. However, ZORINA *et al.* (2008) advocated a global extent of the sedimentary break at the Jurassic/Cretaceous transition. If so, the condensed section in the Uljanovsk–Saratov Basin reflects a global eustatic drop of the sea level.

Discussion

GÓMEZ & FERNÁNDEZ-LÓPEZ (1994) distinguished three condensation types. The first type (which is the most common) is stratigraphic condensation, which can be expressed by the SR index (the value representing the average net deposition per time unit). The second type is sedimentary condensation, which is somewhat more complex (Fig. 5); it is determined by the real rate of accumulation, which is the ratio between the thickness of a lithological unit without hiatuses on the one hand, and the duration of its formation on the other hand. As noted by GÓMEZ & FERNÁNDEZ-LÓPEZ (1994), a strong stratigraphic condensation does not always imply a similarly strong (or even any) sedimentary condensation. The third type is taphonomic condensation, which is only an apparent feature because of re-sedimentation or re-working of index taxa.

Our data from the Tatarskie Shatrashany borehole and the Sjundjukovo Quarry indicate strong stratigraphic condensation of the Jurassic/Cretaceous transitional beds. The presence of numerous intraformational disconformities, especially in the interval of the *K. fulgens* and *C. subditus* Zones (Beds 24–25), suggests that the condensed character resulted mainly from multiple interruptions of the local depositional process. Intense re-sedimentation occurred by waves and bottom currents, which produced erosional surfaces in the marine succession. The accumulation rate responsible for the deposition of the various beds may, consequently, not have been truly low (but it cannot be determined with any reasonable accuracy how much sediment was removed during the erosional phases). In any case, stratigraphic condensation is in the transitional beds much more emphasized than sedimentary condensation. The role of the latter is likely to be greater in the lower interval of the studied interval, where the number of intraformational disconformities is lower.

Many reworked ammonites are present in the transitional Jurassic/Cretaceous strata. Their concentration is particularly high in bed 24 of the *K. fulgens* Zone. It should therefore be emphasized here that only those ammonites not bearing any evidence of reworking were used to establish the age of the transitional strata. The presence of reworked taxa indicates taphonomic condensation of the succession. Although the transitional Jurassic/Cretaceous beds of the eastern Russian Platform most probably show a very strong condensation of this type, this does not affect significantly the above interpretations of stratigraphic and sedimentary condensation because both types of condensation are based on reliable dating of the various beds under study.

Conclusions

The present study indicates relatively strong condensation of the transitional Jurassic/Cretaceous beds on the eastern Russian Platform. The condensation coincided with basin shallowing induced by a global eustatic drop in the sea level. It appears that the entire transitional Jurassic/Cretaceous succession in the study area is condensed in both a stratigraphic and a taphonomic respect, whereas sedimentary condensation may be relevant only in the lower part of the succession under study.

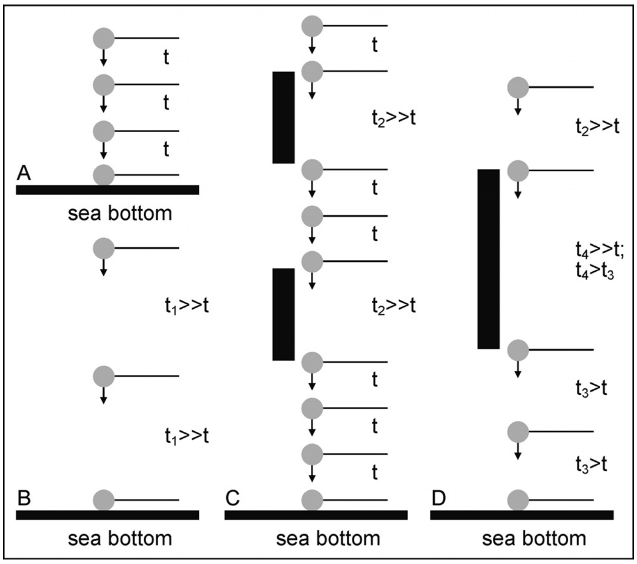

Fig. 5. Condensation mechanisms. A, uncondensed sedimentation; **B,** stratigraphic condensation; **C,** sedimentary condensation; **D,** stratigraphic condensation with a reduction in accumulation rate. t = time intervals between accumulation of sedimentary particles (grey circles); black rectangles mark interruptions in sedimentation, which now form hiatuses.

New data from the eastern Russian Platform confirm that even strong condensation does not occur preferably in deep-marine settings at a time of transgression maximums. Further studies should be aimed at developing more precise models regarding the glaucony and phosphorite accumulations. Such studies might provide the data required for a deeper insight into regional condensation patterns.

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Резиме

Кондензована сукцесија на прелазу јура/креда у плитководном басену на источној Руској Платформи

Источни обод Руске Платформе је изузетан пример за прелазне јурско-кредне седименте, а текође и за дискусију о феномену кондензације. Секвентна стратиграфија успоставља везу између кондензованих изданака и максимума трансгресије, које представљају границе између трансгресивних просторних система и високог нивоа надирања мора. Међутим, нека проучавања истичу могућност појаве кондензованих сукцесија у зависности од различитости седиментационих средина. Проучавана област припада североисточном делу Уљановско--саратовског басена који представља трог усечен у јужни обод Волгско-уралског лука. Прелазни јурско-кредни слојеви су представљени у североисточном делу Уљановско-саратовског базена са зеленим и зеленкастосивим пешчарима са укупном дебљином до 2,5 m. Амонитски таксони указују на стратиграфски интервал од *Virgatites virgatus* до *Craspedites subditus* зона (горњи титон–доњи беријас). Присуство глауконитских зрна, фосфорита и ајкулиних зуба је литолошки доказ кондензације, мада алохтоно порекло глауконитских зрна није увек поуздан показатељ. Седименти профила са прелазним слојевима одговарају четири амонитске зоне (укључујући одсуство *Epivirgatites nikitini* зоне) које указују на снажну кондензацију. Корелација локалних биостратиграфских јединица са светском хроностратиграфијом указује да су слојеви 21-25 Татарско-шатрашанске бушотине стварани за време од ~3,5 Ma, што указује на принос од ~0,05 cm/ka. Седиментациони принос за време депоновања подинске *Dorsoplanites panderi* зоне је био 0.8 cm/ka. Ова проста рачуница, и ако је само приближна, јако подржава кондензацију јурско-кредних прелазних слојеве у проучаваној области. Исти степен кондензације је познат из Сјундјуковског каменолома. Присуство фосфорита у јакоситнозрним пешчарима указује да је дубина била мања од 20 m, која је најчешће била изнад базе олујних таласа. На ово указује и присуство валутака фосфорита. И ако аутохтони глауконити указују на дубину од 50-500 m, у регресивним околностима алохтона зрна теже да се акумулирају ближе обалској линији. У овом случају зрна су премештена таласим и подводним струјама. Горе поменуте промене у дубини басена су се одразиле на значајно продубљавање. Кондензовани профил Уљановско-саратовског басена одражава општи еустатички пад нивоа мора. Овај феномен је у супротности са досадашњим знањима о секвентној стратиграфији. Подаци из Татарско-шатрашанске бушотине и Сјундјуковског каменолома указује

на јаку стратиграфску кондензацију јурско-кредних прелазних слојева. Присуство многобројних интраформационих дискорданција, нарочито у интервалу *K. fulgens* и *C. subditus* зона, указује да је кондензациони карактер проузрокован углавном вишеструким прекидима локалних депозиционих процеса. Принос кондезованих седимената остаје дискутабилан. Присуство реседиментованих таксона указује на тафономску кондензацију сукцесије. И ако прелазни јурско-кредни слојеви источне Руске Платформе највероватније показују веома јаку кондензацију, што не умањује значај горе поменуте интерпретације стратиграфске и седиментолошке кондензације, јер оба типа кондензације су засновани на поузданим одређеним старостима проучаваних слојева.

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The Lower Cretaceous Paraflysch of the Vardar Zone: composition and fabric

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Abstract. The Lower Cretaceous paraflysch forms an outstanding, 250 km-long belt in the Vardar Zone. It is composed of a basal unit, uncomformable over Jurassic limestones and older rocks, and of two megasequences with the a clastic lower and clastic-carbonate upper member. In this study, We analyzed the orientation of the sedimentary bedding, cleavage and schistosity, fold hinges and axial surfaces and cleavage – bedding intersection lineation, were analysed. The area experienced two phases of folding, first with fold hinges oriented NNW and the second with hinges oriented WSW. The regularities of these structures and their relationships are, as shown by these investigations, only statistically to be used in practical study of fabric.

Key words: Vardar Zone, paraflysch, Lower Cretaceous, sedimentology, fabric.

Апстракт. Доњокредни парафлиш гради у Вардарској зони веома изразит појас дуг 250 km. Састоји се од базалне јединице дискордантне преко горњојурских кречњака и меланжа, као и две мегасеквенце са доњим кластичним и горњим кластично-карбонатним чланом. Статистички су анализирани падови свих слојева, преврнутих слојева, кливажа и шкриљавости, оса набора, аксијалних површи набора и пресеци кливажа и слојева. Правилности ових структура и њихових односа су, како је показало ово истраживање, само статистички употребљиве при практичним испитивањима склопа.

Кључне речи: Вардарска зона, парафлиш, доња креда, седиментологија, склоп.

Introduction

The Vardar Zone, a very important and highly controversial member of the Balkan Peninsula geology, was investigated and described by numerous researchers, who gave it different importance, different affinities, different subdivisions and different geotectonics. According to Dimitrijević M.D. (1979, 2001), the Vardar Zone is herein defined as an oceanic zone between the Dinarides and Hellenides to the west and the Serbian-Macedonian Massif to the east.

The idea of the Vardar Zone as the ”Internal Dinarides” was, fortunately, abandoned a long time ago in the circle of researchers, which opened the way for earnest investigation of its importance and history (*e.g.*, Dimitrijević M.D. 1997, 2001; Karamata, 2006).

For the Vardar Zone, especially for its central parts from Belgrade to Kumanovo, a thick Lower Cretaceous succession that shows some flysch characteristics, being thus described as a paraflysch (Dimitrijević M.N. & Dimitrijević M.D. 1976, 1987; Dimitrijević M.N. *et al*. 1996, 1997), is very characteristic.

These strata form at present a narrow belt, only exceptionally wider than 14 km, but probably some 250 km long. The northern part of the belt (Avala and Kosmaj Mts.) is open for discussion concerning its affinity to this or to the adjacent sub-zone, and will not be further discussed in this paper. The belt with the paraflysch is from both the East and West bounded by mafic and ultramafic rocks with some Upper Jurassic limestones, and the deposits in the adjacent belts are completely different. The southern part of the paraflysch is eroded, with only the Kriva Reka (SW of Novo Brdo) as remnants.

The depositional base of the paraflysch appears only at the southwest and in the extreme south, in the Novo

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[1] Unfortunately, M.D. Dimitrijević, because of bad health, was not in position to correct all the remarks made by the reviewers. Some remarks, especially those which did not need a lot of correction, were dealt with by Milan Sudar. The Editorial board, even though not all requests of the reviewers were accepted or included, decided to print the paper in its present form.

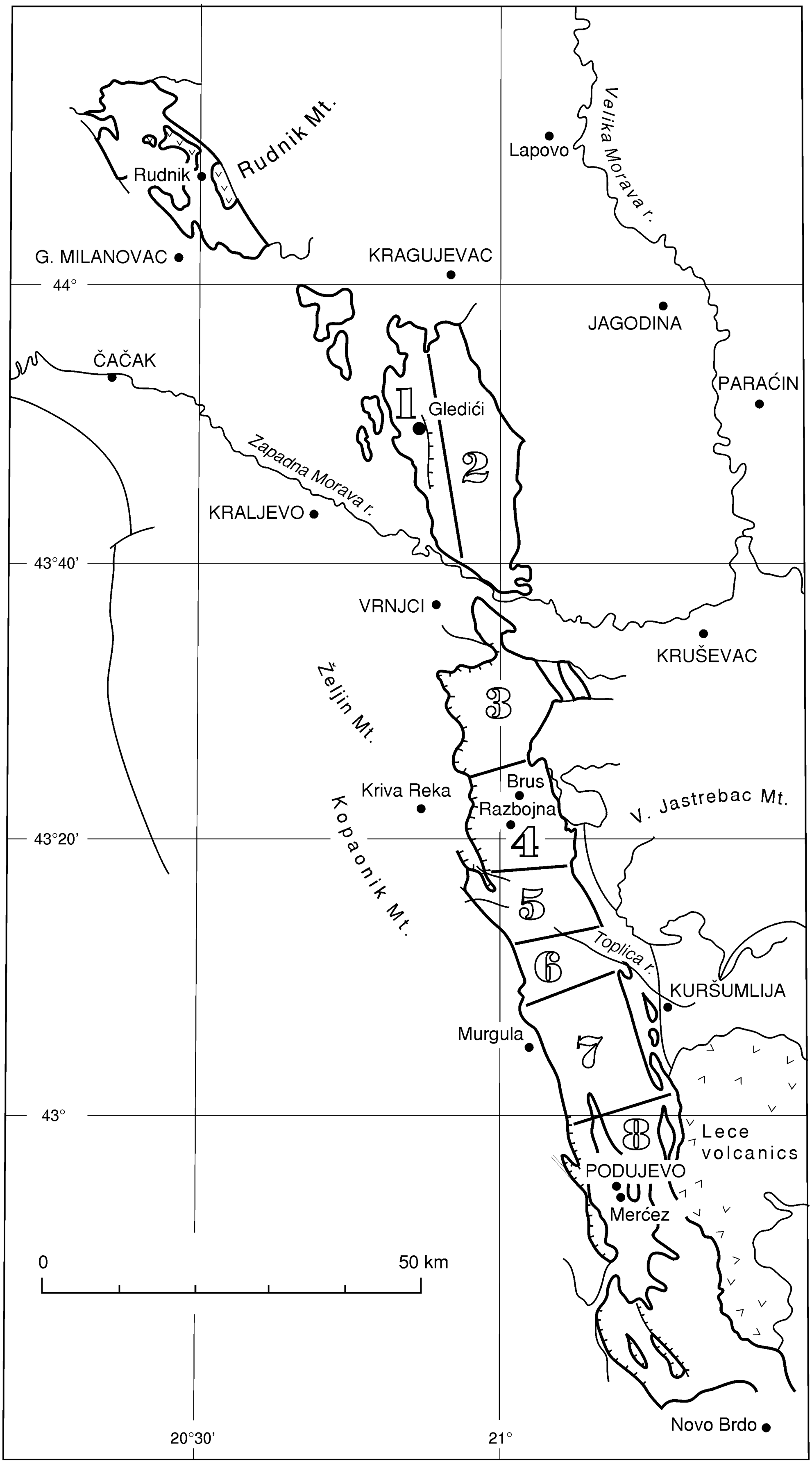

Fig. 1. Sketch of the basin of the Lower Cretaceous Paraflysch of the Vardar Zone with the separate blocks.

Brdo area as shown by the Kriva Reka domain. This domain, the southernmost outcropping part of the paraflysch, is composed of marginal units, the original relations with main part of the basin being not clear.

Paraflysch

Over the basal unit, the paraflysch forms two mega sequences, each with a clastic lower and a carbonate-clastic upper part. The stratigraphic relations between these units were not possible to assure in every locality, and local lateral transitions are also possible. Field mapping was performed by teams lead by M. RAKIĆ, B. MARKOVIĆ, M. VUKANOVIĆ, M. MALEŠEVIĆ and others. The composition of these units was investigated by MARA DIMITRIJEVIĆ, B. RADOŠEVIĆ, RUŽICA MARKOVIĆ, LJUBICA RUDOLF, RAJNA GABRE, LJUBINKA MASLAREVIĆ and M.D. DIMITRIJEVIĆ. The meagre biostratigraphic documentation was studied by OLIVERA MARKOVIĆ, RAJKA RADOIČIĆ, ALEKSANDRA DANILOVA and SULTANA OBRADOVIĆ. The sedimentological field data are by MARA N. and MILORAD D. DIMITRIJEVIĆ.

The data of the field mapping, and the sedimentological and biostratigraphic investigations were presented by DOLIĆ *et al.* (1981), FILIPOVIĆ *et al.* (1978), FILIPOVIĆ & RODIN (1980), MALEŠEVIĆ *et al.* (1980), MARKOVIĆ *et al.* (1968, 1985), PAVIĆ *et al.* (1983), PAVLOVIĆ (1980), UROŠEVIĆ *et al.* (1973a, 1973b), and VUKANOVIĆ *et al.* (1982).

Based on all the available sedimentological and biostratigraphic data, the paraflysch was divided over the basal unit into six units. These are from the base to the top.

A. A microconglomeratic-arenitic unit (probably Lower Valanginian),

B. A silty-calcareous unit (Valanginian–Hauterivian),

C. An arenitic-silty unit (Barremian–Aptian),

D. A calcareous-arenitic unit (Albian–Cenomanian) and

E. Marginal units (E1 and E2; regarded as lateral equivalents of the top units).

Basal unit

Not everywhere exposed and for the large part tectonized, the basal unit shows nevertheless its clear unconformable character. It crops out along the Podujevo–Lebane road at Prepolac, over an ophiolitic mélange and schists ascribed to the Palaeozoic (pers. comm. M. VESELINOVIĆ).

The unit is mostly composed of coarse-grained rocks, with blocks over 80 m in diameter. Basal rudites mostly consist of rocks from the mélange, schists and Berriasian limestones. At Prepolovac, these are composed almost entirely of Berriasian limestones, being regarded by M. VESELINOVIĆ as the Mesozoic base of the paraflysch (unpublished data from 1956 in DIMITRIJEVIĆ M.N. & DIMITRIJEVIĆ M.D. 1976). At Razbojna, Senonian rudites with globotruncanid limestones have also been ascribed to this unit.

These deposits are characteristically disorganized, very poorly sorted, frequently monomictic to oligomictic in composition, with angular blocks, pointing to a very short and catastrophic sinking and deposition, without progressive abrasion typical for a transgression.

Very interesting is the position and types of limestones found in the basal unit. From various localities two types of limestones have been described: shallow marine, frequently reefal, and basinal with Aptychi. It seems, nevertheless, that the opening of the trough began at the end of the Upper Jurassic, in a shallow sea with reefs which was attached to a large shallow open sea.

A. Microconglomeratic – arenitic unit

This unit, some 80 to 100 m thick, crops out along the south-eastern border of the basin and in the cores of anticlines. It is composed of conglomerates, disorganized pebbly sandstones (coarse-grained feldspathic subgreywackes to greywackes), massive sandstones, slump facies, normal turbidites, siltstones and subordinate other facies. Rudites bear fragments of Tithonian–Berriasian limestones, schists and other rocks. Olistostromes, fluxoturbidites and thin conglomerate layers are frequent. The volume content of $CaCO_3$ is low. Garnet is outstanding among the heavy minerals (over 50 %), followed by some tourmaline, rutile, zircon and others.

Turbidites are subordinate. They are proximal, mostly showing intervals of graded bedding and the lower interval of horizontal lamination. The interval *c* bears large convolutions, while other intervals are mostly absent. Sole markings are sparse – flute casts and tool marks. Sparse organic markings show only the simplest forms. Sparse observations indicate a longitudinal palaeotransport towards the south-southeast.

Very rare fauna (*Calpionellopsis oblonga*, *Spirillina* sp., *Trocholina* ex gr. *waldensis*, sponge spicules) probably of Lower Valanginian age were found (DIMITRIJEVIĆ M.N. & DIMITRIJEVIĆ M.D. 1976).

B. Silty – calcareous unit

It probably occurs in the Avala–Kosmaj domain over the ophiolitic mélange, being 100–200 m thick. It consists there of siltstones and marly limestones, with some calcarenites and micrites.

The unit is best developed in the Brus-Podujevo area where it overlies unit A, with a thickness of 90 to 150 m. It consists of siltstone laminites, fine grained greywackes, shales and platy pelagic micrite, distal turbidites, some slump deposits and rare normal turbidites. The deposits are mostly dark, thin bedded, composed of fine-grained rocks corresponding to the outer fan and the basin, probably also the active part of the outer fan with a sufficiently steep slope (slumps). The unit mainly consists of silty-pelitic rocks with ample slump phenomena. Graded bedding is sparse and various types of current lamination prevail. Organic markings are ample and specific. Ilmenite and magnetite prevail in the heavy fraction, with infrequent garnet. Microfauna is infrequent and poorly preserved (tiny globotruncanids, radiolarians, bryozoans, fragment of miliolids; *Lenticulina muensteri*, *Lenticulina* sp., *Ammobaculite*s cf. *gramatus*, *Am. gratus*) indication to Valanginian–Hauterivian age (Dimitrijević M.N. & Dimitrijević M.D. 1976).

C. Arenitic – silty unit

This is the thickest unit (over 600 m in the Gledići Mts.), cropping out over the largest area. Its basal part is of finer grain, while the upper part is coarser.

The lower part of the unit bears very infrequent and thin fluxoturbidites and olistostromes, except for the western portion of the Rudnik Mt. domain. The turbidites consist of a thin interval of graded bedding, interval *b,* interval *c* with very characteristic tiny cross and wavy lamination, in places also convolution. The sequences are mostly base cut-up and truncated, and turbidites are frequently subordinate. Very frequent and characteristic are non-turbiditic laminites, deposited grain-by-grain, with current lamination and small-scale ripple marks pointing to a lower flow regime with a low energy environment.

Submarine slumping is frequent in this part of the unit. Sole markings are sparse (brush and prod casta, scattered tiny groove marks). Infrequent data measured in the Gledići domain show a palaeotransport towards the southwest, less frequently east, and in the Brus–Podujevo domain towards the south-southwest, south and south-southeast.

Deposits of this part of unit C correspond to the outer fan, partly also mid-fan with depositional lobes. They mostly consist of distal turbidites, turbidites, lesser to organized pebbly sandstones, massive sandstones, thin beds of fine-grained sandstones and very infrequent slumped masses. The volume content of $CaCO_3$ is conspicuously low. The rocks are mostly fine-grained micaceous greywackes and siltstones. This part of unit C is 80 m thick in the eastern part of the Rudnik domain and about 200 m in its western portion. In the Gledići Mts., its thickness is about 300 m (according to some estimates even over 600 m), varying in the Brus–Podujevo area between 150 and 500 m.

The upper part of the unit is conspicuously coarser, consisting of thick-bedded arenites and microconglomerates of the mid-fan depositional lobes, in places also with channel associations. Characteristics are organized pebbly sandstones, massive sandstones and normal turbidites, with some distal turbidites, organized conglomerates, disorganized pebbly sandstones and slump masses and olistostromes. The palaeotransport in the northern part of the trough is towards the south-southwest, and in the Gledići Mts towards the south-east. The thickness is 350 m in the western portion of the Rudnik domain (it is missing in the eastern portion), decreasing to *ca*. 100 m in the Gledići Mts., and increasing a new to *ca*. 300 m in the Brus–Podujevo domain.

The fauna found at the Rudnik Mt. is very sparse, largely transported from shallow marine regions (fragment of pelecypods, echinoderms, bryozoans, alternating orbitolinids, lagenids; part of algae (*Corallinaceae*); they also contain belemnites and inoceramid prisms. Unit C also yielded a microflora, *Pinus haploxylon*, *Ligodium* sp., *Ginko* sp., conifers and dominating gymnosperms of the genus *Beneltites* of Barremian–Aptian age (Dimitrijević M.N. & Dimitrijević M.D. 1976).

D. Calcareous – arenitic unit

This unit, mostly 100 to 150 m thick, is characterized by a high $CaCO_3$ content of most of the rocks and a relative abundance of arenites. It corresponds to the outer fan with some influences of the basin and the active part of the outer fan. Unit D is generally composed of distal turbidites and thin-bedded fine-grained sandstones, with some typical turbidites, slumps, pelagic and hemipelagic deposits, and some massive sandstones. The turbidites are mostly without an interval of graded bedding, with other intervals well developed. In places, senile turbidites occur, but ortholaminites prevail. The most important are siltstones, subgreywackes and calcareous greywackes, together with marls, marly micrites and graded sandy intrasparites. In the lower part of the unit, laminated marls prevail, and in the upper part characteristic are calcareous laminites and intrasparites in well separated beds. Epidote is dominant in the heavy fraction, with some tourmaline and ilmenite-magnetite.

Sole markings are exceptionally rare, represented mostly by tool marks. The palaeotransport is towards the south-southwest to south-southeast.

In the micrites and biomicrites here are tiny pelagic globigerinids (*Hedbergella*, *Ticinella*) together with rare allothigene coralinaceans and other transported forms. *Agardhiellopsis cretacea*, *Archaeolithothamnium amphiroephormis*, *Pseudolithothamnium album* were determined, which indicate Albian–Cenomanian age (Dimitrijević M.N. & Dimitrijević M.D. 1976).

E. Marginal units

The southern end of the paraflysch area is characterized by a prominent change of facies.

The trough deposits form here a belt several kilometres wide, where two units can be distinguished: the olistostrome (E1) and the carbonate-clastic (E2) one. The structure of the area prevents the definite determination of relations between these two units, but the olistostrome unit is probably lower. Lateral relations of these with the units of the main trough are not visible, but they are regarded as equivalents of the higher units from the trough, with a possible extension into the Cenomanian.

The olistostrome unit consists chiefly of olistostromes, organized conglomerates, massive sandstones, and turbidites, both typical and distal. The olistostromes are even over 10 m thick. They consist of a silty groundmass with clasts and bed fragments of arenites from the unit itself, with also some fragments of the adjacent Veleš Series. The arenites form thick layers with ample traces of slumping. Conglomerates are less profuse, with pebbles mostly of quartz and ludite, together with rocks of the unit itself in slump structures.

The unit shows a distinct proximal character, being deposited on an unstable slope.

The carbonate-clastic unit, estimated to be about 150 m thick, is mostly coarse grained. It is composed of thick layers of calcirudite with microconglomerates, coarse-grained arenites and laminated marly siltstones. Turbidites occur only exceptionally. The limestone horizons are several metres thick, showing very often a characteristic sequence: the ruditic basal part, with limestone fragments up to 10 cm in diameter grading into clastics with pebbles 2–3 cm in size, topped with roughly laminated sandy calcarenites, and ending with flaggy micrites. Some similar sequences, with the same organization, are even decametres thick.

No fossils were found in these units.

Depositional history of the basin

Reconstruction of the motions of the basin was greatly impeded by numerous factors. The basin deposits are, first of all, greatly tectonized, the original width of the depositional area being largely reduced by folding and tectonic dismembering and separation of lateral parts. This also rendered obscure the thicknesses and stratigraphic relations of units. Interpretation of the depositional environments is in places uncertain for some units, because observations and statements required for reaching conclusions were incomplete. The observations were made at different times, by different observers and based on different tenets. The depositional ages of the units were determined too broadly, first of all due to the presence of only a sparse and poorly preserved fauna, and for the obvious mixing of fauna of different origin (from pebbles and fragments from other coeval environments; re-deposited from older strata). Data on palaeotransport were not systematically collected. They show a wide scatter, for which the reason is not known (dispersal of palaeotransport, too small samples). This made the reconstruction of the basin geometry practically impossible. Finally, the interpretations were unavoidably burdened by the conceptions of the researchers wherever reliable material argumentation was missing, which greatly hampered generalization. Only preliminary speculations are thus possible, based on the existing data.

The very sparse measurements of palaeotransport show the predominance of the longitudinal south-southeast direction, besides highly scattered lateral directions which show the very important fact that the basin was fed both from the eastern and western border. This makes untenable the idea of the depositional area as a marginal apron, and defines it as a trough flanked on both sides by the source areas. This is also demonstrated by the occurrence of shallow marine deposits of the uppermost Jurassic along both sides of the paraflysch zone, which seems to rule out the hypothesis of oceanic deposition.

The clastic base appears only in the Avala–Kosmaj domain, as a thin blanket below unit B, and along the eastern border of the Brus–Podujevo domain, where it forms the thick floor of unit A. This permits the idea of a basin superposed over the ophiolitic mélange in a horizontally diversified area, where the foundering began in the southeast, with a catastrophic sinking and very rapid denudation. A fan system originated there, with mid-fan deposits occurring only in the eastern part of the Brus–Podujevo domain (unit A), with a possible partial extension up to the western border. Outer fan deposits follow (unit B), visible along the whole eastern border. Taking into consideration the absence of unit B in one part of western border (Vrnjci), a supposition is possible that the sequence indicates an eastern onlap.

The lower part of unit C (C1), progressing towards the west, might mark a progradational phase, representing a deposition in the mid-fan to the outer fan with depositional lobes.

Unit C2 is missing north of the Gledići Mts. It was deposited in the channelled mid-fan. The appearance of this unit only in the Gledići Mts. and the Brus–Podujevo domain might indicate a further progradation with the building of a narrower fan in the south-eastern portion of the area. This is also corroborated by a palaeotransport towards the west-southwest and south-southwest, reported in this unit from the Kraljevo area (MARKOVIĆ *et al.* 1968).

Internal kinematics of the basin

The internal structure of the basin is characterised by complex folding with frequent transposition of the bedding surfaces and broad zones which interrupt the continuity of the units. The degree of deformations is completely varied – there are parts of the column where strata are not deformed, together with decametric to hectometric domains where they are highly deformed and disrupted along the cleavage or schistosity. The principal

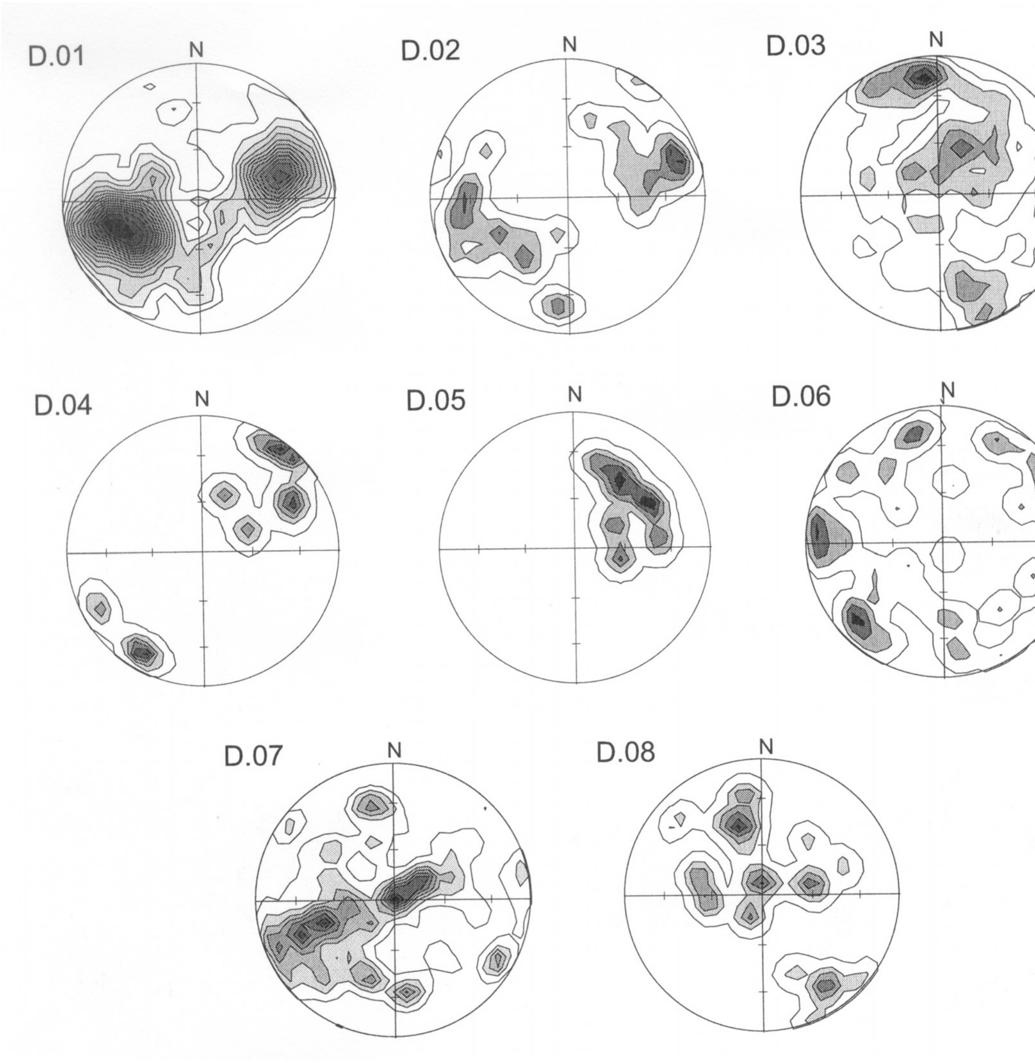

Fig. 2. Structural diagrams. D.01 All bedding surfaces. D.02 Overturned beds. D.03 Fold hinges. D.04 Bedding Domain Merćez–Kuršumlija. D.05 Bedding Murgula. D.06 Axial surfaces. D.07 Cleavage. D.08 cleavage – bedding intersection lineation.

planar fabric is dominantly represented by the cleavage, which deforms the bedding up to full transposition.

Analyses of the folding have been performed on various levels, from the most regional to detailed. The structural diagrams show the orientation of bedding planes for the whole basin (1363 data; D.01, Fig. 2), and in each of the 8 blocks, the basin was subdivided into (D1 to D8, Fig. 3).

All bedding surfaces

Poles to bedding are loosely assembled around the main maximum corresponding to the 75/47 and the submaximum 251/46. Statistical fold axis is plunging 163/3 and the statistical axial plane is roughly vertical striking 163–343. These data are conformable with the strike of the paraflysch trough (163–343). The pole diagram (Fig. 2, D.01) shows a high scatter of data. The fabric is roughly monoclinic, corresponding to an asymmetric fold with a better developed north-eastern and a less developed south-western limb, with a roughly horizontal axis and a vertical axial plane.

Overturned beds

In the diagram D.02 (Fig. 2) of 30 overturned beds, two maxima appear, corresponding to the dips 89/66 and 249/74, with overturned beds almost equally distributed in both maxima. This shows that the folds in the area have no uniform vergence, but form a kind of fan with vergences both towards west-southwest and east-northeast.

Fold axes

The hinges were measured for cm-m folds (Fig. 2, D.03, 104 measurements). The poles form only a not very expressed maximum corresponding to 356/18, with a faint suggestion of a disconnected girdle. A good

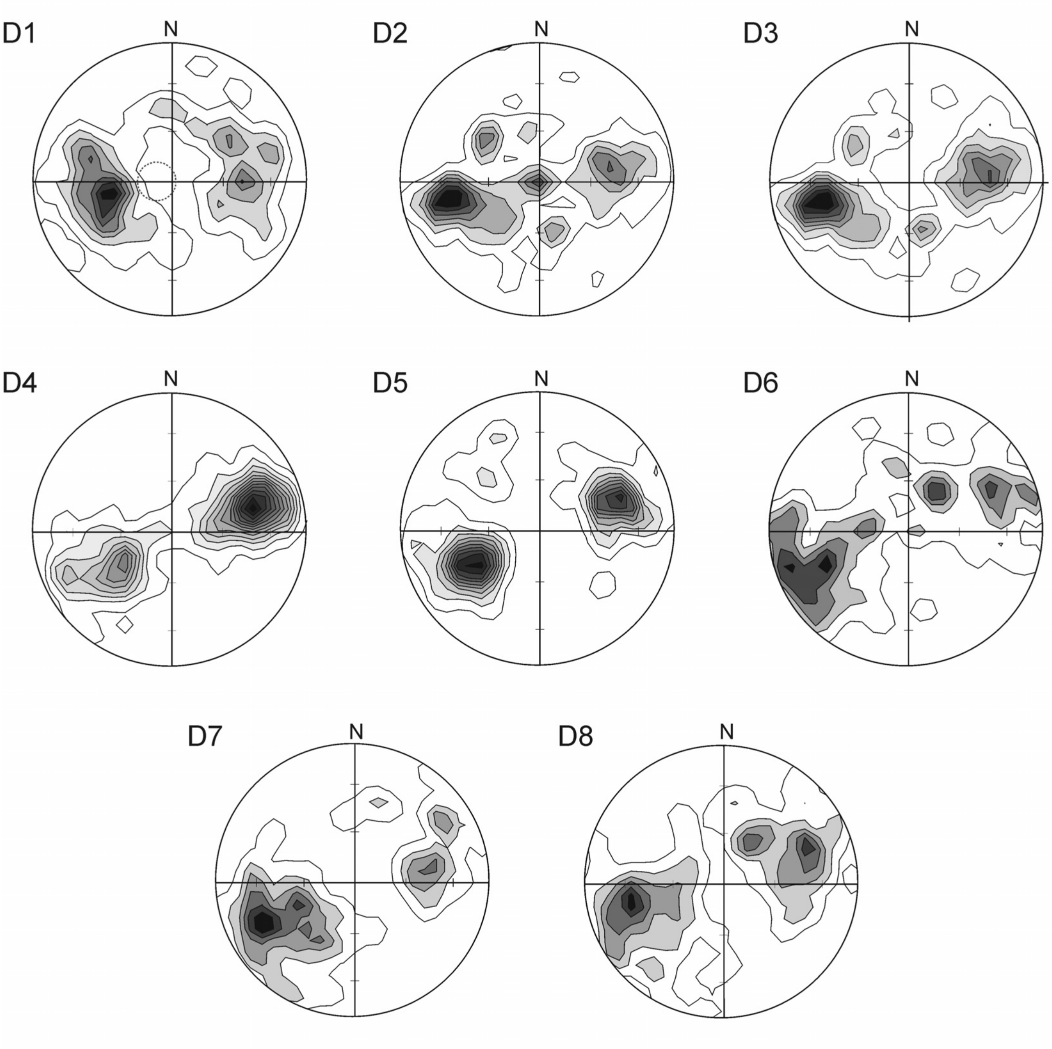

Fig. 3. Fabric diagrams of the bedding for the structural domains 1–8 blocks (see Fig 1 for locations).

example of a hinge orientation is shown by the diagram D.04 (Fig. 2, Merćez–Kuršumlija domain) in which the data are disseminated along a great circle normal to the younger fold axis, and the diagram D.05 (Fig. 2, Murgula domain) where hinges show a maximum at 28/60.

Axial surfaces

In the field, 44 axial surfaces of folds, most of the metric size (D.06, Fig. 2) were measured. The poles are disseminated with two maxima corresponding to 98/82 and 49/72. Although steep, these maxima do not fit the virtual axial plane of the bulk of the bedding surfaces, which is vertical – the observed metric folds in the field show a slight western and south-western vergence.

Cleavage

Some of cleavage data correspond to the axial planar cleavage, but for the greater number of them, their relation with the folds was not established. The diagram does not show well expressed maxima; several minor maxima are dispersed throughout the diagram (D.07, Fig. 2).

Cleavage – bedding intersection lineation

In the case when cleavage is parallel to the axial plane and folding is regular with rhombic or monoclinic symmetry, statistically the intersection lines between the bedding and an axial cleavage should be parallel to the regional fold axis. Diagram D.08 shows 125 intersection lines constructed with all the available data (Fig. 2). The poles are widely disseminated in a broad girdle normal, with several maxima, the closest to the regional axis representing the plunge 148/20. This shows that the symmetry of fabric is rather close to triclinic.

To unravel regional structural trends, the area was divided into 8 structurally homogeneous domains (Fig. 1).

Table 1. Statistical orientation of the bedding in the structural domains.

Block	maximum	submaximum
1	78/38	267/42; 232/42
2	80/54	255/43
3	79/53	264/46
4	252/53	57/34
5	63/45	246/52
6	67/61	260/48
7	81/57	245/57
8	67/52	251/30

This Table shows that only block 4 has a distinct deviation in that the dips are mostly toward the north-east, whereas in the other blocks, the dips are mostly to the southwest.

Discussion

The diagrams of the individual blocks and especially the details of the fold hinges (D.04 and D.05, Fig. 2) show that the area exerted a slight general rotation around an axis oriented WSW with appearance of younger folds corresponding to it. This younger act did not affect the fabric penetratively, and did not change the generalized picture of the domain fabric (see D.01, Fig. 2). Without detailed measurements of fold hinges, it would remain imperceptible.

This investigation also showed that the regularities known from the ellipsoid of deformations can be practically used only in a broad statistical manner, and that single measurements should be regarded with due suspicion.

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Резиме

Доњокредни парафлиш Вардарске зоне: састав и склоп

Вардарску зону, веома важан и веома контроверзан члан геологије Балканског полуострва испитивали су и описивали бројни истраживачи, дајући јој различит значај, различиту припадност, различите поделе и различиту геотектонску важност. Идеја о Вардарској зони као "унутрашњим Динаридима" напуштена је, срећом, већ дуго времена у кругу озбиљних истраживача, што је отворило могућности за озбиљно испитивање њеног значаја и историје.

Један веома упадљив појас у њој карактерише дебела доњокредна сукцесија која показује само извесне флишне карактеристике па су је МАРА Н. ДИМИТРИЈЕВИЋ и МИЛОРАД Д. ДИМИТРИЈЕВИЋ описали као парафлиш (1974 и други радови).

Ови слојеви сада граде узан појас пружања ССЗ–ЈЈИ, само изузетно шири од 14 km, али дуг вероватно својих 250 km. О његовом северном делу (Авала и Космај) још увек се дискутује у погледу припадности овој или суседној области, па он овде није детаљније разматран. Парафлиш је са обе стране затворен узаним појасима базита и ултрамафита са нешто горњојурских кречњака, а кредне творевине суседних региона су потпуно различите. Јужни део парафлиша је еродован, са подручјем Криве Реке (ЈЗ од Новог Брда) као јединим заостатком.

Оригинална подина басена откривена је само на крајњем југу, у области Новог Брда, као што показује подручје Криве реке. Ово подручје је грађено од пренабраних, јако тектонизованих и разломљених слојева који не показују карактеристике маргиналних јединица. Положај му није јасан и вероватно је последица сложених тектонских процеса.

Парафлиш

Изнад базалне јединице парафлиш граде две мегасеквенце, од којих свака има кластични доњи и карбонатно-кластични горњи део. Вертикални односи ових јединица нису били видљиви на бројним локалитетима, тако да су и делимични бочни прелази такође могући. На бази свих расположивих седиментолошких и биостратиграфских података, парафлиш је изнад базалне јединице издељен на шест јединица. То су: (A) микроконгломератско-аренитска јединица (без биостратиграфских података о старости), (B) алевролитско-кречњачка јединица (валендин–отрив), (C) аренитско-алевролитска јединица (барем–апт), (D) кречњачко-аренитска јединица (алб–ценоман) и (E) маргиналне јединице (E1 и E2; вероватно латерални еквиваленти највиших јединица).

Базална јединица

Ова јединица, која није свугде добро откривена и у великом делу је тектонизована, ипак показује јасан дискордантан карактер. Она се посебно јасно може пратити дуж пута Подујево-Лебане на Преполцу, изнад офиолитског меланжа и кристаластих шкриљаца. Јединица је углавном састављена од грубозрних стена, са блоковима чак и до 80 m у пречнику. Рудити се састоје највећим делом од стена из меланжа, кристаластих шкриљаца и беријаских кречњака. На Преполцу се они састоје скоро у потпуности од беријаских кречњака, тако су сматрани мезозојском подином парафлиша. На Разбојни су, опет, сенонски кречњаци са глоботрунканама били приписивани парафлшу. Све ове творевине су карактеристично неорганизоване, врло слабо сортиране, често мономиктног или олигомиктног састава, са угластим блоковима, што све указује на врло брзо и катастрофично тоњење и депозицију, без прогресивне абразије типичне за трансгресију.

