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Radiolarian assemblage from radiolarites of the Krš Gradac section (SW Serbia): on the way to a better reconstruction of the Middle-Late Jurassic geodynamic history of the Inner Dinarides

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Abstract. The type section of the Gonje Formation (Krš Gradac, Sjenica area) is characterized by an abundance of radiolarian tests, which, however, are generally recrystallized and poorly preserved. This paper focuses on the age of radiolarite sequence below the series with intercalated turbidites and mass transport deposits. The Callovian/Oxfordian (?early Oxfordian) moderately preserved radiolarian assemblage was determined from the higher part of the radiolaritic sequence without mass transport deposits. The new biostratigraphic age is consistent with the previously published data of the authors and reveals that the radiolaritic sequence without mass transport deposits of the Gonje Formation was deposited between the Bathonian and Oxfordian. The biostratigraphic age of this part of the Gonje Formation evidence that the Ljubiš Basin underwent in Late Oxfordian to earliest Tithonian times a phase of starvation with reduced sediment supply or production. The reasons for this starvation are discussed.

Key words. *Gonje Formation, radiolarians, Callovian/Oxfordian boundary, Ljubiš Basin.*

Апстракт. Типски локалитет Гоње Формације (Крш Градац, Сјеница) карактерише обиље фосилних љуштура радиоларија, али су углавном рекристализоване и слабо очуване. На основу радиоларијске асоцијације одређена је старост радиоларита који леже испод серије коју карактерише присуство турбидита. Осредње очувана радиоларијска асоцијација, келовејско-оксфордске (?доњи оксфорд) старости, одређена је у радиоларитима које карактерише потпуно одсуство турбидитског материјала. Новодобијени биостратиграфски податак у складу је са раније публикованим подацима и потврђује да је део радиоларитске секвенце без турбидитског материјала Гоње Формације депонован у временском интервалу бат – оксфорд. Биостратиграфска старост овог дела Формације Гоње јасно указује на значајно смањену седиментацију у басену Љубиш, у периоду од горњег оксфорда до почетка титона. У овом раду разматрани су и могући узроци такве кондезоване седиментације.

Кључне речи. *Гоње Формација, радиоларије, граница келовеј/оксфорд, басен Љубиш.*

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Introduction

The Krš Gradac section is a well-known locality with a complete Upper Triassic to Upper Jurassic sedimentary succession in geological literature, situated in the Inner Dinarides of SW Serbia (Kossmat, 1924; Ledebur, 1941; Ćirić, 1954, 1984; Radoičić-Brstina, 1956; Jovanović, 1963; Rampnoux, 1974; Grubić, 1980; Ljubović-Obradović et al., 1998; Radovanović, 2000; Radovanović et al., 2004; Radoičić et al., 2009; Vishnevskaya et al., 2009; Vishnevskaya & Djerić, 2009; Gawlick et al., 2009a, 2017, 2020; Djerić et al., 2012). It is one of the best-exposed and most important sections, because the contact between radiolarites and the underlying Triassic and lower Liassic carbonates is directly exposed here. This parautochtonous sedimentary sequence as part of the East Bosnian-Durmitor megaunit (Fig. 1) is tectonically overlain by the Middle Jurassic ophiolitic mélange around the Jurassic-Cretaceous boundary (Gawlick et al., 2009a, 2017, 2020). Historically, this locality was mostly considered to be a part of the ophiolitic mélange that structurally underlies the ophiolites of the Dinaridic Ophiolite Belt (e.g., Karamata et al., 1997).

Recently, the section of the locality Krš Gradac was described in detail and attributed to the Triassic–Jurassic parautochthonous sequences of the East Bosnian-Durmitor megaunit below the Dinaridic Ophiolite nappe (Gawlick et al., 2020). According to these authors the section occurs in a window below the overthrusted Middle Jurassic ophiolitic mélange and ophiolites with the following formations: 1) the Norian–Rhaetian Dachstein Limestone in open lagoonal facies; 2) the Lower to Middle Jurassic Krš Gradac Formation and 3) the Bathonian to ?Tithonian Gonje Formation.

