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.

Stratigrafija od Krš Gradac sekcije (JZ Srbija)

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Kondenzovana sekvensa doljej dogera sa protoglobigerinidama do sada nije bila evidentirana.


U sukcesiji radiolarita Krš Gredaca autori prepoznaju dvije dubokovodne formacije: stariju, od gorje tijeta do doljej tijeta, između hardgrounda preko kondenzovane dojodogerske sekvensi i gradiranog sloja, i mlajšu, koja počinje gradiranim slojem, a na osnovu stratigrafske pozicije odgovara vremenskom intervalu ?stariji–dolj tijeta – najmlađa doja kreda.


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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 Triassic in age, in the other numerous papers (Albrecht 1925; Kossmat 1924; Lebedur 1941; Ćirić 1954, 1984, 1996; Radić 1962; Jovanović Ž. 1963; Rampoux 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. Dóztály). According to the results of these studies, 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. Radić, 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 Prijeplje 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 em-bedded 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.](image-url)
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 *Koninkckella* is found (Pl. 6, Figs. 11, 12).

The unit ends with a 0.6 m thick, in upper part red-dish wackestone, with middle Toarcian ammonites: *Hildoceras bifrons*, *Lithoceras septatum*, *Calliphyloceras capitanioi*, *Harpoceratoides strangewaysi* (Cirić 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.

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

The shallow-water carbonate grains are mostly wackestones. Some of them contain unspecified biogenic 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 Protopenopolaris striata, Pararugonina caelinensis, Labyrinthina mirabilis, Mohlerina basiilens. 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-
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.

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 *Petrotrabs 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. minoenis, 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 (Čirić 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 Liasic–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 uniform 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-radiolarite formations: an upper, older Bathonian–lower Tithonian (below the graded bed) and a younger, ?middle–?upper Tithonian – lowermost Cretaceous, which commenced with the graded bed.

Supplementary note (R. Radoićić)

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 Крш Градац (ЈЗ Србија)

Локалитет Крш Градац је добро познат у геолошкој литератури јужоанатолског дела Србије. Као један од најбоље откриених и интересантних профил старејег мезозоика Динариде Србије, био је тема истраживања геолога и раније, нарочито са аспекта одређивања старости традиционално познате дијабаз-рожначке формације са простора Балканске полуострви. Налази се на западној страни пута Сjenica–Нова Варош и на јужоанатолским падинама брда Градац. Геолошки стуб је састојан од карбонатих и силицилактичних делова који су у текстонском контакту са меланжом.

Најстарије седименти су масивни горњотријаски кречњаци дахастијског типа и доњолијаски плитководни карбонати, после којих следе седименти средњолијаско–доњодоњерогерског Ammonitico Rosso и Bositra–протоглобигериндске фације који се завршавају hardground-ом. Сукцесија се продужава средњојурско–доњокредним радиоларитама у чији је средњоме део унете hardgriди, а у виши mass flow слој.

У раду су у оквиру стратиграфског стуба локалитета Крш Градац прихваћени само средњолијаско–најмодерни делови доњокредних седимената и они су развођени у пет јединица.

Јединица А је дебела 12,3 m и чине је средњо и горњолијаски кречњаци фације типа Ammonitico Rosso. Јединицу В гради 1,2 m дебела севенци црвених кречњака доњодоњерогерске старости са три hardground-a. Црвени, зелени, тамносиво до сиво црне радиоларити и рожаци са унетим црвеним радиоларитским шкрилицама сачињавају јединицу C дебелу 9,5–10 m; њена старост је још бјо грађаног оxic–фрид. Јединица D је представљена са 1,2 m дебелим градираним карбонатним слојем који је уложен у црвено радиоларите и са старошћу која није старија од доњег титона, а вероватно је ?доње–горњи титон. Укупна дебелина силицилактиста јединице Е је 3,8 m, а у њеним средњим деловима налази се 0,07–0,2 m дебео mass flow слој. Сагласно стратиграфском полођају јединица Е није старија од ?средњег–горњег титона до у најнижем крету, a mass flow слој, узимајући у обзир последицу активности унутар басена, може бити прихваћен као беријаски. Изнад највише дела радиоларитске севенце јединице Е следи текстонит (меланж) са cm–dm блоковима метааналезита.

Доњи део црвено кондензоване кречњачке севенце (јединица В), између средњег (?делимично горњег) тоарског и бајеског протоглобигеринида.

У доњем делу јединице С документоване су радиоларске асоцијације горњег бата до доњег келова (запажено појављивање Pterotrabs marculus и C. carpatica) као и средњег келова до оксфорда (UAZ 8–9 са Archaeodictyomitra minoensis, E. unumaense с.1. и Z. ovum) (Vishnevskaya et al. 2009).

Компоненте градираног слоја (јединица D), на основу података из овог рада, су ектрабасенског и интрабасенског порекла. Ектрабасенска зена (горњи тријас—донај титон) указује на депоновање у амбијентима карбонатне платформе/рампе (данас непознате на месту у оквиру оближњих пространа) утворених на подластој карбонатној платформи/рампи. Зрна интрабасенског порекла су силициласте аргилити, са или без радиоларија, радиоларити (неки од њих су ?тријаски), радиоларска микрити, рожаји и метаанадзити.


Седименти локалитета Крш Градца представљају типичну прелазну сукицу од карбонатне платформе у басен: седименте најниших делова тријаске платформе днаштајског типа следе доњиласки платководни карбонати. Касније, од средњег лијаса до бајеса, депоновали су се Ammonite Rosso фации потпуњене платформе и басенски Bositra-протоглобигериински кречњаци, који се завршавају са тамно црвеним седиментом и hardground-ом. Интензивно басенско потањање је окакретирано седиментацијом дубоких басенских радиоларита кроз касни бат до у најнижу керду. Лагана басенска седиментација била је прекинута у време ?средњо—горњег титон (карбонатни градирани слој), као последња тектонског дождеваја, тј. разламања карбонатне платформе, а такође и околних областити басена. Овај значајан тектонски дождевац не може бити старији од ?најкаснијег кимеријаног титона, тако да сагласно томе, јединица Е не може бити старија од ?средње—горњег титона.


Radojović et al. (2004) увршћују силициластите у неформалну формацију Златара горњојурско—титонске старости. Gawlick et al. (2009) сматрају их средњо до горњојурским—?днојекретним делом горњотитонске старости—?днојекретне тектонске слите испод радиоларитско—офилолитског меланжа. Поред тога, цела комплексна сукицисда Крш 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, поменути силициластите такође не укључују у тектонит (меланж), и у оквиру њих разликују две дубоководне аргилитско—радиоларитске формације: старију, горњобатско—днојєктитонску (испод градираног слоја) и млађу, ?средњо—горњотитонску — најнижу доњекретну, која почиње са градираним слојем.

PLATE 1

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

1–2. Sparse bionomicite 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.
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.
Figs. 1–4. **Unit D, graded bed.**

1–2. *Clupeina 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.

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.
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.
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.

Figs. 11–12. Unit A, different sections of the brachiopod Koninckella sp. (determination by V. RADULOVIC), thin section RR 5146.