Веома су занимљиви положај и типови кречњака који су нађени у базалној јединици. Из разних локалитета су описана два типа кречњака – плиткоморски, добрим делом спрудни, и басенски са аптихусима. Односи ових типова нису описани у тумачима ОГК СФРЈ (1:100.000), делом због врло сложеног састава области, а делом због концепцијских разлика међу ауторима. Ипак изгледа да је отварање трога започето у најгорњој јури у плитком мору са спрудовма које је било везано са широким отвореним и плитким басеном.

Микроконгломератско-аренитска јединица

Ова јединица, дебела 80 до 100 m, издањује дуж југоисточног обода басена и у језгрима антиклинала. Састоји се од конгломерата, неорганизованих шљунковитих пешчара (грубозрних фелдспатских субграувака и граувака), масивних пешчара, фација клизишта, нормалних турбидита, алевролита и подређених других фација. Рудити носе фрагменте титон-беријаских кречњака, кристаластих шкриљаца и других стена. Чести су олистостроми, флуксотурбидити и танки слојеви конгломерата. Проценат $CaCO_3$ је низак. Међу тешким минералима истиче се гранат (преко 50%), праћен турмалином, рутилом, цирконом и другима. Турбидити су подређени. Они су проксимални, показујући интервал градације и доњи интервал хоризонталне ламинације. Интервал с носи крупну конволуцију, а други интервали су већином одсутни. Трагови на доњим површима слојева су ретки – отисци трагова течења и отисци трагова предмета. Ретки органски трагови показују само најједноставније облике. Оскудна осматрања указују на лонгитудинални палеотранспорт према југ-југоистоку.

Алевролитско-кречњачка јединица

Ова јединица се вероватно јавља у подручју Авала–Космај преко меланжа, са дебљином од 100–200 m. Она се ту састоји од алевролита и лапоровитих кречњака, са нешто калкаренита и микрита. Јединица је најбоље развијена у подручју Брус–Подујево где лежи преко јединице А, са дебљином од 90 до 150 m. Састоји се од алевролитских ламинита, ситнозрних граувака, глинаца и плочастих пелашких микрита, дисталних турбидита, нешто депоната клизишта и ретких нормалних турбидита. Слојеви су већином тамни, танки, а састоје се од ситнозрних стена које одговарају спољњој лепези и басену, можда и активном делу спољње лепезе са довољно стрмим падинама (клизишта). Највећи део јединице граде алевролитско-пелитске стене са много феномена клижења. Градациона слојевитост је ретка, и преовађују различити типови ламинације течења. Органске структуре су бројне и специфичне. У тешкој фракцији преовлађују илменит и магнетит, са ретким гранатом. Микрофауна је оскудна и лоше очувана (ситне глоботрункане, радиоларије, бриозои, фрагменти милиолида) указујући на валендин-отривску старост.

Аренитско-алевролитска јединица

То је најдебља јединица (преко 600 m у Гледићким планинама), која издањује на највећем простору. Њен доњи део је ситнозрнији, док је горњи крупнозрнији. Доњи део јединице носи ретке и танке флуксотурбидите и олистостроме, осим у западном делу подручја Рудника. Турбидити се састоје од танког интервала градације, интервала *b*, интервала *c* са врло карактеристичном ситном косом и таласастом ламинацијом, местимице и конволуцијом. Секвенце су већином подсечене и одсечене, а турбидити су често подређени. Врло чести и карактеристични су нетурбидитски ламинити, депоновани зрно-по-зрно, са ламинациијом течења и ситним траговима таласа који указују на доњи режим тока са ниском енергијом средине. Подморска клизишта су честа у овом делу јединице. Трагови на доњим површима слојева су ретки (отисци трагова отирања и задирања, ретки ситни трагови вучења). Ретки подаци мерени у подручју Гледића показују палеотранспорт према југозападу, ређе истоку, а у подручју Брус–Подујево према југ-југозападу, југу и југ-југоистоку. Депонати овог дела јединице одговарају спољњој лепези, делом и средњој лепези са депозиционим лобовима. Они се већином састоје од дисталних турбидита, турбидита, ређе од организованих шљунковитих пешчара, масивних пешчара, танких слојева ситнозрних пешчара и врло ретких депоната клизишта. Проценат $CaCO_3$ је упадљиво низак. Стене су претежно ситнозрне лискуновите грауваке и алевролити. Овај део јединице дебео је око 80 m у подручју Рудника, а око 200 m у његовом западном делу. У Гледићима дебљина му је око 300 m (према неким проценама чак и преко 600 m), док у подручју Брус–Подујево варира између 150 и 500 m. Фауна је врло оскудна (Рудник), у великом делу транспортована из плићих маринских региона и показала је барем-аптску старост. Горњи део јединице је упадљиво крупнозрнији, састојећи се од дебелослојевитих аренита и микроконгломерата депозиционих лобова средње лепезе, местимице и са каналским асоцијацијама. Карактеристични су организовани шљунковити пешчари. масивни пешчари и нормални турбидити, са нешто дисталних турбидита, организованих конгломерата, неорганизованих шљунковитих пешчара, творевина клизишта и олистострома. Палеотранспорт је у северном делу трога према југ-југозападу, а у Гледићима према југоистоку. Дебљина износи 350 m у западном делу подручја Рудника; у источном делу овог дела јединице нема, а у Гледићима дебљина расте на неких 100 m. Према подручју Брус–Подујево дебљина овог дела јединице поново расте на 300 m.

Кречњачко-аренитска јединица

Ова јединица, већином дебела 100 до 150 m, карактерише се високом садржајем $CaCO_3$ у већини стена, и релативним богатством аренита. Она одговара спољњој лепези са извесним утицајима басена и активног дела спољње лепезе. Састоји се највећим делом од дисталних турбидита и танкослојевитих ситнозрних пешчара, са нешто типских турбидита, депоната клизишта и пелашких до хемипелашких творевина, уз мало масивних пешчара. Турбидити су већином без интервала градације, са осталим добро развијеним интервалима. Местимично се запажају и сенилни турбидити, али ортоламинити преовлађују. Најважнији су алевролити, субграуваке и вапновите грауваке, заједно са лапорцима, лапоровитим микритима и градираним песковитим интраспаритима. У доњем делу јединице преовлађују ламинирани лапорци, а за горњи део јединице карактеристични су кречњачки ламинити и интраспарити у добро одвојеним слојевима. У тешкој фракцији доминира епидот, са нешто турмалина и илменит-магнетита. Трагови на доњим површима су изванредно ретки, а представљени су углавном отисци трагова предмета. Палеотранспорт је према југ-југозападу до југ-југоистоку. У биомкритима су нађене ситне пелашке глобигерине заједно са транспортованим формама, што све указује на алб–ценоман.

Маргиналне јединице

Јужни завршетак парафлишне области карактерише изразита промена фација, тако да се јединице из главнине трога више не могу разазнати. Депонати трога граде овде појас широк неколико километара, са две јединице које се међусобно разликују: олистостромском (E1) и карбонатно-кластичном (E2). Структура подручја не дозвољава сигурну одредбу односа ових јединица, али је олистостромска вероватно нижа. Бочни односи ових јединица са главнином трога нису видљиви, али се оне сматрају еквивалентима виших јединица трога, са могућим прелазом у ценоман. Јединица показује јасан проксимални карактер, депонована на нестабилној падини. Олистостромска јединица се састоји углавном од олистострома, организованих конгломерата, масивних пешчара и турбидита, нормалних и дисталних. Олистостроми су дебели и преко 10 m. Они се састоје од алевритске основне масе са кластима и деловима слојева аренита из саме јединице, са нешто фрагмената кристаластих шкриљаца из суседне Велешке серије. Аренити граде дебеле слојеве са бројним депонатима клизишта. Конгломерати су ређи, са валуцима већином од кварца и лидита, заједно са стенама из саме јединице у депонатима клизишта. Карбонатно-кластична јединица, дебела вероватно око 150 m, углавном је грубозрна. Она се састоји од дебелих слојева калцирудита са микроконгломератима, грубозрним аренитима и ламинираним лапоровитим алевролитима. Турбидити се јављају само изузетно. Хоризонти кречњака су дебели по неколико метара, показујући врло често карактеристичну секвенцу: рудитски базални део, са фрагментима кречњака до 10 cm у пречнику; они се градирају у кластите од валутака пречника 2–3 cm; секвенце се завршавају грубо ламинираним песковитим калкаренитима и најзад листастим микритима. Неке сличне секвенце, са истом организацијом дебеле су и више декаметара. У овим јединицама нису нађени фосили.

Депозициона историја басена

Реконструкција кретања у басену била је увелико отежана бројним факторима. Депонати басена су, пре свега јако тектонизовани, тако да је оригинална ширина басена увелико редукована набирањем и тектонским раскидањем и раздвајањем делова. То је утицало и на нејасност дебљина и односа јединица. Интерпретација депозиционих средина је на неким местима несигурна за поједине јединице, пошто су осматрања потребна за добијање закључака била недовољна. Осматрања су вршена у разна времена, од стране разних истраживача и на бази различитих схватања. Временске координате јединица одређене су врло нашироко и на бази оскудне документације, пре свега због ретке и слабо очуване фауне, као и због јасног мешања фауне различтог порекла у изворима података (из валутака и фрагеманата из истодобних твревина; редепоноване из старијих слојева) што је отежавало искоришћавање и интерпретацију података. Подаци о палеотранспорту нису систематски прикупљани током картирања тако да оно мало њих потиче из изолованих итинерера седиментолога. Ови подаци показују широко расипање, за које разлог није јасан (расипање палеотранспорта, превише мали узорак). То је учинило практично немогућим реконструкцију геометрије басена. Најзад, интерпретације су биле неопходно оптерећене концепцијама истраживача гдегод је недостајала одговарајућа материјална аргументација. Због тога су могућа само прелиминарна разматрања, базирана на постојећим подацима. Врло оскудна осматрања палеотранспорта показују преовлађивање лонгитудиналног југ-југоисточног смера, уз широко разасуте бочне правце који показују да је басен био храњен и са западног и са источног обода. То искључује идеју о депозиционом басену као маргиналном застору, и дефинише га као трог који је са обе стране имао изворишна подручја материјала. На то такође указује и присуство плиткоморских творевина најгорње јуре дуж делова оба обода парафлишног басена, што искључује океанску хипотезу депозиције. Кластична база се јавља само у подручју Авала–Космај као танак застор испод јединице В, и дуж источног обода подручја Брус-Подујево, где гради дебелу подину јединице А. То упућује на идеју да је басен суперпонован преко офиолитског меланжа у хоризонтално разуђеном простору, где је тоњење почело на југоистоку, са катастрофичним потањањем и веома брзом денудацијом. Створен је систем са депонатима средње лепезе само у источном делу подручја Брус–Подујево (јединица А), са могућим делимичним простирањем све до западног обода. Депонати спољње лепезе следе (јединица В) што се запажа практично дуж целог источног обода. Ако се узме у обзир одсутност јединице В у једном делу западног обода (Врњци) може се претпоставити да секвенца указује на миграцију басена према истоку. Доњи део јединице С (С1), који напредује према западу, вероватно означава једну проградациону фазу представљајући депозицију у средњој до спољњој лепези са депозиционим лобовима. Јединице С2 нема северно од Гледића. Она је депонована у средњој лепези са каналима. Појављивање ове јединице само у Гледићима и у подручју Брус-Подујево могло би указивати на даљу проградацију са изградњом једне уже лепезе на југоисточном делу области. То потврђује и палеотранспорт према југозападу и југ-југозападу осматран на листу Краљево у овој јединици.

Склоп басена

Реконструкција интерне структуре басена била је увелико отежана бројним факторима. Набирање је веома сложено, са честом транспозицијом ss-површи и широким тектонским зонама које прекидају континуитет јединица. Степен деформисаности је крајње неуједначен – постоје делови стуба где су слојеви мирни и униформни, једва деформисани, заједно са декаметарским до хектометарским подручјима која су крајње деформисана и разломљена дуж кливажа или шкриљавости. Главне s-површи у великом делу стуба представља кливаж, који деформише слојевитост и до потпуне транспозиције. Анализа слојевитости урађена је на различитим нивоима, од најрегионалнијег до детаљних. Дијаграми склопа показују оријентацију слојних површи за цео басен како је забележена на штампаним картама и мерена на терену (укупно 1383 пола; D-01), у сваком од 8 блокова на које је басен био подељен (D1 до D8) и на теренским осматрањима. Сви дијаграми су рађени рачунарским програмом Сферистат, те се донекле разликују од оних који се раде ручно.

Све ss површи (D.01)

Полови слојевитости су широко расути око главног максимума који одговара паду 75/47, са субмаксимумом 251/46. Статистичка б-оса тоне 163/3, а статистичка аксијална раван је грубо вертикална 163–343. Ови подаци се поклапају са пружањем парафлишног трога (163–343). На дијаграму полова D.01 види се да су подаци јако расути и да је склоп слабо уређен. Склоп је грубо моноклиничан, одговарајући виртуалном асиметричном набору са боље развијеним северозападним и слабије развијеним југозападним крилом, са субхоризонталном осом и вертикалном аксијалном равни.

Преврнути слојеви (D.02)

У дијаграму D.02 са 30 полова преврнутих слојева појављују се два максимума који одговарају падовима 89/66 и 249/74, а праћени су субмаксимумима 63/65, 7/78 и 1/54 са преврнутим слојевима скоро подједнако распоређеним у оба максимума. То показује да набори у области немају униформну вергенцу, него граде неку врсту лепезе са вергенцама и према запад-југозападу и према исток-североистоку.

Осе набора (D.03)

Осе b биле су мерене на свим cm-m наборима где је то било могуће (укупно 111 мерења). Полови граде максимум који одговара тоњењу од 356/18, са широким и дисконтинуираним појасом управном на осу *a*. Добар пример оријентације b оса показује дијаграм D.04 (домен Мерћез–Куршумлија) где су полови расејани дуж круга управног на нову *b* осу и дијаграм D.05 (Мургула), где осе граде максимум на 28/60.

Аксијалне површи (D.05)

На терену су мерене 44 аксијалне површи набора, већином метарских величина. Број мерења је доста мали, пошто су на терену такви набори осматрани само изузетно. Полови су расути, са два максимума који одговарају падовима 98/82 и 49/72. Иако су стрми, ови максимуми се не поклапају са виртуелном аксијалном равни свих познатих сс површи – осматрани метарски набори показују западну и југозападну вергенцу.

Кливаж (D.06)

Механичке с површи које не представљају слојне површи означаване су као кливаж. Измерено је 166 равни у целој области парафлиша. Дијаграм показује максимуме 70/44 и 0/0, што би одговарало наборима главне фазе.

Пресек кливажа и слојева (D.07)

Кад је кливаж паралелан са аксијалним површима а набирање је регуларно са ромбичном или моноклиничном симетријом, пресечне праве слојева и аксијалног кливажа треба да буду паралелне са регионалном осом набора. Дијаграм D.08 приказује 125 пресека конструисаних на свим осматраним наборима. Полови су расути у расплинутом појасу нормалном на осу *a*, са неколико максимума од којих је регионалној оси *b* најближи онај са тоњењем 148/20. Ово показује да је симетрија склопа блиска триклиничној симетрији.

Набирање – ближе испитивање

Да би се избегло "пеглање" својстава наборног склопа сувишном генерализацијом област је подељена на 8 блокова (D1–D8). Најмањи је блок 1 (северозападни обод) који једини садржи базу, док су остали блокови мање-више подједнаке величине. Табела 1. показује да само блок 4 изразито одступа јер су у њему већином падови ка југозападу, док у осталим блоковима претежу падови ка југоистоку.

Дискусија

Дијаграми појединачних блокова показују да је део области претрпео благу ротацију око осе а, која није била праћена пенетративном деформацијом стена (D8). Блок 4 показује ротацију око осе *a*, тако да је вероватно представљао осу регионалне ротације. Ово испитивање показује такође да се правилности познате из модела елипсоида деформација могу практично користити само у широком статистичком смислу, и да појединачна мерења треба посматрати са одговарајућом сумњом.

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Stratigraphy of the Krš Gradac section (SW Serbia)

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Abstract. In the Krš Gradac section (near to Sjenica, SW Serbia), a transition of a carbonate platform to basin facies are outcropped: Norian-lower Liassic shallow-water carbonates, middle Liassic–lower Dogger *Ammonitico Rosso* facies, and upper Bathonian into lowermost Cretaceous deep-water radiolarites in which the carbonate graded bed and mass flow layer are intercalated.

The presence of a lower Dogger condensed sequence with the Bajocian protoglobigerinid event was hitherto not evidenced.

It is documented that components of a graded bed are of extrabasinal (upper Triassic–lower Tithonian carbonate platform sediments) and intrabasinal (radiolarite, meta-andesite) origin, indicating a tectonic event not older than the early Tithonian. This tectonic event caused the fracturing of the carbonate platform, also partly basinal area. Consequently, the age of the graded bed is not older than the lower Tithonian.

In the uppermost radiolaritic sediments in the Krš Gradac section (?middle–upper Tithonian–lowermost Cretaceous), a mass flow layer appears, which contains clasts of intrabasinal origin – different radiolarites, siliceous radiolarian argillites (some of which are unconsolidated with washed radiolarians and sponge spicules in a ferruginous sediment), sandstone grains, *etc*. The mass flow event is estimated as Berriasian.

In the Krš Gradac radiolarite succession, the authors recognized two deep-water formations, an older one, upper Bathonian–lower Tithonian, between hardground (Dogger) and a graded bed, and a younger formation, which started with a graded bed. This formation, according to its stratigraphic position, corresponds to ?middle–upper Tithonian–lowermost Cretaceous.

Key words: stratigraphy, Jurassic–lower Cretaceous, carbonates, siliciclastites, condensed limestone sequence, graded carbonate bed, mass flow layer, Krš Gradac section, SW Serbia.

Апстракт. На локалитету Крш Градац откривена је сукцесија која обухвата прелаз од фација карбонатне платформе до дубоководних басенских седимената: норичко–доњолијаских плитководних карбоната, седимената средњег лијаса–доњег догера *Ammonitico Rosso* фације и дубоководних радиоларита (са уметнутим карбонатним градираним слојем и mass flow слојем) који су депоновани од горњег бата до у најстарију доњу креду.

Кондензована секвенца доњег догера са протоглобигеринидама до сада није била евидентирана.

Анализом компоненти градираног слоја документовано је присуство плитководних седимената карбонатне платформе од горњег тријаса до доњег титона, као и седимената интрабасенског порекла (радиоларити, метаандезити). Овакав састав градираног слоја указује на тектонски догађај који је проузроковао разарање карбонатне платформе, као и дела басенског ареала, а који није старији од горњег титона. У најмлађем делу радиоларита Крша Градца (?средњи–горњи титон – најнижа креда) евидентиран је mass flow слој који садржи интрабасенске класте – различите радиоларите, силицијске радиоларијске глинце (нпр. из неконсолидованих потичу испране радиоларије и спикуле спонгија, расуте у основном гвожђевитом седименту). Овај слој се приписује беријасу.

У сукцесији радиоларита Крша Градца аутори препознају две дубоководне формације: старију, од горњег бата до доњег титона, између хардграунда преко кондензоване доњодогерске секвенце и градираног слоја, и млађу, која почиње градираним слојем, а на основу стратиграфског положаја одговара временском интервалу ?средњи–горњи титон – најнижа доња креда.

Кључне речи: стратиграфија, јура–доња креда, карбонати, силицикластити, кондезована кречњачка секвенца, градирани карбонатни слој, mass flow слој, Крш Градац, ЈЗ Србија.

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Introduction

The Krš Gradac section is well known in the geological literature of the SW part of Serbia. It, as one of the most well-exposed and interesting sections belonging to the older Mesozoic of the Dinarids of Serbia and has inspired geologists for many years, particularly because of the age determination of the traditional, known Diabase-Chert Formation of the Balkan Peninsula area.

Except two papers of HAMMER (1921), and PETKOVIĆ (1934) in which limestones from this locality were considered as Triasssic in age, in the other numerous papers (ALBRECHT 1925; KOSSMAT 1924; LEDEBUR 1941; ĆIRIĆ 1954, 1984, 1996; RADOIČIĆ-BRSTINA 1956; RADOIČIĆ 1962; JOVANOVIĆ Ž. 1963; RAMPNOUX 1974; JOVANOVIĆ O. *et al.* 1979; GRUBIĆ 1980; LJUBOVIĆ-OBRADOVIĆ *et al.* 1998; *etc.*) different ages, based on ammonite and brachiopod fauna and microfossil associations, from upper Triassic to upper Liassic were assigned to these sediments. For the Liassic part of this section, the unformal name Krš pod Gradcem Formation was proposed (LJUBOVIĆ-OBRADOVIĆ *et al.* 1998; RADOVANOVIĆ *et al.* 2004).

During last 20 years, the radiolarian fauna from radiolarites and different siliceous rocks belonging to the upper part of Krš Gradac section was studied (DJERIĆ 2002; VISHNEVSKAYA *et al.* 2009; GAWLICK *et al.* 2009; unpublished data of Š. GORIČAN, L. DOSZTÁLY). According to the results of these studied, the age of Krš Gradac radiolarites was documented by different radiolarian assemblages as being from the upper Bathonian to the lower Tithonian.

The aim of this paper is to present the stratigraphy of the Krš Gradac section in regards to: a) the condensed limestone sequence (the lowermost part of the Dogger) for which no published data exists; b) the composition of the graded carbonate bed (which is not older than middle–upper Tithonian) and its significance and c) the presence of a mass flow layer of assumed Berriasian age. The paper is based on new investigations of the authors, including data of R. RADOIČIĆ, sampled in 1968, from the carbonate part of section, which is still lacking. In this manner, presenting data, especially those dealing with the condensed sequence, gives a more complex access to fill the lack of the stratigraphy of the area. The carbonate part of the Krš Gradac section was devastated during work on the road to the Jadovnik Mt. The destruction of the siliciclastics has continued to date because of stone exploitation for the construction of roads.

Geological setting

According to the last published geological map (Sheet Prijepolje 2, 1:50 000, RADOVANOVIĆ *et al.* 2004), ophiolite mélange in the western and northwestern region of Sjenica is widely distributed. In the mélange are embedded blocks, olistoliths and slides of carbonate rocks, gabbros, pillow lavas, ultramafics, as well as some exotic granite. According to GAWLICK *et al.* 2009, one of these sedimentary bodies, below the Middle Jurassic mélange, is the Krš Gradac tectonic slice (carbonates and radiolarites).

Krš Gradac section

The Krš Gradac section (Fig. 1; coordinates: x 4793454, y 7416424), is located on the western side of the road Sjenica–Nova Varoš, on the SW slope of the Gradac Hill. Generally, the geological column of this section consists of carbonatic and siliciclastic parts which are in tectonic contact with the mélange.

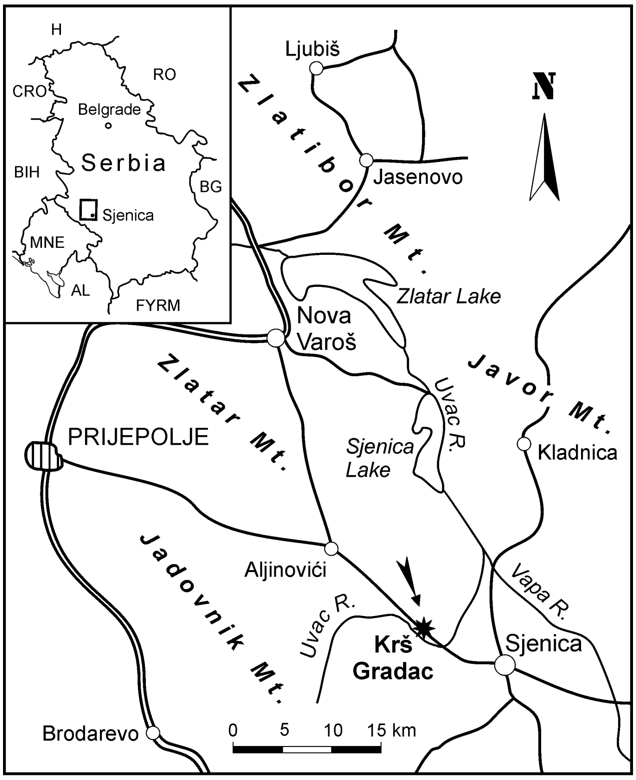

Fig. 1. Geographic position of the Krš Gradac section.

The oldest are massive limestones of upper Triassic age of the Dachstein type and lower Liassic shallow-water carbonates, then Middle Liassic–Lower Dogger *Ammonitico Rosso* and *Bositra*-protoglobigerinid facies which ends with hardground. The succession continues into middle Jurassic–lowermost Cretaceous radiolarites in which the middle part is intercalated with the graded bed and the mass flow layer in the upper part.

In this paper, in the stratigraphic column of the Krš Gradac section, only the middle Liassic–lowermost Cretaceous sediments, which are in five separated units (Fig. 2, units A–E) were studied.

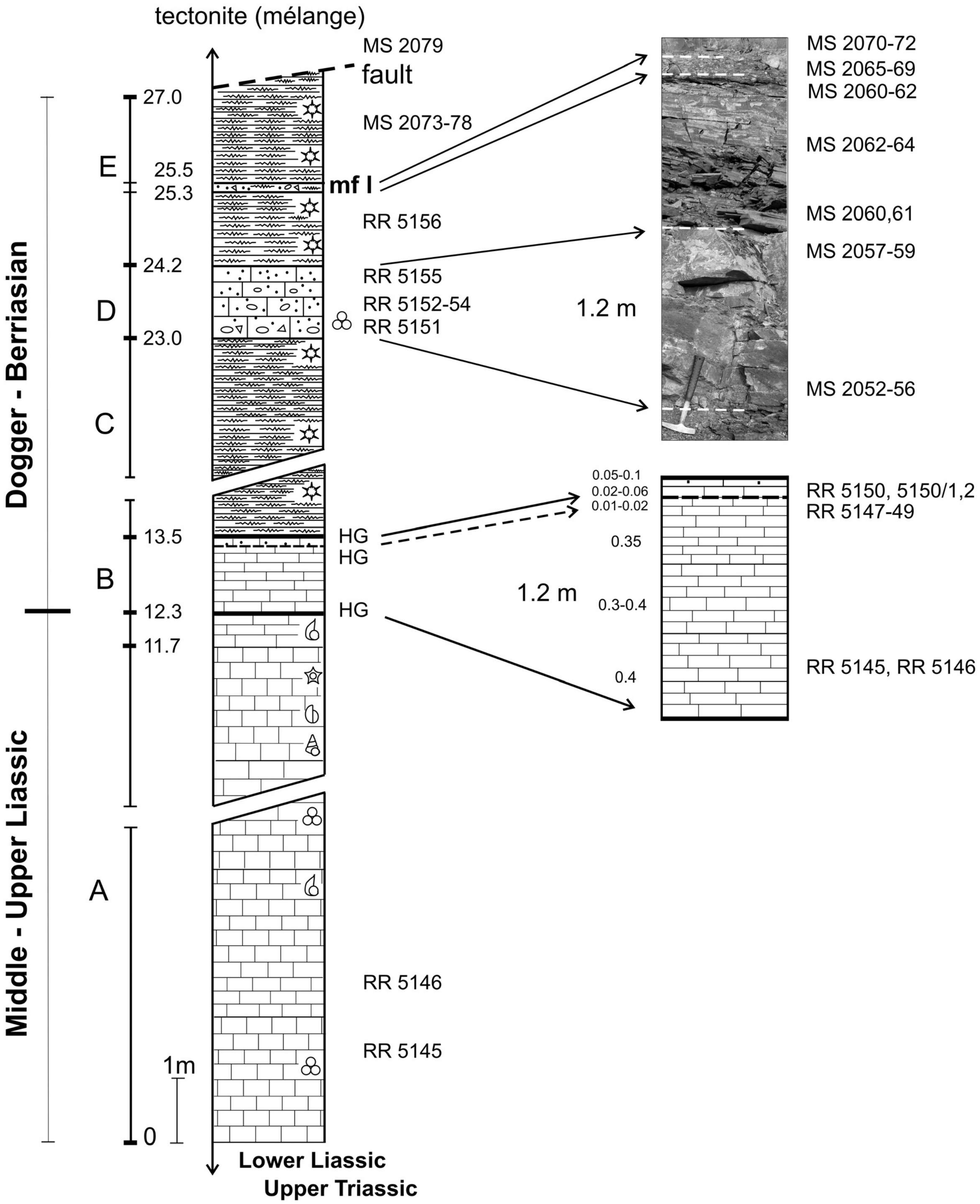

Fig. 2. Stratigraphic column of the Krš Gradac section (Abbreviations: mf l = mass flow layer; HG = hardground).

Unit A

The unit A, 12.3 m thick, is of Middle and Upper Liassic limestones of *Ammonitico Rosso* type facies.

In the lower part of unit A (facies with *Involutina liassica*), a little known brachiopod of the genus *Koninckella* is found (Pl. 6, Figs. 11, 12).

The unit ends with a 0.6 m thick, in upper part reddish wackestone, with middle Toarcian ammonites: *Hildoceras bifrons, Lithoceras septatum*, *Calliphyloceras capitanioi, Harpoceratoides strangewaysi* (Ćirić 1954; Rampnoux 1974), and a rich foraminiferal fauna – *Involutina liassica, Agerina martana, Ophthalmidium* cf. *macfadyeni, Trocholina* sp., then *Lingulina, Dentalina, Nodosaria* and other lagenids (Radoičić 1962). This bed is covered by thin hardground.

Unit B

The unit B is represented by a 1.2 m thick, condensed red limestones sequence made up of:
- 0.4 m reddish wackestone with scarce biota;
- 0.3–0.4 m reddish wackestone with rare fossils;
- 0.35 m, wackestone with rare ammonites and brachiopod embryos, mollusk fragments and minute echinoderm grains (Pl. 1, Fig. 1). This bed in the upper part passes into dark red, ferruginous pervaded wackestone with filaments debris (Pl. 1, Fig. 2), followed by thin hardgound;
- 0.01–0.02 m dark red, ferruginous pervaded wackestone with a few ammonite embryos and rare filaments;
- 0.02–0.06 m pink limestones in which is clearly visible a minor discontinuity between (a) slightly deformed and altered wackestone with a rough surface containing irregularly dispersed *Bositra* fragments (Pl. 1, Figs. 3a, 4a), and overlying (b) packstone with mm laminae of more or less accumulated *Bositra* filaments or fragments, some ammonite embryos, a few microgastropods, numerous protoglobigerinids and rare minute *Spirillina* and *Ophthalmidium* (Pl. 1, Figs. 3b, 4b, and 5–7);
- 0.05–0.1 m, a very ferruginous dark red sediment with hardground.

The age of the condensed sequence is lower Dogger. Limestones, 1 m thick, between middle–?upper Toarcian and the Bajocian protoglobigerinids event, according to the stratigraphic position correspond to the Aalenian. The latest, uppermost part of the condensed sequence, a very ferruginous dark red sediment with hardground, which could be ?uppermost Bajocian–lower Bathonian, because it is overlain by upper Bathonian–Oxfordian radiolarites (VISHNEVSKAYA *et al.* 2009).

Unit C

Unit C, 9.5–10 m thick, is composed of red, green and dark radiolarites and cherts with intercalations of red radiolarian shales (Fig. 3). According to the available data based on radiolarian assemblages and UAZs (VISHNEVSKAYA *et al.* 2009) the age of this unit is upper Bathonian–Oxfordian.

Unit D

Unit D is represented by a 1.2 m thick graded carbonate bed (which laterally became thinner), intercalated in red radiolarite (Fig. 4a, Pl. 2, Figs. 1–6, Pl. 3, Figs. 1–3). The size of the grains vary from 1–10 mm, and decrease up into 0.02–0.06 mm in fine-grained, well-sorted calcarenite (Fig. 4b). Between the grains is rare sparite, at place ferruginous. The components of bed are mostly different shallow water carbonates, less present are argillites, siliceous argillites, with more or less frequent radiolarians (some filled with chlorite), radiolaritic micrites, cherts, spongolites, *etc*., and grains of magmatic rocks, such as meta-andesite. Quartz grains are rare.

Fig. 3. Siliciclastics of the western part of the Krš Gradac section. The arrows show the position of the graded bed (unit D).

The shallow-water carbonate grains are mostly wackestones. Some of them contain unspecified biogene debris, others algae, foraminifera, or different bioclasts. Some grains are sparites-biosparites, or rare ooides. Recrystallized grains also occur. Numerous of these grains are of Upper Jurassic age and contain: *Clypeina jurassica, Salpingoporella* sp.; *Radiomura cautica* (Pl. 6, Figs. 1–9) and foraminifera *Protopeneroplis striata, Parurgonina caelinensis, Labyrinthina mirabilis, Mohlerina basiliensis*. A few grains can be ascribed to the Liassic. Grains of shallow water upper Triassic limestones are also present (Pl. 3, Fig. 3; Pl. 6, Fig. 10).

The uppermost part of the graded bed is calcarenite with sponge spicules (Pl. 3, Fig. 4).

The unit is not older than lower Tithonian, probably ?middle–upper Tithonian.

Unit E

The total thickness of unit E is 3.8 m**.** It commences with argillitic limestones, with laminae bearing sponge spicules and spongolite (Pl. 3, Figs. 5, 6), continues into parallel laminated red radiolaritic argillites and shales, shales with radiolarians, cherts, radiolaritic cherts (in some, laminae radiolarians are deformed, flattened, or calcified; Pl. 4, Figs. 1, 2). This part of unit E, below the flow mass layer is 1.1 m thick.

Upward the 0.07–0.2 m thick, loosely packed ferruginous **mass flow layer** occurs (Fig. 5; Pl. 4, Figs. 3–6, Pl. 5. Figs. 1–3), made predominantly of grains of dif-

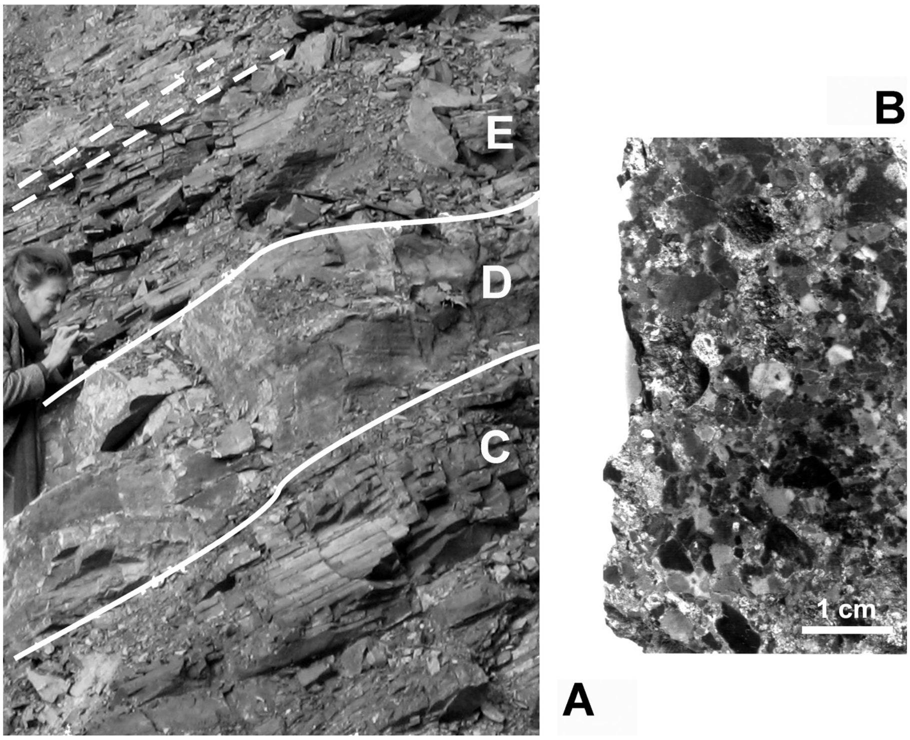

Fig. 4. **A,** Detailed view of the different units (C, D, E) from the Krš Gradac section; **B,** Polished sample from the basal part of the graded bed (horizontal section).

ferent radiolarites, argillites, radiolaritic argillites, unconsolidated and an unequally destroyed sediment with large radiolarians. They are partly washed, or washed and dispersed in ferruginous matter mixed with microcrystalline quartz. Grains of rare sandstone fragments are also present. The components of the flow mass layer are of intrabasinal origin, which indicates that the event resulted in intrabasinal destruction of a part of deep water sediments.

Fig. 5. Mass flow layer of unit E.

The studied stratigraphic column ends with 1.5 m thick argillitic and ferruginous cherts, radiolaritic cherts and radiolarites. Very interesting are radiolarians filled with chlorite or a bed disturbed in a semi-consolidated condition with rare grains of radiolaritic cherts, sandstones, carbonized radiolarites and radiolaritic cherts (Pl. 5, Figs. 4–6).

According to its stratigraphic position, unit E is not older than ?middle–upper Tithonian into the lowermost Cretaceous. The mass flow layer, presumed the consequence of intrabasinal activity, can be estimated as Berriasian.

The uppermost part of the radiolaritic sequence of unit E is followed by tectonite (mélange) in which cm–dm blocks of meta-andesite (sample MS 2079) are present.

Discussion

The lower part of the red condensed limestone sequence (unit B), between the middle (?partly upper) Toarcian and Bajocian protoglobigerinid layer, correspond to the ?latest Toarcian–Aalenian time interval. There is no discussion about to which part of the Bajocian the protoglobigerinid event could be ascribed. The top of the condensed sequence, *i.e.*, dark red sediments with hardground, partly ?Bathonian, is overlain by a red argillite-radiolarite succession. In this lower part of the sequence, the radiolarian assemblage of upper Bathonian to lower Callovian (co-existence of *Pterotrabs marculus* and *C. carpathica*) and the middle Callovian to Oxfordian (UAZz 8–9 with *Archaeodictyomitra minoensis*, *E. unumaense* sl. and *Z. ovum*) are documented (VISHNEVSKAYA *et al*., 2009).

The components of the graded bed (unit D), according to data from this paper, are of extrabasinal and intrabasinal origin. The extrabasinal grains (upper Triassic–

–lower Tithonian) indicate deposition in carbonate platform/ramp environments (presently, not known *in situ* in large adjacent Dinaridic area). Subordinate are grains of intrabasinal origin, such as siliceous argillites, with or without radiolarians, radiolarites (some of them are ?Triassic), radiolarian micrites, cherts and magmatic rocks.

The mass flow layer, which occurs in unit E, contains different fragments of deep basinal sediments, including those of unconsolidated radiolarite. This indicates a ?latest Tithonian–Berriasian event which caused the destruction of a part of the deep basin sequence. The mass flow event is considered as Berriasian.

In the radiolarites from the lowermost parts of the unit E according to the former investigations (Vishnevskaya *et al.* 2009) the youngest radiolarians of middle Oxfordian to early Tithonian age (UAZs 9-11 with the species *A. minoensis, Z. ovum* and *T. brevicostatum*) are documented.

The Krš Gradac section represents a typical transitional succession from a carbonate platform into a basin: the uppermost Triassic platform of Dachstein type is followed by Lower Liassic shallow-water carbonates. Furthermore, from the middle Liassic to Bajocian, an *Ammonitico Rosso* facies of a drowned platform and Bajocian *Bositra*-protoglobigerinid limestones were sedimented, which ends in a dark red sediment and hardground. Intensive basin deepening is characterized by sedimentation of deep basinal radiolarites through the late Bathonian into the earliest Cretaceous. The slow basin sedimentation was interrupted during the ?middle–upper Tithonian (carbonate graded bed), as a consequence of a tectonic event, *i.e.*, the fracture of the carbonate platform and also the adjacent area of the basin. This important tectonic event can not be older than ?latest Kimmeridgian–early Tithonian; consequently, unit E can not be older than the ?middle–upper Tithonian.

Siliciclastics over limestones in the upper part of Krš Gradac succession was considered mostly to be a part of the Diabase-Chert Formation, *i.e.*, volcanogeno-sedimentary series or an ophiolitic complex of different ages: Jurassic (Ćirić 1954), middle–upper Jurassic (Jovanović 1963; Ćirić 1984, 1996) and Tithonian (Jovanović O. *et al.* 1979; Grubić 1980), *etc.*

According to Rampnoux (1974), the breccia intercalations inside the siliciclastics (= in this text graded bed, unit D and mass flow layer in unit E) contain Liassic–Portlandian biota. Therefore, Rampnoux (*op. cit.*, p. 46) concluded that an important stratigraphic gap existed between the middle Toarcian with hardground and the volcanogeno-sedimentary formation, which was dated "au moins du Malm supérieur". Consequently, the siliciclastics below the breccia intercalations, has also been ascribed to the upper Malm. Between the underlying limestones and the Diabase-Chert Formation, Ćirić (1984, 1996) observed certain discordances, which indicate some tectogenetic movements on the boundary between the Liassic–Dogger, *i.e.*, to the influence of the late Kimmerian phase in the Dinarides.

Radovanović *et al.* (2004) assigned the siliciclastics to one unformal Zlatar Formation of upper Triassic– Tithonian age. Gawlick *et al.* (2009) treated them as a Middle to Upper Jurassic/?Lower Cretaceous part of the Upper Triassic–?Lower Cretaceous tectonic slice below the radiolaritic-ophiolitic mélange. Besides, the whole complex succession of Krš Gradac is interpreted as "a tectonic window or as a tectonically incorporated sliver scraped off the footwall due to younger tectonic shortening" (*op. cit.*, p. 299).

The authors of this paper, also did not include the mentioned siliciclastites into tectonite (mélange) and inside of them recognized two deep-water argillite-radiolaritic formations: an older, upper Bathonian–lower Tithonian (below the graded bed) and a younger, ?middle–upper Tithonian – lowermost Cretaceous, which commenced with the graded bed.

Suplementary note (R. Radoičić)

The distribution of the Liassic sediments of the proximal basinal facies (limestones with *Involutina farinacciae*) in the eastern Zlatibor Mt. (Drežnik) and Sjenica area (Vrelo) is a fact that should be mentioned.

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Резиме

Стратиграфија седимената локалитета Крша Градца (ЈЗ Србија)

Локалитет Крш Градац је добро познат у геолошкој литератури југозападног дела Србије. Као један од најбоље откривених и интересантних профила старијег мезозоика Динарида Србије, био је тема истраживања геолога и раније, нарочито са аспекта одређивања старости традиционално познате дијабаз-рожначке формације са простора Балканског полуострва. Налази се на западној страни пута Сјеница–Нова Варош и на југозападним падинама брда Градац. Геолошки стуб је састављен од карбонатних и силицикластичних делова који су у тектонском контакту са меланжом.

Најстарији седименти су масивни горњотријаски кречњаци дахштајнског типа и доњолијаски плитководни карбонати, после којих следе седименти средњолијаске–доњодогерске *Ammonitico Rosso* и *Bositra*-протоглобигеринидске фације који се завршавају hardground-ом. Сукцесија се продужава средњојурско–доњокредним радиоларитима у чији је средњи део уметнут градирани, а у виши mass flow слој.