The Gonje Formation was proposed by Gawlick et al. (2017) as Middle to Upper Jurassic (Bathonian–?Tithonian) radiolarites and radiolaritic-argillaceous sedimentary rocks deposited in the distal parts of the Ljubiš Basin (in the western part of the Dinaridic Ophiolite belt).

Therefore, the Gonje Formation corresponds to the Ljubiš Formation to the east (Gawlick et al., 2017, 2020; Bragin & Djerić, 2020), deposited in the distal (western) part of the Ljubiš Basin. In contrast to the radiolaritic Ljubiš Formation with mass transport deposits in its lower part, the Gonje Formation contains mass transport deposits and turbidites in the upper part (Kimmeridgian-Tithonian age), which have a different component spectrum and its redeposition is younger (Gawlick et al., 2017), while it does not contain turbidites or fine-grained mass transport deposits at the Bathonian–Oxfordian level.

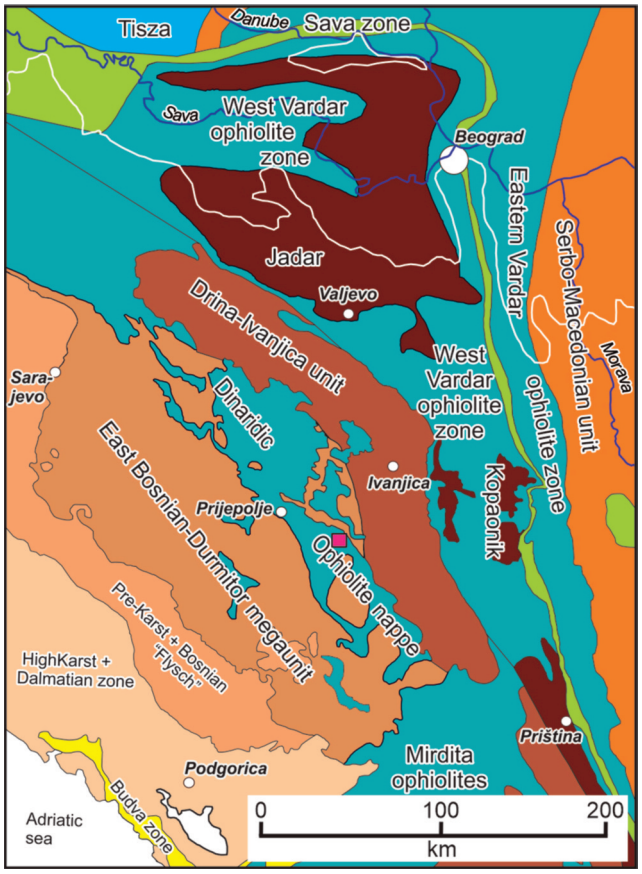

Fig. 1. *Overall tectonic map of the Dinarides in Serbia and adjacent countries redrawn after Schmid et al. (2008, 2020) and based on new results (Gawlick et al., 2017; Djerić et al., in press; Sudar et al., this volume). The position of the Krš Gradac section is marked by a purple square.*

Mesozoic radiolarian biochronology is essential for the understanding of the stratigraphy, palaeogeography and overall tectonic structure of the Dinarides and the new presented data provide the opportunity to fill a gap in the stratigraphy of the area. Numerous radiolarian studies have been carried out at the Krš Gradac locality during the last two decades (Vishnevskaya et al., 2009; Vishnevskaya & Djerić, 2009; Gawlick et al., 2009a, 2017, 2020;

Djerić et al., 2012), but the age of the whole radiolaritic succession (Gonje Formation) is still not exactly dated and several open questions remained open. This paper deals with the study of radiolarian assemblage from the Krš Gradac section with its biostratigraphic analysis and correlation.

Section description and biostratigraphy

The studied section is located on the northern side of the Uvac River at the beginning of the local road to Jadovnik Mt. (Fig. 2).

The section starts with Rhaetian Dachstein Limestone in open lagoonal facies (Fig. 3). Directly on top of the Dachstein Limestone, a four-meter-thick part of the micro-oncoidal limestone with shallow-water material and crinoids was deposited. Gawlick et al. (2020) assigned this part of the section as being deposited around the Triassic/Jurassic boundary. Above occurs 8 meter thick ?Middle/Upper Hettangian to Sinemurian sequence of grey-reddish micro-oncoidal limestones with ammonoids, crinoids, ostracods and benthic foraminifera.

