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The Middle Miocene (Badenian) holoplanktonic mollusks (Euthecosomata - Pteropoda) from Serbia, Central Paratethys

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Abstract. The present paper deals with holoplanktonic gastropods (Pteropoda) from the Middle Miocene (Badenian) deposits of Serbia. The material for the present study comes from three localities at the southern margin of the Pannonian Basin (Central Paratethys): Konjarnik (greater center of Belgrade), Sumijevac stream near Koceljeva (western Serbia), and Radljevo (Kolubara Basin, central Serbia). A total of four taxa were recorded and their stratigraphic value is discussed. Two taxa were identified to species level: *Vaginella austriaca* Kittl, 1886, belonging to the family Cavoliniidae Gray, 1850 (1815), and *Limacina valvatina* (Reuss, 1867)?, from the family Limacinidae Gray, 1847. Four specimens could only be identified to genus level (*Vaginella* sp. indet. and *Clio*? sp. indet.). The specimen of *Clio*? sp. indet. is possibly the first find of the genus *Clio* in Serbia. Here presented records of the genera *Vaginella* and *Clio*? from the late Badenian (NN6 nannozone) modify the insight into their paleogeographical distribution in the Middle Miocene of the Central Paratethys.

Key words:
Langhian-Serravallian, sea butterflies, Serbia.

Апстракт. Овај рад се бави холопланктонским гастроподима (Pteropoda) из средњомиоценских (баденских) седимената Србије. Материјал за ову студију је прикупљен са три локалитета која се налазе на јужном ободу Панонског басена (Централни Паратетис): Коњарник (шири центар Београда), поток Сумијевац код Коцељеве (западна Србија) и Радљево (Колубарски басен, централна Србија). Забележена су укупно четири таксона и разматран је њихов стратиграфски значај. На нивоу врсте су одређена два таксона: *Vaginella austriaca* Kittl, 1886, која припада породици Cavoliniidae Gray, 1850 (1815) и *Limacina valvatina* (Reuss, 1867)? из породице Limacinidae Gray, 1847. Четири примерка било је могуће

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одредити само на нивоу рода (*Vaginella* sp. indet. и *Clio*? sp. indet.). Примерак *Clio*? sp. indet. је важан будући да могуће представља први налаз рода *Clio* у Србији. Овде представљени налази примерака родова *Vaginella* и *Clio*? из горњобаденских наслага (NN6 зона) коригују њихову до сада познату палеогеографску распрострањеност у Централном Паратетису током средњег миоцена.

Кључне речи: *лангиј-серавал, морски лептири, Србија.*

Introduction

Around the Eocene–Oligocene boundary, the western Tethys was divided into the proto-Mediterranean Sea in the south and the Paratethys Sea in the north. Based on paleogeographic and geotectonic characteristics, the Paratethys is divided into Western, Central and Eastern Paratethys (e.g. Rögl, 1998, 1999; Kováč et al., 2007, 2017, 2018; Piller et al., 2007; Palcu et al., 2023 and references therein). The term Paratethys was coined by Vladimir Laskarev in 1924, and since then the diverse biota has been studied with the aim of explaining the evolution of the Paratethys and relationships with neighboring regions.

During the Middle Miocene (Badenian), marine landscapes prevailed in the Pannonian Basin System in the Central Paratethys, including parts of present-day Serbia (e.g. Anđelković et al., 1989). The Middle Miocene represents a very favorable and climatically dynamic period for the development and distribution of diverse biota. The Badenian marine mollusk fauna was extremely rich and included holoplanktonic gastropods (pteropods). This interesting group of mollusks spends its entire life in the water column between the bottom and the surface and has characteristically modified foot into two wing-like "fins" for swimming. Pteropods comprise the suborders Thecosomata and Gymnosomata (e.g. Burridge et al., 2017 and references therein; Janssen & Peijnenburg, 2017 and references therein). Thecosomata mainly comprise taxa with aragonitic shells in the adult stage, and Gymnosomata represent pteropod taxa without shells. Pteropods fragile aragonitic shells limit their fossil preservation.

The Badenian deposits of the Central Paratethys contain pteropod representatives of genera *Limacina* Bosc, 1817, *Clio* Linnaeus, 1767, *Diacrolinia* Janssen, 1995, *Cuvierina* Boas, 1886, *Creseis* Rang, 1828, *Vaginella* Daudin, 1800, and *Styliola* Gray, 1847 (e.g. Bohn-Havas & Zorn, 1993; Bohn-Havas et al., 2004), with the recorded increase in richness during the Badenian NN5 nannozone. They were recorded in the Badenian deposits of Austria (e.g., Janssen, 1984; Zorn, 1991; Bohn-Havas & Zorn, 1993, 1994), the Czech Republic (e.g., Janssen & Zorn, 1993; Zorn, 1999), Poland (e.g., Bohn-Havas & Zorn, 1993, 1994; Janssen & Zorn, 1993; Zorn, 1999), Hungary (e.g., Bohn-Havas & Zorn, 1993, 1994; Zorn, 1999; Bohn-Havas et al, 2004; Selmeczi et al., 2012), Slovakia (e.g., Zorn, 1999); Slovenia (e.g. Mikuž et al., 2012), Croatia (e.g., Bošnjak et al., 2017; Derežić, 2018; Sremac et al., 2022), Bosnia and Herzegovina (e.g., Eremija, 1970; Vrabac et al., 2013, 2017, 2020; Gašparič et al., 2019; Mandic et al., 2019a), Romania (e.g., Janssen, 1984; Bohn-Havas & Zorn, 1993, 1994; Zorn, 1999; Suciu et al., 2005), Bulgaria (e.g., Zorn, 1999; Nikolov, 2010), and Ukraine (e.g., Janssen & Zorn, 1993; Bohn-Havas & Zorn, 1994; Zorn, 1999). The most widespread species were *Vaginella austriaca* Kittl, 1886 and *Limacina valvatina* (Reuss, 1867). Stratigraphic range of *V. austriaca* is the upper Karpatian to the end of the Badenian, and of *L. valvatina* throughout the Badenian (e.g., Janssen, 1984; Janssen & Zorn, 1993; Zorn, 1991, 1999; Bohn-Havas & Zorn, 1993, 2002; Bohn-Havas et al., 2004). Species *L. valvatina* is especially abundant in the "*Spirialis* Beds" (old name for the genus *Limacina*) representing an important species for the correlation of the upper Badenian deposits (e.g., Karnkowski, 1994; Peryt, 2006; Kováč et al., 2017). The genus *Clio* is recorded in the Badenian deposits of Austria (e.g., Zorn, 1991), Poland (e.g., Bohn-Havas & Zorn, 1993, 1994; Janssen & Zorn, 1993; Zorn, 1999), Hungary (e.g., Bohn-Havas & Zorn, 1993, 1994; Zorn, 1999; Selmeczi et al., 2012), Czech