У раду су у оквиру стратиграфског стуба локалитета Крш Градац проучавани само средњолијаско–најнижи делови доњокредних седимената и они су раздвојени у пет јединица.

Јединица A је дебела 12,3 m и чине је средњо и горњолијаски кречњаци фације типа *Ammonitico Rosso*. Јединицу B гради 1,2 m дебела секвенца црвених кречњака доњодогерске старости са три hardground-а. Црвени, зелени, тамносиви до скоро црни радиоларити и рожнаци са уметнутим црвеним радиоларитским шкриљцима сачињавају јединицу C дебелу 9,5–10 m; њена старост је горњи бат–оксфорд. Јединица D је представљена са 1,2 m дебелим градираним карбонатним слојем који је уложен у црвене радиоларите и са старошћу која није старија од доњег титона, а вероватно је ?доњи–горњи титон. Укупна дебљина силицикластита јединице E је 3,8 m, а у њеним средњим деловима налази се 0,07–0,2 m дебео mass flow слој. Сагласно стратиграфском положају јединица E није старија од ?средњег–горњег титона до у најнижу креду, а mass flow слој, узимајући у обзир последице активности унутар басена, може бити прихваћен као беријаски. Изнад највишег дела радиоларитске секвенце јединице E следи тектонит (меланж) са cm–dm блоковима метаандезита.

Доњи део црвене кондензоване кречњачке секвенце (јединица B), између средњег (?делимично горњег) тоарског и бајеског протоглобигеринидског слоја одговара временском интервалу ?најкаснији тоарс–ален. У овом моменту не постоје аргументи којем делу бајеса би се могао приписати протоглобигеринидски догађај. Врх кондензоване секвенце, тј. тамно црвени седименти са hardground-ом, делимично ?батске старости је препокривен црвеном аргилитско-радиоларитском сукцесијом.

У доњем делу јединице C документоване су радиоларијске асоцијације горњег бата до доњег келовеја (заједничко појављивање *Pterotrabs marculus* и *C. carpathica*) као и средњег келовеја до оксфорда (UAZz 8–9 са *Archaeodictyomitra minoensis*, *E. unumaense* s.l. и *Z. ovum*) (VISHNEVSKAYA *et al.* 2009).

Компоненте градираног слоја (јединица D), на основу података из овог рада, су екстрабасенског и интрабасенског порекла. Екстрабасенска зрна (горњи тријас–доњи титон) указују на депоновање у амбијентима карбонатне платформе/рампе (данас непознате на месту у оквиру оближњих пространих Динаридских региона). Зрна интрабасенског порекла су силицијски аргилити, са или без радиоларија, радиоларити (неки од њих су ?тријаски), радиоларијски микрити, рожнаци и метаандезити.

Mass flow слој, из вишег дела јединице E, садржи различите фрагменте дубоких басенских седимената, укључујући и оне од неконсолидованих радиоларита. Такође, он указује и на ?најкаснији титонско–беријаски догађај који је проузроковао разарање дела секвенце дубоког басена. Mass flow слој је разматран као беријаски.

Из радиоларита најнижих делова јединице E досадашњим истраживањима (VISHNEVSKAYA *et al.* 2009) документоване су најмлађе радиоларије средњооксфордске до доњотитонске старости (UAZs 9-11 са врстама *A. minoensis, Z. ovum* и *T. brevicostatum*).

Седименти локалитета Крша Градца представљају типичну прелазну сукцесију од карбонатне платформе у басен: седименте највиших делова тријаске платформе дахштајнског типа следе доњолијаски плитководни карбонати. Касније, од средњег лијаса до бајеса, депоновали су се *Ammonitico Rosso* фација потопљене платформе и бајески *Bositra*-протоглобигеринидски кречњаци, који се завршавају са тамно црвеним седиментом и hardground-ом. Интензивно басенско потапање је окарактерисано седиментацијом дубоких басенских радиоларита кроз касни бат до у најранију креду. Лагана басенска седиментација била је прекинута у време ?средњи–горњи титон (карбонатни градирани слој), као последица тектонског догађаја, тј. разламања карбонатне платформе, а такође и околних области басена. Овај значајан тектонски догађај не може бити старији од ?најкаснијег кимерица–раног титона, тако да сагласно томе, јединица E не може бити старија од ?средњег–горњег титона.

Силицикластити који се налазе изнад кречњака у горњем делу сукцесије Крша Градца углавном су сматрани као део дијабаз-рожначке формације, тј. вулканогено-седиментне серије или офиолитског комплекса различите старости: јурске (ĆIRIĆ 1954), средњо–горњојурске (JOVANOVIĆ 1963; ĆIRIĆ 1984, 1996), титонске (JOVANOVIĆ O. *et al.* 1979; GRUBIĆ 1980) итд.

RAMPNOUX (1974) наводи да уметнута бреча унутар силицикластита (у овом тексту то је градирани слој, јединица D) садржи микрофосиле лијаско–портландске старости. На основу тога RAMPNOUX (претходни цитат, стр. 46), закључује да постоји значајна стратиграфска празнина између средњег тоарса са hardground-ом и вулканогено-седиментне формације која је датирана “au moins du Malm supérieur”. Сагласно наведеном, силицикластити испод уметнуте брече, могу такође бити приписани горњем малму. Између подинских кречњака и дијабаз-рожначке формације ĆIRIĆ (1984, 1996) запажа благу дискорданцију која указује на одређене тектогенетске покрете на граници између лијаса и догера, тј. на утицај касно кимеријске фазе у Динаридима.

RADOVANOVIĆ *et al.* (2004) уврштују силицикластите у неформалну формацију Златара горњотријаско–титонске старости. GAWLICK *et al.* (2009) сматрају их средњо до горњојурским–?доњокредним делом горњотријаско–?доњокредне тектонске слице испод радиоларитско-офиолитског меланжа. Поред тога, цела комплексна сукцесија Крша Градца је интерпретирана “as a tectonic window or as a tectonically incorporated sliver scraped off the footwall due to younger tectonic shortening” (претходни цитат, стр. 299).

Аутори овог рада, поменуте силицикластите такође не укључују у тектонит (меланж), и у оквиру њих разликују две дубоководне аргилитско-радиоларитске формације: старију, горњобатско–доњотитонску (испод градираног слоја) и млађу, ?средњо–горњотитонску – најнижу доњокредну, која почиње са градираним слојем.

PLATE 1

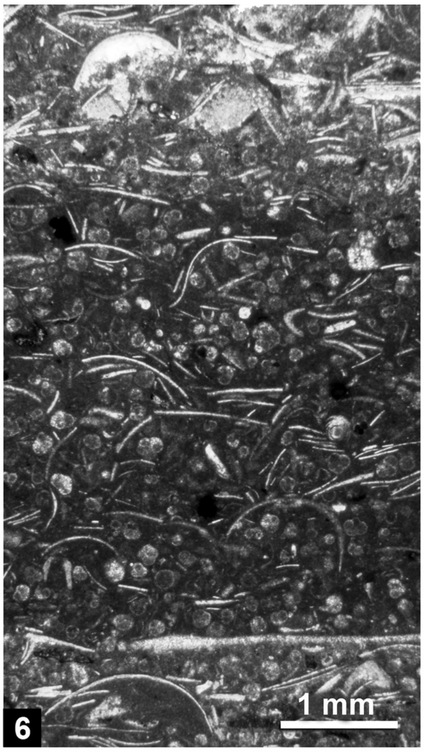
Figs. 1–7. **Unit B, condensed sequence**.

1–2. Sparse biomicrite with rare ammonite embryos and mollusk fragments: on Fig. 2 ferruginous matter pervades the upper part of the same bed, thin sections RR 5147, RR 5149, Aalenian–?Bajocian.

3–7. Thin sections RR 5150 and RR 5150/1 (sample 09150).

3–4. a) slightly disturbed and altered wackestone with *Bositra* fragments forms a clear boundary (arrows) with b) packstone, with mm laminae of more or less accumulated *Bositra* filaments and numerous protoglobigerinids (see also Figs. 5–7), Bajocian.


1 mm
5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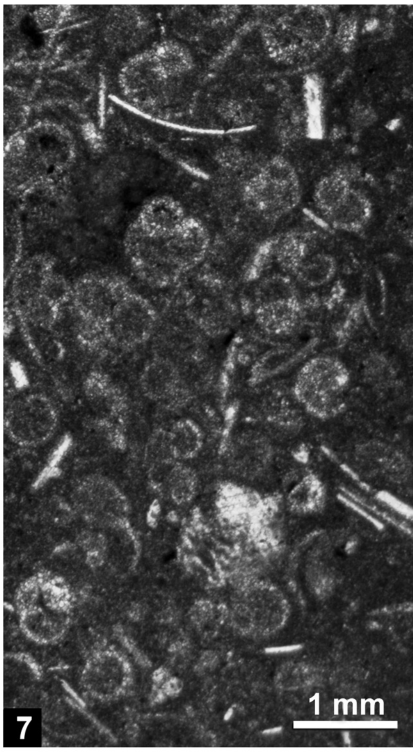
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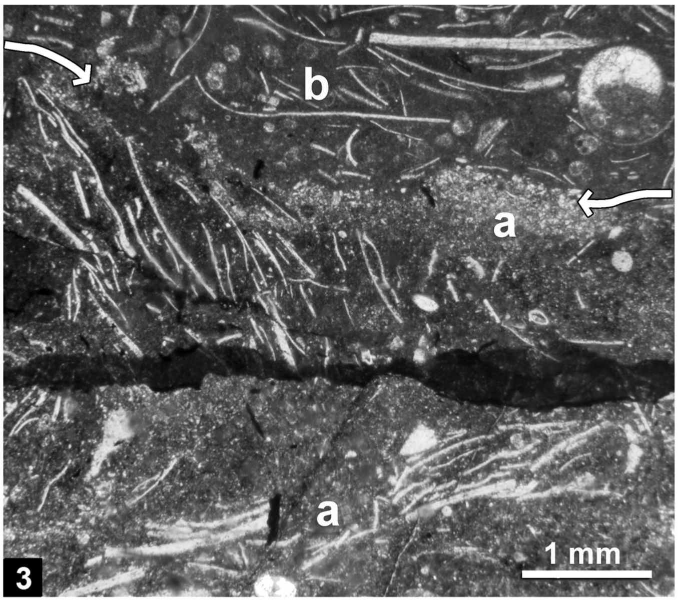
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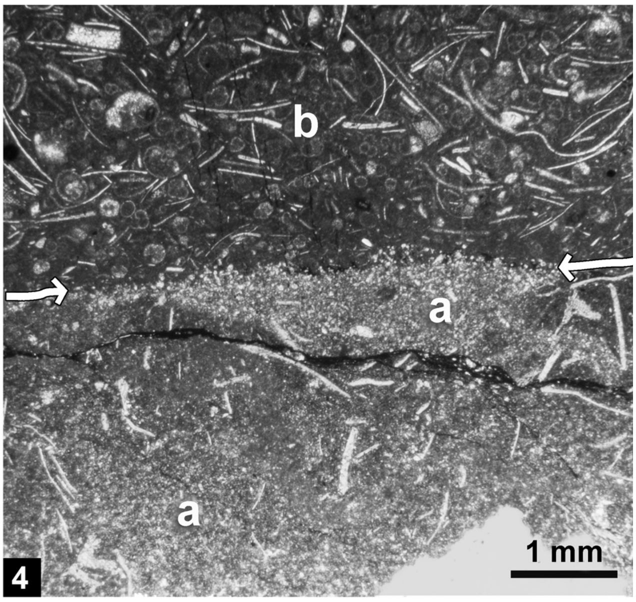
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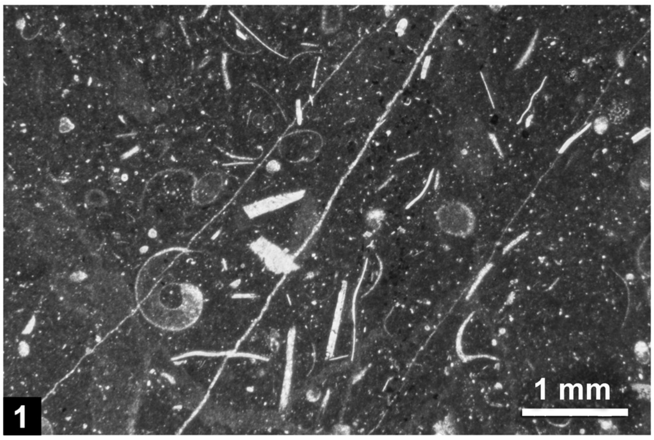
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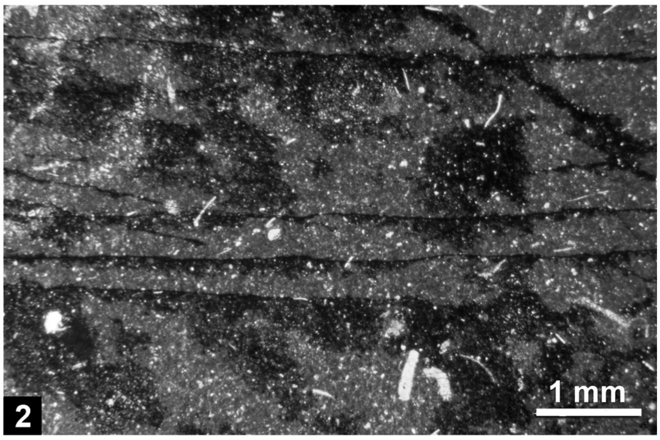
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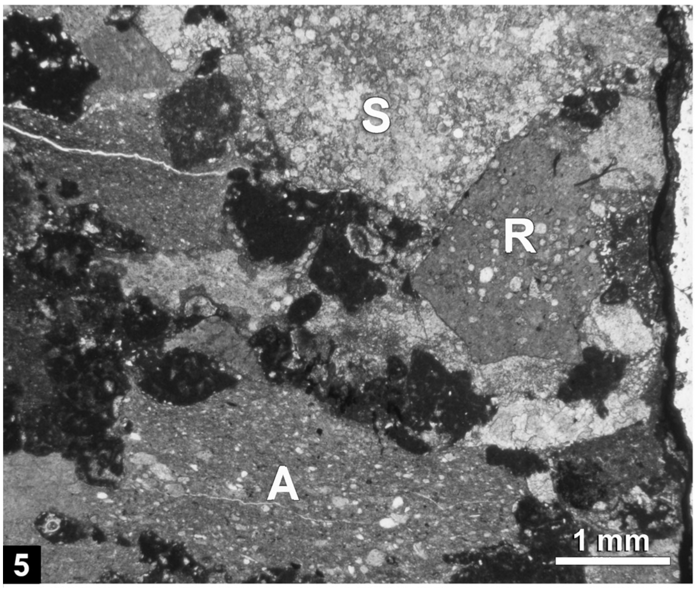
PLATE 2

Figs. 1–2. **Contact between units C and D;** argillites with rare radiolarians and the basal part of the graded bed: authigenous quartz around or inside some micrite grains and crinoid fragment in Fig. 2, thin sections RR 5151/2, RR 5151/3.

Figs. 3–6. **Unit D**, different components of the graded bed: grains of spongolite (S), argillite (A) and limestones with radiolarians (R); in Fig. 6, *Salpingoporella* sp., thin sections RR 5151/2, RR 5153, RR 5153/1 and MS 2059.


S
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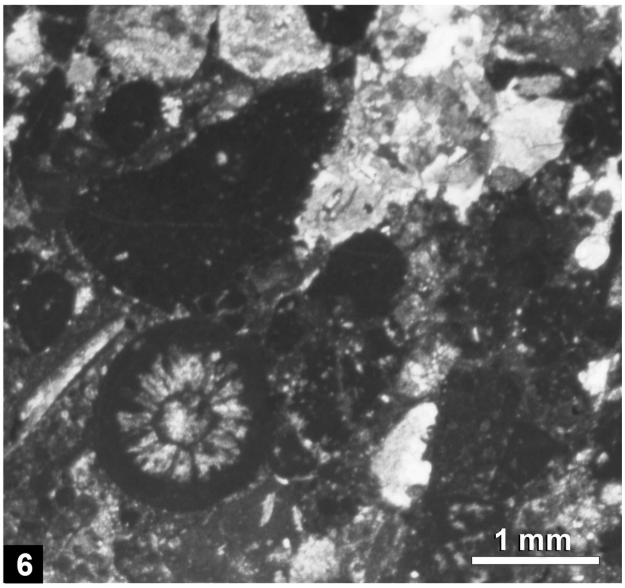
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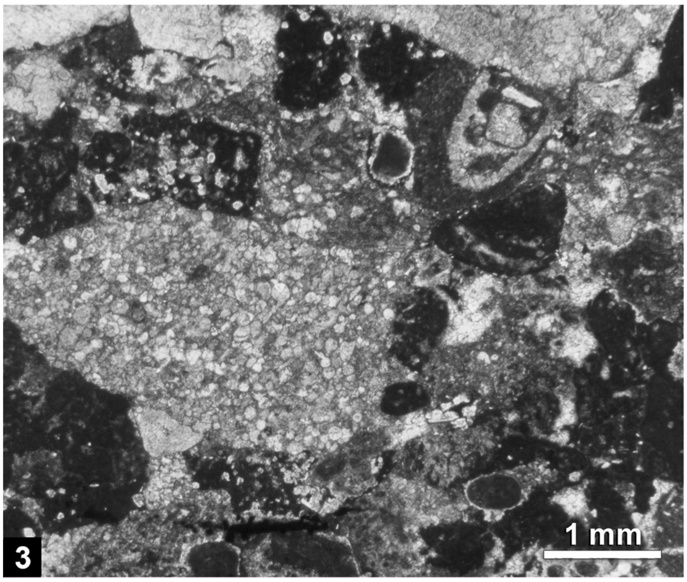
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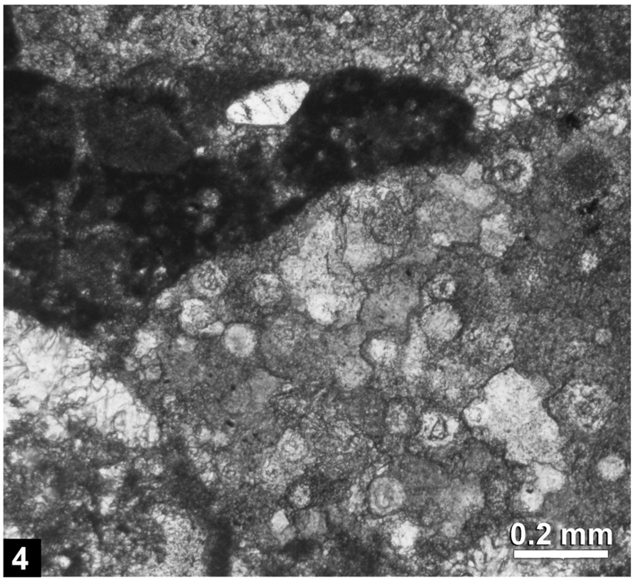
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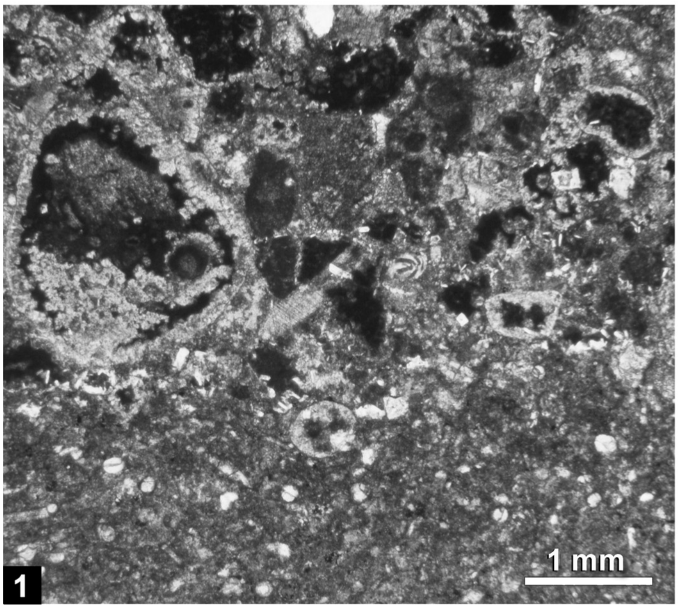
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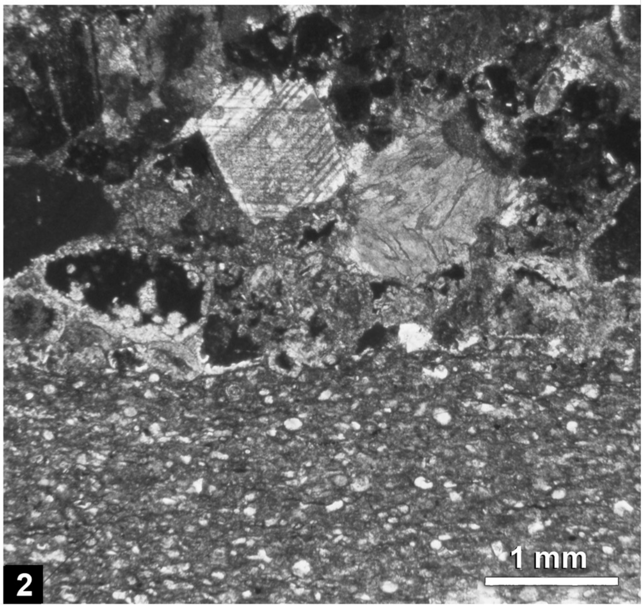
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PLATE 3

Figs. 1–4. **Unit D, graded bed**.

1–2. *Clypeina jurassica* and radiolaritic grains, thin sections MS 2057, MS 2053.

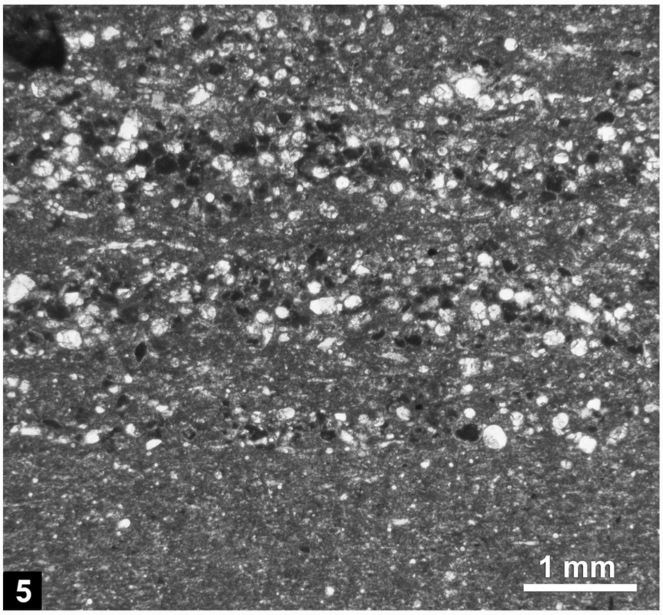
3. Grain of the Upper Triassic limestones with foraminifer aff. *Galeanella*; thin sections MS 2058.

4. Calcarenite with sponge spicules, uppermost part of the graded bed, thin section RR 5155.

Figs. 5–6. **Unit E**.

5. Argillite with spicules accumulated in parallel laminae; thin section MS 2060.

6. Spongolite, thin section RR 5156.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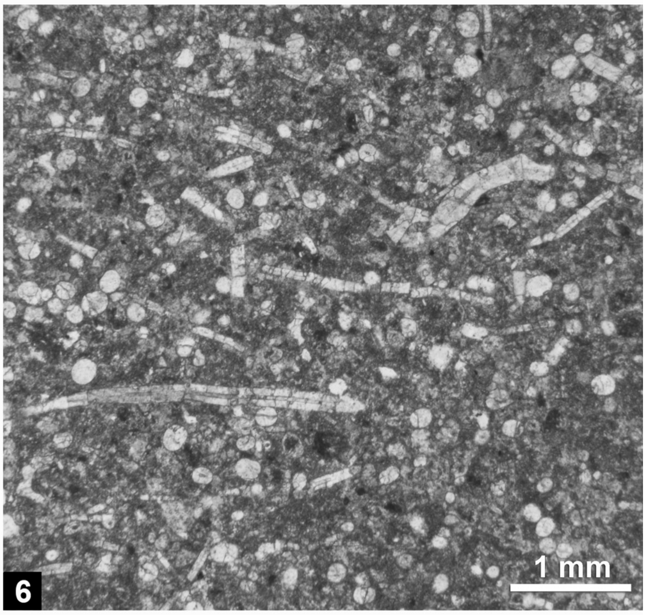
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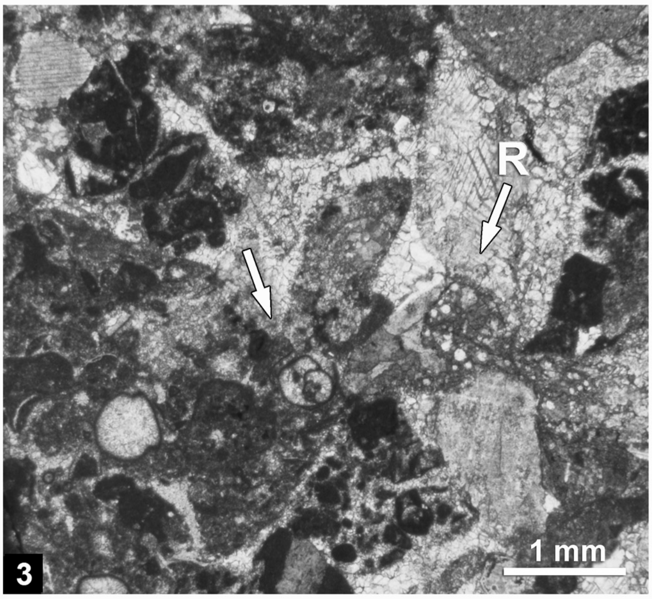
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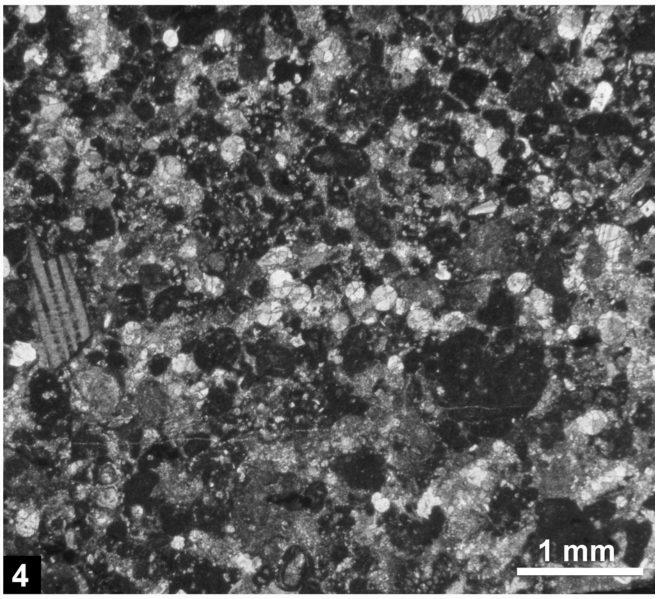
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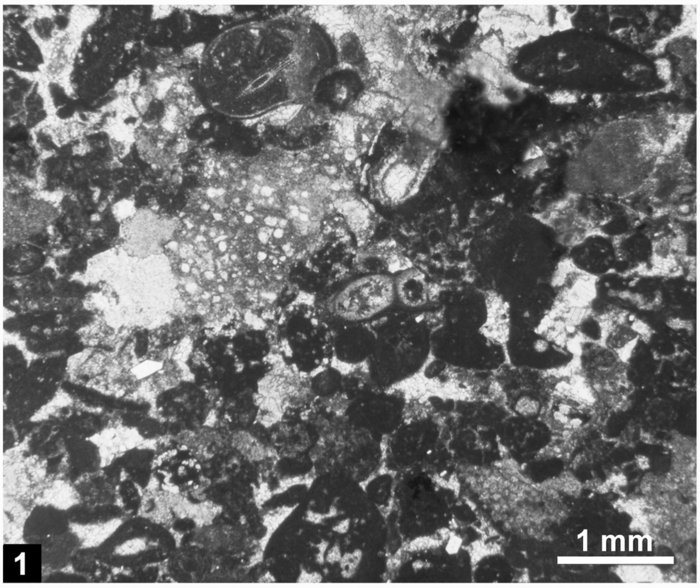
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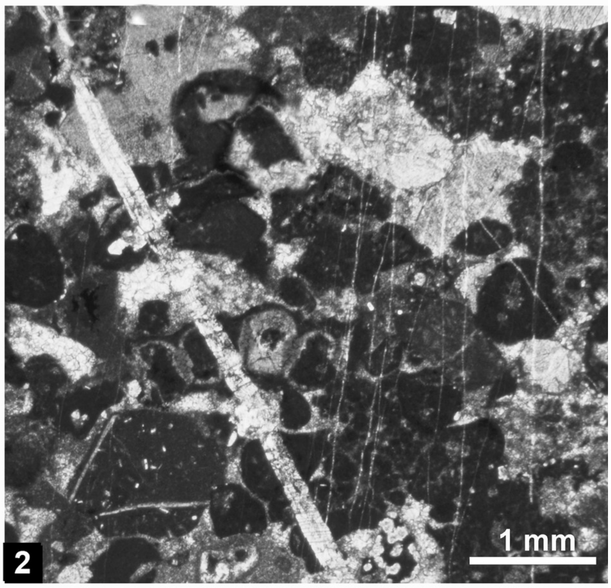
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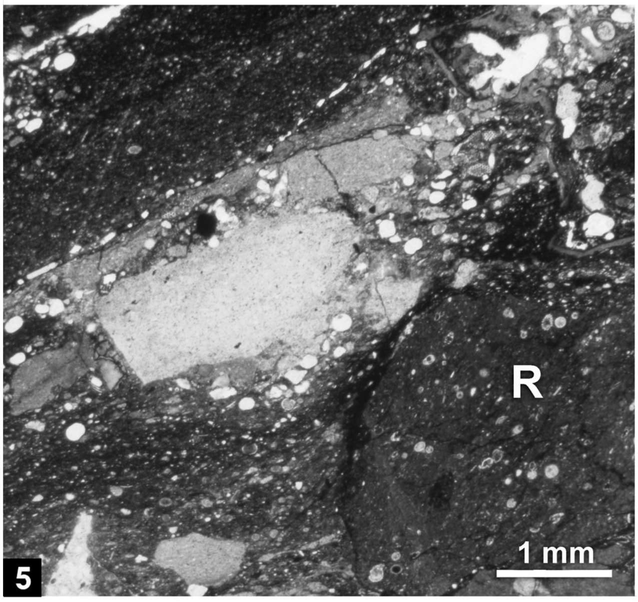
PLATE 4

Figs. 1–6. **Unit E.**

- 1–2. Siliceous argillites with abundant radiolarians, thin sections MS 2062 and MS 2063.
- 3–6. Different components in the ferruginous matrix of mass flow layer.
  - 3–4. Grains of unconsolidated dissolved radiolarite with partly washed radiolarians (in Fig. 3, some radiolarians are deformed), thin sections MS 2065, MS 2067.
  - 5. Grains of reddish limestones with radiolarians, thin section MS 2067.
  - 6. Grains of calcareous sandstone; thin section MS 2067.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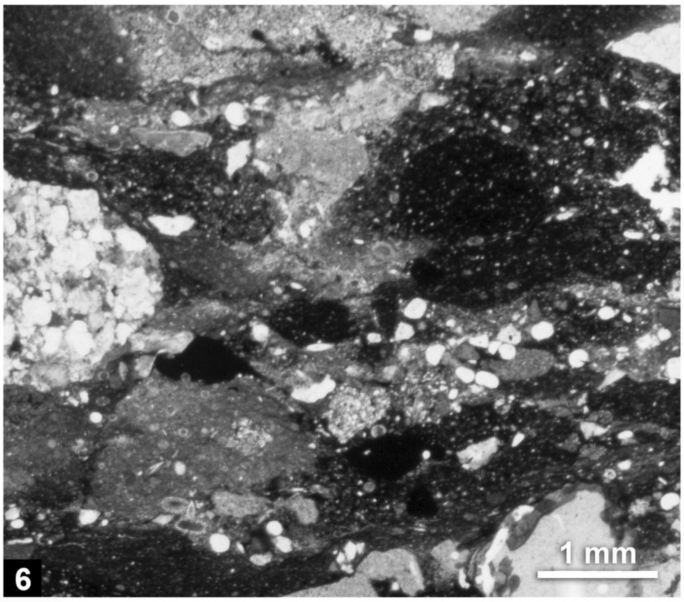
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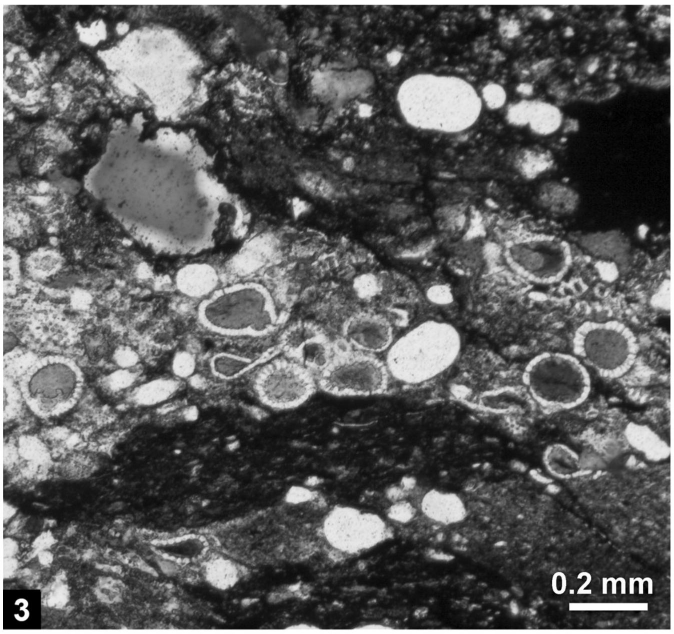
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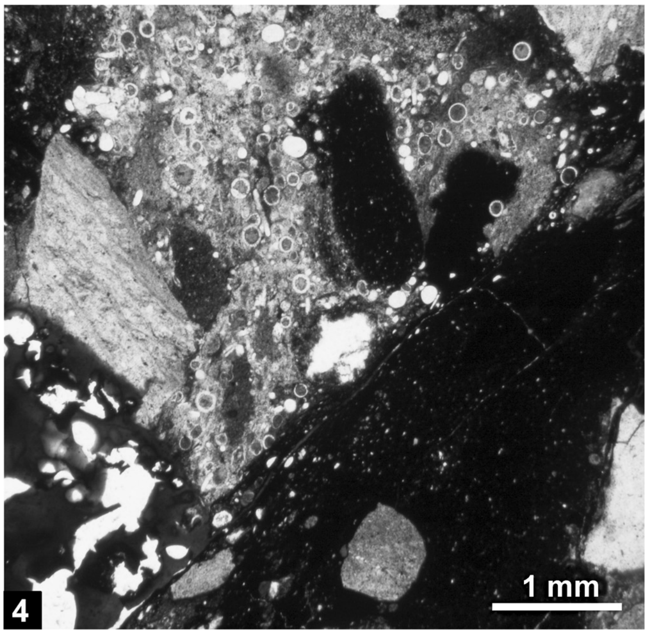
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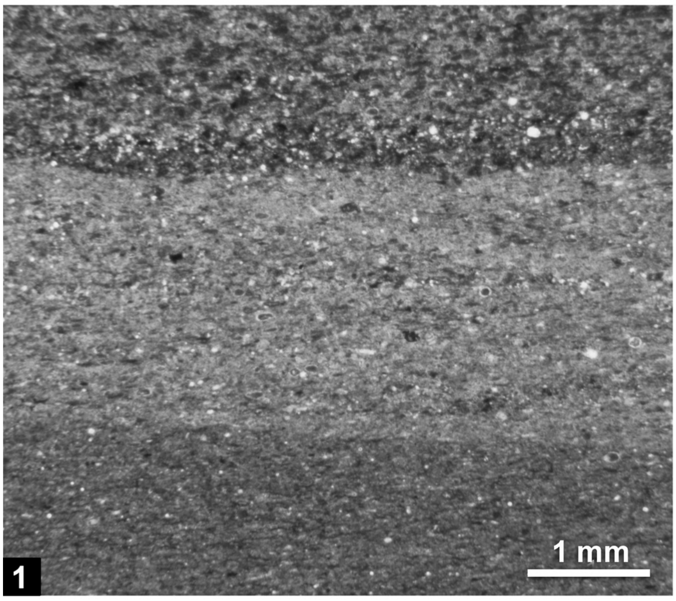
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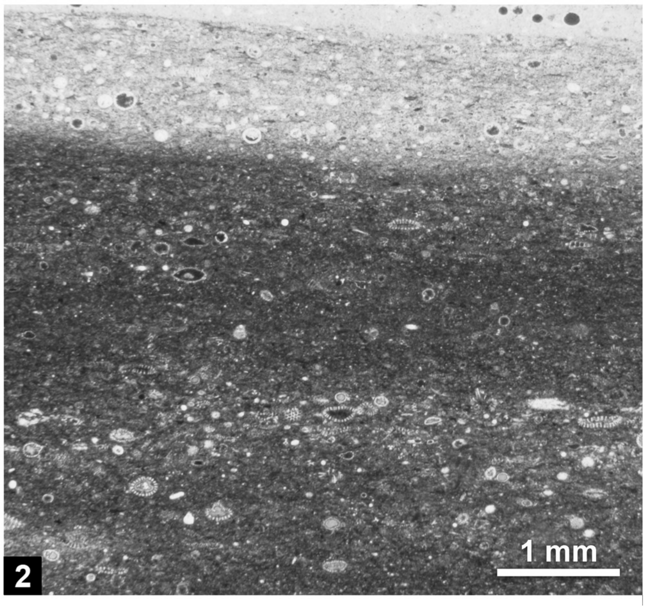
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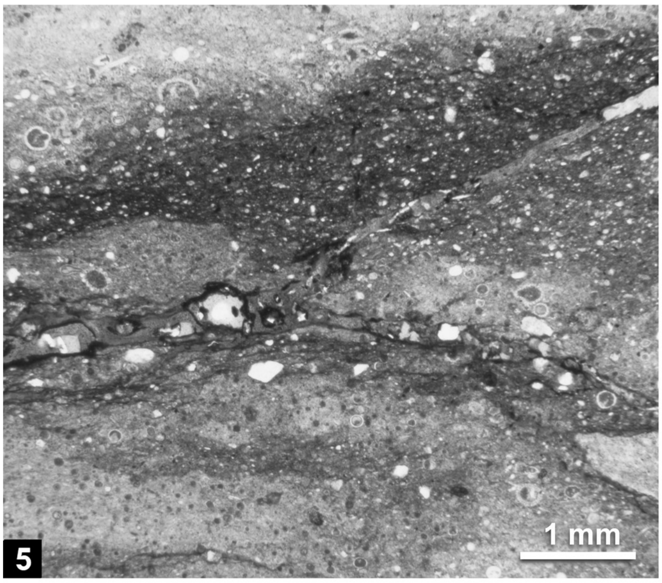
Plate 5

Figs. 1–6. **Unit E.**

- 1–3. Different components in ferruginous matrix of mass flow layer.
  - 1. Detailed view of Fig. 2 showing dissolved unconsolidated radiolarite with washed and partly washed radiolarians dispersed in the ferruginous matrix, thin section MS 2066.
  - 3. Radiolarite with siliceous clasts, thin section MS 2069.
- 4. Chert, thin section MS 2070.
- 5–6. The mixing of different grains under semi-consolidated condition.
  - 5. Argillite with minute radiolarians (filled with chlorite), thin section MS 2071.
  - 6. Grain of radiolarite, thin section MS 2072.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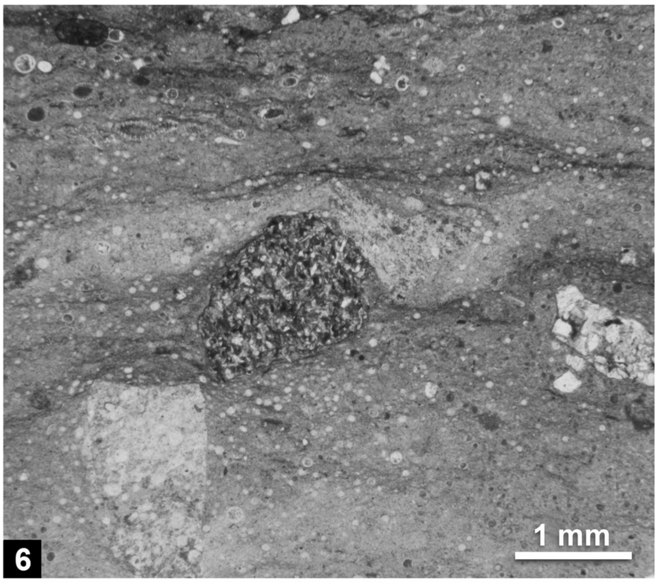
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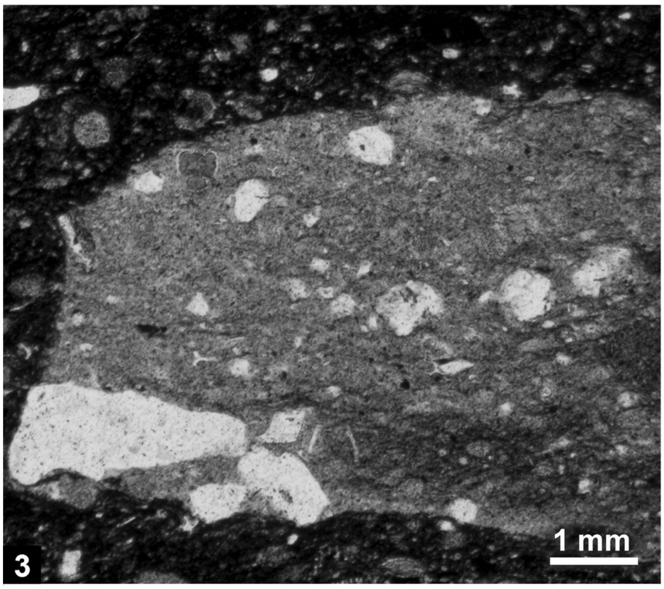
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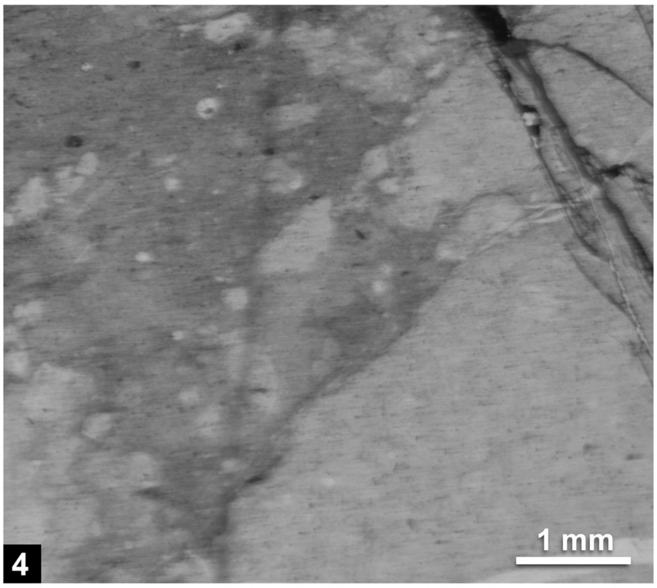
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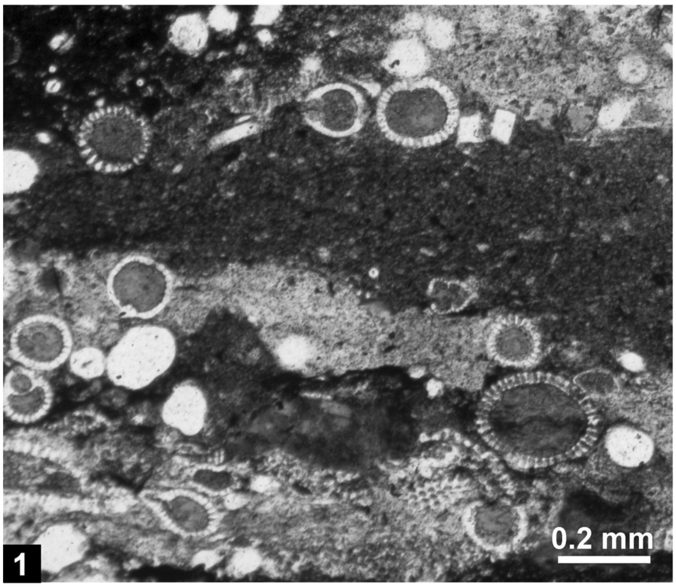
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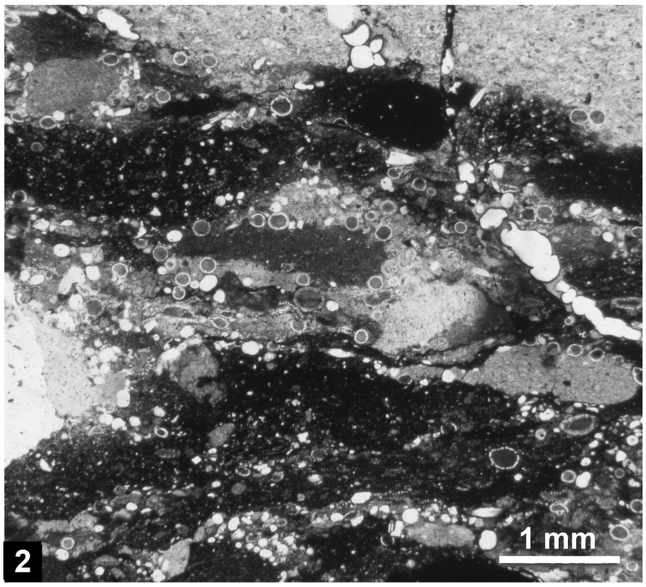
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PLATE 6

Figs. 1–10. **Algae and foraminifera from the graded bed.**

1. Dasycladalean fragment, thin section RR 5151/3.
2. *Radiomura cautica* SENOWBARY-DARYAN & SCHAEFER, thin section MS 2054.
3. *Clypeina jurassica* FAVRE, fragment (authigenous quartz in the laterals), thin section RR 5151/3.
4. *Salpingoporella* sp., thin section RR 5151/1.