These nodular limestones with micro-oncoids are topped by a hardground (Fig. 3), dated by ammonites as Lower Toarcian (Ćirić, 1954). The contact between the Toarcian ammonoid-crinoidal-foraminifera limestones and the (Upper) Bajocian to (Lower) Bathonian *Bositra-Protoglobigerina* red nodular limestones is also marked by a hardground with a long-lasting gap (Fig. 3). These Lower–Middle Jurassic red nodular limestones of the Krš Gradac section were firstly described by Ljubović-Obradović et al. (1998) as Krš Gradac Formation. This Formation is recently emended based on the microfacies characteristics and the ages (Gawlick et al., 2017). Above the Ammonitico Rosso follows the Bathonian to ?Tithonian radiolaritic sequence of the Gonje Formation (Figs. 2, 3). An onset of radiolaritic deposition in the (Late) Bathonian is proven by recent radiolarian dating (Gawlick et al., 2017).

Based on the microfacies characteristics and the age, Gawlick et al. (2017) differentiated the radiolaritic sequence of the Gonje Formation into three members: 1) the Bathonian-Oxfordian lower radiolaritic sequence without mass transport deposits;

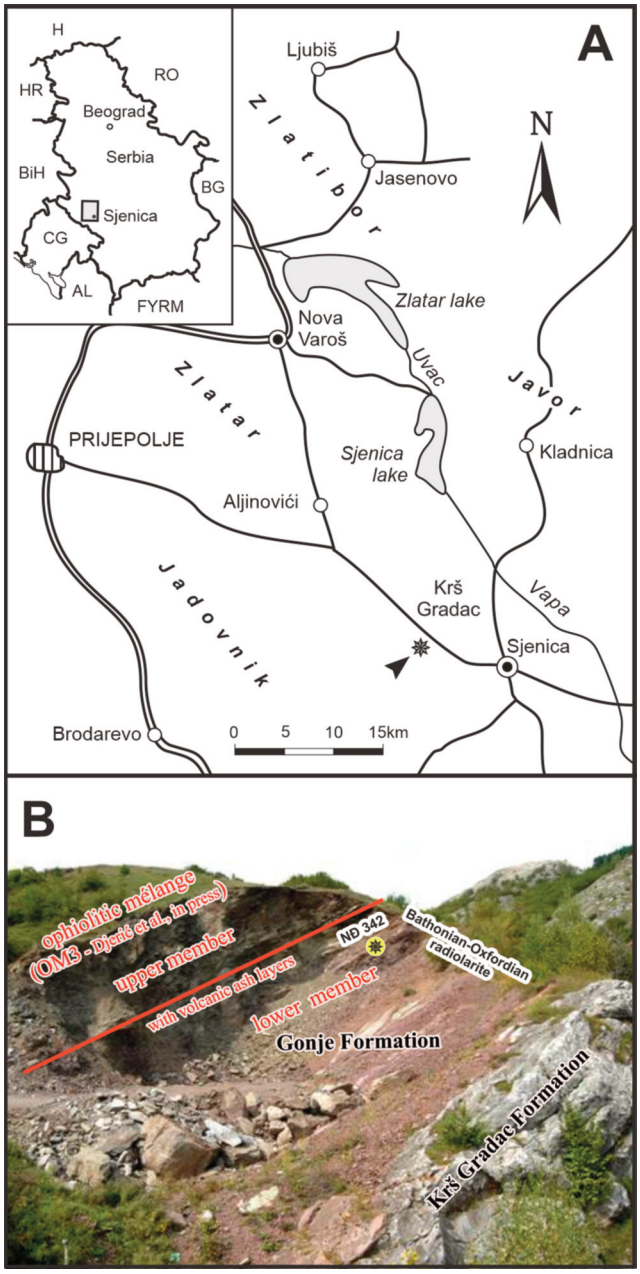

Fig. 2. *A. Geographical position of the locality Krš Gradac in southwestern Serbia. The star indicates the studied section. B. Upper Triassic to Upper Jurassic parautochthonous sequence in a window below the overthrusted Middle Jurassic ophiolitic mélange and ophiolites at the Krš Gradac locality. The star indicates the position of the sample NĐ 342.*

2) the higher radiolaritic sequence with intercalated mass transport deposits and turbidites (Kimmeridgian-?Lower Tithonian) and 3)the topmost part of the sequence contains more fine-grained sandstone layers which consist of quartz grains, heavy mine-

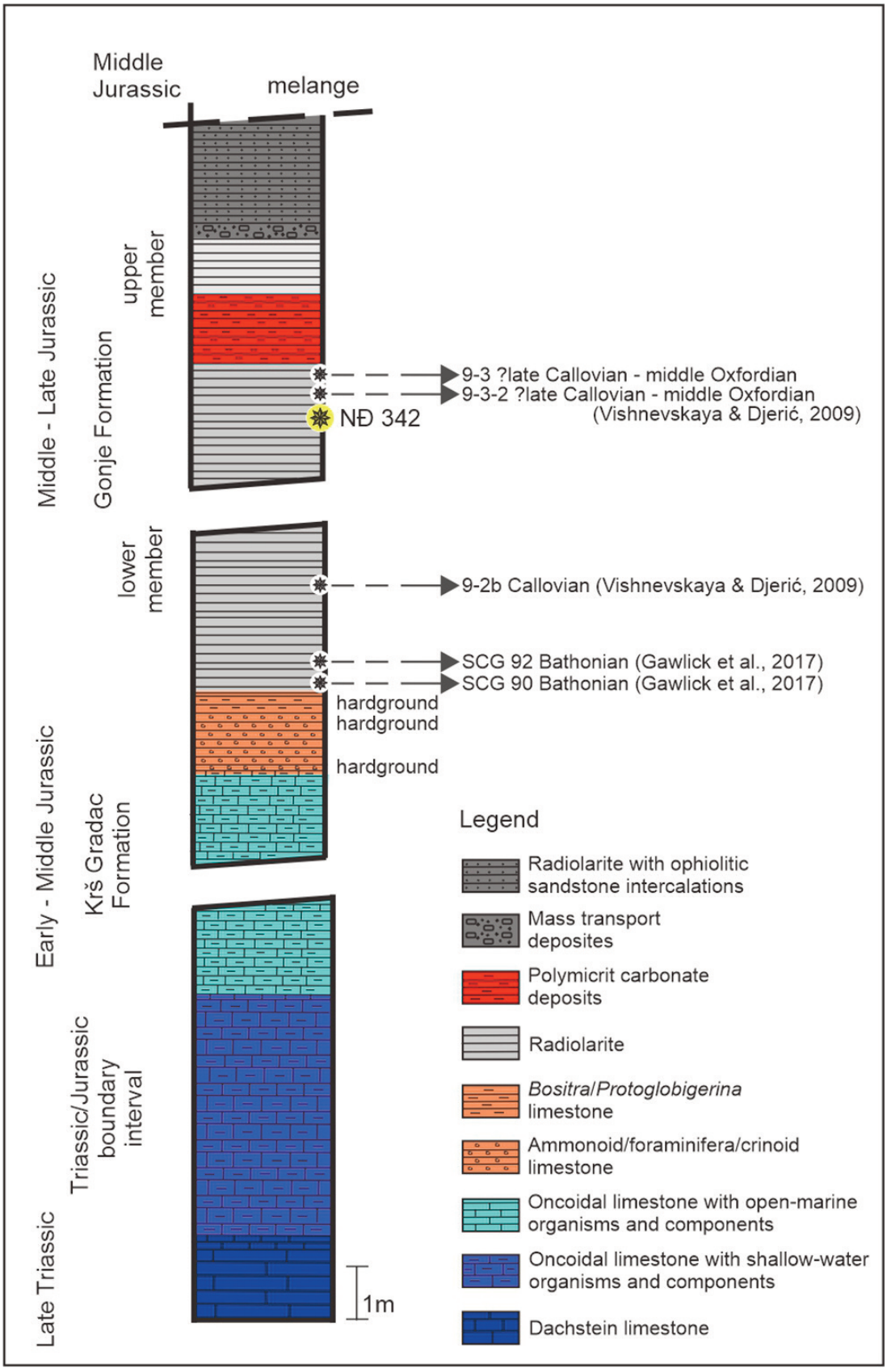

Fig. 3. *Uppermost Triassic to Upper Jurassic sedimentary succesion of the Krš Gradac locality (simplified after Gawlick et al., 2020). The stars indicate positions of the previosly published radiolarian dated samples and newly described sample NĐ 342.*