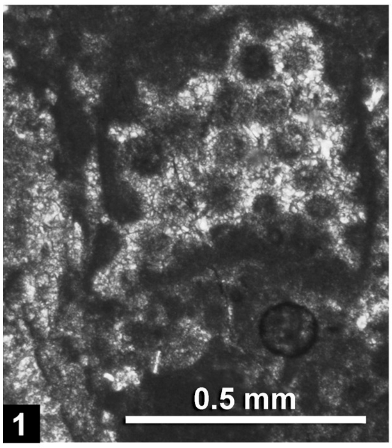
5–6. *Protopeneroplis striata* WEYNSCHENK, thin sections MS 2058, MS 2053.

7. *Labyrinthina mirabilis* WEYNSCHENK, thin section RR 5151/2.

8–9. *Parurgonina caelinensis* CUVILLIER, FOURY & PIGNATTI-MORAANO, thin sections RR 5154, RR 5151/3;

10. Foraminifer of a Triassic age aff. *Galeanella*, thin section MS 2058.

Figs. 11–12. **Unit A.** different sections of the brachiopod *Koninckella* sp. (determination by V. RADULOVIĆ), thin section RR 5146.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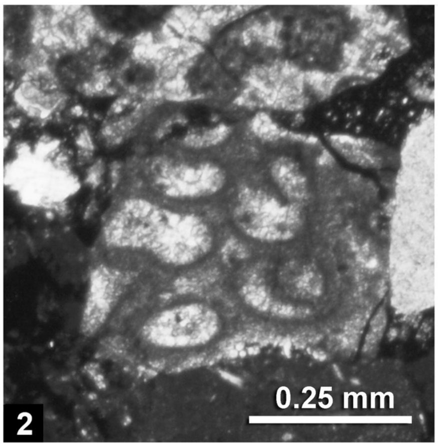
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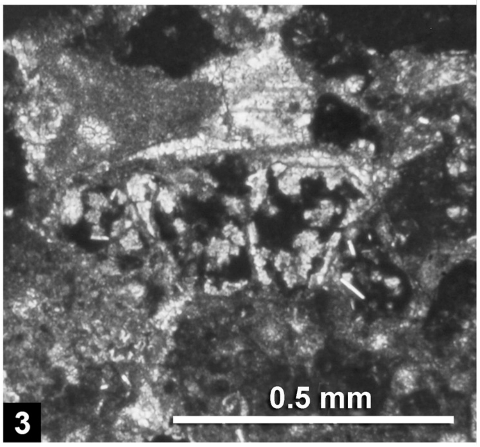
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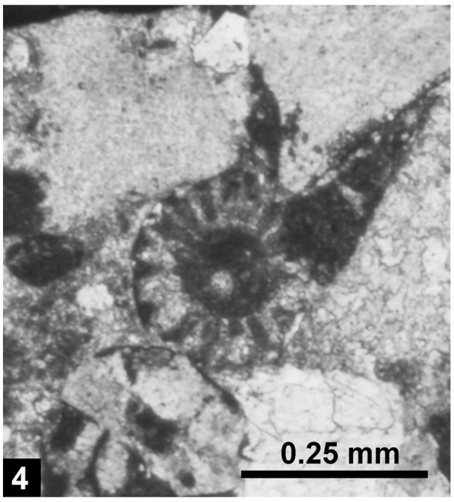
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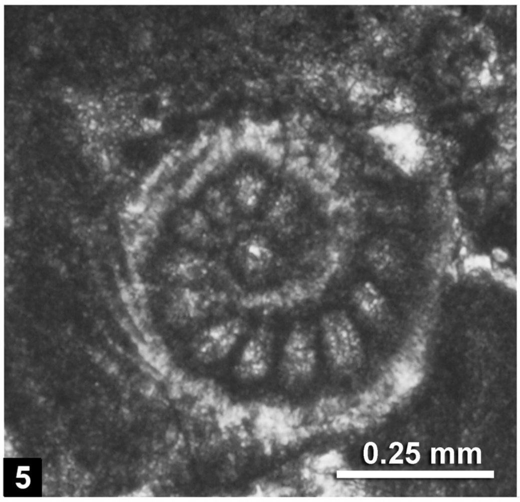
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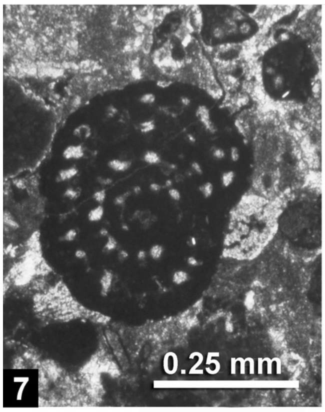
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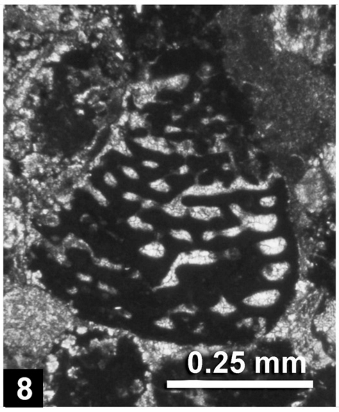
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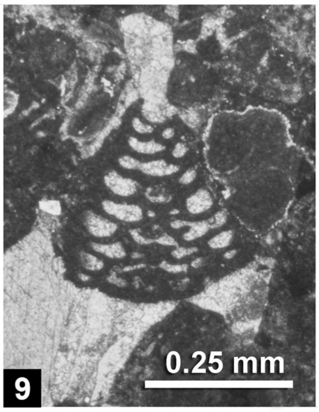
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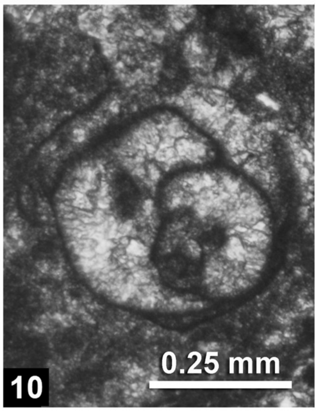
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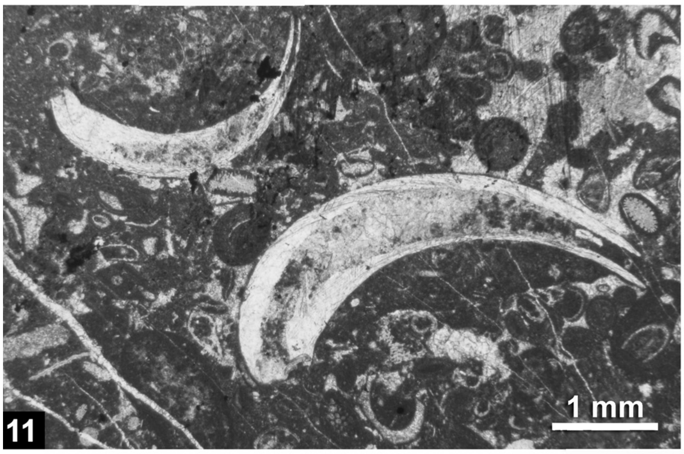
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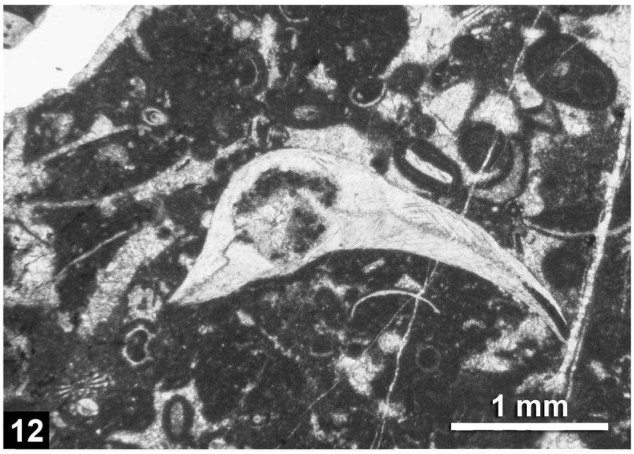
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Геолошки анали Балканскога полуострва Annales Géologiques de la Péninsule Balkanique	70	43–59	Београд, децембар 2009 Belgrade, December 2009

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Two look-alike dasycladalean algae: *Clypeina isabellae* Masse, Bucur, Virgone & Delmasso, 1999 from the Berriasian of Sardinia (Italy) and *Clypeina loferensis* sp. n. from the Upper Jurassic of the Northern Calcareous Alps (Austria)

Felix Schlagintweit[1], Iginio Dieni[2] & Rajka Radoičić[3]

Abstract. New material from the Berriasian of eastern Sardinia, Italy, and from the NW of Sardinia published by Pecorini in 1972 as "*Clypeina* sp. A", allows a better characterization and an emended diagnosis of *Clypeina isabellae* Masse *et al*., 1999 from the Berriasian of SW France. Another morphologically somehow similar *Clypeina* species from the Upper Jurassic of the Northern Calcareous Alps of Austria is described as *Clypeina loferensis* n. sp. Remarks on the genera *Clypeina* Michelin and *Hamulusella* Elliott, a *Clypeina*-type dasycladalean alga with proximal bulged laterals, and *Clypeina jurassica-sulcata* are also provided.

Key words: Dasycladales, Green Algae, new species, emendation, Upper Jurassic, Berriasian, Northern Calcareous Alps, Sardinia.

Апстракт. Нови материјал из беријаса источне Сардиније, као и већ публиковани материјал од стране Pecorini-а (1972), као "*Clypeina* sp. A", омогућио је боље сагледавање карактеристичних особина ове врсте и допунску дијагнозу за врсту *Clypeina isabellae* Masse *et al*., 1999 из беријаса југозападне Француске. Друга морфолошки слична *Clypeina* из горње јуре Сјеверних кречњачких Алпа, Аустрија, описана је као *Clypeina loferensis* n. sp. Дате су примедбе о роду *Clypeina* Michelin и *Hamulusella* Elliott, као и о клипеинама са проксималним испупчењем огранака. Такође је дат осврт на однос *Clypeina jurassica* и *Cl. sulcata*.

Кључне речи: Dasycladales, зелене алге, нова врста, емендација, горња јура, беријас, Сјеверни кречњачки Алпи, Сардинија.

Introduction

In 1999, Masse *et al*. described the new dasycladalean alga *Clypeina isabellae* from the Middle–Upper Berriasian of southern France. As the description was based mainly on transverse and oblique sections, some biometric parameters (e.g. verticil spacing = h) and morphological details (e.g. connection of the laterals with the main axis) are unknown. Denoting that this species is only recorded from its type-locality, to the authors obviously escaped notice of the good illustration of the same taxon from the "Purbeckian" of NW Sardinia shown by Pecorini (1972, as *Clypeina* sp. A). Since its description, *Clypeina isabellae* was so far reported from the Upper Jurassic of Romania (Bucur & Sasaran 2005, without illustration) the Northern Calcareous Alps of Austria (Schlagintweit & Ebli 2000, without illustration; Schlagintweit 2005, *C.* aff. *isabellae*). Well-preserved and abundant material from the Berriasian of Eastern Sardinia allows the redescription and emendation of *Clypeina isabellae*. Additional material from the Upper Jurassic of the Northern Calcareous Alps shows the distinctiveness of the Alpine specimens, here introduced as *Clypeina loferensis* sp. n.

Geological Setting

Northern Calcareous Alps

Clypeina loferensis n. sp. was found in brownish marly limestones (wackestones) referred to a restricted

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lagoonal facies of the Late Jurassic shallow-water evolution of the Northern Calcareous Alps known as Plassen Carbonate Platform, respectively the so-called Lärchberg Formation (FERNECK 1962; DARGA & SCHLAGINTWEIT 1991; DYA 1992; SCHLAGINTWEIT & EBLI 2000; SCHLAGINTWEIT 2005; SANDERS *et al.* 2007, for details). Rarely, the new species occurs also in mass-flows of the Barmstein Limestones containing clasts of PCP lagoonal facies (STEIGER 1981; GAWLICK *et al.* 2005).

Based on previous studies on the facies evolution of the Plassen Carbonate Platform (e.g. SCHLAGINTWEIT *et al.* 2005) and the accompanying microfossils, *Clypeina loferensis* sp. n. was identified in samples ranging from Late Kimmeridgian to Tithonian (?Early Berriasian). The samples containing the new species are coming from the following localities.

Mount Dietrichshorn. Mount Dietrichshorn is located about 3 km north of Lofer, topographic map of Austria no. 92, sheet Lofer. The Lärchberg Formation of Mount Dietrichshorn was investigated by DARGA & SCHLAGINTWEIT (1991) and DYA (1992).

Mount Lärchberghörndl. Mount Lärchberghörndl and its eastern part, the Lofer Kalvarienberg, are the type-locality of the Lärchberg Formation established by FERNECK (1962). Topographic Map of Austria no. 92, sheet Lofer. Literature: DYA (1992), FERNECK (1962). Mount Lärchberghörndl is the type-locality of *Clypeina loferensis* sp. n. (Fig. 1). Samples were taken at the way along the Loferbach (samples LOF) and the so-called Konradsweg (KOWG) and Ensmannsteig (ENS).

Mounts Litzelkogel-Gerhardstein. Lärchberg Formation. Topographic map of Austria no. 92, sheet Lofer. Literature: DYA (1992), FERNECK (1962), not DYA (1962).

Mount Trisselwand. Plassen Formation. East of Lake Altaussee. Topographic map of Austria no. 96, sheet Bad Ischl. Literature: SCHLAGINTWEIT & EBLI (1999).

Mount Zwerchwand. Barmstein Limestones. Mount Zwerchwand is located near Bad Goisern in the central Salzkammergut area. Topographic Map of Austria no. 96, sheet Bad Ischl. The occurring Barmstein Limestones (mass-flows, breccias, calciturbidites) are intercalated in calpionellid-bearing limestones. Late Tithonian is evidenced by the occurrence of *Crassicollaria intermedia* (DURAND-DELGA).

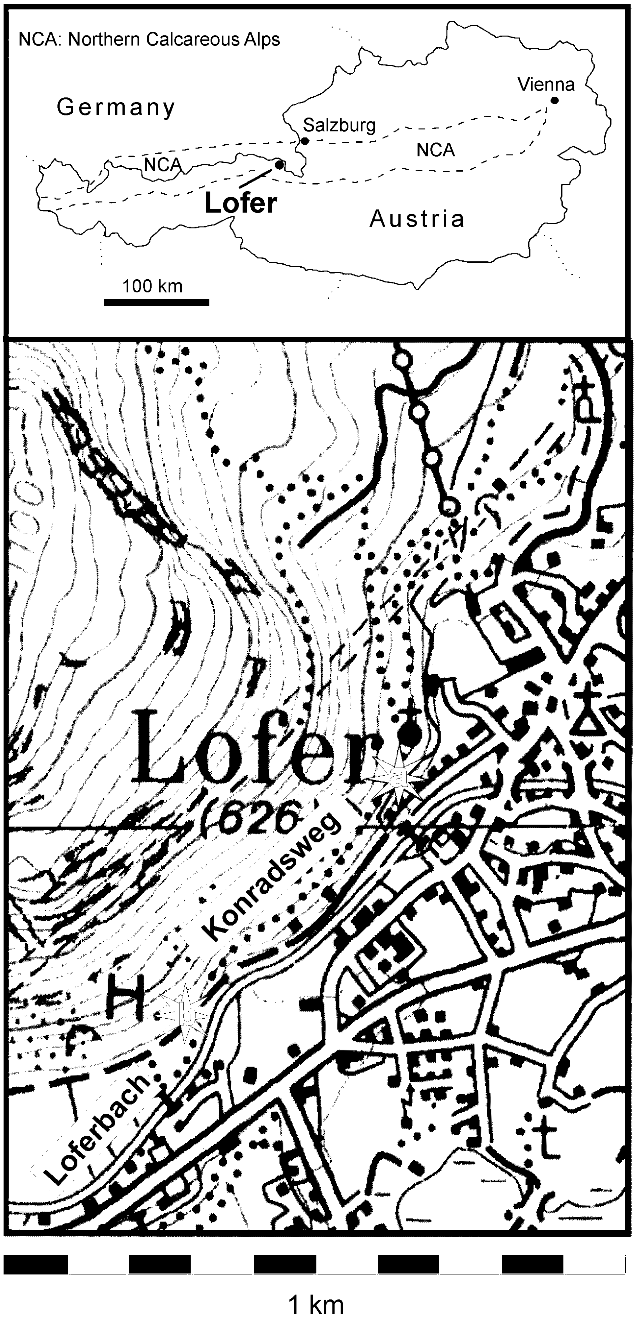

Fig. 1. Topographic sketch map of the type-locality of *Clypeina loferensis* n. sp. near the village of Lofer, Austria.

Sardinia

Within the ambit of studies on the sedimentary cover of Eastern Sardinia, which have continuing for many decades at the Department of Geosciences of the University of Padova, detailed litho- and biostratigraphic analyses have been carried out on the carbonate platform deposits of Late Jurassic–Early Cretaceous age cropping out in the Oliena–Orgosolo–Urzulei massif (the so-called Supramonte). These researches have led to findings of abundant macro- and micropalaeontological associations. In particular, as regards calcareous algae, as well as species already quoted in the literature for Sardinia and other European regions, forms not referable to any known taxa were identified. Among these, *Clypeina dragastani* and *Salpingoporella granieri* were erected by DIENI & RADOIČIĆ (2000) for dasycladaleans occurring in beds of Early Berriasian age of the Sa Marghine Ruja section, in the Oliena territory (Fig. 2). This section represents the terminal part of the very thick Mt. Bardia Limestone formation, the age of which is Tithonian to Berriasian in most areas, but locally extending downwards into Kimmeridgian and Oxfordian. The Tithonian–Berriasian interval of the lithostratigraphic unit is

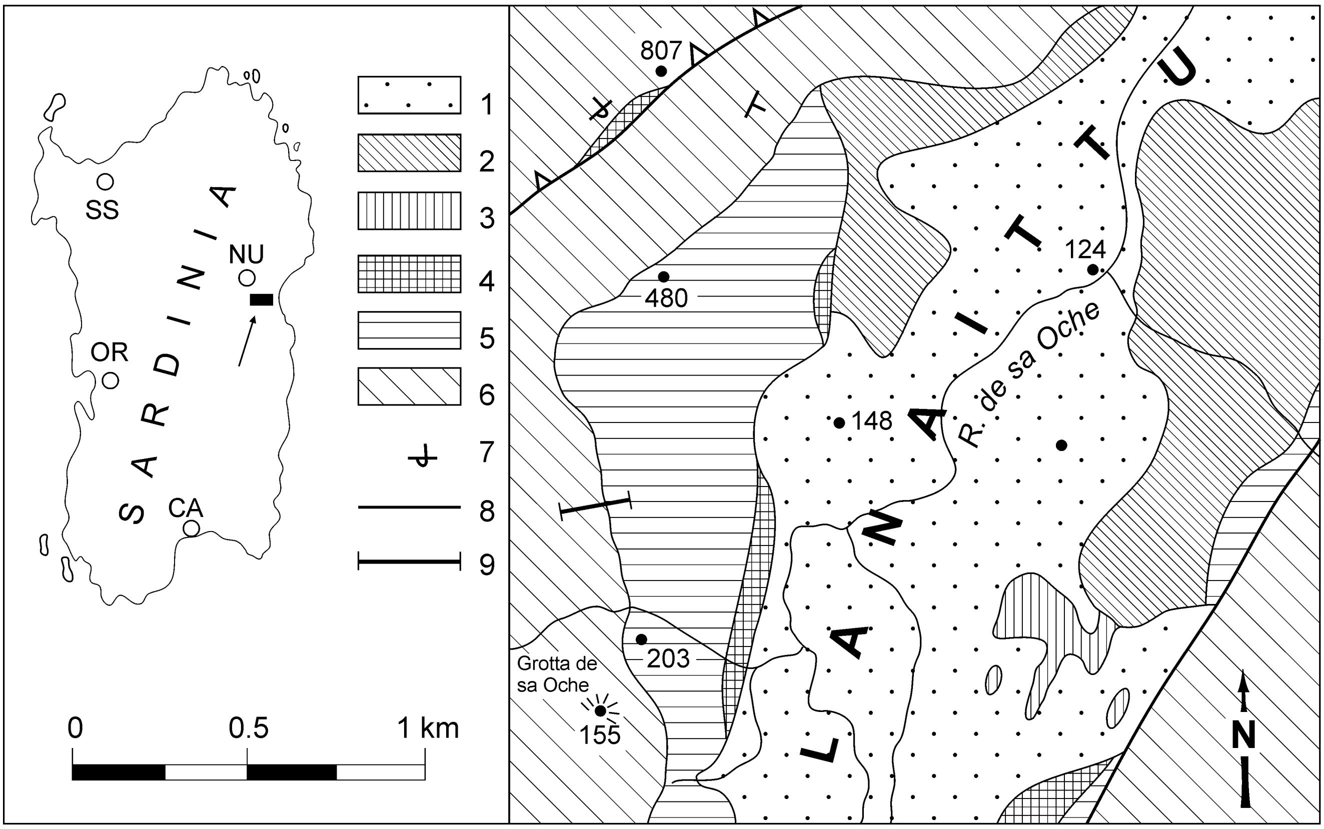

Fig. 2. Geological sketch map of the Lanaittu area (Oliena, Eastern Sardinia). **1,** Quaternary deposits; **2,** Lutetian polymictic conglomerates (Cuccuru 'e Floras Conglomerate); **3,** Upper Santonian–Maastrichtian marls (Lanaittu Marl); **4,** Upper Cenomanian–Lower Santonian marly and in places cherty limestones (Gorropu limestone); **5,** Valanginian–Upper Aptian marls and limestones (Orudè Calcarenite–Borrosca Limestone); **6,** Bathonian–Berriasian dolostones and limestones (Dorgali Dolostones and Monte Bardia Limestone); **7,** Overturned beds; **8,** Fault; **9,** Sa Marghne Ruja section (from DIENI *et al.* 2000, modified).

characterized by a rather uniform facies association, corresponding to a generalized peritidal environment with well-developed microbial mats and fine-grained fenestral limestones. A regressive acme is reached in the upper part of this complex, which is marked by many horizons of black-pebble breccias, mud-cracked laminites and oligotypic assemblages consisting of charophytes, ostracods and small mollusks suggesting a scenario of wide supratidal flats disseminated with lagoonal to fresh-water ponds. The succession is commonly split into a number of high-frequency metre-scale cycles (DIENI & MASSARI 1985).

One of the best exposures illustrating the peritidal deposits is just that of Sa Marghine Ruja (Fig. 3), where the depositional pattern shows the characters of the well-known "Purbeckian facies". This section (illustrated by DIENI & MASSARI 1985 under the name of "Sa Oche section") is located within the Lanaittu valley, which is a structural depression corresponding to an asymmetric syncline bounded by a NNE- trending fault system on the eastern side (Fig. 2). Within the mud-cracked almost barren laminated facies, volumetrically dominant, a number of packstone layers are intercalated, rich in microfossils of restricted environment, peloids and flat intraclasts. These facies are thought to represent the record of storm flows intermittently encroaching on mud-cracked supratidal flats and depositing their load from suspension. A slight transgressive trend and increasing open-marine influence is suggested by the upward increment in number of these layers and appearance in the uppermost layer package of higher-diversity fauna and flora.

In the Sa Marghine Ruja section, the Tithonian–Berriasian boundary can be traced with sufficiently good approximation only by means of the content in plant remains, since foraminifers give no significant information from the bio- and chronostratigraphic viewpoint. The boundary may be located approximately between beds 848 and 851 (the sample numbers were marked with colored enamel paint on the beds cropping out along the studied succession). As regards Dasycladales, starting from bed 857, in addition to species already quoted in the Upper Jurassic, such as *Actinoporella podolica* (ALTH), *Clypeina maslovi* (PRATURLON), *Clypeina solkani* CONRAD & RADOIČIĆ, *Otternstella lemmensis* (BERNIER) and *Salpingoporella annulata* CAROZZI there are taxa which, at least until now, have only been recorded beginning from the Berriasian, such as

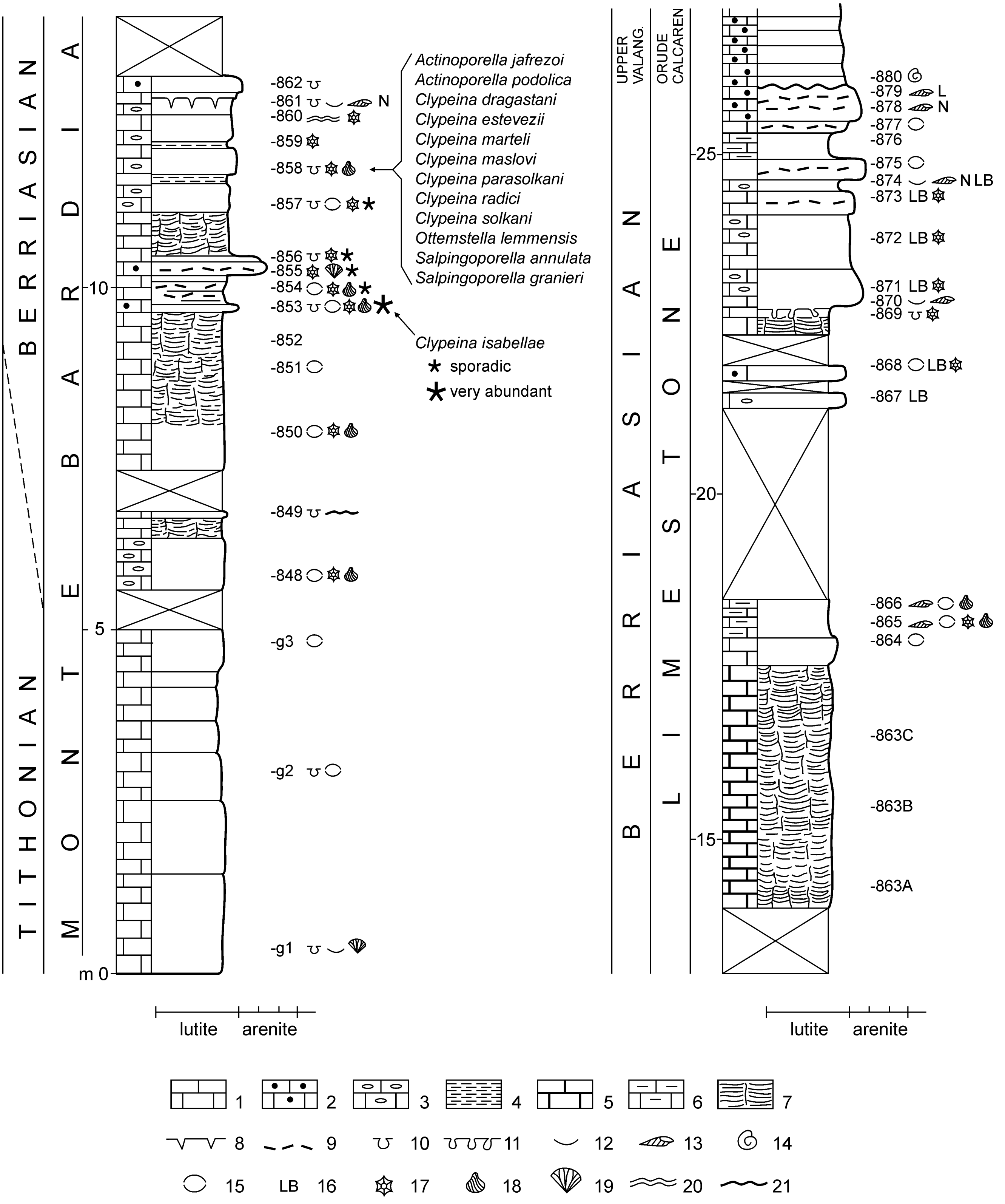

Fig. 3. Sa Marghine Ruja section (Oliena, Sardinia) (from DIENI *et al.* 2000). Legend: **1,** Limestone; **2,** Bioclastic limestone; **3,** Nodular, styolite-bearing limestone; **4,** Crumbly limestone; **5,** Fine-grained limestone subdividing into flakes; **6,** Marly limestone; **7,** Mud-cracked, thin-laminated calcilutite; **8,** Mud-cracks; **9,** Intraformational clasts, commonly blackened by organic matter; **10,** Burrows; **11,** Borings by bivalves; **12,** Bivalves; **13,** Gastropods, mostly nerineids(N): L = *Leviathania leviathan* (PICTET & CAMPHICE); **14,** Ammonites; **15,** Ostracods; **16,** Lithocodium-Bacinella; **17,** Dasycladaleans; **18,** Charophytes; **19,** Codiaceans; **20,** Algal lamination; **21.** Disconformity.

Actinoporella jaffrezoi Granier, *Clypeina estevezii* Granier, *Clypeina parasolkani* Farinacci & Radoičić and *Salpingoporella granieri* Dieni & Radoičić. In addition, in this bed 857 and downwards until bed 853 (for a total thickness of about 170 cm) is just present *Clypeina isabellae* Masse, Bucur, Virgone & Delmasso, subject of this note, and until now only known from the Berriasian of Provence (SE France, Fig. 4) ("l'espèce n'est pas pour le moment connue que du Berriasien moyen et supérieur de Basse Provence. La dificulte de separer clairement le Berriasien inférieur du Berriasien moyen conduit a penser qu'elle pourait exister dès le Beriassien inférieur", Masse *et al.* 1999, p. 240).

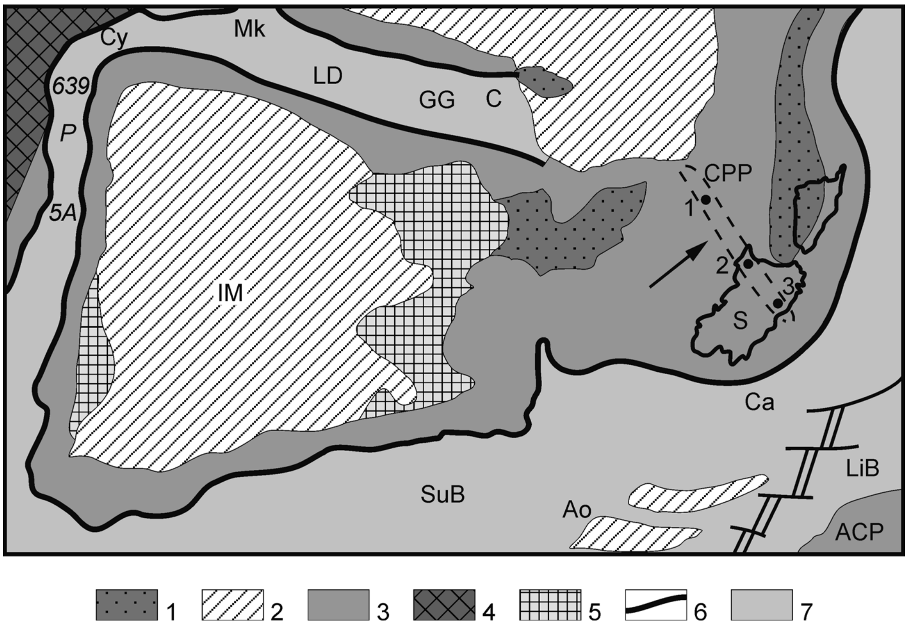

Fig. 4. Partial Late Tithonian–Berriasian palaeoenvironmental map of the western Mediterranean area (from Fourcade *et al.* 1993, simplified and modified, approximative scale 1 : 400 000). Legend: **1,** Exposed land; **2,** Margin-litoral and lacustrine environments; **3,** Shallow platform; **4,** Terrigenous shelf and shallow terrigenous basin; **5,** Chalky platform; **6,** Slope or shelf edge/slope boundary; **7,** Slope and deep basin above CCD. S – Sardinia (for the other acronyms see Fourcade *et al.* 1993). Dached line – Possible "endemism" area of *Clypeina isabellae* (1. Provence, 2. Western Sardinia, 3. Eastern Sardinia).

Micropalaeontological Part

Order Dasycladales Pascher, 1931
Genus *Clypeina* (Michelin 1845) Bassoullet *et al.* 1978

Clypeina loferensis sp. n.
Fig. 5 A–J; Pl. 1, Figs. 1–17,

1985 *Clypeina* sp. A Pecorini – Bernier: 487, pl. 8, figs. 1–7.
1992 *Actinoporella podolica* (Alth) – Dya: 68, pl. 7, figs. 6–8.
?1996 *Clypeina* aff. *parasolkani* Radoičić & Farinacci – Ercegovac, Jeremic & Radoičić: pl. 2, figs. 1–9.
2005 *Clypeina* aff. *isabellae* Masse *et al.* – Schlagintweit: pl. 2, fig. 11.

Origin of the name. The specific name refers to the village of Lofer, near the German–Austrian border (Fig. 1).

Holotype. Oblique transverse section figured in Pl. 1, fig. 9, thin-section BSP-2009-XI-1, deposited at the Bayerische Staatssammlung für Paläontologie und Historische Geologie (BSP), University of Munich, also other 9 thin-sections (BSP-2009-XI-2 to -10). For the type-locality the original sample numbers refering to the indications in textfigure 1 are given.

Isotypes. All other figurations.

Type-locality. The so-called Konradsweg along the Lofer Kalvarienberg and the SE slope of the Lärchberghörndl, located on the topographical map of Austria 1:50 000 ÖK 92 Lofer (Fig. 1). This locality corresponds to the profile no. 7 described by Dya (1992: p. 22–24) and is also the type-locality for *Carpathocancer*? *plassenensis* (Schlagintweit & Gawlick) (Schlagintweit *et al.* 2003, Fig. 1) (coordinates: length 12°41', width 47°35').

Type-level. Light brown wackestone of the Lärchberg Formation s*ensu* Ferneck (1962) containing stromatoporoids, *Clypeina loferensis* sp. n., *Salpingoporella annulata* Carozzi, *Rajkaella* gr. *bartheli* (Bernier), *Clypeina catinula* Carozzi, *Clypeina jurassica* Favre & Richard, more rarely *Deloffriella quercifoliipora* Granier & Michaud and benthic foraminifers among which *Anchispirocyclina lusitanica* (Egger).

Age. Tithonian, presumably Late Tithonian.

Diagnosis. Medium-sized dasycladalean alga with clearly spaced-out laterals inclined upwards 60°–80° in respect to the main stem, euspondyl in arrangement. Laterals elongate, fusiform, and connected to the small main stem starting from a comparatively narrow pore. Along their distal half the laterals are clearly separated from each others. Thin calcification covering main axis and laterals.

Dimensions. Outer thallus diameter (D) 0.48–1.92 mm (mean value: 0.79 mm, n = 11); inner thallus diameter

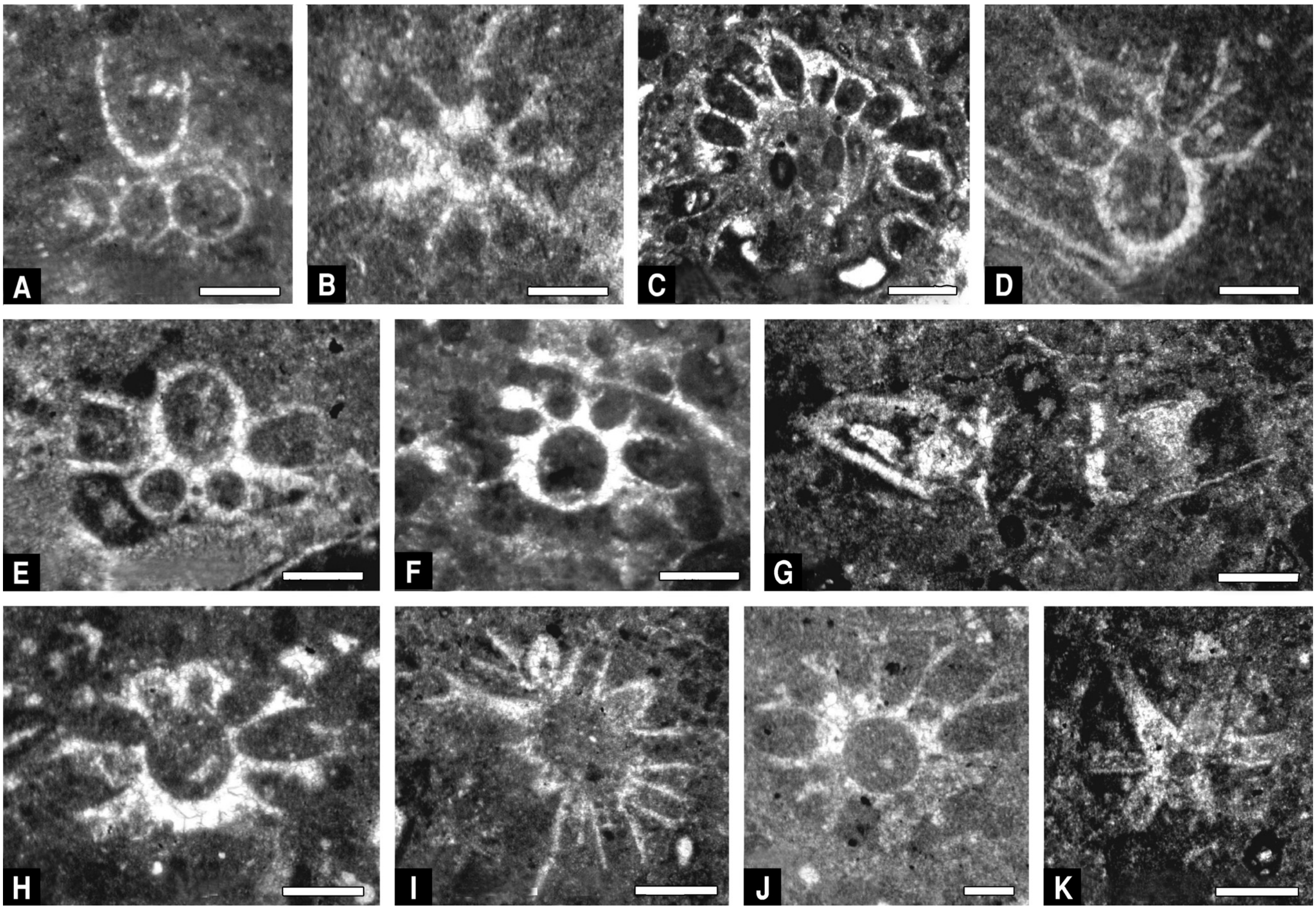

Fig. 5. *Clypeina loferensis* n. sp. (**A–J**) and *Clypeina* sp. (K) from the Upper Jurassic (Kimmeridgian–Tithonian) of the Northern Calcareous Alps (Austria, Germany). **A,** Tangential-oblique section, sample LOF-3, Lofer Kalvarienberg-Lärchberghörndl; **B,** Transverse section, slightly oblique, sample DIE-163, Mount Dietrichshorn; **C,** Oblique section of a specimen with comparable large main axis and unusual high number of laterals (?17), sample Die-Gipfel, Mount Dietrichshorn; **D–F,** Oblique sections, samples ENS-1, LOF-2 and DIE-8; **D–E,** Lofer Kalvarienberg-Lärchberghörndl; **F,** Mount Dietrichshorn; **G,** Longitudinal section, cutting one vertcil; note upward bending of laterals, sample EIS-7, Lofer Kalvarienberg-Lärchberghörndl; **H–I,** Oblique-transverse sections, sample DIE-164, Mount Dietrichshorn; **J,** Transverse section, slightly oblique, sample DIE-165, Lofer Kalvarienberg-Lärchberghörndl; **K,** Transverse section of *Clypeina* sp. with tiny main axis, low number of nearly unfused laterals interpreted as top part of the thallus, sample EIS-7, Mount Dietrichshorn. Scale bars = 0.3 mm.

(D) 0.06 mm to 0.8 mm (mean value: 0.19 mm, n = 20). Due to the many oblique sections in our material and the inclination of the laterals only few data about the d/D ratio are available ranging from 0.24 to 0.32 mm (mean value 0.27, n = 8). For the verticil spacing (h) only two values are available, 0.32 and 0.4 mm. The maximum pore diameter (p) is 0.145–0.16 mm. Number of laterals/whorl (w): 8–16 (most values between 10–12).

Description. Medium-sized representative of *Clypeina* with a small main axis amounting to less than 1/3 of the total diameter. Calcification of laterals and main axis is thin (thickness 0.02 to 0.04 mm). Due to the weak calcification of the main axis, longitudinal sections comprising two or more consecutive whorls are rare; in no case more than two verticils were observed (Pl. 1, fig. 4). Secondary non-fibrous calcification present at the base of the laterals. Most probably the distal parts of the laterals were poorly if at all calcified, open to its exterior. Laterals are elongate-tubiform, inclined to the main axis (60°–80°), connected to the axis by a small pore (Pl. 1, figs. 1, 5). Due to their inclination, the laterals show a slight asymmetry in longitudinal sections (Fig. 5G). The upper side more or less directly stretches away from the axis, whereas the lower side of the lateral is a little bit more rounded, however, without forming a downward bulging. Transverse sections through the lower part of a verticil with less inclined laterals give rise to a more regular rosette (Pl. 1, figs. 2, 11); in these cases laterals are circular to ovoid in longitudinal sections. The laterals stay in contact for 1/3 to 1/2 of their length before becoming untouching, individualized. Normally, the laterals are gradually widening, seemingly becoming narrower again toward their distal ends. The verticils are rather widely spaced-out.

Comparisons. *Clypeina loferensis* sp. n. is closely related to *Clypeina isabellae* MASSE *et al.* differing from this species above all by the lack of a bulge at the lower side of the lateral's proximal parts. Moreover, the observed intralateral fibrous calcification of *C. isabellae* and *C. jurassica* is missing in *C. loferensis* sp. n. Both species share similar dimensions also with a comparable variation grade of rare tiny and large specimens; the weak calcification of the membran of the laterals is present in both species.

Occurrences. Austria (Northern Calcareous Alps, this work), Montenegro, Switzerland (?) (see synonymy).

Clypeina isabellae MASSE, BUCUR, VIRGONE & DELMASSO, emend.
Pl. 2, Figs. 1–24; Pl. 3, Figs. 1–20

1972 *Clypeina* sp. A – PECORINI: 378, fig. 3, a–f, non g and h.

?1998 *Clypeina* sp. A PECORINI – EBLI & SCHLAGINTWEIT: 15–16, pl. 3, figs 1, 7, ?9.

non 1985 *Clypeina* sp. A PECORINI – BERNIER: 487, 746, pl. 8, figs. 1–7.

1999 *Clypeina isabellae* nov. sp. – MASSE, BUCUR, VIRGONE & DELMASSO: 237, pl. 2, figs. 1–8.

Original diagnosis. Petite espèce de *Clypeina* à thalle calcifié fibreux jaunâtre, à ramifications fertiles courtes, peu nombreuses, de section subcirculaire, soudées sur la plus grande partie de leur longueur (MASSE *et al.* 1999, p. 237).

In the description of their taxon, the authors furthermore added that the laterals are connected to the main axis by a short peduncle, poorly if at all recognizable in the original figurations.

Emended diagnosis. Tallus of elongate-cylindrical main axis bearing spaced-out fertile whorls of horizontal or slightly upward inclined (up to 16°) laterals. Relatively large tubular fertile laterals, containing ampulla, of slightly irregular shape with a small bulge on the lower side immediately near the main axis; in transverse section they are distally somewhat narrower. The skeleton prevailing consists of fibrous yellowish calcite, but also of colorless calcite. Individual calcification of laterals affects only their proximal and middle part, whereas the distal area is uncalcified. Main axis is feeble calcified. Very thin primary calcification characterizes also the wall of laterals, while yellowish calcite is intracellular deposition, usually united with wall skeleton by recrystallization.

Dimensions. The size of the Sardinian specimens varies more than 1: 3. D: 0.23–0.74 mm, d: 0.081–0.31 mm. The number of laterals per whorl is 6–15, generally varies between 10–12, rarely arrived to 14, exceptional are 6 or 15 laterals. Amongst the small-sized specimens, that one with an inner diameter of 0.123 mm and 10–11 laterals and another with 6 laterals and an inner diameter from 0.081 to 0.125 mm are worth noting (Pl. 2, Figs. 19, 22). Distance between consecutive whorls 0.020–0.030 mm. The main axis diameter is nearly of the same value as the length of the calcified part of the laterals, only sometimes larger and exceptionally smaller. Unique, extremement large specimen, here presented as *Clypeina* cf. *isabellae* (Fig. 6) derives from the Purbeckian of NW Sardinia (Nurra) illustrated by PECORINI (1972, Fig. 3d). The dimensions of this specimen (D: 1.15 mm, d: 0.48 mm) were obtained from the thin-section of the PECORINI collection. The similar example of an extreme large specimen in the population of *Clypeina marginiporella* MICHELIN was presented by GÉNOT (1987, pl. 26, fig. 1) as *C.* cf. *marginiporella*.

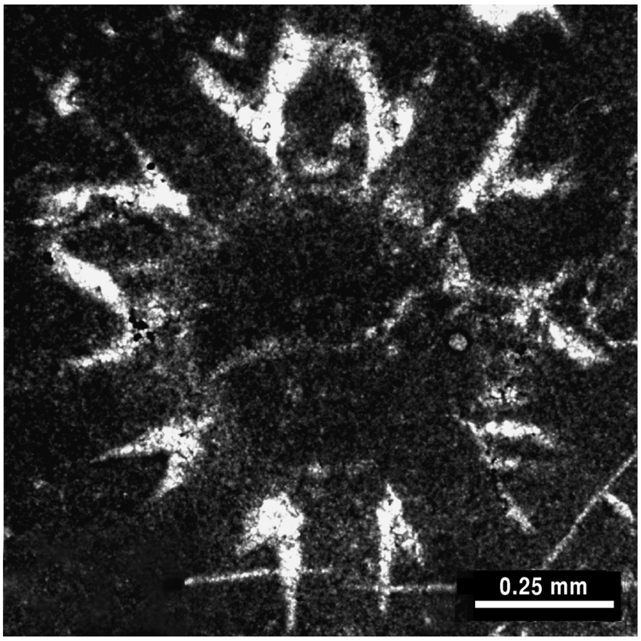

Fig. 6. *Clypeina* cf. *isabellae* (= *Clypeina* A PECORINI, 1972, fig. 3d). Nura, NW Sardinia.

Description. As the main axis is weakly calcified, scattered individual whorls are prevailing, rarely two successive whorls, or, exceptionally four whorls as those in Pl. 2, Fig. 18, are preserved. Whorl rosette generally has very regular shape; in specimens with elevated number of lateral they are irregularly composed, somewhat overlapped (Pl. 2, Figs. 5, 14). Adjacent laterals, depending of their number per whorl, may be more or less fused. In some very deep tangential section of specimens with elevated *w* number they occur, along fused portion, laterally congested having flattened shape (Pl. 2, Fig. 10). The bulge in the initial portion of whorl is clearly visible in number of longitudinal and different tangential sections shown on Plates 3 and 4. In transverse sections through the lower part of the whorl, the bulges occur as small circles around the main axis (Pl. 2, Figs. 1, 8), and this results also in some oblique sections (Pl. 3, Fig. 16). Ampullae are rarely preserved, usually as remains of calcite filling (Pl. 2, Figs. 15, 18, 21). Only well preserved ampulla (Fig. 7; Pl. 2, Fig. 9) is enclosed in intracellular calcification (as in *Clypeina jurassica*, Figs. 8A, B).

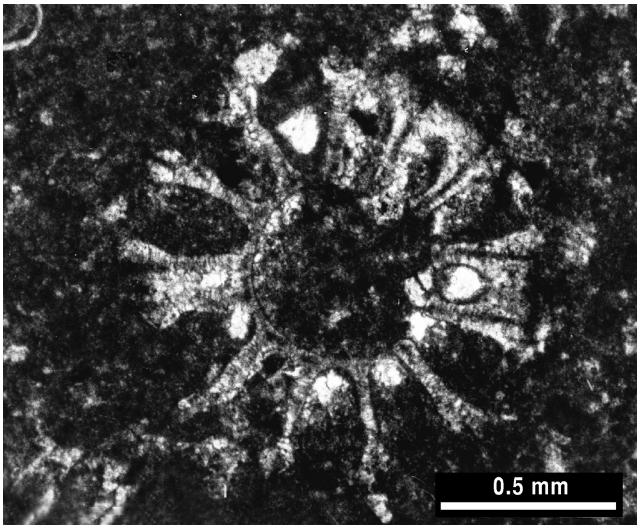

Fig. 7. *Clypeina isabellae* Masse, Virgono & Delmasso (= Pl. 2, Fig. 9), transverse section with well preserved ampulla enclosed in the intracelular calcification, from the Upper Jurassic of Podgorica, Montenegro.

Relationships. *Clypeina isabellae* is related to the group of *Clypeina* species characterized by a more or less expressed bulge on the proximal lower side of lateral's wall (= small lower protuberance of De Castro, 1997, pl. 20, fig. 1) including *Cl. digitata* (Parker & Jones), *Cl. neretvae* Radoičić, *Cl. inopinata* Favre, *Cl. jurassica* Favre & Richard, *Cl.*? *sedalanensis* Elliott, and *Cl. liburnica* Radoičić. It is especially similar to *Cl. inopinata* and *Cl. jurassica* having intracellular filling by fibrous yellowish calcite, but differs in form of laterals.

Species with larger bulges such as *Cl.*? *sedalanensis* and *Cl. liburnica*, according to Barattolo (1998, p. 84), belong to genus *Hamulusella* Elliott as the "short proximal portion below the junction point" of the primary lateral "... is not visible or recorded in the type-species of *Clypeina*". Consequently, the question is: which value of the bulge size can be taken as genus specific and is it an important character for distinguishing the two genera *Clypeina* and *Hamulusella*? Noteworthy, that the genus *Hamulusella* was considered a junior synonym of *Actinoporella* by Granier (1994), a view that is not followed here (see also Barattolo, 1998); other authors, though recognizing its affinities to *Clypeina*, maintained its validity (Deloffre & Génot 1982; Deloffre 1988; Deloffre & Granier, 1992; Granier & Deloffre 1993).

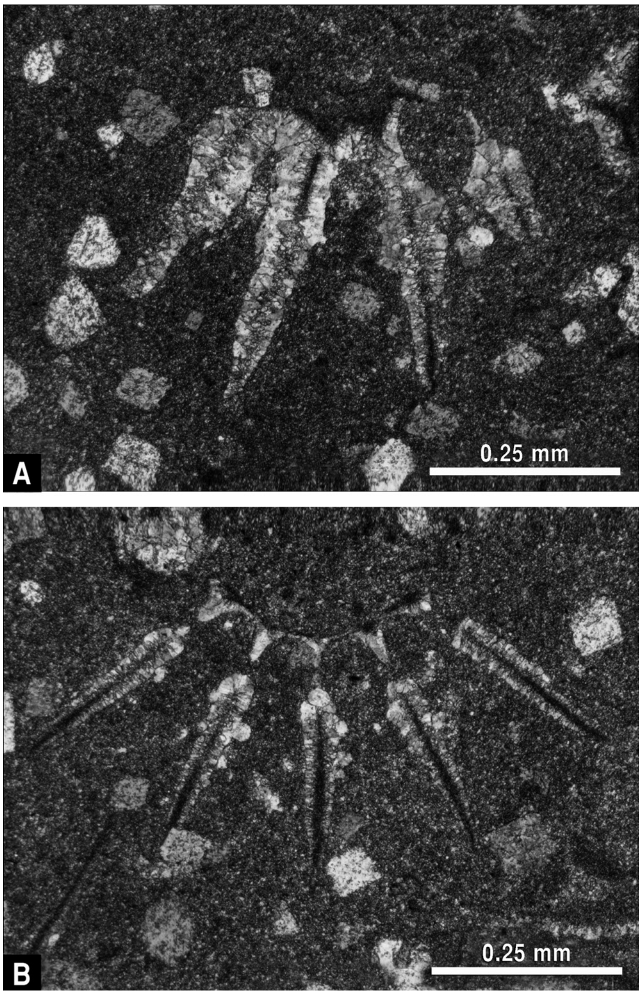

Fig. 8A, B. *Clypeina jurassica* Favre & Richard, fragments of transversale sections with imprints of ampulla, from upper Jurassic of Podgorica, Montenegro, thin section RR1015.

Occurrences. *Clypeina isabellae* is so far known from SE France (type-area) and Sardinia (Fig. 4).

The thin-sections with *Clypeina isabellae* Masse *et al.* from the Berriasian of Sardinia are housed in the Museo di Geologia e Paleontologia, University of Padova.

Remarks on *Clypeina jurassica* FAVRE & RICHARD – *Clypeina sulcata* (ALTH) relationships

Actinoporella sulcata (Alth) is known only as an imprint of transversal whorl's section from the Upper Jurassic Nizniów Limestone of the Ukraine illustrated by Pia (1920, Pl. 7, Fig. 8). Since that time, the species has not again been identified. Radoičić (1969) mentions that *Actinoporella sulcata* more appropriates to some *Clypeina* (cf. *jurassica*?). With respect to Pia's illustration, Conrad *et al.* (1974) stated that undoubtedly there is a close resemblance to *Clypeina jurassica* or *Clypeina inopinata,* thus, necessitating the study of further material from its type locality. In the monography of Jurassic–Cretaceous dasycladaleans provided by Bassoullet *et al.* (1978, p. 32), *Actinoporella sulcata (*was regarded a synonym of *Clypeina jurassica* although the former was described prior to the latter.

Granier & Brun (1991) were considering *Clypeina jurassica* as a junior synonym of *Clypeina sulcata* without going further into discussion. Consequently, *C. jurassica* was not included in the "Critical Inventory" provided by Granier & Deloffre (1993). It is worth mentioning that no *sulcata* specimen or fragment was identified in 6 samples (8 thin slides, R.R.) from the type-locality which were kindly collected by S. Pasternak (The National Academy of Sciences of Ukraine). Even in case where *Clypeina jurassica* (not *inopinata*) would be documented as junior synonym of *Clypeina sulcata*, there would be some solid arguments in favour of retaining the name *jurassica* as *nomen conservandum*. The present authors will refer to the General Committee of ICBN with an appropriate recomendation for a ruling this matter.

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Резиме

Двије сличне дазикладацејске алге: *Clypeina isabellae* Masse, Bucur, Virgone & Delmasso, 1999 из беријаса Сардиније (Италија) и *Clypeina loferensis* sp. n. из горње јуре Сјеверних кречњачких Алпа (Аустрија)

На основу богатог фосилног материјала из беријаских седимената западне (PECORINI 1972) и источне Сардиније (I. DIENI), дата је допунска дијагноза за врсту *Clypeina isabellae* MASSE *et al.*, 1999, која је била описана из беријаских седимената Провансе, а на основу пресјека који нијесу могли дати све податке о њеној грађи. Притом, аутори су превидели рад PECORINI (1972) у којем је ова врста била приказана као *Clypeina* sp. A. Овом приликом уводи се *Clypeina loferensis* sp. n. из горње јуре Сјеверних кречњачких Алпа која у неким пресјецима има сличност са *Clypeina isabellae.*

Clypeina loferensis sp. n.

Холотип: искошен попречан пресјек приказан на Табли 1, сл. 9, преп. BSP-2009-XI-1.

Дијагноза: Дазикладацеа средње величине са равномјерно распоређеним пршљеновима огранака, под нагибом 60°–80° према главној оси, који су еуспондилно распоређени.

Огранци су фусиформног облика, проксималним дилелом у латераном контакту, дистално слободни. Калцификација је обухватала дио пршљена око главне осе и знатан дио огранака.

Clypeina isabellae (MASSE *et al.*, 1999)

Допуњена дијагноза: Талус главне осе издужено-цилиндричног облика са пршљеновима хоризонталних или благо навише нагнутих огранака. Релативно крупни тубиформни огранци (са ампулом) благо су неправилног облика са малим испупчењем у доњем проксималном дијелу. У попречном пресјеку огранци су незнатно дистално сужени. Скелет чини фиброзни чуђкаси калцит, али такође и безбојни калцит. Веома танка примарна калцификација захватала је зид гравне осе огранака, док је жућкасти калцит депонован интрацелуларно, а често прекристализацијом сједињен са танким скелетом зида.

Clypeina isabellae је сродна групи клипеина са мање или више израженим проширењем на доњој страни огранака, уз главну осу. У највећој мјери је сродна врстама *Clypeina jurassica* и *Cl. inopinata* које се такође карактеришу интрацелуларним испуњењем фиброног калцита, али се од ових разликује обликом огранака.

Однос *Clypeina jurassica – Clypeina inopinata*

Actinoporella sulcata (ALTH, 1878), описана из горњојурског кречњака Нижњева (Украјина), била је позната само на основу једног отиска трансверзалног пресјека који је приказао PIA (1920; таб. 7, сл. 8). Од тада није била идентификована. У шест узорака (8 препарата, Р.Р.) који су љубазно добијени од С. ПАСТЕРНАКА (Украјинска Академија Наука) није нађен ни један пресјек или фрагмент ове врсте. RADOIČIĆ (1969) помиње да је *A. sulcata* слична некој клипеини (cf. *jurassica*?). CONRAD *et al*. (1974) потврђују њену несумњиву сличност са *Clypeina jurassica* или *Cl. inopinata* и упућују на потребу даљег проучавања материјала из типског локалитета.

Према GRANIER & BRUN (1991), *Cl. jurassica* млађи синоним врсте *Cl. sulcata*, не улазећи у дискусију о овој материји, аутори сматрају да постоје, чак и у случају ако се потврди да је *Clypeina jurassica* (не *inopinata*) млађи синоним врсте *Cl. sulcata*, веома јаки аргументи да се специфичко име *jurassica* задржи као *nomen conservandum*.

Plate 1

Clypeina loferensis n. sp. from the Late Jurassic (Kimmeridgian–Tithonian)
of the Northern Calcareous Alps (Austria, Germany)

Figs. 1–2.	Oblique sections, samples DIE-164 and ENS-1; 1, Lofer Kalvarienberg-Lärchberghörndl; 2, Mount Dietrichshorn.
Fig. 3.	Oblique section, sample MT-947, Mount Trisselwand.
Fig. 4.	Longitudinal section cutting two verticils; note upward bending of laterals, sample KOWG-1, Lofer Kalvarienberg-Lärchberghörndl.
Fig. 5.	Oblique section, sample E 109, Mount Zwerchwand.
Fig. 6.	Longitudinal-oblique section, sample LK 3, Mount Litzelkogel.
Figs. 7–8.	Longitudinal sections, slightly oblique, samples LOF-2 and KOWG-D, Lofer Kalvarienberg-Lärchberghörndl.
Fig. 9.	Holotype, oblique transversal section, sample LOF-1, Lofer Kalvarienberg-Lärchberghörndl.
Fig. 10.	Oblique-tangential section through one verticil, sample Die-170, Mount Dietrichshorn.
Fig. 11.	Oblique-transverse section, sample KOWG-B, Lofer Kalvarienberg-Lärchberghörndl.
Fig. 12.	Transverse section with 8 laterals, sample KOWG-D, Lofer Kalvarienberg-Lärchberghörndl.
Fig. 13.	Wackestone with *Pseudocyclammina* cf. *lituus* (Yokoyama) (left) and *Clypeina loferensis* n. sp. (right), sample MT-323, Mount Trisselwand.
Fig. 14.	Oblique section; note comparable thin calcification covering the main axis, sample DIE-642, Mount Dietrichshorn.
Fig. 15.	Wackestone with several sections of *Clypeina loferensis* n. sp., sample MT-947, Mount Trisselwand.
Fig. 16.	Oblique-transverse section, sample KOWG-E, Lofer Kalvarienberg-Lärchberghörndl.
Fig. 17.	Transverse section, slightly oblique ; note micritic envelopping, sample LOF-4, Lofer Kalvarienberg-Lärchberghörndl.

Scale bars = 0.3 mm.

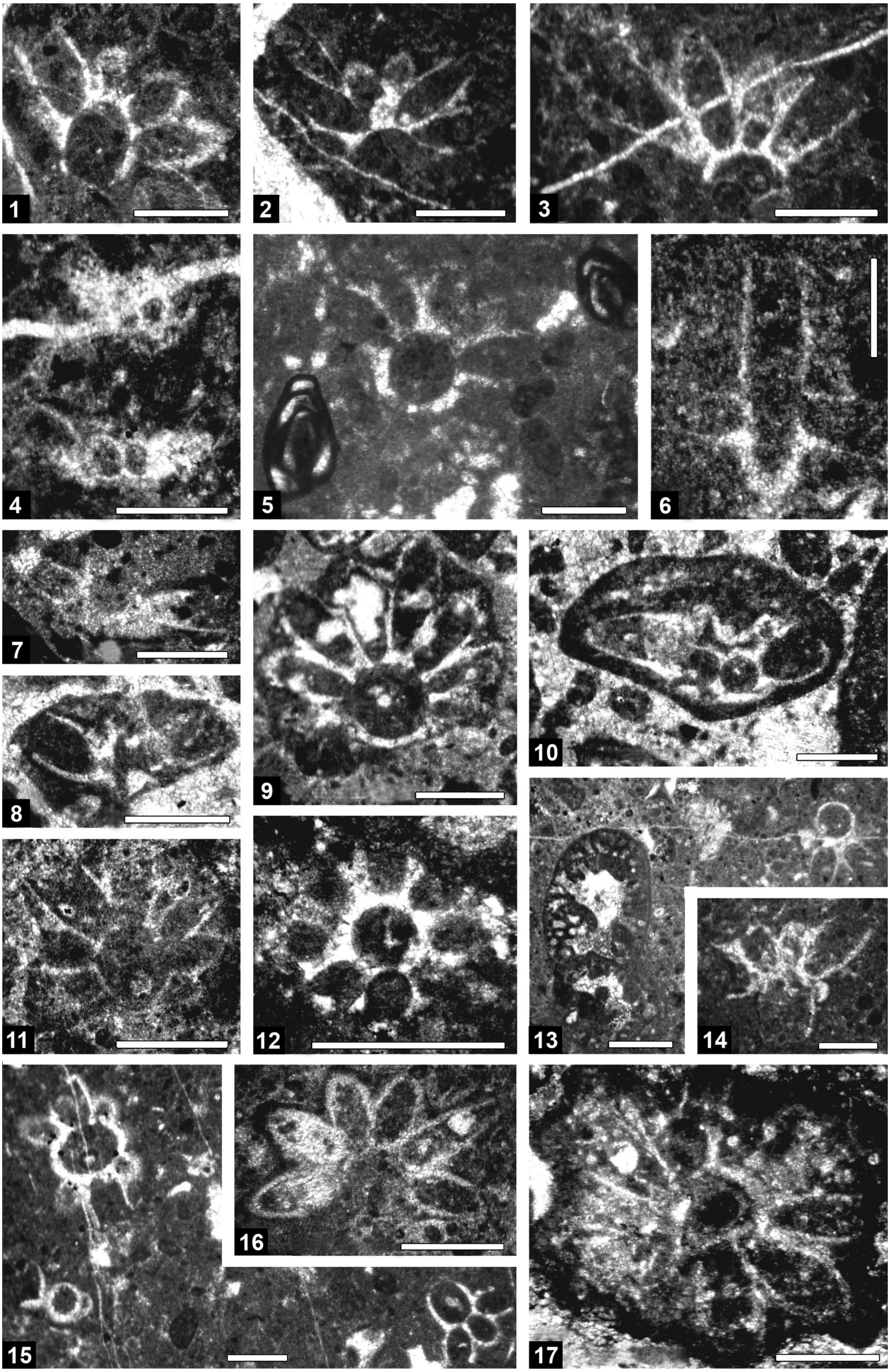
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Plate 2

Clypeina isabellae Masse, Bucur, Virgone & Delmasso, emend.,
from the Late Jurassic (Kimmeridgian–Tithonian) of the Northern Calcareous Alps (Austria, Germany)

Fig. 1. Transverse and longitudinal section, note: the bulge in the upper whorl; sample 853/1.

Fig. 2. Sub-axial section; sample 853/3.

Fig. 3. Axial section (fragment) showing the bulge and secondary enlarged pore (853/1).

Fig. 4. Transverse and oblique section; sample 853/4.

Fig. 5. Transverse section of a whorl with 13 laterals which are not lying in the same plane, instead corresponding to tangential section of overlapping laterals (compare Fig. 14); sample 853/5.

Fig. 6. Transverse-oblique section; sample 853/4.

Fig. 7. Transverse slightly oblique section cutting some bulges of laterals, note: thin primary calcification of the main axis; sample 853/4.

Fig. 8. Slightly oblique transverse section passing through the lower part of whorl – through bulges; sample 853/5.

Fig. 9. Transverse, slightly oblique section with, in the one lateral on right, clearly visible well preserved ampulla; sample 853/2.

Figs. 10–14. Different tangential sections; the section in Fig. 14 with overlapping laterals corresponds to specimen as that one shown in Fig. 5; samples 853/4, 853/2, 853/3, 853/2, 853/1.

Figs. 15–17. Different transverse-oblique and transverse sections, note thin primary calcification of the main axis in Figs. 16 and 17; samples 853/a, 853/1, 853/2.

Fig. 18. Longitudinal-tangential section crossing 4 successive whorls; sample 853/a.

Figs. 19–23. Different transverse-oblique and transverse section of small-sized specimens; samples 853/4, 853/1, 853/6, 853/7.

Fig. 24. Transverse section with poorly preserved laterals. Some of the laterals are filled with secondary calcite (as in some other specimens also); sample 853/1.

Scale bar for all figures: in fig. 24 = 0.5 mm


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PLATE 3

Figs. 1–16. *Clypeina isabellae* MASSE, BUCUR, VIRGONE & DELMASSO, emend. from the Berriasian of the Sa Marghine Ruja stratigraphic section (Oliena, East Sardinia).

1–2. Different tangential sections; samples 833/7, 853.

3–5. Axial and sub-axial sections showing the bulge; samples 853/5, 853/4, 853/6.

6. Transverse section of large whorl with slightly recrystallized wall of the main axis and some laterals; note: in lower left corner, a specimen of *Nautiloculina bronnimanni* ARNAUD-VANNEAU & PEYBERNES; sample 855/b.

7. Transverse oblique section; sample 853/7.

8. Transverse section, note: thin primary colorless calcification of the main axis and of tubuliform laterals; sample 853/7.

9. Partly preserved transverse section in which the tubuliform shape of laterals with slightly recrystalized walls are well visible; sample 853/1.

10–11, 13. Different more or less oblique sections; samples 853/7, 853/4, 853/7.

12. Transverse section of a a whorl consisting of 13 densely set laterals, some of them filled with calcite (dissolved and recrystalized internal moulds of ampulae; corresponding tangential section is that in Pl. 1, Fig. 10); sample 853/7.

14–15. Fragments of transverse oblique sections; sample 853/c.

16. Oblique section of whorl crossing bulges; sample 853b.

Figs. 17–20. "*Clypeina* A" PECORINI, 1972 original thin sections of the Pecorini Collection, Cr V3, V4 and V9; Purbeckian (Berriasian) of Nura, SW Sardinia.

17–19. Different transverse sections, PECORINI, 1972 – figs. 3f, 3a, 3c.

20. Oblique section, (this section Cr V9, was not illustrated by Pecorini).

Scale bar for figures 1–16: on Fig. 1 = 0.5 mm

Scale bar for figures 17–20 = 0.25 mm.


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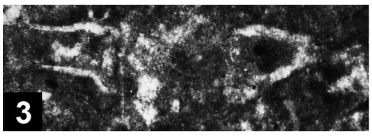
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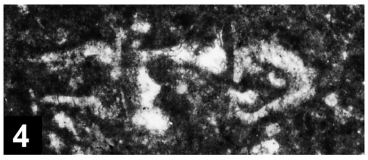
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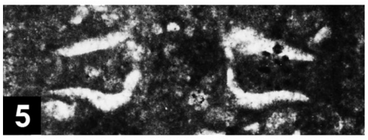
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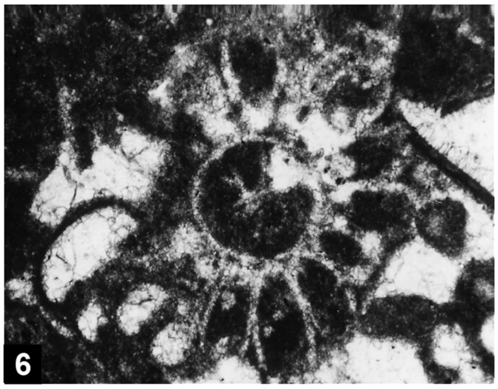
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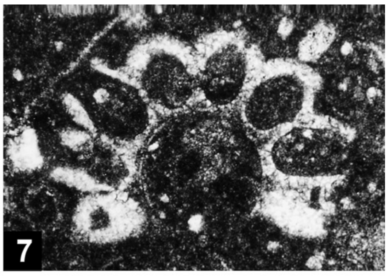
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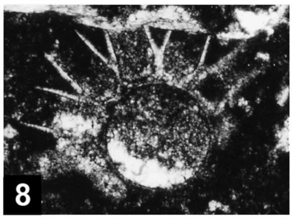
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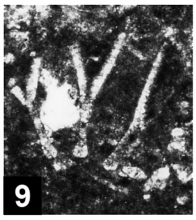
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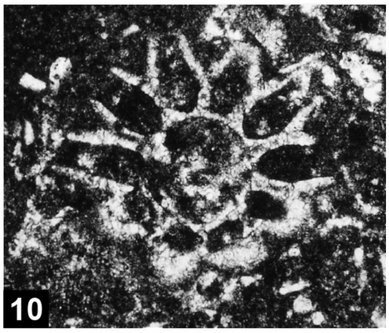
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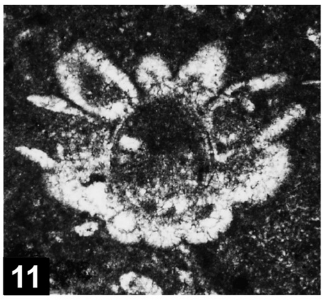
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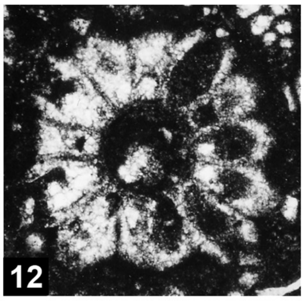
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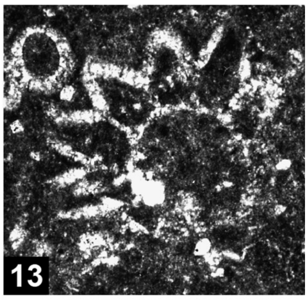
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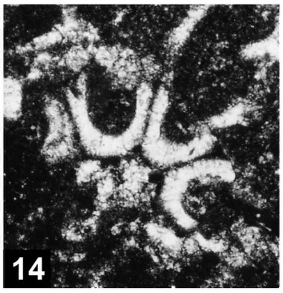
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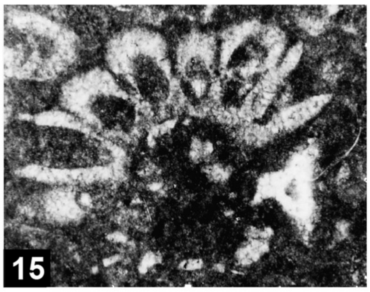
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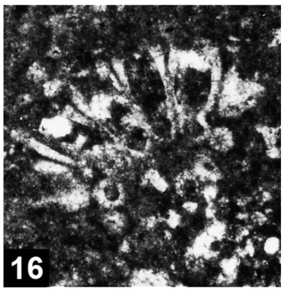
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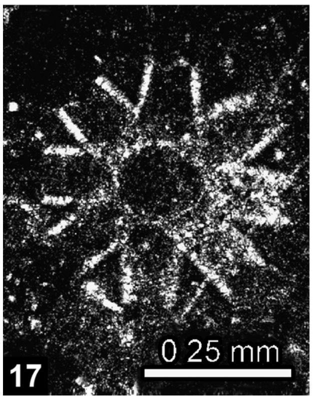
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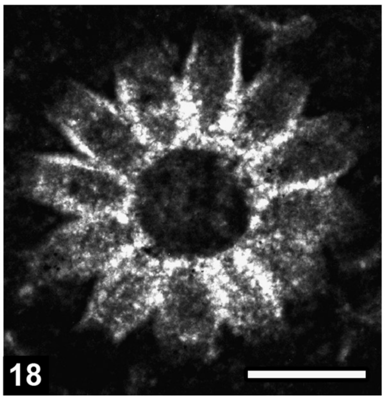
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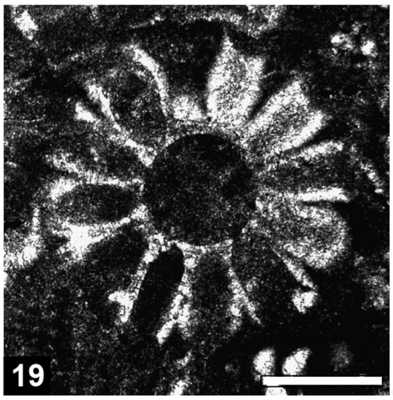
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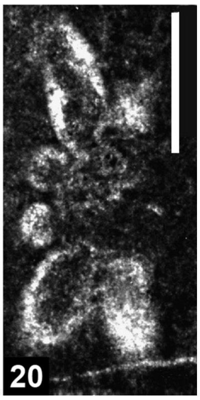
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Linoporella buseri Radoičić, 1975, revisited. A Liassic dasycladalean alga from the Dinarides and continental Italy

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Abstract. The Liassic *Linoporella buseri* is re-examined, on the basis of an abundant material of reefal origin, originating from the newly described type-locality in Slovenia. It is compared with the Berriasian–Valanginian type-species *L. capriotica*, studied by Barattolo & Romano (2005). Both species have three orders of laterals. In *L. buseri*, however, apart of other, clear cut differences, the tertiary laterals are usually hair-like, occasionally phloiophorous at tip, forming a distal cortex such as in *L. capriotica*. Consequently, the genus *Linoporella* is slightly emended, to fit observations made on the two species.

Key words: Dasycladales, *Linoporella buseri*, Liassic, Slovenia.

Апстракт. Преиспитана је лијаска алга *Linoporella buseri* на основу обилног материјала спрудног подручја који потиче из накнадно описаног типског локалитета у Словенији. Упоређење је вршено са типском беријаско-валендиском врстом *L. capriotica* према студији Barattolo & Romano (2005). Обје врсте имају по три реда огранака. Међутим, *L. buseri* се разликује по томе што има терцијарне огранке, обично танке, ријетко флоиоформне на врху, гдје формирају кортекс као и *L capriotica*. Сходно овоме, род *Linoporella* је благо емендиран на основу обсервација у обје врсте.

Кључне ријечи: Dasycladales, *Linoporella buseri*, лијас, Словенија.

Geological introduction by late *Stanko Buser*

In 1975, while mapping in the Kanin mountain range of the Julian Alps, a small outcrop of Liassic limestone containing *Linoporella buseri* was discovered at coordinates 46°18'36.9" N; 13°27'51.13" E. So far, it is the only known locality containing this alga in Slovenia (Radoičić, 1975). The site (Fig. 1) is on the left bank of the small Učja river, about 1200 m west of a bridge crossing this river at Žaga, southwest of Bovec, exactly 100 m west of a hay-barn at Hlebišče.

The Liassic limestone containing the algae occurs as a tectonically isolated klippe covering some 500 m^2 along the Idrija fault, between the Upper Triassic Dachstein limestone and the Main dolomite. The klippe forms in the landscape an about 4-m high terrace step. Rare algae are found in the massive primary limestone and also as fragments of rubble at foot of the wall.

The limestone with algae was deposited on the mobile margin of the Julian carbonate platform. In this area, the Dinaric and the Julian carbonate platforms occur directly next to the other, without the intermediate Slovenian basin that pinches out and does not extend farther westward to neighboring Italy. North of the aforementioned locality, at Bovec, a Liassic oolitic and sparitic limestone conformingly overlies the Upper Triassic Dachstein limestone with megalodontids. Both the Dachstein limestone and the Liassic limestone are cut by sedimentary dikes consisting of Liassic red coloured calcareous breccias and crinoid limestone. These dikes are especially frequent in the Kanin Mountains. At Bovec, the oolitic Liassic limestone is overlain by a pelagic limestone of the Ammonitico rosso type containing manganese nodules.

Systematic taxonomy

The following, indicative hierarchy is given provisionally, pending a more general revision of concepts

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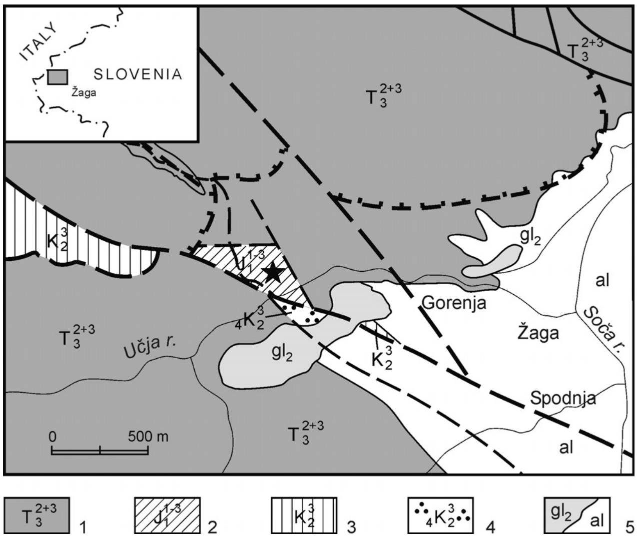

Fig. **1,** Upper Triassic; **2,** Lower Jurassic (Liassic); **3,** Senonian pink marly limestone and marl; **4,** Kampanian–Maastrichtian flysch; **5.** Glacial sedimnets and Aaluvial.

governing the definition of a genus in certain fossil Dasycladales. A few comments are given below.

Family *Triploporellaceae* (Pia, 1920) Berger & Keaver, 1992
Tribe *Triploporelleae* (Pia, 1920) Bucur, 1993

Genus ***Linoporella*** Steinmann, 1899, emend.

Emendation of the genus. Barattolo & Romano (2005, p. 238) provided the following emendation of the genus *Linoporella*, in the wake of their outstanding revision of the Berriasian-Valanginian type-species *Linoporella capriotica* Steinmann: “Cylindrical to slightly club-shaped simple thallus. Primary laterals arranged in close whorls. Short primary laterals and long, thin secondary laterals. Tertiary laterals are phloiophorous in shape and form a cortex. Reproductive organs probably placed within the central stem (endosporate-type).” Previous emendations of *Linoporella* were proposed, first by Bassoullet *et al.* (1978), calling for the occurrence of only two orders of laterals, then by Dieni *et al.* (1985), based on the presence of three orders in *Linoporella buseri*. As shown by Gawlick *et al.* (2006, p. 116), the genus *Pentaporella* Senowbari-Daryan is a junior synonym of *Linoporella*.

A re-description of *L. buseri* is given below. It includes the occasional presence of a distal enlargement of the tertiary laterals, forming a cortex. Consequently, a slight emendation of the genus *Linoporella* is proposed as follows: “Thallus simple, cylindrical to slightly club-shaped. Main axis cylindrical or slightly intusannulated, bearing contiguous whorls of up to three orders of laterals. Primary laterals comparatively short and thick, oblique or perpendicular to the main axis, tubular or slightly widening outwards. Elongated, tubular and comparatively slender secondary laterals are clustered at tip of the primaries. Slender tertiary laterals are clustered at tip of the secondaries. They are either hair-like throughout, or phloiophorous at tip, forming a distal cortex. Reproductive organs probably placed within the central stem (endosporate-type).”

Systematics. Reference is made to the work of Barattolo & Romano (2005, p. 238) for discussion on the species referable to *Linoporella* and its probable endospory. Consequently, at a higher level, diagnosis of the family *Triploporellaceae*, as far as applicable, should be emended to include endospory. Herein, the following diagnosis proposed by Bucur (1993, p. 78) for the tribe *Triploporelleae* is provisionally taken into account: “Thallus cylindrical, claviform, moniliform or spherical; ramifications of the first and second order, possibly the third or fourth.” On the other hand, the subtribe *Linoporellinae* Pia, 1927, nom. transl. should be emended, for, according to Berger & Keaver (1992, p. 38) it includes taxa with only two orders of laterals, while three are present in *Linoporella*.

Recently, Bucur *et al.* (2009) created another new genus, *Steinmanniporella* (type-species the Upper Jurassic *S. kapelensis,* sub-tribe *Linoporellinae*), with only two orders of laterals instead of three in the type-species *L. capriotica*. Purpose was to include four Upper Jurassic to Paleocene species originally assigned to the genus *Linoporella*. Endospory is inferred or taken as possible for both *Linoporella* and *Steinmanniporella*. Worth mentioning, quoting Sokač & Nikler (1976) “Spores [= cysts] can sometimes be observed in the wider part of both the primary and secondary branches” of the Upper Jurassic–Lower Cretaceous *Linoporella* ? *svilajaensis*.

Linoporella buseri Radoičić, 1975
Pls. 1, 2

1975 *Linoporella buseri* sp. nov. – Radoičić, p. 277, fig. 1. [Liassic of the Julian Alps, Slovenia].

1978 *Linoporella ? buseri* Radoičić, 1975 – Bassoullet *et al.*, p. 147, pl. 17, figs. 10-12. [Review work, the genus is emended].

1985 *Linoporella buseri* – Dieni *et al.*, p. 14. [three orders of laterals occur; the genus is emended].

1994 *?Linoporella buseri* Radoičić – Chiocchini *et al.*, pl. XXXIV, fig. 3, 4. [Sinemurian, Latium, Italy].

2001 *Palaeodasycladus asteriscus* n. sp. – Sokač, p. 166, pls. 39, 40. [Lower Liassic, Croatia].

2005 *Linoporella buseri* Radoičić – Barattolo & Romano, p. 238. [Species referable to the genus].

Type specimens, depository. The holotype is depicted in Pl. 1, Fig. 2. All other herein-illustrated specimens from the type-locality are isotypes. The holotype and the isotypes are housed in the R. Radoičić collection, in the Geological Institute of Serbia, Belgrade.

Diagnosis, revisited. The short diagnosis given in Radoičić (1975) is elaborated as follows. "Thallus simple, cylindrical, rounded or slightly acuminated at tip. Main axis cylindrical or slightly intusannulated, bearing contiguous whorls of up to three orders of laterals. Primary laterals rather stout, tubular, proximally and distally constricted (spindle-like), first horizontal or slightly tilted in main portion of the thallus, markedly tilted at the apex. Four or five, tubular and comparatively slender, more or less diverging and curved second order laterals are clustered at tip of the primaries. In most cases, three hair-like tertiary laterals are clustered at tip of the secondaries. Occasionally, the tertiaries are phloiophorous at tip, apparently forming a cortex. Calcareous skeleton solid, forming a sleeve, assumed of primary aragonitic origin. Endospory inferred.

Description. The calcareous skeleton is massive, neither undulated or fissurated, cylindrical with no evidence of a capitulum-shaped head. As shown by Pl. 1, Fig. 1 and Pl. 2, Fig. 5, the axial cavity is cylindrical, even if slightly altered, matching the axis. Occasionally however, as shown by a nice oblique-longitudinal section illustrated by Sokač (2001, pl. 39, fig. 1), the stipe is slightly intusannulated.