rals and ophiolitic detritus, radiolaritic matrix as well as spicula-rich layers. Later, based on new data, Gawlick et al. (2020) subdivided this radiolarite succession into only two members: 1) the Bathonian–Oxfordian lower part without mass transport deposits (roughly 20 meter-thick) and 2) the ?Upper Kimmeridgian–?Upper Tithonian higher parts of the radiolarites with intercalated polymictic calcareous turbidites and mass transport deposits with reworked radiolarite and ophiolite clasts.

Anyhow, the age of the topmost part of the radiolaritic sequence of the Gonje Formation, in the Krš Gradac section is still questionable (?Upper Tithonian), since it has not been precisely dated (Gawlick et al., 2017, 2020). This series is overthrusted by the Middle Jurassic ophiolitic mélange (Gawlick et al., 2009a, 2017, 2020).

Radiolarian dating

Radiolarites of the Gonje Formation are characterized by an abundance of radiolarian tests, but they are generally strongly recrystallized and poorly preserved.

A moderately preserved radiolarian fauna (Fig. 4) was analyzed from one sample (NĐ 342), collected from the dark-grey slightly bioturbated radiolarian wacke- to packstones slightly below the upper part of the Gonje Formation with intercalated turbidites and breccia layers (higher part of the lower member of the Gonje Formation; Figs. 2, 3). The sample was treated with diluted (5%) hydrofluoric acid. The assemblage was dated on the basis of the zonation of Baumgartner et al. (1995), with updated age ranges of several radiolarian species (Suzuki & Gawlick, 2020 and references therein). For the taxonomy of radiolarian genera we followed O'Dogherty et al. (2006, 2009, 2017).

The radiolarian assemblage distinctive of the Callovian/Oxfordian boundary was isolated from the sample NĐ 342. The age of the radiolarite sample is attributed to the Callovian/Oxfordian (most probably early Oxfordian) based on the co-occurrence of *Striatojaponocapsa conexa* (Matsuoka), *Zhamoidellum ovum* Dumitrica, *Campanomitra tuscanica* (Chiari, Cortese & Marcucci), *Campanomitra ulivii* (Chiari, Cortese & Marcucci), *Theocapsommella medvednicensis* (Goričan), *Protonuma* sp. cf. *P. Japonicus* Matsuoka & Yao and *Archaeodictyomitra* sp. cf. *A. minoensis* (Mizutani).

According to Baumgartner et al. (1995) *Striatojaponocapsa conexa* (Matsuoka) has its last occurrence in Callovian (UAZ 7), but this species has also been reported from the early Oxfordian age (e.g., Onoue & Sano, 2007; Suzuki & Gawlick, 2020). Chiari et al. (1997) consider for *Campanomitra ulivii* (Chiari, Cortese & Marcucci) a range from Callovian to ?Kimmeridgian (UAZ 7–11?). The species *Campanomitra tuscanica* (Chiari, Cortese & Marcucci) is supposed to be restricted to Oxfordian–early Kimmeridgian (UAZ ?8-10; Chiari et al., 1997). Chiari et al. (2007) suggested that the proposed range of this species should be extended down to the Middle Jurassic, with a first appearance in Callovian (UAZ 7). *Zhamoidellum ovum* Dumitrica is, according to Baumgartner et al. (1995) known from the interval middle–late Oxfordian to late Kimmeridgian–early Tithonian (UAZ 9-11). After Suzuki & Gawlick (2003), this species has a more longer range and these authors indicate the first appearance of *Zhamoidellum ovum* during the late early Callovian. Šmuc & Goričan (2005) state that this taxa has its first occurrence during Bathonian-Callovian (UAZ 6-7). Halamić et al. (1999) consider a latest Bajocian–early Bathonian age (UAZ 5) for the range of *Theocapsomella medvednicensis* (Goričan), but this species has also been reported from the Callovian age (Gawlick et al., 2007; Suzuki & Gawlick, 2009; O'Dogherty et al., 2017; Chiari et al., 2023). The radiolarian association also includes *Protonuma* sp. cf. *P. japonicas* Matsuoka & Yao (first appearance in Callovian; Baumgartner et al., 1995) which is one of the most common Oxfordian taxa, as well as *Archaeodictyomitra* sp. cf. *A. minoensis* (Mizutani) and therefore we cannot exclude a younger age of this sample (up to the middle Oxfordian). Additionally, the presence of *Eucyrtidiellum unumaense* s.l. (Yao) suggest that sample is not younger than middle Oxfordian (UAZ 8).