Primary laterals: due to the alteration of the axial cavity, the proximal constriction denoting the attachment of the primaries to the axis is seldom left, such as in Pl. 1, Fig. 6 and, pro parte, Pl. 1, Fig. 1. As shown for example by Pl. 1, Fig. 1, in the main, cylindrical portion of the thallus, the primaries are perpendicular or slightly oblique to the stipe. But there are exceptions, such as in the oblique section shown in Pl. 2, Fig. 5, with primary laterals oriented at 45°. On the other hand, at or close the apex of the thallus, the primaries are characteristically oblique (Pl. 1, Fig. 7; Pl. 2, Figs. 1, 8).

Second order laterals: the quite irregular orientation of the 4-5, tubular second order laterals is best shown in the tangential section of Pl. 1, Fig. 11. Close to the apex of the thallus (Pl. 2, Fig. 7), the secondaries keep their modest width throughout their length.

Third order laterals: although often obliterated by microbioerosion, clusters of three, hair-like tertiaries are found in most sections of *L. buseri*, in both the main cylindrical portion (Pl. 1, Fig. 2; Pl. 2, Fig. 10) and the apex of the alga (Pl. 2, Fig. 6; Pl. 1, Fig. 7). Occasionally, however, as shown by the tangential section of Pl. 1, Fig. 11, the tertiary laterals are phloiophorous at tip, apparently forming a cortex. The same applies to certain sections illustrated by Sokač (2001; pl. XXXIX, figs. 1-3), under the name of *Palaeodasycladus asteriscus*.

Dimensions. Measurements carried out on numerous topotype specimens of *L. buseri* are as follows:

Outer diameter (D): 1.0–2.9 mm.
Diameter of the axis, or axial hollow (d): 0.36–1.5 mm.
d/D ratio: 0.28–0.51.
Distance between the whorls (h): 0.46–0.60 mm.
Number of primary laterals (w): 12–20 per whorl.
Length of the primary laterals (l): 0.28–0.48 mm.
Thickness of the primary laterals (p): 0.11–0.20 mm.
Number of secondary laterals (w'): 4–5 per cluster.
Length of the secondary laterals (l'): 0.21–0.32 mm.
Thickness of the secondary laterals (p'): 0.04–0.12 mm.
Number of tertiary laterals (w''): three per cluster.
Calcified length of the tertiary laterals (l''): 0.21–0.32 mm.
Thickness of the tertiary laterals (p''): in most cases ca. 0.4 mm; in one case 0.13 mm at tip, forming a cortex.

Euendolithic microorganisms. Many fragments of *L. buseri* and accompanying dasycladalean algae are more or less heavily altered, eroded or even disintegrated by one or several epi- and/or euendolithic microrganisms. Microbioerosion was at work on the margin of the skeleton (e.g. Pl. 1, Fig. 11, 12) and penetrated the first order laterals, spreading laterally (Pl. 1, Fig. 5; Pl. 2, Fig. 10). Seldom (Pl. 2, Fig. 11), a yet unidentified, calcifying euendolithic microorganism is embedded in the bioeroded cavities, forming ca. 0.3 mm-wide rosettes. Interestingly, similar processes of bioerosion were also at work in some of the specimens of *L. buseri* of Italy and Croatia.

Comparisons. The Berriasian–Valanginian type-species *Linoporella capriotica* also has three orders of laterals. In this species however, the thallus is cylindrical to slightly club-shaped, the primary laterals are shorter, compared to *L. buseri*, the secondaries (2–5 in number) much longer, and the tertiaries (2–3 in number) phloiophorous, forming a distal cortex, according to Barattolo & Romano (2005).

Accompanying biota. Numerous pieces of a large (outer diameter up to 3.5 mm) dasycladalean alga, provisionally named *Palaeodasycladus* ? sp. (Pl. 2, Figs. 11-14), are present in the type-material of *L. buseri*. The thallus looks simple, cylindrical or slightly club-shaped, with a wide, intusannulated axial cavity and, separately, up to five orders of slender laterals. An ad hoc description and correct naming of this taxon is beyond the scope of this article, also because it requires a reconsideration of the systematic taxonomy adopted by Sokač (2001). Other biota include *Dinarella* ? sp. (Pl. 2, Fig. 9), *Involutina liassica* (foraminifer), *Rivularia* ? sp. ("Porostromata"), brachiopods and bivalves.

Distribution, depositional environment. So far, *Linoporella buseri* was reported from the Liassic of Slovenia, Croatia and continental Italy. The stratum-typicum of *L. buseri* consists of coarse grained grainstones containing numerous, freshly broken pieces of dasycladalean algae. As shown by the presence of isopachous and palisade cements, part at least of the deposit is of meteoric, phreatic or upper intertidal origin. Comparable environments are reported for the other occurrences of the species.

Conclusions

Further to the work of Barattolo & Romano (2005), the genus *Linoporella* is again slightly emended, to comply with observations carried out on numerous topotype specimens of *Linoporella buseri*. *Linoporella* now comprises three species, all with three orders of laterals: the Rhaetian *L. rhaetica* (Senowbari-Daryan), the Liassic *L. buseri* Radoičić and the Berriasian–Valanginian *L. capriotica* (Oppenheim). Four other, Upper Jurassic to Paleocene species originally assigned to *Linoporella*, all with two orders of laterals, are transferred by Bucur *et al*. (2009) to their new genus *Steinmanniporella*.

Acknowlegments

Several persons generously helped preparing this article: Matevž Novak (University of Ljubljana), supplied a geological map of the Bovec area, as originally mapped by late Stanko Buser, Radmilo Jovanović (Naftagas, Novi Sad) prepared the location map, Filippo Barattolo (University of Naples) advised on the status of *Linoporella*. Finally, both Daria Ivanova (Geological Institute, Sofia) and Felix Schlagintweit (München), as reviewers, brought useful suggestions to improve the content of the manuscript.

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Резиме

Linoporella buseri Radoičić 1975, преиспитивање. Лијаска дазикладалеска алга из Динарида и континенталне Италије

Фамилија *Triploprellaceae* (Pia,1920) Berger & Keaver, 1992
Трибус *Triploporelleae* (Pia, 1920) Bucur, 1993

Род ***Linoporella*** Steinmann, 1899, emend.

Barattolo & Romano (2005, p. 238) дали су следећу емендацију рода *Linoporella* у свијетлу изразито добре ревизије типске беријаско-валендиске врсте *L. capriotica*: "Једноставан цилиндричан или благо кијичаст талус. Примарни огранци сложени у густе пршљенове. Кратки примарни и дуги танки секундарни огранци. Терцијарни огранци су флоиоформног облика и чине кортекс. Репродуктивни органи вјероватно су смјештени унутар централне стабљике (ендоспоратни тип)". Раније емендације биле су предложене најприје од Bassoullet *et al*. (1978), позивајући се само на два реда огранака, док се емендација Dieni *et al*. (1985) базирала на присуству три реда огранака код врсте *Linoporella buseri*. Сагласно преиспитивању врсте *L. buseri*, род *Linoporella* је поново благо емендиран: "Једноставан цилиндричан или благо кијичаст талус. Главна оса, цилиндрична или слабо интусанулатна, носи слијед пршљенова са три реда огранака. Примарни огранци су релативно кратки и дебљи, искошени или управни на главну осу, цјевасти или мало дистално проширени. Издужени, тубуларни и релативно танки секундарни огранци чине скупину на врху примарних огранака. Танки терцијарни чине такође скупину на врху секундарних огранака. Они су или сасвим танки, или на врху флоиоформни, те формирају кортекс. Репродуктивни органи вјероватно унутар централне стабљике (ендосоратни тип).

Linoporella buseri Radoičić, 1975
Таб. 1, 2

Холотип: Пресјек приказан на табли 1, сл. 2. Сви остали пресјеци на таблама 1 и 2 су изотипови.

Ревидирана дијагноза: једноставан талус заобљеног или благо заоштреног врха. Главна оса, цилиндрична или интусанулатна, носи пршљенове са три реда огранака. Претежно јаки примарни огранци проксимално и дистално су стањени (вретенаси). Најприје су, у главном дијелу талуса, хоризонтални или благо нагнути, а упадљиво нагнути у апикалном дијелу. Примарни огранци дају скупину од 4–5 тубуларних, танких мање или више дивергентних и повијених секундарних огранака. Ови потоњи, најчешће носе скупину од три истањена терцијарна огранка. Кречњачки скелет је чврст, примарно највјероватније арагонитски. Репродуктивни ограни ендоспоратног типа.

PLATE 1

Linoporella buseri RADOIČIĆ. All specimens from the type-level.

Fig. 1. Oblique section in the main, cylindrical portion of the thallus. Third order laterals, are visible on the eroded margin of the calcareous skeleton. Thin section RR3121, ×14.

Fig. 2. The holotype. Oblique section in the main, cylindrical portion of the thallus. Slender third order laterals, are clearly visible. Thin section RR3101, ×13.

Fig. 3. Oblique section in the main, cylindrical portion of the thallus. Although hardly visible, slender third order laterals are present. Thin section RR3108, ×14.

Fig. 4. Almost transversal section in the main, cylindrical portion of the thallus. Note the wide axial cavity and the relatively thick first, second and third order laterals. Thin section RR3132, ×14.

Fig. 5. Oblique section in the main, cylindrical portion of the thallus. Slender third order laterals are visible. Note bioerosion penetrating and progressively destroying the first order laterals. Thin section RR3121, ×11.

Fig. 6. Broken oblique section in the main, cylindrical portion of the thallus. Three orders of laterals are clearly visible despite bioerosion. Thin section RR3105, ×12.

Fig. 7. Broken oblique section close to the apex of the thallus. Three orders of laterals are present, oblique to the bioeroded axial cavity. Thin section RR3129, ×20.

Fig. 8. Two, partly broken oblique sections, with three orders of laterals. The right hand side section is heavily bioeroded. Thin section RR3128, ×17.

Fig. 9. Oblique section in the main, cylindrical portion of the thallus, with three orders of relatively slender laterals. Note the irregular, bioeroded axial cavity. Topotype specimen, ×28.

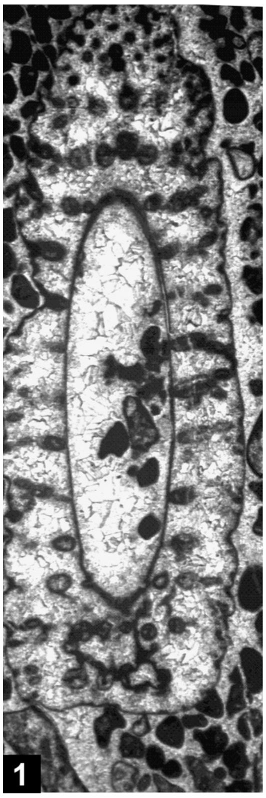
Fig. 10. Oblique – tangential section. Clusters of five second order laterals arise from the top of the primaries. Slender third order laterals are hardly visible on the bioeroded margin of the skeleton. Thin section RR3141, ×20.

Fig. 11. Slightly oblique, tangential section. Clusters of four, rather slender second order laterals arise from the top of the primaries. Clusters of three third order laterals (arrow) are also visible. In this section, the tertiaries are phloiophorous at tip, indicating the presence of a distal cortex. Thin section RR3103, ×14.

Fig. 12. Longitudinal section of the main, cylindrical portion of the thallus. Primary and secondary laterals are rather thick. Third order laterals look missing, or are bioeroded. Thin section RR3111, ×20.

Fig. 13. Slightly oblique, tangential section. The spindle-like, bioeroded primary laterals bear clusters of four secondaries (arrow). Thin section RR3113, ×14.

Fig. 14. Two transversal sections, showing the presence of third order laterals at bottom of the picture. Thin section RR3124, ×13.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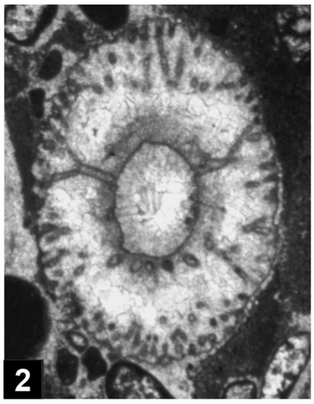
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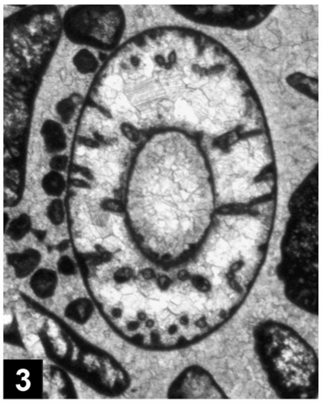
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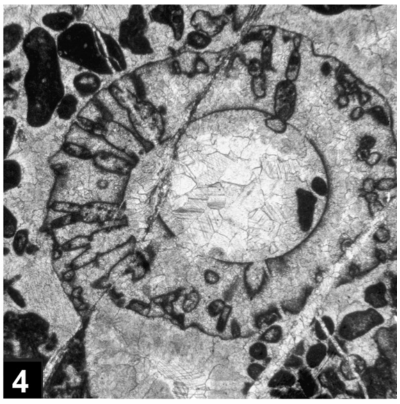
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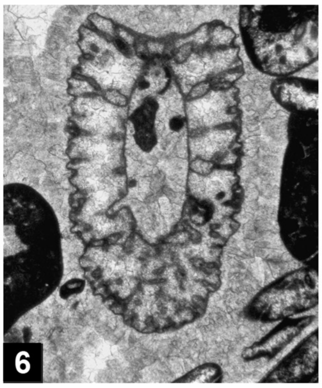
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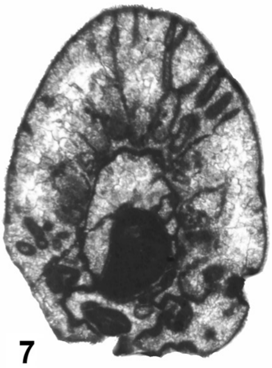
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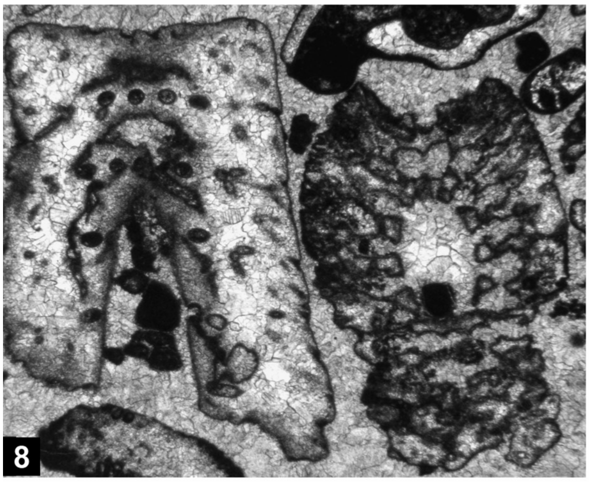
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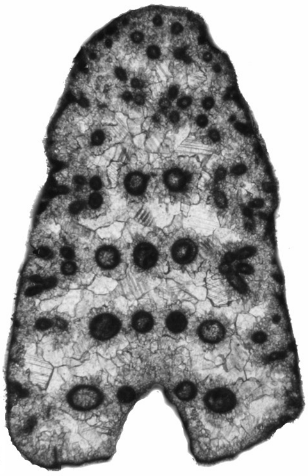
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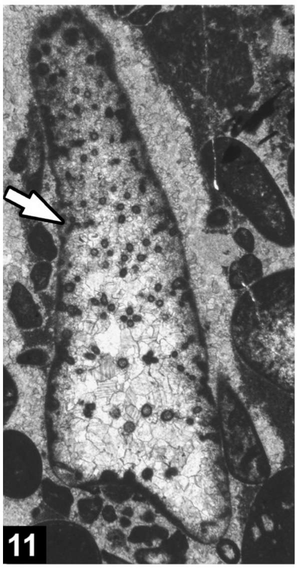
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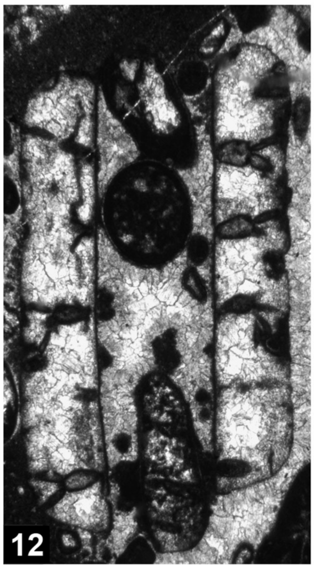
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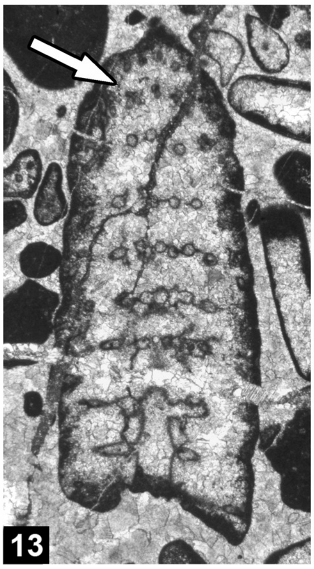
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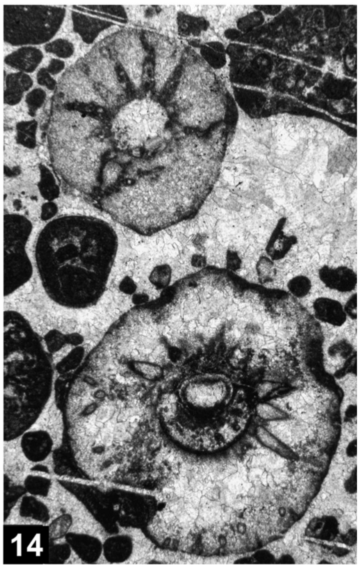
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PLATE 2

All specimens are from the type-level of *Linoporella buseri* RADOIČIĆ.

Fig. 1. *Linoporella buseri* RADOIČIĆ. Asymmetry suggests the oblique section is close to the apex of the thallus. Only two orders of laterals are visible next to the eroded margin of the skeleton. Third order laterals are possibly missing. Thin section RR3118, ×16.

Fig. 2. *Linoporella buseri* RADOIČIĆ. Oblique section of a small specimen. Second order laterals are hardly visible on the bioeroded margin of the calcareous skeleton. Third order laterals are possibly missing. Thin section RR3104, ×27.

Fig. 3. *Linoporella buseri* RADOIČIĆ. Oblique section of a small specimen with three orders of relatively thick laterals. Thin section RR3138, ×27.

Fig. 4. *Linoporella buseri* RADOIČIĆ. Transversal section of a large specimen. Although bioeroded, third order laterals (arrow) are present. Thin section RR3132, ×18.

Fig. 5. *Linoporella buseri* RADOIČIĆ. Oblique section in the main, cylindrical part of a large specimen with oblique primary laterals. Although bioeroded, rather thick third order laterals (arrow) are present. Thin section RR3133, ×20.

Fig. 6. *Linoporella buseri* RADOIČIĆ. Tangential section, transversal to the rounded apex of a rather large specimen. Clusters of three, hair-like third order laterals arise from the tip of the secondaries. Thin section RR3140, ×16.

Fig. 7. *Linoporella buseri* RADOIČIĆ. Deep tangential, slightly oblique section cutting the tip of the axial cavity, just below the rounded apex. Four second order laterals are clustered at tip of very short primaries. Hair-like third order laterals are visible at the margin of the section. Thin section RR3111, ×25.

Fig. 8. *Linoporella buseri* RADOIČIĆ. Oblique section close to the rounded apex. Clusters of five, rather slender second order laterals arise from the tip of the primaries. Note bioerosion (arrow). Thin section RR3101, ×28.

Fig. 9. Oblique section of a piece of *Dinarella* ? sp. Thin section RR3105, ×30.

Fig. 10. *Linoporella buseri*. Oblique section in the main, cylindrical portion of a rather large specimen, with three orders of laterals. Note pervasive bio-erosion around the axial cavity. Thin section RR3132, ×30.

Fig. 11. Oblique-tangential section of a piece of *Palaeodasycladus* ? sp. In this specimen, cavities generated by bio-erosion are filled by a yet unidentified calcifying organism forming rosettes. Thin section RR3103, ×17.

Fig. 12. Oblique section of a piece of *Palaeodasycladus* ? sp. with up to five orders of laterals. The axial cavity is heavily bioeroded. Thin section RR3130, ×12.

Fig. 13. Oblique section questionably corresponding to the capitulum-shaped head of *Palaeodasycladus* ? sp. 1. Note the wide axial cavity. Thin section RR3144, ×11.

Fig. 14. Transversal section of *Palaeodasycladus* ? sp. 1. Thin section RR3144, ×12.


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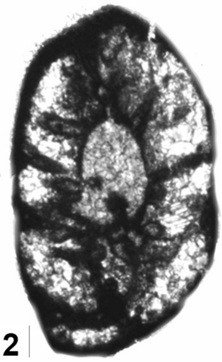
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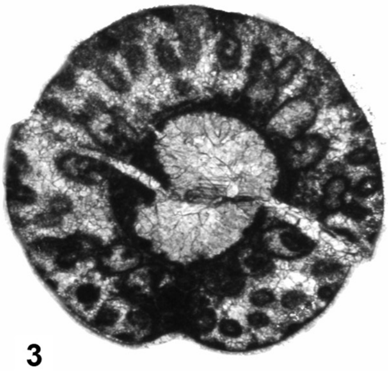
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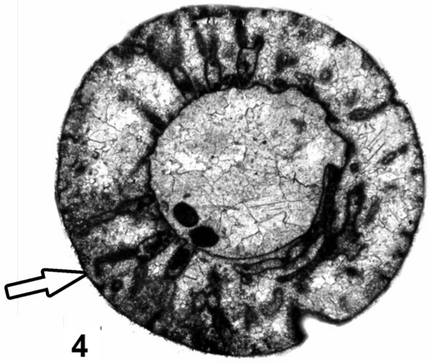
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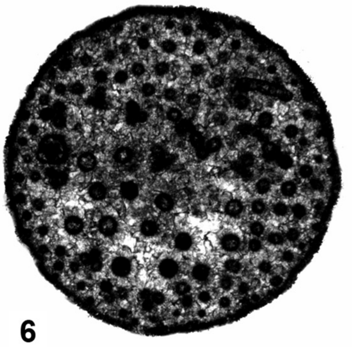
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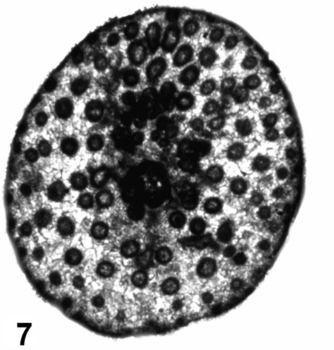
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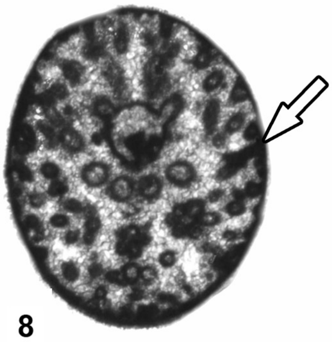
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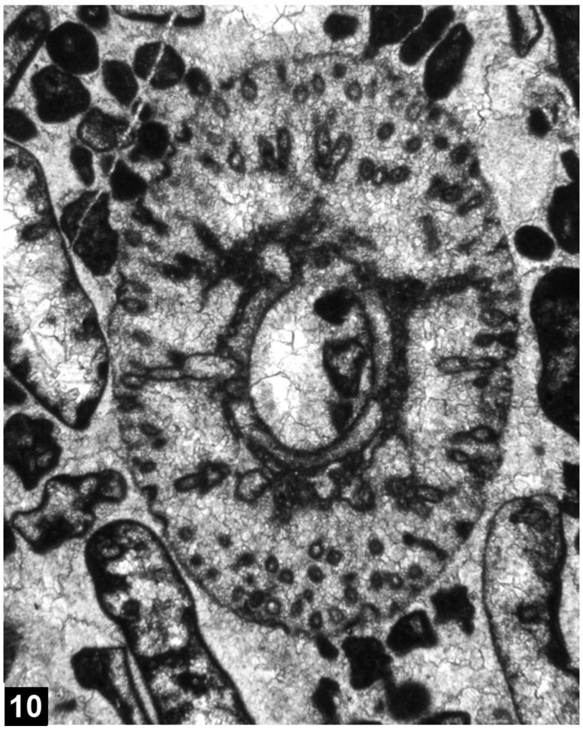
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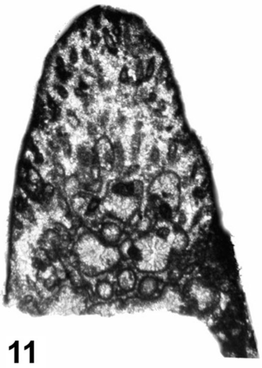
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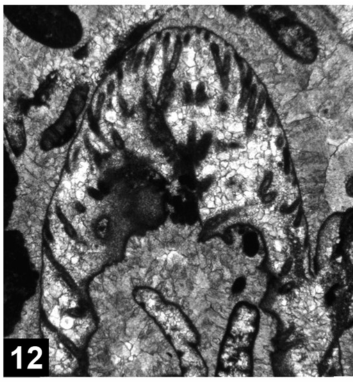
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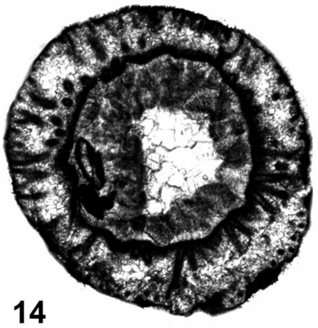
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Geology and hydrogeology of the Čemernica Mountain Massif, western Serbia

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Abstract. The mountain massif of Čemernica, western Serbia, is an orogenic feature of the Inner Dinarides. Hitherto, hydrogeological prospecting of the Massif was all on a regional scale, not detailed. Only scanty data, previously collected, were mappable on a scale larger than 1:100 000. The 2005 to 2008 research of the Čemernica Mountain Massif included geological and hydrogeological reconnaissance and mapping, the employment of remote sensing, a geophysical survey, the monitoring of quantitative and qualitative groundwater variation parameters, *etc*. The groundwaters of Čemernica are a large potential resource of water supply to multiple users. This paper is a contribution to the study of the geology and hydrogeology of the Čemernica Mountain Massif.

Key words: The mountain massif of Čemernica, western Serbia, Karst, Ćurčića Spring, Štitkovo Spring.

Апстракт. Планински масив Чемернице налази се у западном делу Србије. У геотектонском погледу, подручје истраживања припада рејону Унутрашњих Динарида. Досадашња хидрогеолошка истраживања на подручју планинског масива Чемернице нису имала карактер детаљних истраживања. Сва хидрогеолошка истраживања, подручја планинског масива Чемернице, имала су регионални карактер. Ретки су подаци који су прикупљени пре ових истраживања, а који се односе на ниво истраживања у размери крупнијој од 1:100 000. Истраживања планинског масива Чемернице која су изведена у периоду од 2005. до 2008. године, обухватила су геолошко-хидрогеолошко рекогносцирање терена и картирање терена, анализу терена методама даљинске детекције, геофизичка испитивања, осматрања квантитативних и квалитативних параметара режима подземних вода итд. Подземни водни ресурси планинског масива Чемернице представљају значајан потенцијал са аспекта вишенаменског коришћења. Овај рад има за циљ да дâ допринос познавању геолошких и хидрогеолошких карактеристика планинског масива Чемернице.

Кључне речи: Планински масив Чемернице, западна Србија, карст, Ћурчића врело, Штитково врело.

Introduction

The mountain massif of Čemernica extends over more than 50 km^2. Its geology and hydrogeology were explored in detail from 2005 to 2008 and mapped for the first time on a scale larger than 1:100000. The collected data were used to describe the geomorphology, hydrography, geology and hydrogeology of the massif. In addition to internal and external research, some laboratory analyses were made and are reported in the respective chapters of this paper. The identification of the lithostratigraphic units and their spatial relationships, the classification of groundwater bodies and their formation, recharge and discharge mechanisms of the largest karst aquifer are all based on the acquired research data. The qualitative properties in addition to the quantitative aspect of groundwater for the karst aquifer were studied.

Geographical Location

The mountain massif of Čemernica in western Serbia is an area of 581 km^2 in the municipality of Nova Varoš, Zlatibor District. The size of the exploration area was greater than 50 km^2. The Čemernica Massif encompasses many heights within the elevation range from 1000 m

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to 1500 m, precisely from 1072 m (Štitkovo Spring) to the highest peak (Bijele Stene) 1494 m. The economy in the region is stagnant or declining. The tourist potential of the region, primarily the pearl of nature – the Uvac Lake, a meander cut-off of the Uvac River, habitat of the large griffon vulture, *etc*., is undeveloped.

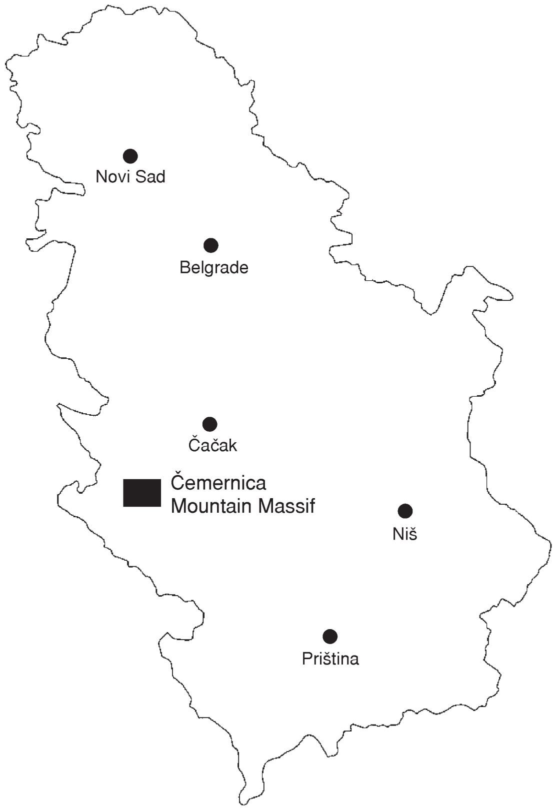

Fig. 1. Geographical location of Čemernica.

Research Concept and Methods

The steps of the geological and hydrogeological investigations in the Čemernica area were the following:

- Detailed analysis of the available research data, or identification of the morphologic features and the geological and hydrogeological character of the Čemernica Mountain Massif.
- Assessment of relevant climatic factors and hydrologic budget accounting.
- Spatial delineation of aquifers.
- Establishment of groundwater occurrence, movement and discharge.
- Interpretation of the physical and chemical properties, gaseous, radioactive and microbial compositions of the groundwater.
- Quantitative and qualitative assessment of the groundwater and its variation in time.
- Groundwater control conditions.

The Ćurčića and Štitkovo Springs were monitored for one year to evaluate the usability of their waters with low concentrations of mineral matter.

The results obtained by multidisciplinary research of the water from the two springs were the basis for this work. The monitoring at the Ćurčića and Štitkovo Springs was continuous over the year, while that at the Bursać and Kušića Springs was periodic.

Geology

Čemernica is one of the many carbonate rock areas in the region of Ivanjica and Golija. It belongs to the Drina–Ivanjica fault block (DIMITRIJEVIĆ & DIMITRIJEVIĆ 1974), or the former "inner Palaeozoic zone" (PETKOVIĆ 1961), or "Golija Zone" (AUBOUIN 1974). Previous study of geology of Čemernica has a short history and no published records.

General knowledge of its geology, acquired through mapping and from the base geological map, was used to identify the geologic formations in the field, to study their sedimentological and petrographic nature and structural character.

The mountain massif of Čemernica is composed of rocks formed through two sedimentation cycles. The older, prevailing cycle of the Ivanjica block is the Palaeozoic sedimentation cycle, not exposed everywhere on Čemernica, but lying under all newer formations. The other, Mesozoic cycle, is represented by more than one formation deposited from the Triassic through the Jurassic.

Palaeozoic

Late Palaeozoic rocks, represented by the Birač Formation, lie exposed in the deeply eroded Tisovica and Trudovačka valleys in the area of Štitkovo village (DJOKOVIĆ 1985).

The Birač Formation is composed of thin-bedded, laminated siltstones, metasandstones and some limestone lenses. Horizontal and wavy laminae in the siltstone bear ferruginous crusts. Successive on the siltstone is bedded metasandstone with a high proportion of angular quartz.

The stratification and attitude of the siltstone and sandstone in cross-sections indicate frequent turbidity currents, which produced turbidites.

The rocks of the Birač Formation were strongly folded and faulted through the Variscan and later Alpine orogenies. The stratigraphic position of the Formation is speculative. It was identified through evidence of the superposition of the subjacent Kovilje conglomerates and the superjacent Kladnica clastics.

Mesozoic depositional cycle

The Mesozoic cycle of deposition produced different formations, more during the Triassic than through the Jurassic. In the Čemernica area, the Kladnica, Bioturbate and Ravni Formations are Triassic, and the Diabase-Chert Formation is Jurassic.

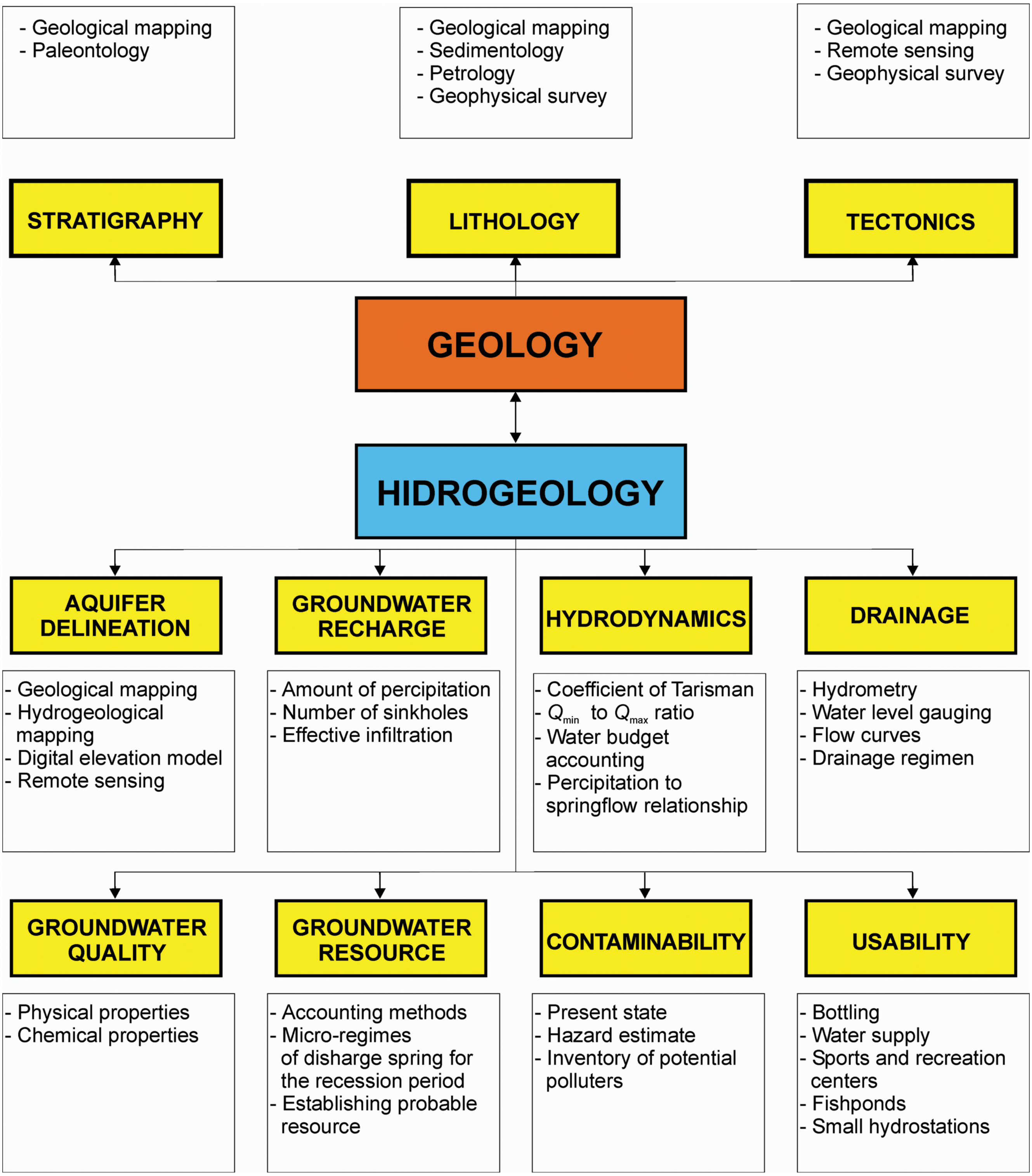

Fig. 2. Geological and hydrogeological research methods employed in the Čemernica Mountain Massif.

Triassic (T_1)

Sporadic exposures of continental clastics between the villages of Božetići and Štitkovo on the Čemernica SW ridges were identified as the Kladnica Clastics (Nastić 1990, unpublished).

These clastics lie unconformably over Palaeozoic sedimentary and metamorphic rocks and under the Bioturbate Formation with the contact almost concealed but in tectonic contact with an ophiolitic mélange.

An exposure of the Kladnica Clastics is located near the Štitkovo Spring in siliceous rocks of dominantly quartz grains, quartzite and chert clastics in siliceous cement, reddish-coloured by Fe-minerals.

This time-stratigraphic unit was determined (beyond the limits of the Štitkovo village area) as Lower Triassic, based on its few conifer pollen grains.

Bioturbate Formation (T_1)

A succession of thin-bedded and shaley clay, identified as the Bioturbate Formation (DIMITRIJEVIĆ *et al.* 1980) on the Geologic Map Sheet Prijepolje, on the scale 1:50 000, can be recognized under massive limestone of the Ravni Formation in the Štitkovo and Trudovo village areas.

New cuttings of a village road near the spring exposed the internal lithologic structure of the Formation, which consists of thin micrite strata and silt and shale laminae. Micrite layers are torn in the sequence and strongly folded together with shale and silt (Fig. 3).

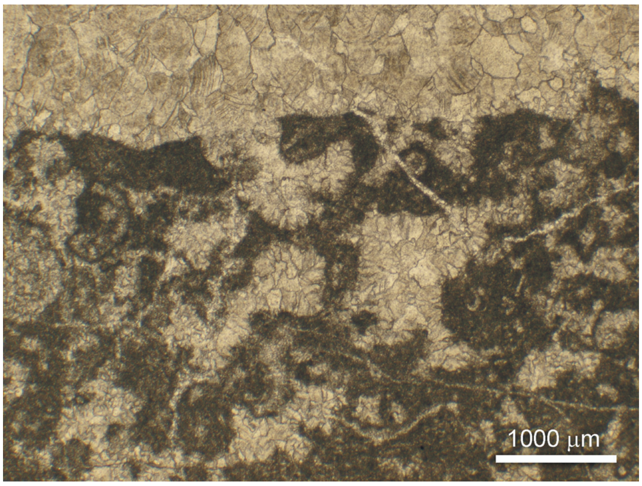

Fig. 3. Photographed thin-section from the Bioturbate Formation.

The Formation contains bioturbations of various sizes. Lower Triassic age was determined by its mega- and micro-faunal fossils (bivalves and foraminifers).

Ravni Formation (T_2)

Limestones of the Ravni Formation are most extensive in the Čemernica Mountain Massif, building up a varied surface topology from mountain peaks to karst poljes. The fault block of Čemernica varies in altitude from 110 m SW, where it is thin, to almost 1500 m in the north.

The limestones are slightly recrystallized and dolomitic (Fig. 4). Massive limestones prevail over thick sets of beds in Čemernica, while stratified limestones are recognized only low in the column above springs. The SW border of Čemernica is steep, produced by an overthrust, and the entire mass of limestone is karstified. The limestone block is thin in the centre, its surface mildly trough - like, like the Rujište and Veliko Polje, which allow percolation of surface water and groundwater recharge.

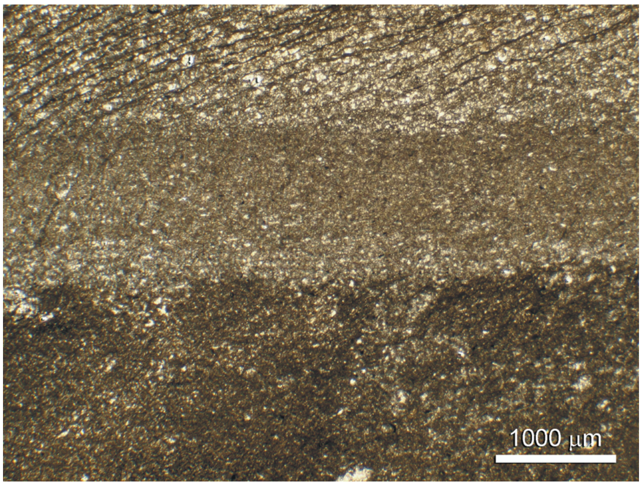

Fig. 4. Photographed thin-section from the Ravni Formation.

Triassic rocks in the ophiolite belt and its border were taken formerly for exposures of the basal diabase-chert, and Triassic rocks on the SW margin of the Ivanjica Palaeozoic for transgressive, deposited where they still are. It was proved that many Triassic plates, in the form of oligoplacas, lie over the diabase-chert formation, which implies that kilometric limestone plates slid by gravity from the Palaeozoic base into a mélange trough.

Jurassic (J)

A Jurassic ophiolite mélange was recognized in Trudovo area. Its constituents are greywacke, shale, sandstone, limestone, chert and radiolarite. Other rocks of the formation are diabase, spilite, keratophyre, *etc*. Direct contact of Jurassic rocks and limestones of Čemernica is normally tectonic, extending NW of Ćurčići. Rocks of the ophiolite mélange will not be described in detail as they are irrelevant to the mentioned springs.

Photogeology

The task of photogeology was defined as: photographic recording and study of the wider structural pattern of Čemernica: faulting and folding features, lithologic variation, and intensity of karstification within the carbonate rocks extent (unpublished, PAVLOVIĆ & ČOLIĆ *et al*. 2006).

The photogeological interpretation was initially confined to the carbonate extent of Čemernica and its direct contact with the non-carbonated basement, but it was later extended to Carboniferous, Permian and Lower Triassic clastics. The photogeological study eventually included all features of some hydrogeologic relevance. The interpreted aerial photographs covered an area of 54 km^2.

The sedimentary rocks that build up Čemernica Mountain and its ranges are Lower or Middle Triassic in age. Triassic rocks lie over Permian–Triassic coarse clastics (quartz conglomerate and sandstone) in the northern, southern and south-eastern ranges and over Carboniferous metasandstones in the north-eastern ranges. In the west, the Triassic carbonates of Čemernica are in tectonic contact with Jurassic carbonate and chert of the diabase-chert formation.

Fractures, distinctive morphologic features in the surface configuration, were identified on satellite images of the pattern of fractures (Fig. 5). These are kilometric to decakilometric fractures. Given the size of the study area and the photo and map scales, the identified faults were not classified by importance, even if some of them extend beyond the area limits. These features were classified only in relation to the reliability of identification: observed and inferred. With respect to their expressive morphology, these features may be said to be the factures of neotectonic activity, which may be important in addressing hydrogeological problems. The faults in the Čemernica area are classified into two systems.

The NNE–SSW to E–W systems are particularly well arranged, sub parallel, cutting through Čemernica and extending eastward into Permian–Triassic or Carboniferous rocks.

The other system of kilometric to some decakilometric, the faults have the strike direction NNE–SSW. The morphologic features of these faults suggest that the former system may be more significant for groundwater flow.

A regional fault on the Čemernica western border runs across the entire study area from NNW to SSE, mostly being the contact between Triassic limestones and the older clastics. Several strong springs occur at the cross points of this and the faults in NE–SW strike direction. The regional fault is a complex morphologic feature, of a fault zone type in places. It crosses numerous minor faults where its disruption and displacement are manifested.

The detailed structural pattern and the lithologic units obtained by stereoscopy are given on a photogeological map. The fractures are classified only on the reliability of identification. The carbonate-built Čemernica is densely faulted by hkm- and km-long fractures of two fracture systems: the dominant one with a NE–SW strike direction and the other with a NW–SE strike direction. The systems are conspicuous in the surface configuration, marked by series of elongated sinkholes, short dry valleys or abrupt changes in the slope angle.

Fractures in noncarbonated rocks in the south-eastern and eastern parts of the area control the flow direction or divert it at a right angle. East to west oriented fractures in the SE control largely the surface morphology and possibly also the groundwater flow.

The fault pattern in the easternmost part of the area differs greatly from the carbonate-built Čemernica. Kilometric and decakilometric faults strike dominantly in the N–S direction. Faults in other directions are fewer and shorter.

Morphologic features of hydrogeological interest in Čemernica may be the well-exposed large faults in the strike directions NE–SW to E–W; a complex system on the western border of Čemernica with the occurrences of strong springs and a gravity fault in Zečko Polje.

Geophysical Information

Geophysical prospecting was the basic additional exploration for the study of the geology or the type and extent of the lithologic units The measurements were performed in Rujište Polje (Fig. 6).

The purpose of the geoelectrical survey was to establish the thickness of the uppermost rock complex, the spatial distribution and depth of each lithologic unit, then to measure the depths to aquifers and to identify faults and fault zones. The method used in the exploration was geoelectrical resistivity sounding in order to estimate the extent and depth of each lithologic unit. Geoelectrical soundings were taken along sections 1 and 2 (Figs. 7 and 8), with measurements in eleven sounding points with an AB/2 current electrode separation of up to 300 meters, at the azimuth direction 110°/280°. A symmetrical, Schlumberger array of current and potential electrodes, A-MN-B, was applied. The resistivity measurement results were interpreted both qualitatively and quantitatively. The former covered interpretation of the resistivity plots that show horizontal changes in the electrical resistivity, and the latter, interpretation of the resistivities and thicknesses of the logged formations. The specific electrical resistivity (ρ) and thickness (h) were computerized for each logged lithologic variety. The obtained parameteric values were plotted on sections 1-IPI and 2-IPI, and deep geoelectric sections.

The specific electrical resistivities were measured by geoelectric sounding from ES-1 to ES-11, on which four different lithologies were identified;

- Broken Triassic limestone,
- Broken Triassic limestone and water?,
- Massive or thick Triassic limestone, and
- Quartz conglomerate and sandstone.

The values of ρ indicated a vertical discontinuity or fault of SW–SE strike direction.

The conclusions based on the geophysical exploration in Rujište Polje, Čemernica, are the following:

– The lithologic units determined based on specific resistivities are: fragmented Triassic limestone over a water table, water-bearing fragmented Triassic lime-

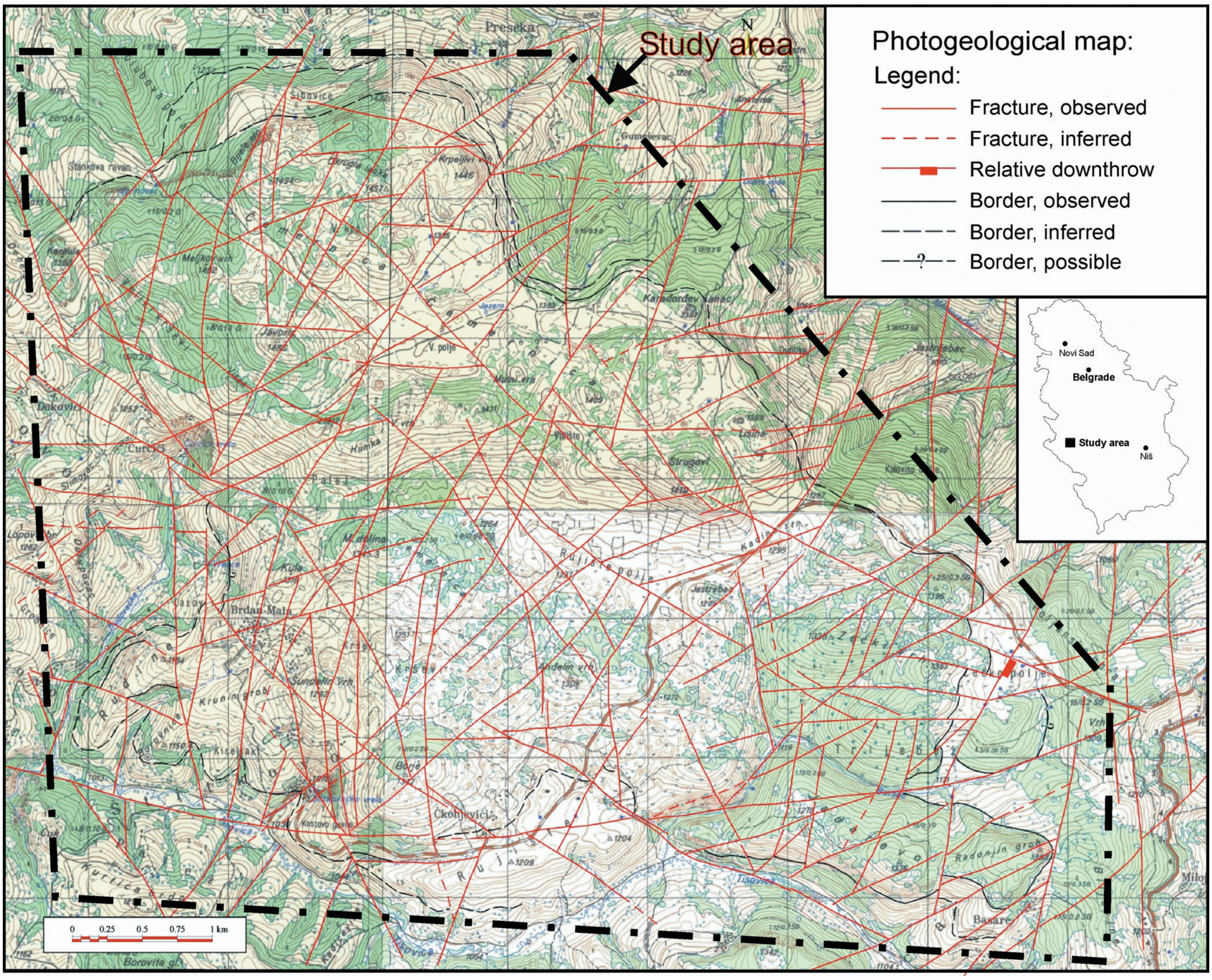

Fig. 5. Regional fault pattern (PAVLOVIĆ & ČOLIĆ 2006, unpublished).

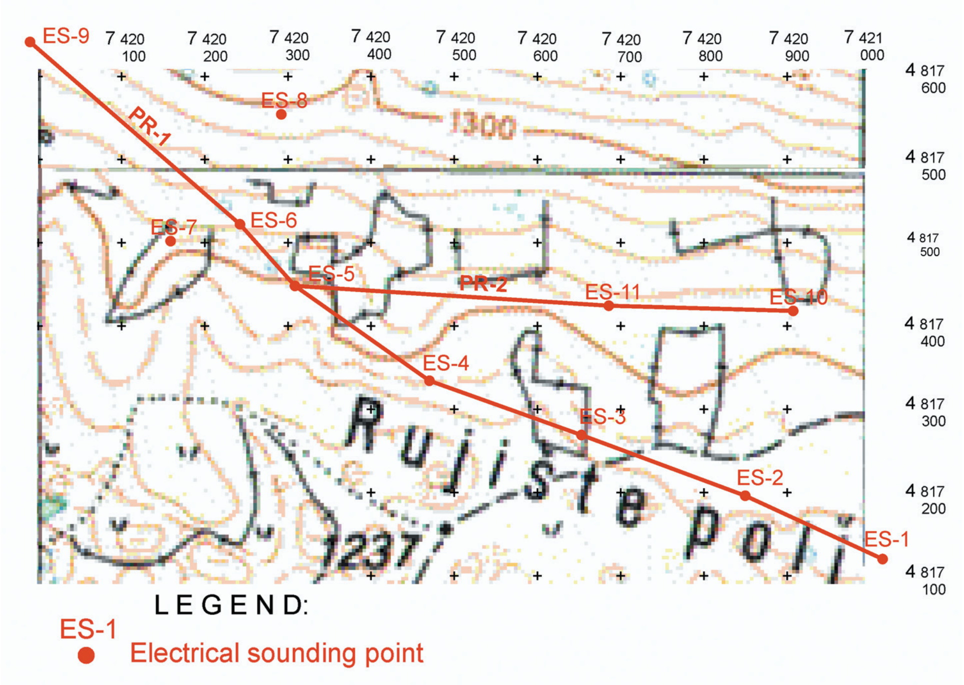

Fig. 6. Configuration of the geophysical sections in Rujište Polje.

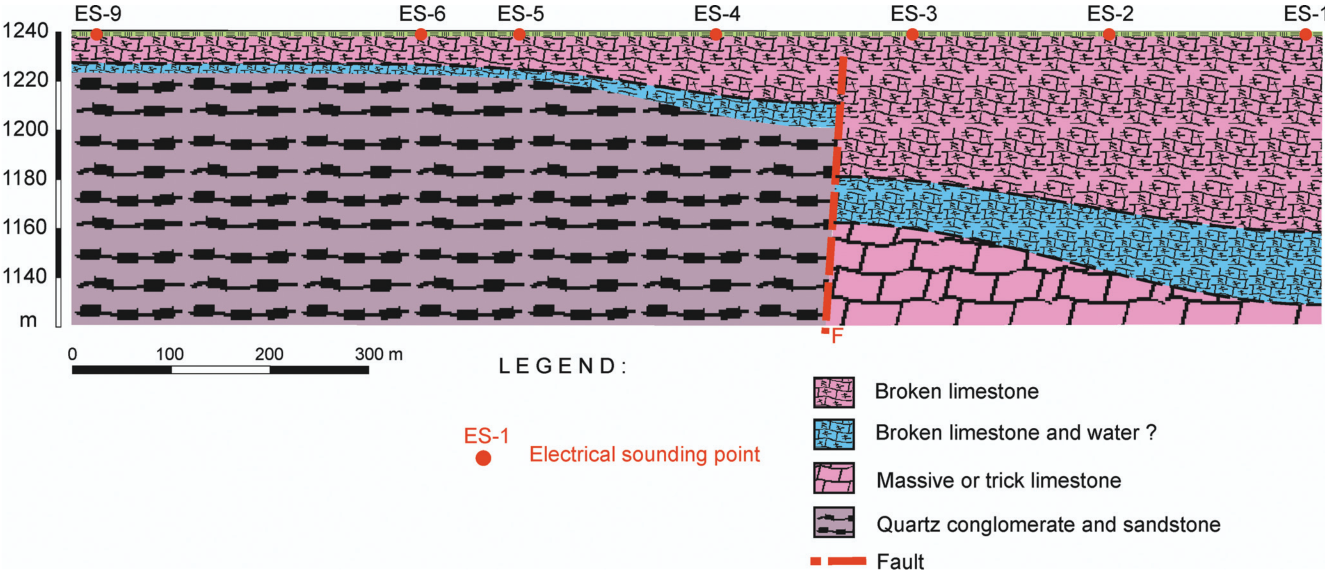

Fig. 7. Deep geoelectric section 1 across Rujište Polje.

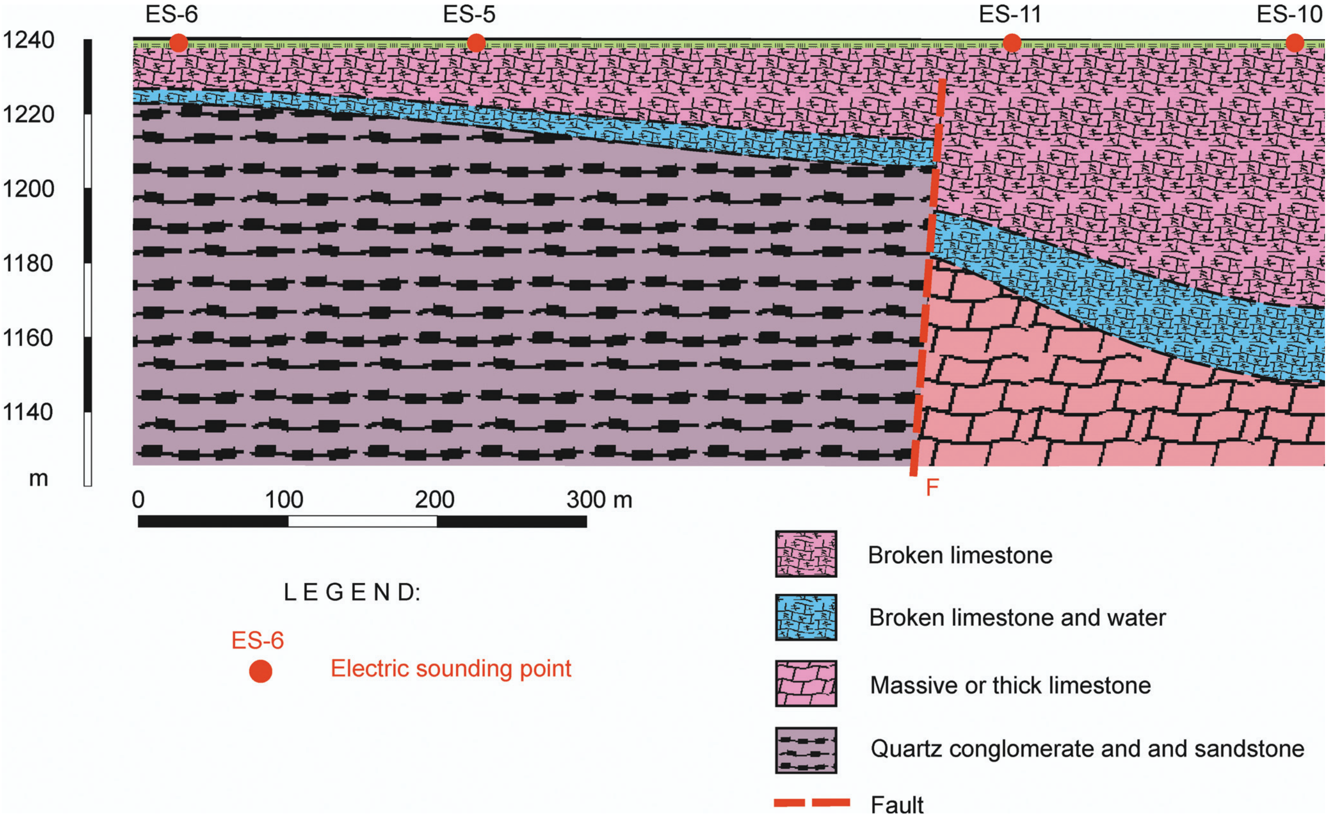

Fig. 8. Deep geoelectric section 2 across Rujište Polje.

stone, massive or thick Triassic limestone, quartz conglomerate and sandstone.

– A vertical break or fault in the SW–NE strike direction was registered in both electric profiles based on the values of the parameter *r*.

Hydrogeology

The water-bearing rocks of the Čemernica Mountain Massif are classified by porosity into the following types (Fig. 9):

- Intergranular aquifer in alluvial deposits of the Tisovica.
- Karst aquifer in Middle Triassic limestone (Ravni Formation).
- Fractured aquifer of low potential in Lower Triassic rocks (Bioturbate Formation).

There is a fourth type – provisionally "waterless" rocks.

The Intergranular aquifer in alluvial deposits of the Tisovica is linear, narrow, directly controlled by a fault that predisposed the Tisovica course. The alluvial deposits of the Tisovica vary in thickness between 6 m and 8 m to 10 m at the most. An aquifer of this type is of minor economic importance for groundwater utilization because its extent is restricted and the water storage is small and variable.

The Karst aquifer of Middle Triassic limestone is centrally located in the Massif area. As limestones occupy almost half the Čemernica area, this type of aquifer is the largest in area and depth.

In terms of groundwater resources, the karst aquifer is the most important in the region. Carbonate rocks formed in the Triassic are also extensive in the Inner Dinarides of western Serbia and traceable over a long stretch in this region.

The mountains of the Dinarides, with few exceptions, extend NE to SW (Čemernica, Zlatar, Zlatibor, Tara, Jadovnik, *etc.*) and are structured largely of Triassic limestones. It follows from all the above-stated that the groundwaters in the aquifers formed by the disolution action – carbonate rocks – are the most abundant in the region.

The principal source of groundwater recharge in the characteristic open hydrogeologic structure of Čemernica is the atmospheric precipitation that falls on limestone outcrops. The high capacity and velocity to respectively receive and transmit atmospheric water are attributed to the geological set-up, structural pattern and degree of karstification.

Groundwater flow, predisposed by the structural pattern, has the general direction from east to west, as indicated by spring flows draining this type of aquifer. The volumes of water discharged by the Štitkovo and Ćurčića Springs in the west are much higher than spring flows elsewhere in the area. The groundwater flow directions depend, as mentioned before, on faults, factures and karst caverns formed through either tectonic events and/or karstification.

Groundwater in the extensive karst aquifer naturally drains through a number of karst springs. The major springs are Štitkovo, Ćurčića, Bursać and Kušića. Their minimum flows vary from 4 l/s to 17.6 l/s (Štitkovo and Ćurčića) and from 5 l/s to 10 l/s (Bursać and Kušića). All springs that drain the Čemernica Karst Massif are contact springs between the permeable Triassic limestone and impervious rocks. Each of the four springs is natural and undeveloped.

Fractured aquifer has a smaller water-yielding capacity and extent than the karst aquifer. It is the most widespread in the NE and W of the considered area. Two major springs (Štitkovo and Ćurčića) discharge at the contact of the two formations and the Middle Triassic limestones of Čemernica. A smaller area of Lower Triassic, fractured but of lower potential, rocks is located SW of the Bursać Spring. This aquifer has two sources of recharge. The groundwater in the aquifer of the fractured carbonate and Lower Triassic rocks is replenished by infiltrated atmospheric water and ground water from the adjacent, karst aquifer. The primary flow directions and qualitative properties of groundwater in this type of aquifer have neither been determined, nor can a satisfactory estimate of the water budget be given.

Provisionally "waterless" rock areas are those built up of Jurassic (Malm, Dogger) ophiolitic mélange and Permian–Triassic sedimentary rocks. The rocks identified on the basis of field data as provisionally "waterless" lie in contact with karstified or fractured rocks of low-potential capacity.

Quantitative Groundwater Regime

The total quantity of groundwater involved in the drainage of the Čemernica Massif was monitored at the Ćurčića and Štitkovo Springs and intermittently measured at the Bursać and Kušića Springs. Gauging stations were set up for precipitation and hydrologic parameters at the Ćurčića and Štitkovo Springs in order to obtain representative information for a quantitative estimate of spring flows. The measurements in the Ćurčića and Štitkovo Springs were taken once in two months, or a total of six measurements in both springs. The measured flows were used to construct flow curves, which were used as the basis for the estimation of other parameters of the flow of the Ćurčića and Štitkovo Springs (Tab. 1).

Tab. 1. Quantitative parameters for the different springs.

Occurrence	Q_{min} (l/s)	Q_{max} (l/s)	Mode of discharge
Ćurčića Spring	43.6	495	Gravity flow
Štitkovo Spring	17.5	313	Gravity flow
Bursać Spring	4	10	Gravity flow
Kušića Spring	10	25	Gravity flow

The flow data for the Ćurčića and Štitkovo Springs were used for an interpretation of the retention properties of the Triassic limestone aquifer of Čemernica.

Different drainage micro regimes, or drainage coefficients, have respective physical implications. Drainage coefficients of the order $\alpha \sim 10^{-2}$ are generally related to large karst caverns or fractures, while lower slopes of the straight lines ($\alpha \sim 10^{-3}$) indicate slow discharge via smaller fractures, fissures or clastic-filled karst cavities (KREŠIĆ 1991).

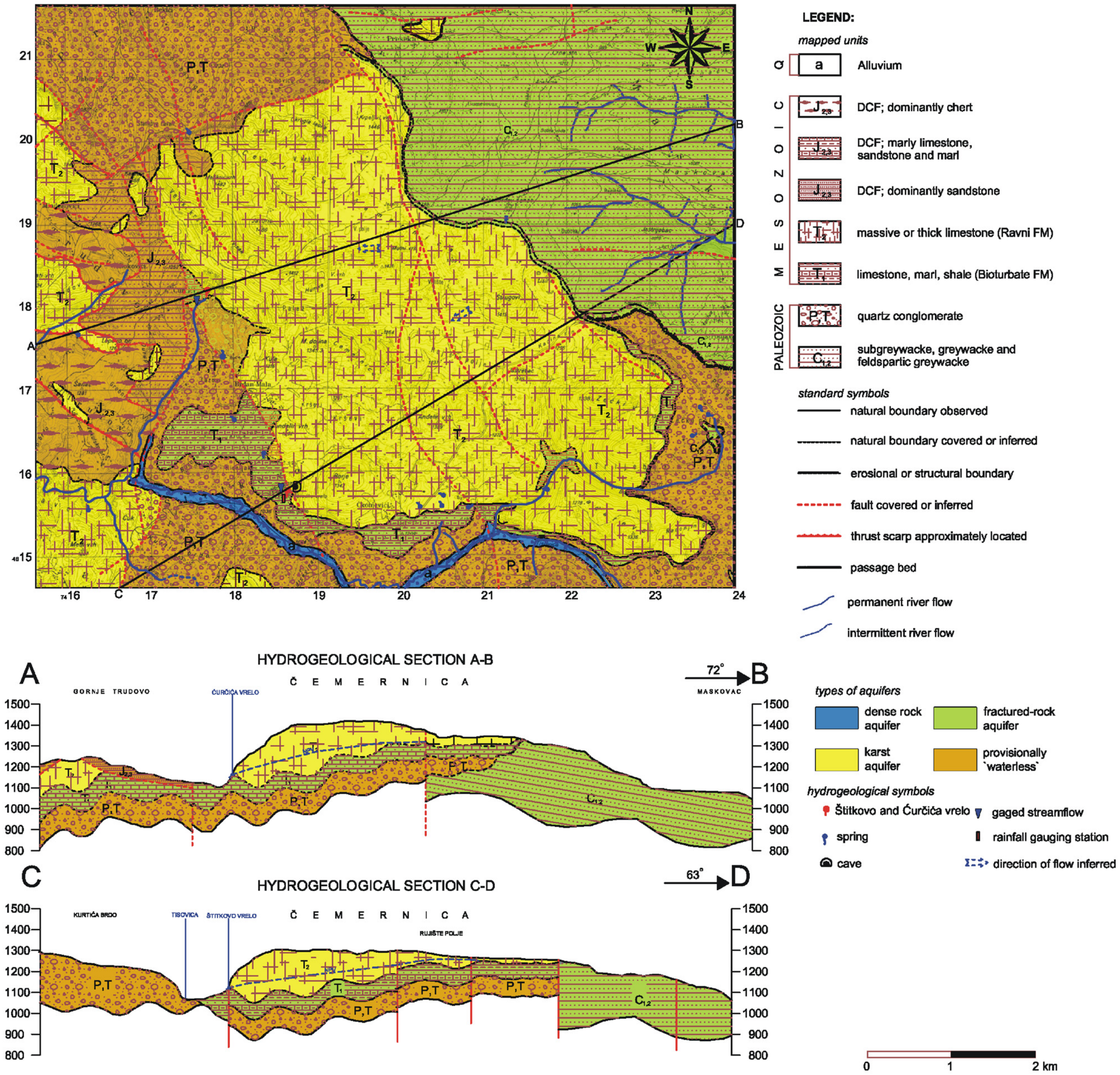

Fig. 9. Schematic hydrogeological map of the Čemernica Mountain Massif.

For a valid analysis of the retention capacity of an aquifer, a new period was necessary of no less than ninety days effective rainfall, resulting in continuous runoff without replenishment (groundwater recession).

An interval of constant runoff or groundwater recession was registered at the Štitkovo Spring within the observation period from 30 August 2006 to 9 January 2007. The recession continued for 131 days, an interval of constant runoff without replenishment sufficiently long for analysis.

The considered recession limb of the hydrograph is shown in Fig. 10. Note that there were some ineffective rainfalls in the observation period.

As the maximum to minimum spring flow ratio ($Q_{max} : Q_{min}$) was 1 : 3.63 during the groundwater recession, the obtained analytical results should be taken with due caution (a reliable ratio by this method should be Q_{max}:Q_{min}=1:10). The recession limb of the hydrograph indicates two different runoff micro regimens.

The obtained runoff coefficients (α_1 = 0.071779 and α_2 = 0.0142) are of the same order of magnitude ($\alpha \sim 10^{-2}$), but are different between themselves. The value of the coefficient α_1 indicate higher retentive properties in one micro regimen and the value of α_2 suggests lower retentive properties of karst in the other micro regimen.

The Štitkovo Spring flow data from one hydrogeologic cycle were used to calculate the degree of karstification and to determine the dominant groundwater flow directions. The maximum to minimum Štitkovo Spring

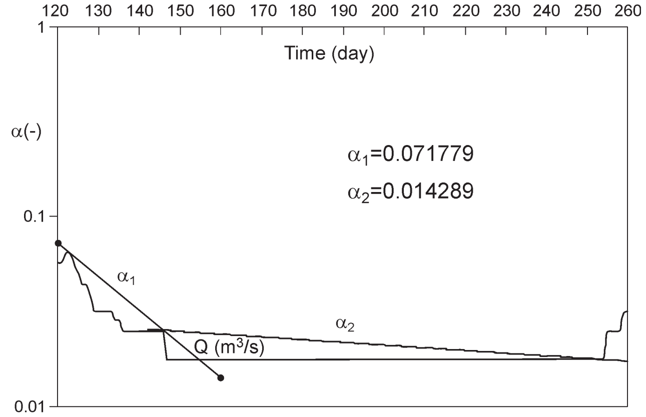

Fig. 10. Analysed recession limb of the Štitkovo Spring hydrograph for the runoff period from 30 August 2006 to 9 January 2007.

flow ratio (for the whole period) of about eighteen indicated one dominant flow direction, almost certainly controlled by the structural features of the karst aquifer and many minor water paths.

An interval of continuous groundwater runoff, or recession, was registered at the Ćurčića Spring during observation of the flow regime from 1 July to 16 October 2008. The recession of the groundwater lasted 108 days and could be used in the analysis. The recession curve is shown in Fig. 11. The value of the coefficient α_1 indicates a higher, and α_2 lower retentive properties in the former and latter micro regimes, respectively. Intermittent rainfalls were ineffective in affecting the groundwater runoff regimes.

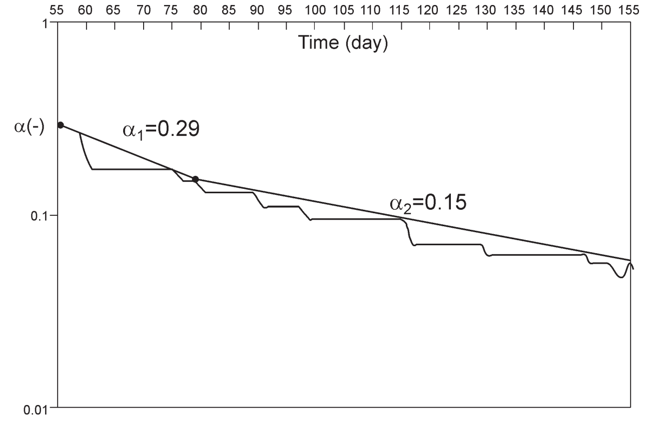

Fig. 11. Analyse of the recession limb of the Ćurčića Spring hydrograph for the runoff period from 1 July to 16 October 2008.

As with the Štitkovo Spring, the maximum to minimum flow ratio ($Q_{\max} : Q_{\min}$) was less than 1 : 10, specifically 1 : 5.31. The analytical results obtained by the Tarisman method should, therefore, be taken with due caution.

Qualitative Groundwater Regimes

Groundwater from the karst aquifer only was tested for its qualitative properties, because the karst aquifer is much more abundant in water than the others in the region. The tested samples were mainly of the calciumhydrocarbonate (Ca-HCO_3) class of water, directly related to the source of origin. Another essential characteristic of the water was comparatively uniform mineral matter in water, not higher than 300 mg/l.

The **temperature** range of the water is from 6.5° C in the Kušića Spring to 9.3° C in the Štitkovo Spring. All spring waters in the area may be assigned to the group of cold waters. Only the water from the Kušića Spring was below the temperature range 7° C to 12° C, considered suitable for human consumption (DRAGIŠIĆ 1997).

The **acidity** of the water is uniform within the pH range from 7.5 to 8. In this respect, all the waters, except for springs, were neutral to mildly basic.

The **specific conductance** of the tested groundwater samples was uniform, being within the range from 349 μS/cm (Kušića Spring) to 430 μS/cm (Štitkovo Spring).

The **mineral matter** in the groundwater varied within the range from 225.56 mg/l (Kušića Spring) to 290 mg/l (Štitkovo Spring). According to this parameter, the tested samples were low-mineralized groundwater.

The **total hardness** range was from 11.20° dH (Kušića Spring) to 12.18° dH (Bursać Spring). In the classification after Klut, the water of the two springs is moderately hard. In addition to total hardness, the water was tested on permanent and temporary hardness. The difference between total and temporary hardness was very small, indicating a high proportion of carbonate salts, primarily calcium salt, and low proportion of Cl^- and SO_4^{2-} ions.

Sodium and Potassium (Na^++K^+). The sum of the sodium and potassium ion concentrations varies from 0.76 mg/l (Ćurčića Spring) to 9.96 mg/l (Kušića Spring), the highest being in the latter spring.

Calcium (Ca^{2+}). The dominant cation in the spring waters was the calcium ion, Ca^{2+}. All spring waters in the given area therefore belong to the calcium (Ca^{2+}-water group) in the O.A. Alekin classification. The calcium ions are derived from the extensive limestones in the area. The calcium concetration varies from 69.3 mg/l (Ćurčića Spring) to 86.4 mg/l (Štitkovo Spring).

Magnesium (Mg^{2+}). The magnesium ion concentrations, much lower than those of calcium, in the spring water varied from 1.22 mg/l (Kušića Spring) to 4.26 mg/l (Bursać Spring).

Hydrocarbonates (HCO_3^-). All the tested water samples were in the Alekin Hydrocarbonate Class. Concentrations of dominant hydrocarbonate HCO_3^- ion were within the range from 97 mg/l (Ćurčića and Štitkovo Springs) to 251.94 mg/l (Kušića Spring).

Sulphates (SO_4^{2-}). The sulphate concentrations were very low, from 2 mg/l (Ćurčića Spring) to 7 mg/l (Bursać Spring).

Chlorides (Cl^-). Like the sulphates, the chloride concentrations in the spring water samples were very low, varying from 1 mg/l (Ćurčića Spring) to 12.76 mg/l (Bursać Spring).

Nitrates (NO_3^-). The nitrate concentrations were very low, far below the maximum allowed concentration. A nitrate ion (NO_3^-) concentration of 5.2 mg/l was detected in the Štitkovo Spring water.

Generally, the samples from all springs in the area were of the calcium hydrocarbonate Class, Ca-HCO_3, with a mineral matter content below 300 mg/l.

The spring waters were cold, neutral to mildly basic and moderately hard. The concentration of the individual elements in the water was below the maximum allowed concentration. The waters tested in the field were clear, without colour, taste and odour. Figure 12 illustrates A graphical presentation of the chemical composition of the tested groundwater (Piper Plot) is illustrated in Figure 12.

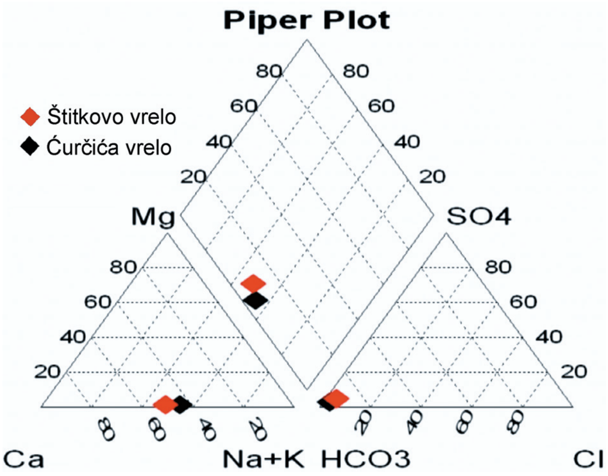

Fig. 12. Trilinear diagram of chemical composition of groundwater draining the karst aquifer of Čemernica.

Conclusions

Geological and hydrogeological explorations in the Čemernica Mountain Massif were carried out from 2005 to 2008, through field and laboratory research including stages of hydrogeological reconnaissance and mapping.

The groundwater regimes were monitored at the discharge points of the Ćurčića and Štitkovo Springs over one year, from 1 May 2006 to 1 May 2007. The qualitative and quantitative properties of groundwater were intermittently tested in the Bursać and Kušića Springs.

Other relevant parameters – daily precipitation height, springflow rates and water temperatures – were also monitored over the same period, while the physical and chemical properties of spring water (four full sets of analyses,) were determined quarterly. The inferences are the following:

The Mountain Massif of Čemernica is a structural part of the western-Serbia Inner Dinarides, structured of Palaeozoic and Mesozoic rocks.

The tectonic pattern of the Massif, based on remote sensing information, indicates two dominant strike directions, NNE–SSW to E–W. The whole Čemernica is intersected by faults, which extend eastwards into Permian–Triassic or Carboniferous rocks. The surface features of the faults suggest their being preferential conductors of groundwater.

Middle Triassic limestones form a karst aquifer, the largest in the Massif.

The karst aquifer is an uncovered hydrogeologic structure of known recharge and discharge zones.

The springs that drain the karst aquifer are characterized by high flow rates (Q_{min} 4 to 43.6 l/s; Q_{max} 10 to 495 l/s).

The mean monthly water temperature varies from 8.5° C to 9.9° C.

The Ćurčića Spring belongs the calcium hydrocarbonate water group with the content of dissolved solids ranging from 0.2 to 0.3 g/l with a temperature range from 8.6° C to 9.7° C.

The information acquired by geological and hydrogeological research indicates potentially available resources of groundwater for various purposes (water supply, fish ponds, bottling, small power stations).

The results of this research provide for the first time a thorough insight into the water resources in the Čemernica Mountain Massif.

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Резиме

Геологија и хидрогеологија и планинског масива Чемернице, западна Србија

Геолошко-хидрогеолошка истраживања планинског масива Чемернице су трајала од 2005. године до 2008. године. Истраживања су метолодолошки била подељена у неколико фаза са применом пуног обима теренских, лабораторијских и кабинетских метода, укључујући фазе хидрогеолошког рекогносцирања и картирања терена.

Режим подземних вода које се дренирају на Ћурчића врелу и Штитковом Врелу, праћен је континуално у периоду од годину дана, тачније од 01. 05. 2006. до 01. 05. 2007. године. На врелу Бурсаћ и Кушића врелу вршена су периодична осматрања квантитативних и квалитативних својстава подземних вода.

Током тог периода праћени су режимски параметри попут дневних сума падавина, издашности и температуре подземних вода које се дренирају на овим врелима, као и квартално одређивање параметара физичко-хемијског састава ових вода (4 комплетне анализе "В" обима). На основу овако постављеног концепта закључује се следеће:

– Планински масив Чемернице у геотектонском смислу припада Унутрашњим Динаридима западне Србије и изграђен је од стена палеозојске и мезозојске старости.

– Анализа тектонског склопа, вршена методама даљинске детекције указала је на постојање два доминантна правца руптура ССИ–ЈЗЗ до И–З. Ове руптуре секу целу Чемерницу, а према истоку пружање им се наставља и у пермотријаским или карбонским седиментима. Према њиховом морфолошком изразу на површини терена, може се претпоставити да је први систем значајнији за циркулацију подземних вода.

– Карстни тип издани формиран у оквиру средњотријаских кречњака је доминантан на подручју истраживања.

– Карстни тип издани формиран је у оквиру отворене хидрогеолошке структуре, где су познате зона прихрањивања и зона истицања.

– Извори који дренирају карстни тип издани карактеришу се значајном издашношћу (Q_{min} = 4–43.6 l/s, Q_{max} = 10–495 l/s).

– Средња месечна температура воде кретала се од 8.5° C до 9.9° C.

– Изворске воде "Ћурчића врела" су маломинерализоване воде са минерализацијом од 0.2 до 0.3 g/l, хидрокарбонатне класе-калцијумске групе са температуром у опсегу 8.6–9.7° C.

– Резултати добијени геолошко-хидрогеолошким истраживањима указали су на значајан потенцијал подземних вода које се могу користити за различите потребе (водоснабдевање, рибњаци, флаширање, мини хидроелектране).

Резултати добијени овим истраживањима представљају прва детаљнија истраживања овог типа на планинском масиву Чемернице.

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The influence of the grain-size distribution and soil structure on the unsaturated shear strength of loess sediments in Belgrade, central Serbia

Gordana D. Hadži-Nikolić[1]

Abstract. There is a negative pore water pressure or matric suction in the zone above the ground water level in silty loess soil, which can be as deep as 5–10 m in the Belgrade area. This primary characteristic of unsaturated soil, *i.e.*, matric suction, should be included in laboratory testing and geotechnical analyses. Direct shear or triaxial testing of unsaturated soil are very expensive and time-consuming and require specially modified equipment. Instead, the prediction of unsaturated shear strength using the soil water characteristic curve, SWCC, and the effective shear strength parameters c’ and φ ‘ is a widely accepted practice. In this study, constitutive soil-water characteristic curves were obtained from the results of experimental testing by draining saturated soil samples under different pressures. This testing was performed for the first time in Serbia in a 15 bar pressure plate extractor according to ASTM standards. The laboratory testing included natural samples of loess sediments with the original macroporous structure and loess sediments with a destroyed soil structure. The influence of the grain-size distribution and natural soil structure on the unsaturated shear strength of Belgrade loess sediments above the ground water level was also evaluated. The obtained results are in accordance with the results from other investigations.

Key words: unsaturated shear strength, matric suction, loess sediments, soil-water characteristic curve, grain-size distribution, structure of soil.

Апстракт. Надизданска зона у прашинастим лесним седиментима у подручју Београда може да буде дебљине 5–10 m. У овој надизданској зони постоји матрична сукција (негативни порни притисак). Основно својство незасићеног тла – матричну сукцију би требало укључити у лабораторијска испитивања незасићеног тла, али и геостатичке анализе. Опити директног смицања или триаксијалне компресије незасићеног тла су дуготрајни, скупи и подразумевају измену конвенционалне лабораторијске опреме. Уместо тога, све чешће се користи поступак одређивања незасићене чврстоће тла помоћу основне конститутивне зависности незасићеног тла влажност/сукција и ефективних параметара чврстоће засићеног тла c’ и φ ‘. У овом раду су, први пут код нас, приказани резултати одређивања конститутивних зависности ефективни степен засићења/матрична сукција, на основу лабораторијских опита дренирања узорака тла под различитим притисцима. Опити су вршени у 15-bar екстрактору са полупропустљивом плочом према стандардима АСТМ. Опити дренирања су спроведени на непоремећеним узорцима са очуваном и измењеном примарном макропорозном структуром. Анализиран је и утицај гранулометријског састава и примарне структуре на конститутивне зависности лесних седимената надизданске зоне у Београду. Добијени резултати упоређени су са резултатима иностраних истраживача и добијена су добра слагања.

Кључне речи: чврстоћа незасићеног тла, матрична сукција, лесни седименти, карактеристична крива влажности, гранулометријски састав, структура тла.

Introduction

Soil in the terrain is often considered saturated, even when it is actually above the ground water level and with a natural water content, *i.e.*, it is, in fact, unsaturated. Unsaturated soil is the soil mostly subject to matric suction or with the presence of a negative pore-water pressure. There are numerous types of soil in engi-

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neering practice the behavior of which is not consistent with the principles and concepts of classical, saturated soil mechanics: collapsible soil, expansive soil, compacted soil and residual soil. Conventional analyses of the lateral earth pressure, bearing capacity or slope stability, which neglects matric suction in soil, give conservative solutions and low factors of safety. It is proved that matric suction in soil decreases the lateral active earth force and increases: the critical height of a slope, the bearing capacity and slope stability. In spite of that, unsaturated soil was not commonly investigated in geological and geotechnical professional and scientific practice. The justification for this could be found in the fact that the results obtained with saturated soil parameters provide more safety and in the absence of a simple and, for the practice, acceptable method for determining the unsaturated shear strength. Triaxial and direct shear tests on unsaturated soils are very expensive and time-consuming and require specially modified equipment. Instead, the widely accepted practice of determining unsaturated shear strength using the soil water characteristic curve (SWCC) and the effective shear strength parameters, c' and φ', was applied in this study for the first time in Serbia. The paper deals with the results of draining samples in a pressure plate extractor, which were obtained to determine the basic constitutive relations for unsaturated loess soil from the Belgrade zone above the ground water level.

Loess sediments of the zone above the ground water table in Belgrade

It is known that the terrain in the Belgrade area consists of two complexes that are considerably different in the engineering-geological sense: silty Quaternary sediments and clay and marls Tertiary sediments. Due to the structural type of the porosity and the location within the terrain, the silty Quaternary sediments and the weathered zone of Tertiary clays and marls perform the function of hydrogeological collector. This is where the ground water level is most often found, and its depth depends on the depth of unweathered tertiary clay and marls sediments.

The terrain of loess covered soil in the Belgrade area can be classified in accordance with its morphological and other characteristics into:

– lowlands between the Sava and the Danube Rivers,
– hilly terrain of the urban area.

The lowlands between the Sava and the Danube Rivers represent the end of the spacious plains of Srem, better known as the Zemun loess plateau. The loess series consists of five loess horizons separated by four horizons of paleoelluvial loess soil. In lithological composition, the paleoelluvial loess soils are represented by clay-sandy alevrolites.

The specific macro-porous structure of the highest loess horizons and their position within the terrain have enabled the formation of a permanent aeration zone of considerable thickness in the vicinity of the Danube (elevation 110–114 m above sea level) where it reaches 20 or more meters. In the area of lower elevations (80 m above sea level), this zone is thinner and is around 8 m thick.

The loess sediments of the zone above the ground water level of the Zemun loess plateau are mainly preserved primary, loose structures. They are characterized by spherical, cm-size aggregates which cause inter-granular and inter-aggregate porosity. The size of the pores is not constant and is between capillary and super-capillary. The pores are continually vertically elongated, approximately round in cross-section and are consistent with tubular porosity. The solid particles are interlinked by crystallized carbonates.

Regarding the grain-size distribution, they are represented with about 70 % content of the fraction 0.06–0.002 mm; the content of fraction >0.06 mm increases with depth, for macroporous and paleoelluvial loess sediments, it is 10–20 % up to a maximum of 90 % for sandy loess soil. The content of the fraction <0.002 mm is also 10–20 % for macroporous and paleoelluvial loess sediments.