Final remarks

A Callovian/Oxfordian (?early Oxfordian) radiolarian assemblage was discovered in radiolarites of

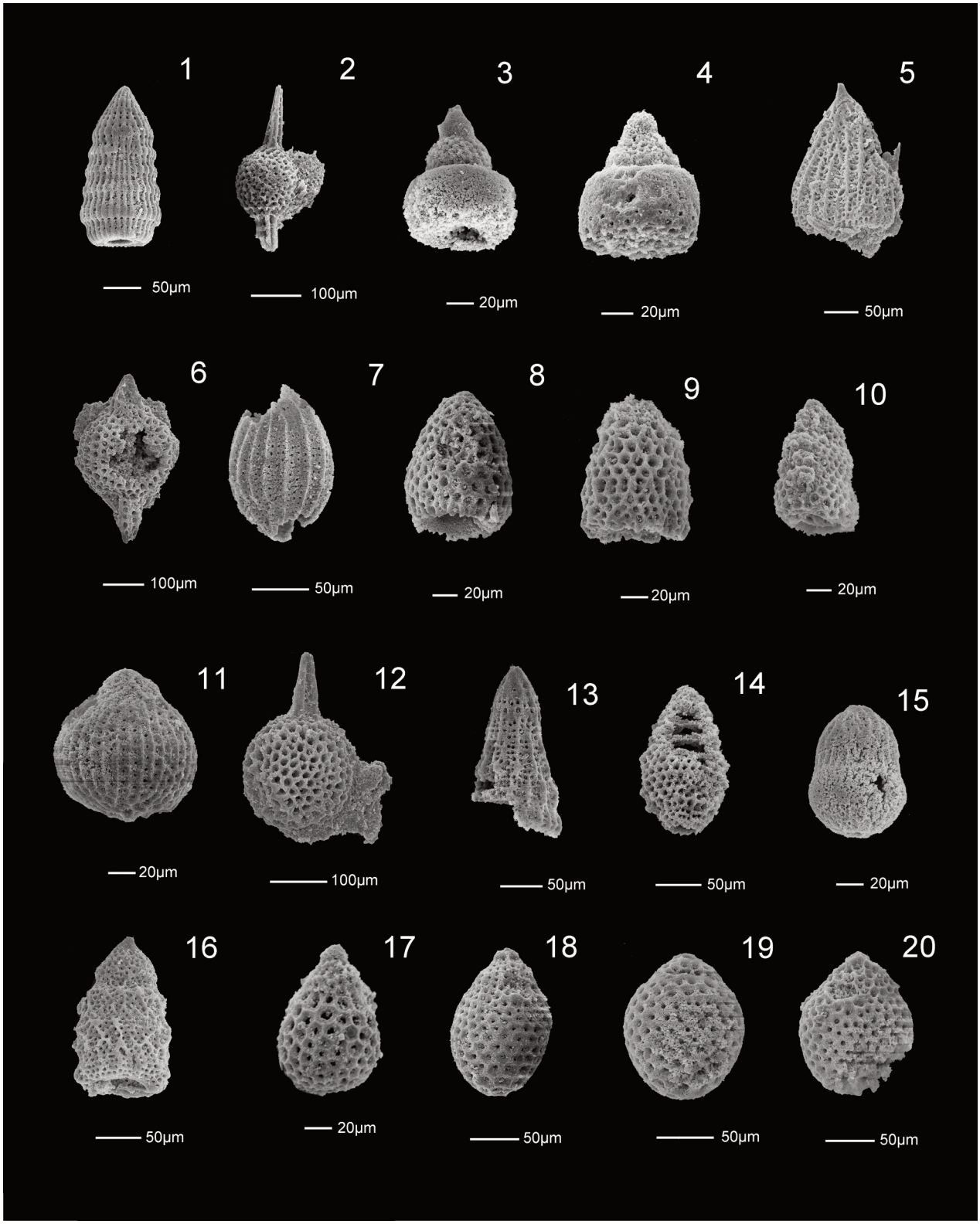

Fig. 4. *Callovian-Oxfordian radiolarians from the radiolarite of the Gonje Formation, Sample NĐ 342.* ***1.*** *Archaeodictyomitra* sp. cf. *A. minoensis* (Mizutani); ***2.*** *Archaeospongoprunum* sp. aff. *A. patricki* Jud; ***3.*** *Eucyrtidiellum unumaense* s.l. (Yao); ***4.*** *Eucyrtidiellum sp. cf. E. unumaense s.l.* (Yao)*;* ***5.*** *Hsuum* sp.*;* ***6.*** *Spinosicapsa* sp.*;* ***7.*** *Protonuma* sp. cf. *P. japonicus* Matsuoka & Yao; ***8.*** *Campanomitra tuscanica* (Chiari, Cortese & Marcucci); ***9.*** *Campanomitra ulivi*i (Chiari, Cortese & Marcucci)*;* ***10.*** *Xitomitra* sp. cf. *X. annibill* (Kocher); ***11.*** *Striatojaponocapsa conexa* (Matsuoka)*;* ***12.*** *Triactoma* sp.*;* ***13.*** *Transhsuum* sp.*;* ***14.*** *Eoxitus?* sp.*;* ***15.*** *Theocapsomella medvednicensis* (Goričan); ***16.*** *Xitus singularis* Hull; ***17.*** *Zhamoidellum* sp. cf. *Z. argandi* O'Dogherty, Goričan & Dumitrica*;* ***18–20.*** *Zhamoidellum ovum* Dumitrica.

the uppermost lower member part of the Gonje Formation in the Krš Gradac section (SW Serbia). The obtained data perfectly comply with other ages reported from radiolarites of the Gonje Formation. Initially Vishnevskaya et al. (2009) assumed that the radiolaritic deposition started in the ?late Bathonian to early Callovian and continued until the middle Oxfordian to early Tithonian, while Vishnevskaya & Djerić (2009) assigned a Middle Jurassic (probably Callovian) age for the various colored cherty limestones directly below the radiolarites and concluded that the age could not be younger than middle Oxfordian for the radiolarite 8–9 meters above the red cherty limestones. The radiolarites from the lower part of the radiolaritic succession, Gawlick et al. (2017) dated