In the phase content, air-filled pores, around 30 %, are much more present, whilst the volume of water-filled pores is around 20 %. Content of solid phase gradually increases with depth. The contribution of pores to the total volume of the loess is 45–55 %. Of the total volume 22–32 % is filled with water. The gravimetric water content is about 15–18 % and the degree of saturation in accordance with this varies from 45 % for macroporous loess, about 55 % for sandy loess and up to 80 % for paleoelluvial loess soil.

The dry unit weight is 14.2–17.2 kN/m^3 and the unit weight with a natural water content is 16.4–20.2 kN/m^3. According to the CASAGRANDE classification, the loess sediments of the aeration zone are clays with low plasticity, CL, with a liquid limit w_l = 24–35 %, a plastic limit w_p = 13–20 %, a plasticity index of I_p = 7–15 % and a colloidal activity of $K_p > 1.25$.

The deeper levels of the loess complex are changed in grain size and in structure: they are either sandier, more compressed with many concretions, like sandy loess or they are of greater clay content and dark in color, like paleoelluvial loess soil. In any case, they are found at considerable depth above the ground water table and are unsaturated. According to this, tests and investigations of these different loess sediments were performed on: typical macroporous loess soil, paleoelluvial loess soil and sandy loess soil, all of the Zemun loess plateau, from a part of the Pregrevica area, near the street of Cara Dušana in Zemun.

A typical example of the loess complex covering the hilly terrain of the city's territory is the investigated location near Kralja Aleksandra Boulevard, west of Deskaševa Street to Aradska Street and south of Milana Rakića Street up to Kralja Aleksandra Boulevard. The terrain is mildly sloping towards the southwest with an

Table 1. Results of the identification-classification tests.

Soil	γ	γ_d	w	G_s	e	S_r	w_l	I_p	Fraction %		
	kN/m^3		%	–	–	%			< 0.002	0.002–0.06	>0.06
Sediments of the Zemun's loess plateau zone above the ground water table – Pregrevica location											
Macroporous loess	16.43	14.22	15.49	2.70	0.898	45	32	10	12	70	18
Paleoelluvial loess	20.22	17.17	17.81	2.75	0.602	81	35	10	12	70	10
Sandy loess	17.54	15.03	16.67	2.74	0.823	55	24	10	12	70	90
Sediments of the zone of loess complex above the ground water table – Boulevard Kralja Aleksandra location											
Destroyed structure loess	18.98	16.01	18.52	2.74	0.655	75	39	16	19	73	8
Paleoelluvial loess	19.80	16.80	17.85	2.70	0.607	80	37	15	15	75	10
Clayey loess soil	19.61	16.44	19.30	2.68	0.630	81	36	13	30	62	8

average gradient of up to 5°, and in places up to 15°. The absolute terrain elevation is between 189.5 and 215.5 meters above sea level in Milana Rakića Street and between 187.5 and 190.0 meters above sea level along this part of Kralja Aleksandra Boulevard. The primary morphological characteristics of the terrain are significantly changed due to the activity of contemporary geological processes and, especially, due to human activities and urbanization: excavations, slope cuts and fillings.

The terrain surface is made of a complex of loess deposits up to 15 m in depth. Two loess horizons with partly destroyed structure can be distinguished in the loess complex – layered with paleoelluvial soil and with clayey loess soil. Under them, delluvial clays 2–4 m in thickness are found. Marls and clays are at a depth of 10–15 m. The ground water level is to be found at a depth greater than 5 m.

The loess sediments of this complex genetically fall into the slope type. Only the loess sediments on the hypsometrically highest elevations have maintained their primary macroporous structure and are identical in quality and mechanical behavior to the loess of the Zemun plateau. Due to the concurrent activity of Aeolian and delluvial processes during formation, the deeper layers are richer in clay components – darker, denser and enriched with a carbonate content and have a destroyed primary structure.

In the phase content, the sediments of the lower zone have an increased content of solid components of 60–65 %. The pore content in the total volume is 35–40 %. The remaining volume is filled with water. The absolute water content is 18–20 % and the degree of saturation varies from 75 to 80 %. Dry unit weight is 16.0–17.0 kN/m^3 and the unit weight including the natural water content is $\gamma = 19.0–20.0\ kN/m^3$.

According to the Casagrande classification, the loess sediments of the aeration zone are medium-plasticity clays, CI, with liquid limit $w_l = 36–39$ %, a plastic limit $w_p = 23$ %, a plasticity index $I_p = 13–16$ % and a colloidal activity $K_p > 1.25$.

In accordance with the listed geological and hydrogeological characteristics of the terrain and the physical soil indices (phase content, pore size, absolute water content, degree of saturation) shown in Table 1, it is clear that the sediments of the Zemun loess plateau – location Pregrevica, as well as those from the investigated area at the Boulevard Kralja Aleksandra are above the ground water level and are unsaturated.

Shear strength of unsaturated soil

An unsaturated soil actually consists of four phases. In addition to the solid, air and water phases, there is the air-water interface that can be referred to as the contractile skin (Fredlund & Rahardjo 1993). The most distinctive property of the contractile skin is its ability to exert a tensile pull. The soil particles are assumed to be incompressible. Any two of three possible normal stress variables can be used to describe the stress state of an unsaturated soil; hence there are three possible combinations which can be used as stress state variables for an unsaturated soil. However, the combination of the net normal stress ($\sigma - u_a$) and matric suction ($u_a - u_w$) appears to be the most satisfactory for use in engineering practice.

Unsaturated shear strength is a function of the two stress variables: the net normal stress and matric suction (Fredlund *et al.* 1976). The relationship of the unsaturated soil shear strength function to the matric suction can be established based on the primary constitutive relationships for an unsaturated soil – soil water characteristic curves. In the literature, different equations have been proposed to represent sorption or desorption curves (Fredlund *et al.* 1996). In this paper, the soil-water characteristic curves are defined as matric suction *vs.* degree of saturation curves according to the Brooks & Corey (1964) function, one of the most used in practice.

There are three soil parameters that can be identified from the matric suction *vs.* degree of saturation curve. These are: the air entry value of the soil, $(u_a - u_w)_b$, the residual degree of saturation S_{res} and the pore size distribution index, λ. These parameters can readily be visualized if the saturation condition is expressed in terms of an effective degree of saturation, S_e, (Fig. 1):

$$S_e = \frac{S_r - S_{res}}{1 - S_{res}} \tag{1}$$

where: S_e is the effective degree of saturation and S_{res} is the residual degree of saturation.

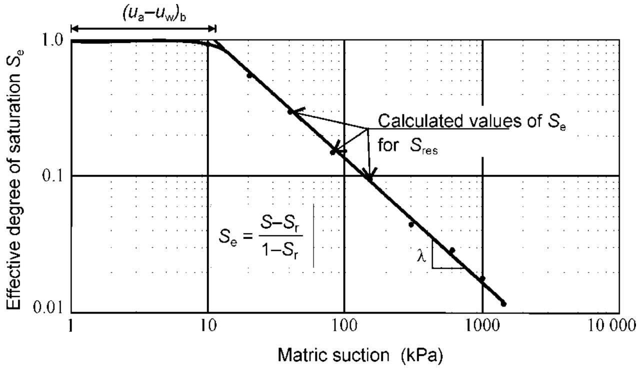

Fig. 1. Effective degree of saturation vs. matric suction (Brooks & Corey 1964).

The residual degree of saturation is defined as the degree of saturation at which an increase in matric suction does not produce a significant change in the degree of saturation.

The air entry value of a soil, $(u_a - u_w)_b$, is the matric suction value that must be exceeded before air recedes into the soil pores. It is a measure of the maximum pore size in a soil. The sloping line for points having matric suctions greater than the air-entry value can be described by the following equation:

$$S_e = \left[\frac{(u_a - u_w)_b}{(u_a - u_w)}\right]^{\lambda} \quad \text{for} \quad (u_a - u_w) > (u_a - u_w)_b \tag{2}$$

where: $(u_a - u_w)_b$ is the air entry value of the soil and λ is the pore size distribution index, which is defined as the negative slope of the effective degree of saturation, S_e, *vs.* matric suction, $(u_a - u_w)$, curve.

It should be stressed that Eqn. (2) is valid for suction values greater than the air-entry value and for degrees of saturation greater than the residual degree of saturation.

The shear strength of unsaturated soil, τ_f, is then evaluated by the approach proposed by Vanapalli *et al.* (1996):

$$\tau_f = c' + (\sigma - u_a)\tan\varphi' + (u_a - u_w)\tan\varphi' S_e \tag{3}$$

where: c' is the effective cohesion of saturated soil, φ' is the effective angle of shear resistance of saturated soil, $(\sigma - u_a)$ is the net normal stress and $(u_a - u_w)$ is the matric suction.

The unsaturated shear strength parameter, φ^b, which is the angle of shear resistance with respect to changes in the matric suction, can also be expressed by the effective degree of saturation (Vanapalli & Fredlund 1999):

$$\tan\varphi^b fn(u_a - u_w) = S_e \tan\varphi' \tag{4}$$

where: $\varphi^b fn(u_a - u_w)$ is the unsaturated shear resistance for changes in the matric suction $(u_a - u_w)$.

Unsaturated shear strength of loess sediments Belgrade zone above the ground water table

The laboratory investigations were performed on undisturbed samples of several loess soils above the ground water level from two different locations: from the Zemun loess plateau – location Pregrevica and from the hilly area near Kralja Aleksandra Boulevard. The following were determined for the typical unsaturated silty soils:

– the soil-water characteristics curves, *i.e.*, the effective degree of saturation, S_e *vs.* matric suction, $(u_a - u_w)$, curves;

– the unsaturated shear strength, τ_f, *vs.* matric suction, $(u_a - u_w)$, curves;

– the changes of unsaturated shear resistance φ^b with matric suction, $(u_a - u_w)$.

The soil-water characteristic curves were obtained from the results of experimental measurements in which saturated soil samples were drained under different pressures in a pressure plate extractor, according ASTM (1993), standards D2325-68 and D3152-72. The friction angle φ^b was also determined in dependence on the matric suction (HADŽI-NIKOVIĆ 2005).

The pressure plate extractor consists of a high air entry ceramic disc placed in an air pressure chamber. The high air entry disk is saturated and is always in contact with water in the compartment below the disk. The compartment is maintained at zero water pressure. The soil specimens are placed on top of the disk and the airtight chamber is pressurized to the desired matric suction. The disk does not allow the passage of air as long as the applied matric suction does not exceed the air entry value of the disk. The air entry value of the disk is related to the diameter of the fine pores in the ceramic disk. Therefore, the air entry value of the disk and the strength of the chamber control the maximum air pressure, or matric suction, which can be applied to soil specimens.

The application of matric suction to the soil causes the pore-water to drain in the water compartment through the disk. At equilibrium, the soil will have a reduced water content corresponding to the increased matric suction. The water content at each equilibrium condition can be computed from measurement of the change in the water volume. The chamber must be dismantled and the weight of the specimen measured after equilibrium at each applied pressure. This procedure is commonly used with a 15 bar ceramic plate extractor.

Direct shear tests for determining the effective cohesion, c' and the effective angle of shear resistance, φ', of saturated soil are also performed. For undisturbed samples of loess soil with a natural water content, the following results were obtained: $c' = 20$ kPa and $\varphi' = 24°$ for loess; $c' = 37$ kPa and $\varphi' = 23°$ for paleoelluvial loess soil and $c' = 10$ kPa and $\varphi' = 25°$ for sandy loess.

With regards to the sediments above the ground water level from the Zemun loess plateau (macroporous loess, paleoelluvial loess and sandy loess), which have a retained primary structure, and the sediments from the hilly area near Kralja Aleksandra Boulevard (destroyed structure loess soil and clayey loess soil), which have a changed structure without macropores, the obtained results confirmed the effect of primary structure of the loess sediments on their unsaturated shear strength.

Unsaturated shear strength parameters for loess sediments having a macroporous structure

The constitutive relations: the effective degree of saturation, S_e, *vs.* the matric suction, $(u_a–u_w)$, curve, Eqn. (2); the unsaturated shear strength, τ_f, *vs.* the matric suction, $(u_a–u_w)$, curve, Eqn. (3), and the friction angle, φ^b, in dependence on the matric suction, $(u_a–u_w)$, Eqn. (4), are presented in Figs. 2, 3 and 4, respectively, for macroporous loess and in Figs. 5, 6 and 7, respectively, for sandy loess soil.

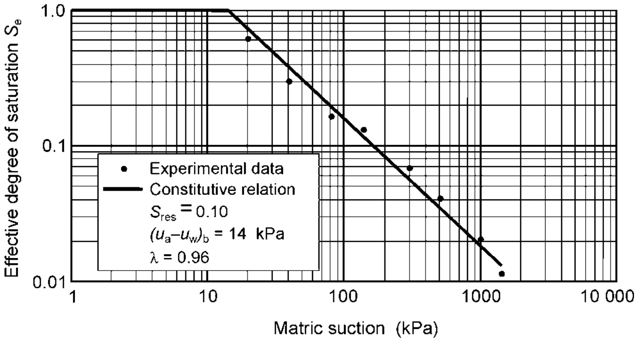

Fig. 2. Effective degree of saturation *vs.* matric suction for macroporous loess soil.

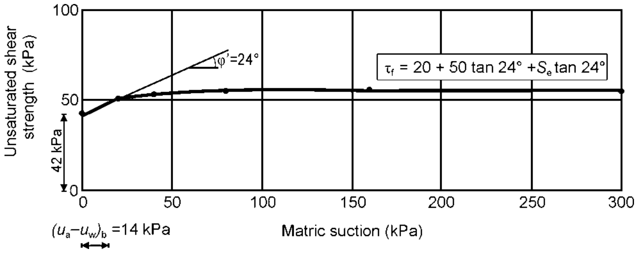

Fig. 3. Unsaturated shear strength *vs.* matric suction for macroporous loess soil.

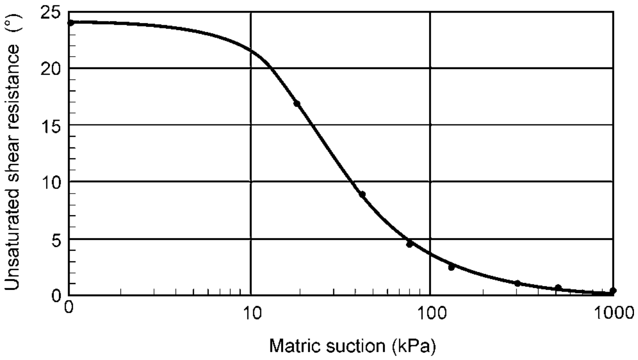

Fig. 4. Unsaturated shear resistance with changes in matric suction for macroporous loess soil.

For eight different values of the matric suction from 20 to 1300 kPa, the obtained values for the degree of saturation were: $S_r = 0.11–0.43$ for macroporous loess; $S_r = 0.39–0.72$ for paleoelluvial loess soil and $S_r = 0.26–0.55$ for sandy loess sediments.

The value of the residual degree of saturation was the lowest for the macroporous loess, $S_{res} = 0.11$, while the values of S_{res} were 0.39 and 0.26 for paleoelluvial loess soil sandy loess sediments, respectively. The desaturation velocity decreased with increasing residual degree of the saturation. This actually means that the unsaturated shear resistance, φ^b, slowly decreased for soil samples with a larger residual degree of saturation.

For values of the matric suction, $(u_a–u_w)$, between 20–50 kPa, the angles of unsaturated shear resistance, φ^b, were 16°–8°, 20°–12° and 11°–7° for macroporous loess soil, paleoelluvial loess soil and sandy loess sediments, respectively. It was observed that the draining occurred very fast for macroporous soils.

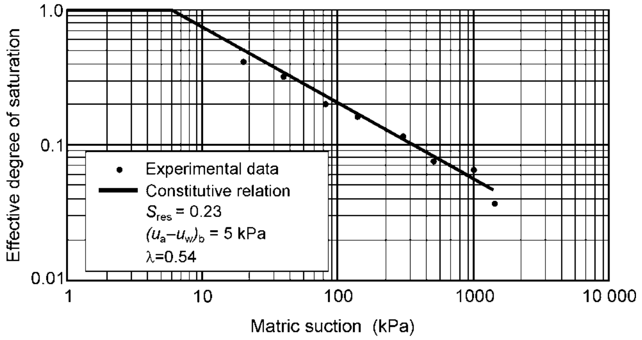

Fig. 5. Effective degree of saturation *vs*. matric suction for sandy loess soil.

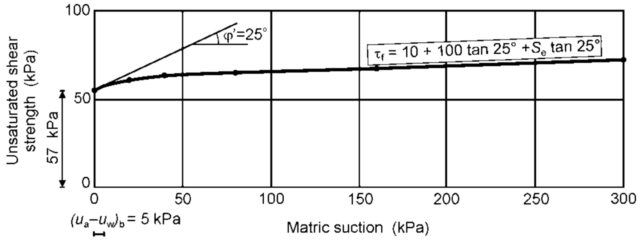

Fig. 6. Unsaturated shear strength *vs*. matric suction for sandy loess soil.

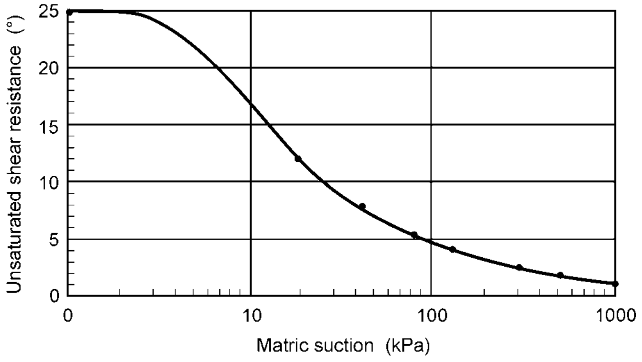

Fig. 7. Unsaturated shear resistance with changes in matric suction for sandy loess soil.

The grain-size distribution was also very significant for both the soil-water characteristic curve and the unsaturated shear strength. With increasing grain size in the soil, the effect of matric suction on the unsaturated shear strength diminished. For macroporous loess soil, however, its primary structure was more significant than grain-size distribution. The macroporous loess samples had the lowest values of the degree of saturation for the same matric suction value, even lower than the value of the degree of saturation for the sandy loess soil having the largest grain size.

The effect of matric suction on the unsaturated shear resistance, φ^b, was more significant at lower matric suction values, with a higher value of the degree of saturation. After a certain matric suction value, the unsaturated shear resistance rapidly decreases.

Unsaturated shear strength parameters for loess sediments with a destroyed structure

The constitutive relations: the effective degree of saturation, S_e, *vs*. the matric suction, $(u_a–u_w)$, curve, Eqn. (2); the unsaturated shear strength, τ_f, *vs*. the matric suction, $(u_a–u_w)$, curve, Eqn. (3), and the friction angle, φ^b, in dependence on the matric suction, $(u_a–u_w)$, Eqn. (4), are presented in Figs. 8, 9 and 10, respectively, for destroyed loess and in Figs. 11, 12 and 13, respectively, for loess clay soil.

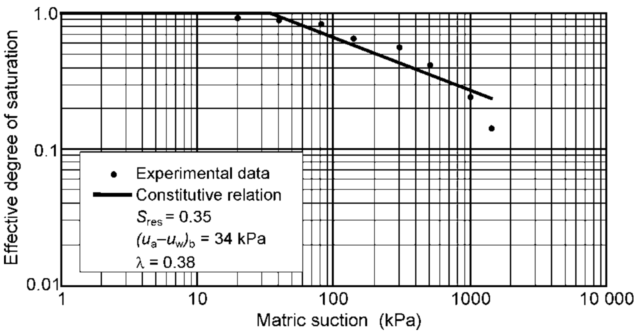

Fig. 8. Effective degree of saturation *vs*. matric suction for destroyed loess soil.

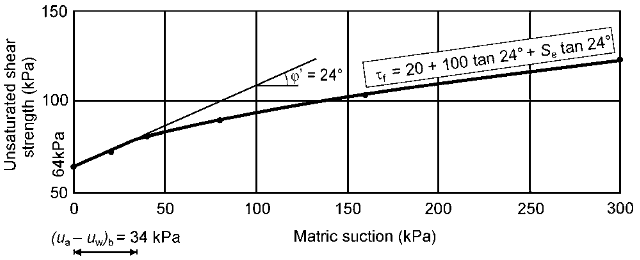

Fig. 9. Unsaturated shear strength *vs*. matric suction for destroyed loess soil.

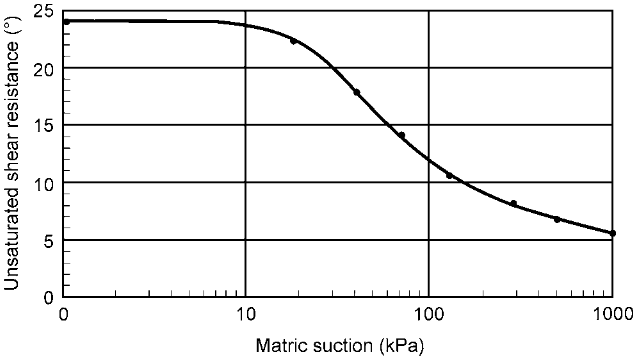

Fig. 10. Unsaturated shear resistance with changes in matric suction for destroyed loess soil.

The soil-water characteristic curves for the destroyed loess soils confirmed that loess sediments in the hilly area of Belgrade had been subjected to processes which led to great changes in their primary structure in comparison with the macroporous loess soils in the Zemun plateau. Namely, the effective degree of saturation *vs.* matric suction curves of the residual loess sediments were above the effective degree of saturation *vs.* matric suction curves for macroporous loess. This means that the soil with a greater silty and sandy fraction had a steeper soil-water characteristic curve in comparison to that of soil with a greater clayey fraction.

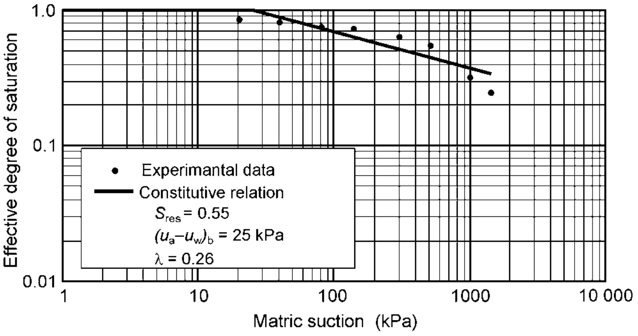

Fig. 11. Effective degree of saturation vs. matric suction for clayey loess soil.

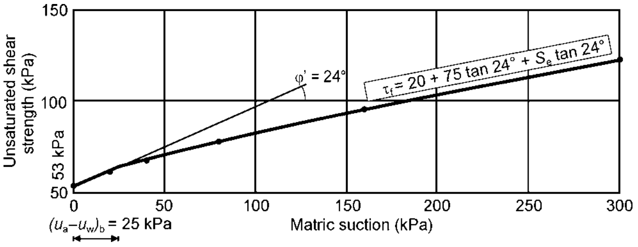

Fig. 12. Unsaturated shear strength vs. matric suction for clayey loess soil.

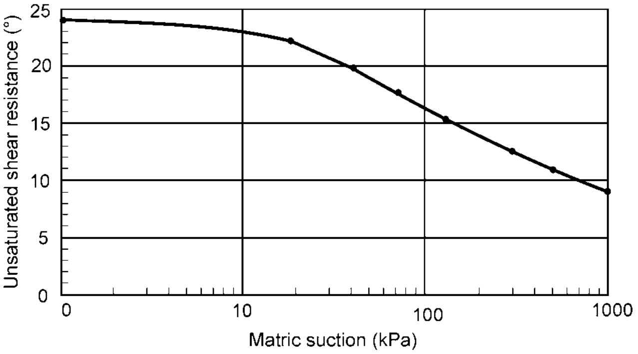

Fig. 13. Unsaturated shear resistance with changes in matric suction for clayey loess soil.

For eight different values of matric suction from 20 to 1300 kPa, the obtained values for the degree of saturation were: $S_r = 0.46–0.95$ for the destroyed loess soil and $S_r = 0.67–0.94$ for the clayey loess soil. The residual degrees of saturation for the destroyed loess sediments were higher than those for the macroporous loess sediments, $S_{res} = 0.35–0.58$.

For values of the matric suction $(u_a–u_w) = 20–50$ kPa, the angles of unsaturated shear resistance, φ^b were 22°–16° for the residual loess soils. The value of the unsaturated shear resistance decreased more slowly in comparison with those of the macroporous loess soil, because desaturation lasted longer.

Verification of obtained results

Bearing in mind that this type of investigations were conducted in Serbia for the first time, the results obtained in this way were checked by comparison with results from known investigations in which a different method was employed.

The obtained results were correlated by use of the non-dimensional parameter, *K,* determined for different types of soil, and the established dependency of the parameter *K* on the plasticity index I_p. VANAPALLI & FREDLUND (1999) suggested the following equation for determining the unsaturated strength:

$$\tau_f = [c' + (\sigma_n - u_a)\tan\varphi'] + (u_a - u_w)\Theta^{K}(\tan\varphi') \quad (5)$$

where: *K* is a fitting parameter for the predicted and measured unsaturated shear strength and $\Theta = w/w_s$, where w is the water content after draining under a certain value of matric suction, $(u_a–u_w)$ and w_s is the saturated water content.

Based on the reverse of this equation, value of correlation parameter *K* was determined for all types of soil for which experimentally determined constitutive relations: the effective degree of saturation *vs.* matric suction and the strength of an unsaturated soil *vs.* the matric suction exist. The obtained values of the parameter *K* are shown in the diagram of the already determined relationship between the fitting parameter, *K*, and the plasticity index, I_p (VANAPALLI & FREDLUND 2000), Fig. 14.

From the diagram, it can be seen that there is a good agreement of the parameter *K* with the established dependency on the plasticity index I_p for silty loess sediments. Furthermore, it can be seen that the parameter *K* is in concurrence with the previously quoted dependency on the plasticity index I_p for silty and silty-sandy loess sediments, primarily for sandy loess and macroporous loess from the Pregrevica location, and also for the destroyed slope loess sediments from Kralja Aleksandra Boulevard. Somewhat less concurrent are the results for the changed loess sediments with a larger clay content at the location in Kralja Aleksandra Boulevard, such as the clayey loess soil and the elluvial loess soil.

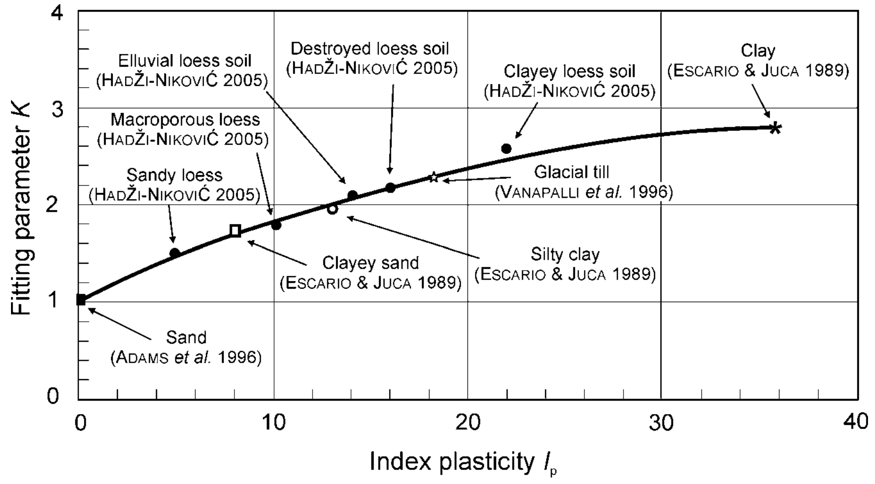

Fig. 14. The relationship between the fitting parameter and the plasticity index (VANAPALLI & FREDLUND 2000).

Concluding remarks

According to the geology and hydrology of terrain in the Belgrade area and the engineering-geological and hydrogeological properties of the soil, it is obvious that the zone above the ground water table can be 5–10 m in depth and the soil is unsaturated in this zone.

Geotechnical analyses of the lateral earth pressure, the bearing capacity and slope stability in respect of the matric suction in the zone above the ground water level confirmed that matric suction can be very important for rational design in geotechnical engineering.

A negative pore-water pressure is present in this zone, which contributes to a larger shear strength of the unsaturated soil. Laboratory investigations were performed on undisturbed samples of several loess soils above the ground water table from two different locations: from the Zemun loess plateau, location Pregrevica, and from the hilly area near Kralja Aleksandra Boulevard. For typically unsaturated silty soils. the following relationships were determined: the soil-water characteristics curves, *i.e.*, effective degree of saturation, S_e, *vs.* matric suction, $(u_a–u_w)$, curves, unsaturated shear strength, τ_f, *vs.* matric suction $(u_a–u_w)$, relations and the changes in the unsaturated shear resistance, φ^b, for changes in the matric suction $(u_a–u_w)$.

Soil-water characteristic curves were obtained from the results of experimental measurements on draining saturated soil samples under different pressures, which were performed in a pressure plate extractor – 15 bar Pressure Plate Extractor 1500 – Soilmoisture Equipment Corporation, Santa Barbara, California, according to ASTM standards D2325-68 and D3152-72.

The unsaturated shear strength was determined by the VANAPALLI Eqn. (1996) using the basic effective degree of saturation *vs.* matric suction curve proposed by BROOKS & COREY (1964), one of the most used in practice.

The contribution of matric suction to the unsaturated shear strength depends on the draining velocity. For the same normal stress and the same matric suction, soil samples with larger degree of saturation have a higher unsaturated shear resistance. Macroporous loess and sandy loess soil with a retained primary structure and large pores exhibited very fast draining with increasing values of the matric suction; hence the rate of the unsaturated shear resistance decreased very fast and abruptly. With decreasing grain size, the velocity of the desaturation decreased. Increasing grain size in a soil, diminished the effect of matric suction on the unsaturated shear strength. However, for macroporous loess soil, its primary structure was more significant than the grain-size distribution.

The obtained results are in accordance with the results of other available investigations.

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Резиме

Утицај гранулометријског састава и структуре тла на незасићену чврстоћу лесних седимената у Београду, централна Србија

Надизданска зона на одређеним локацијама у подручју Београда има значајну дебљину, 5–10 m. У њој постоје негативни порни притисци или матрична сукција, која повећава чврстоћу незасићеног тла. Приликом решавања одређених геотехничких проблема, који се манифестују изнад нивоа подземне воде, као што су проблеми плитког фундирања, одређивања активног притиска тла, стабилности вертикалних ископа или косина са клизном површином изнад нивоа воде, требало би уважавати принципе механике незасићеног тла, а методе истраживања и лабораторијских испитивања, као и геостатичке анализе, ускладити са реалним теренским условима, дакле уз уважавање постојања негативних порних притисака у тлу.

Лабораторијска испитивања чврстоће незасићеног тла опитима директног смицања или триаксијалне компресије су дуготрајна и скупа и захтевају модификовање конвенционалне лабораторијске опреме. Због тога се чврстоћа смицања незасићеног тла све више одређује посредно, преко кривих зависности влажност/матрична сукција и ефективних параметара чврстоће смицања засићеног тла c' и φ'.

У раду су приказани и анализирани резултати дренирања узорака тла, у екстрактору са полупропустљивом плочом под различитим величинама матричне сукције. По први пут код нас, на основу опита дренирања под различитим притисцима, успостављене су криве зависности ефективни степен засићења/матрична сукција и на основу њих и ефективних параметара чврстоће засићеног тла, c' и φ', успостављене зависности незасићена чврстоћа тла/матрична сукција. Такође, одређене су зависности величине незасићене отпорности на смицање φ^b од матричне сукције.

Лабораторијска испитивања су вршена на природним непоремећеним узорцима надизданске зоне са очуваном и измењеном примарном структуром. На тај начин је анализиран утицај појединих чинилаца, а пре свега гранулометријског састава и примарне структуре тла, на конститутивне зависности незасићених лесних седимената.

Повећање чврстоће смицања услед постојања матричне сукције зависи од брзине дренирања тла. За исти нормални напон и исту матричну сукцију, узорци који имају већи ефективни степен засићења имају већу чврстоћу.

Макропорозни лес и песковити лес у природном стању имају велике поре, међусобно повезане и показују веома брзо дренирање са повећањем сукције, тако да величина угла φ^b врло брзо и нагло опада, јер се дренирање обавља веома брзо. Са смањењем величине зрна и величине пора у тлу, брзина десатурације опада.

Гранулометријски састав тла значајно утиче на облик криве влажност/ матрична сукција. Повећањем величине зрна у тлу, опада утицај величине матричне сукције на незасићену чврстоћу. За узорке макропорозног леса, међутим, значајнија је његова структура, величина пора и њихова међусобна повезаност од гранулометријског састава. Због своје цевасте структуре, макропорозни лес има најнижи степен засићења за исту величину матричне сукције, у поређењу са осталим, чак и крупнозрнијим тлом, нпр. песковити лесом.

Криве зависности ефективни степен засићења/матрична сукција падинских измењених лесних седимената потврђују промењену структуру у односу на лесне седименте очуване примарне структуре. Криве зависности ових седимената су изнад кривих зависности неизмењених макропорозних лесних седимената, дакле тло са већим учешћем крупнозрније фракције показује стрмију криву зависности влажност/ матрична сукција од тла са већим учешћем глиновите, ситнозрније фракције.

Узорци измењеног падинског леса са локације Булевар Краља Александра имају спорије опадање угла φ^b, јер се дренирање обавља знатно спорије у односу на неизмењене лесне седименте очуване структуре.

Утицај матричне сукције на незасићену чврстоћу, φ^b, већи је за мање величине матричне сукције, при већем степену засићења. Након одређене величине матричне сукције, чврстоћа незасићеног тла почиње нагло да пада.

Добијени резултати упоређени су са резултатима иностраних истраживача и добијена су добра слагања.

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In memoriam

Проф. др Милева Сладић-Трифуновић
(1930–2005)

Марта 2005. године потпуно неочекивано преминула је Милева Сладић-Трифуновић, редовни професор Рударско-геолошког факултета у пензији и истакнути српски инжењер геологије и палеонтолог. Као педагог и научник оставила је за собом изузено дубоке трагове.

Рођена је у Пучишћу на острву Брачу 4. новембра 1930. године. Отац, Ђуро Сладић био је службеник а мајка Љубица, рођена Видовић, домаћица. Рано детињство провела је у родном месту на острву. Од 1937. живела је с родитељима у Чачку, где је завршила основну школу и Женску гимназију. У јесен 1949. уписала се на Геолошки факултет Техничке велике школе у Београду на којем је и дипломирала 1956. са средњом оценом 9,6. О тим студијама, испитима и професорима често и с одушевљењем је причала јер су те године оставиле на њу снажне утиске.

Августа 1956. постављена је за сарадника (у звању приправника професора средње школе) на Катедри за геологију и палеонтологију Геолошког факултета у Београду. Задатак јој је био да руководи вежбањима студената из предмета Палеонтологија и учествује у извођењу теренске наставе. Ови послови су битно утицали на формирање њеног педагошког искуства и будућег наставничког профила.

У јесен 1961. изабрана је за предавача за предмет Палеонтологија на Рударско-геолошком факултету у Београду. Изводила је целокупну теоријску и практичну наставу из тог предмета. Реизабрана је 1966. и 1977. године али тада већ на Катедри за палеонтологију интегрисаног Геолошког одсека Рударско-геолошког факултета. У том звању је остала све до 1981. године. Током две деценије предавала је разне курсеве палеонтологије и делове тог предмета. Осим тога, направила је програме, припремила је и одржавала предавања и вежбања из потпуно нових курсева: Општа палеонтологија и Микропалеонтологија. Припремајући се за тај озбиљан и замашан посао проучила је организацију наставе из Микропалеонтологије на Сорбони у Паризу 1974. године.

Године 1980. одбранила је докторску дисертацију под насловом “Палеонтолошке карактеристике и биостратиграфски значај рудистног сенонског рода *Pseudopolyconites* Milovanović” на Рударско-геолошком факултету у Београду.

За доцента, за предмет Општа палеонтологија изабрана је 1981., за ванредног професора 1983. а за редовног 1989. године. Уз то предавала је и знатан део Микропалеозоологије. Пензионисана је 1996. године. Од 1993. године била је шеф Катедре за палеоботанику. Преминула је 29. марта 2005. услед апоплексије у Београду и сахрањена у породичној гробници на Новом гробљу.

Као наставник уносила је у своја предавања савремена схватања и методе, много труда и ентузијазма па се развила у беспрекорног педагога. Студенти су са нескривеним интересовањем пратили њена предавања, активно учествовали у њима и са задовољством расправљали о ономе што су научили. Посебне напоре улагала је у рад са студентима дипломцима. Извела је тридесет и пет генерација студената Рударско-геолошког факултета.

Ради унапређења и употпуњавања својих знања из палеонтологије рудиста и микропалеонтологије боравила је у више наврата у иностранству на студијским путовањима. Тако је 1959. и 1966. проучавала на Сорбони и на Високој рударској школи у Паризу чувене, класичне збирке рудиста и упоређивала нашу и француску рудистну фауну. Године 1974. студирала је холотипове рудиста у Грацу, Бечу, Фрајбургу, Бону, Амстердаму, Паризу и Трсту. Уз то се бавила и збиркама макрофораминифера у Бечу и Паризу.

Истраживачки посао започела је још као апсолвент током израде свог дипломског рада о веома специјализованом рудистном роду *Pseudopolyconites* Milovanović. О томе је објавила рад 1957. Затим, у току свог дугогодишњег рада, постигла је веома значајне резултате, које је публиковала у реномираним домаћим и иностраним часописима или их је приказивала на домаћим и међународним скуповима. Радила је на различитим проблемима али се међу њеним достигнућима на првом месту налазе испитивања сенонских рудистних фауна Србије, затим других делова бивше Југославије, Италије и Аустрије. По значају нарочито се истиче њена докторска дисертација али и низ чланака о целокупној палеонтолошкој проблематици псеудополиконита, које је она подигла у ранг фамилије.

Последње две деценије своја проучавања сенонских рудиста синтетизовала је у приказима њихове палеобиогеографије у Тетису. При томе, издвајањем низа рудистних провинција извела је веома занимљиве и логичне палеогеографске реконструкције млађег сенона Средоземља. Ови потпуно оригинални радови имају и шири међурегионални значај. Успешно се бавила, међутим, и другим проблемима као што су палеонтологија и биостратиграфија конодоната из тријаса и макро- и микрофораминифера из горње креде.

Као научни радник испољила је особине истраживача знатне посвећености и пријежности, упадљиве савесности, одговорности и велике инвенције како по методама којима се служила тако и по комплексности проблематике коју је обрађивала. Објавила је стотинак радова чија библиографија је штампана у "Записницима Српског геолошког друштва" за 2005. годину (стр. 85-91).

Са рефератима или без њих учествовала је на готово свим Конгресима геолога Југославије, затим на симпозијумима Динарске асоцијације и на низу седиментолошких скупова у земљи и иностранству. Реферате је подносила и на Међународним геолошким конгресима у Москви (1984) и Фиренци (2004); затим на Симпозијуму о периадријатским карбонатним платформама (Трст, 1987), Симпозијуму о екологији и палеоекологији бентоских заједница (Соренто, 1988) и др. Била је делегат Савеза геолошких друштава Југославије на Међународним геолошким конгресима у Пекингу (1996), Рио де Женеиру (2000) и у Фиренци (2004).

Иницирала је и организовала Прву интернационалну конференцију о рудистима у Београду, 1988. На том скупу је изабрана за председника новоосноване Радне групе за рудисте у оквиру Интернационалне палеонтолошке уније. После, на скуповима те групе у Италији (1991), Мексику (1993) и у Француској (1996) као председник значајно је допринела успешности и континуитету рада овог тела. Уз велику упорност и многе компликације била је и на последњем Конгресу ове Радне групе у Хрватској.

Нарочито треба истакнути њен рад у Српском геолошком друштву у коме је била агилан члан (од 1956), секретар (1981–1985) и председник (1987–1991). За то Друштво учинила је веома много а особито када је оно усред зиме (1998-1999) било практично избачено на улицу од стране тадашњег руководства Економског факултета подржаног насилничким понашањем неких политичара. У тој изузетно тешкој ситуацији обезбедила је просторије за смештај Друштва и пренела у њих сав инвентар и библиотеку. Упорно је прикупљала финансијска средства за рад Друштва. Модернизовала је изглед и структуру "Записника СГД". Одлучно се залагала за одржавање зборова Друштва и за активирање и окупљање чланства. Деведесетих година организовала је и извела читав низ скупова и округлих столова о проблемима и положају геологије у Србији, итд. Најзначајнији допринос у раду Друштва, међутим, обавила је у организацији обележавања сто година Српског геолошког друштва. Припремана систематично и упорно скоро три године прослава тог значајног јубилеја СГД одржана је 30. маја 1991. године веома свечано у лепој сали Српске академије наука и уметности у Београду. О томе је остао опширан траг у "Споменици" (1992) из које ће се и у будућности људи обавештавати о овом догађају. За сав свој допринос у раду Друштва постала је његов почасни члан а после њене смти Друштво јој је посветило посебну књигу "Записника" (2006).

Као председник СГД али и касније била је члан Скупштине и Председништва Савеза геолошких друштава СФР Југославије и његов подпредседник. После распада друге Југославије била је председник тог Савеза у трећој Југославији све до своје смрти.

Последње две деценије много се бавила и уређивањем публикација. Као главни и одговорни уредник спремила је и објавила низ издања високог квалитета. Тако, на пример, Изабране радове Бранислава Миловановића, материјале са Прве конференције о рудистима ("The Rudists"), четири књиге "Записника СГД", "Споменицу 100 година СГД" и две књиге Николе Пантића. Све те књиге добиле су веома много у њиховом квалитету баш захваљујући педантном лекторском и коректорском раду главног и одговорног уредника. У том послу није жалила ни време ни напоре.

Живот, на жалост, није јој био нарочито наклоњен. Пролазила је, као човек и наставник, кроз многе проблеме, тешкоће, шиканирања, препреке, неразумевања и унапред сковане завере. Захваљујући свом снажном духу, упорности, искреној посвећености послу и огромној радној енергији она је све то савладавала и из тих недаћа излазила као препорођена. У томе су јој посебно помагали велики оптимизам и непоколебљива вера у бољу будућност.

Остала је међу савременицима упамћена као одличан и омиљен учитељ, угледан научник, одговоран радник, пријатан саговорник, цењена колегиница, искрен и поуздан пријатељ а изнад свега – маркантна дама.

Нека је хвала за све што је урадила и слава Милеви Сладић-Трифуновић.

Александар Грубић

Instructions for authors

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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.

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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.

RABRENOVIĆ, D. & JANKIČEVIĆ, J. 1984. Contribution to the study of Albian near Topola. *Geološki anali Balkanskoga poluostrva*, 48: 69–74 (in Serbian, English summary).

SMIRNOVA, T.N. 1960. About a new subfamily of the Lower Cretaceous dallinoid. *Paleontologicheskij Zhurnal*, 2: 116–120 (in Russian).

SULSER, H. 1996. Notes on the taxonomy of Mesozoic Rhynchonellida. *In*: COOPER, P. & JIN, J. (eds.), *Brachiopods*, 265–268. Balkema Press, Rotterdam.

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.

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