by a better preserved radiolarian assemblage and concluded that radiolarite deposition began during the late Bathonian. Gawlick et al. (2017, 2020) stated that bad preservation of the radiolarians prevented an exact age determination of the younger part of the radiolaritic succession and assumed that deposition of the higher part of this sequence started around the Kimmeridgian/Tithonian boundary and prevail in the Tithonian, based on presence of the shallow-water components containing organisms (calcareous algae and foraminifera) in the mass flows and calcareous polymictic turbidites.

The radiolarite sequence of the Gonje Formation was deposited in the distal parts of the trench-like Ljubiš Basin in front of the advancing Drina-Ivanjica nappe and is roughly contemporaneous with the widespread onset of radiolarite deposition in the Eastern and Southern Alps, Western Carpathians or Dinarides/Albanides/Hellenides (Gawlick et al., 2020). Presented results show clearly that the Ljubiš Basin is characterized by condensed sedimentation during the time span late Oxfordian to the Kimmeridgian/Tithonian boundary. After erosion and redeposition of the Upper Triassic to Middle Jurassic sedimentary succession of the western Drina-Ivanjica unit during the early-middle Oxfordian time span, the Ljubiš Basin get starved in the period of relative tectonic quiescence after ophiolite obduction west of the Drina-Ivanjica thrust front. Whereas in the proximal Ljubiš Basin (Gawlick et al., 2017) deposition is characterized by a thick radiolaritic sequence with intercalated mass transport deposits and turbidites in the distal part of the basin, i.e. in the Krš Gradac area, radiolarite deposition prevailed. Redeposition started again around the Kimmeridgian/Tithonian boundary respectively the early Tithonian, but redeposition is now related to mountain uplift and unroofing (Djerić et al., in press).

This depositional history in the Ljubiš Basin is comparable with the situation in the Tauglboden Basin in the Northern Calcareous Alps (Gawlick et al., 2007, 2009b, 2012), where radiolarite deposition started around the Bathonian/Callovian boundary also. The proximal Tauglboden Basin received eroded material from an advancing nappe front during early-middle Oxfordian times. In contrast, in the distal Tauglboden Basin radiolarite deposition prevailed until the Tithonian, when deposition of reworked material started.

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Резиме

Радиоларијска асоцијација из радиоларита локалитета Крш Градац (ЈЗ Србија): нови подаци од значаја за реконструкцију средње до горње јурске геодинамичке историје Унутрашњих Динарида

Локалитет Крш Градац један је од најинтересантнијих старије мезозојских локалитета Србије, с обзиром да се на овом профилу уочава директан контакт радиоларита и тријаско-јурских карбоната у подини. Gawlick et al. (2020) су детаљно описали седименте локалитета Крш Градац и закључили да представљају део тријаско-јурске парааутохтоне секвенце Источно Босанско-Дурмиторске мега јединице. Према овим ауторима, тријаско-јурски седименти представљени норичко-ретским дахштајнским кречњацима, доње до средње јурском Формацијом Крш Градац и бат-?титонским радиоларитима Формације Гоње, откривени су у оквиру текстонског прозора и преко њих су навучени средње јурски меланж и офиолити Динаридско офиолитског појаса. Средње до горње јурски (бат-?титон) радиоларити и радиоларитско-аргилошитске седиментне стене Формације Гоње депоновани су у дисталним деловима басена Љубиш (у западном делу Динаридског Офиолитског појаса). На основу одређене старости и карактеристика микрофација, Gawlick et al. (2017) издвајају три члана радиоларитске секвенце Формације Гоње: 1) бат-оксфордску радиоларитску секвенцу без турбидитског материјала; 2) секвенцу са интеркалацијама турбидитског материјала и турбидита (кимериџ-?доњи титон) и 3) највиши део секвенце кога карактерише радиоларитски матрикс, слојеви богати спикулама сунђера и присуство честих прослојака финозрних пешчара, у којима се уочавају зрна кварца, тешких метала и офиолитског детритуса,. На основу нових података, Gawlick et al. (2020) радиоларитску секвенцу деле на два члана: 1) бат-оксфордски део без турбидитског материјала (приближно 20 метара дебљине) и 2) ?горње кимериџски до ?горње титонски део са прослојцима карбоната и присуством турбидитског материјала. Старост највишег дела радиоларитске секвенце Гоње Формације још увек није прецизно одређена.

Из радиоларита највишег дела бат-оксфордског члана Формације Гоње изолована је радиоларијска асоцијација келовејско-оксфордске (?доњи оксфорд) старости. Прикупљени подаци сагласни су публикованим подацима о старости радиоларита Формације Гоње (Vishnevskaya et al., 2009; Vishnevskaya & Djerić, 2009; Gawlick et al., 2017).

Радиоларити Гоње Формације таложени су у дисталним деловима „trench-like“ басена Љубиш, формираног испред Дринско-Ивањичке јединице. Депоновање ових радиоларита синхроно је таложењу радиоларита у источним и јужним Алпима, западним Карпатима и другим областима Динарида, Албанида и Хеленида (Gawlick et al., 2020). На основу приказаних резултата, може се закључити да басен Љубиш карактерише кондензована седиментација од горњег оксфорда до границе кимериџ-титон. Након ерозије проузроковане обдукцијом офиолита и редепоновања горње тријаских до средње јурских седимената западног дела Дрина-Ивањице, у периоду релативне мирне тектонске активности (доњи-средњи оксфорд), басен Љубиш пролази кроз период смањеног приноса материјала. Око границе кимериџ-титон, највероватније током доњег титона, поново започиње већи принос материјала, али ово таложење је сада повезано са издизањем планинских венаца у залеђу и тектонском ерозијом орогена (Djerić et al., in press). Еволуција басена Љубиш може се упоредити са еволуцијом басена Tauglboden у северним кречњачким Алпима (Gawlick et al., 2007, 2009b, 2012).

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