Republic (e.g., Janssen & Zorn, 1993; Zorn, 1999), Slovenia (e.g., Mikuž et al., 2012); Croatia (e.g., Bošnjak et al., 2017), Romania (e.g., Bohn-Havas & Zorn, 1993, 1994; Zorn, 1999), and Bulgaria (e.g., Zorn 1999; Nikolov, 2010). Mass occurrences of pteropods during the Miocene are recorded in the Lower to Middle Miocene deposits in the Mediterranean ('Marne a pteropodi' in northern Italy), in Aquitaine and Caribbean Basin as well as in the Pacific (Japan, Australia, New Zealand, United States) (after Janssen & Peijnenburg, 2017; Janssen & Wilson, 2019).

The Badenian pteropods record from Serbia is poor. Their first finding was reported by Stevanović (1970) at the Konjarnik locality, in the wider area of Belgrade (Fig. 1A,B), from what is known as "pteropod schlier" (Stevanović, 1970, 1977; Anđelković & Anđelković, 1997). East of Belgrade, the species *Vaginella austriaca* was mentioned by Bohn (2007) from the Kozara hill section near Veliko Selo and from the Slanci borehole. Jovanović (2018) also reports a specimen of a pteropod with a narrow angle (*Vaginella* cf. *lapugyensis* Kittl, 1886) not far from there. The generally poor preservation of this pteropod prevents a more precise taxonomic affiliation, and recently this species has been considered a synonym of *Vaginella bicostata* (Gabb, 1881) (e.g., Janssen & Wilson, 2019). Finally, the only illustrated (but not described) pteropod from Serbia is *Vaginella austriaca* from the Sumijevac stream near Koceljeva (Jovanović et al., 2019; Fig. 1D). Two genera were found from these localities: *Vaginella* Daudin, 1800 and *Limacina* Bosc, 1817.

In this paper we present the current state of knowledge on the Badenian pteropods from Serbia, including a new fossil locality in Radljevo (Fig. 1A,C), and discuss their correlation to the neighboring areas in the Central Paratethys.

Geological setting

The studied Middle Miocene (Badenian) pteropods originate from three sites: Konjarnik, Koceljeva, and Radljevo (Fig. 1), situated at the southern margin of the Pannonian Basin and the Central Paratethys, respectively. At the investigated localities, the Badenian sediments directly overlie the Mesozoic marine or Miocene terrestrial and limnic deposits and are covered by the Sarmatian, Pannonian and Quaternary sediments (Anđelković et al., 1989; Rundić, 2000). In Konjarnik and Radljevo the Badenian deposits are not subaerially exposed, and the present study is based on borehole data.

During the Badenian, Sarmatian and Pannonian, the Konjarnik region (Fig. 1A,B) was a deep depression filled with marly-clayey deposits. During the Sarmatian and Pannonian argillaceous deposits were interbedded with up to 2 m thick fine sand packages (Stevanović, 1970). The 251 m long Konjarnik borehole (approximate coordinates: 43°08′00″N; 21°41′45″E) ended in the Badenian without reaching the pre-Cenozoic basement. The Badenian deposits comprise gray, somewhat sandy and bituminous clays with interlayers of pteropod-foraminiferal shaly clays. The microfauna is abundant in gray clay, while the macrofauna is very scarce. The Badenian–Sarmatian transition was detected at a depth of 150 m (Stevanović, 1970). Benthic bivalves *Nucula nucleus* (Linnaeus, 1758) and *Lembulus pella* (Linnaeus, 1758) as well as the gastropods *Rissoina lueli* Deshayes, 1860 and *Turritella* sp. indet. are mentioned in Stevanović (1970).

The second site (Radljevo well Nqr-137.5; 44°29′48″N; 20°10′14″E, Fig. 1A,C) is located in the central part of the Kolubara basin. The oldest Neogene formations are distributed along the southern margin of the basin and consist of the Middle Miocene conglomerates, sandstones, clays, marls, limestones, and dolomites. The Badenian deposits are represented by clay, sandstones, carbonaceous limestone and *Lithothamnion* limestones (Mitrović et al., 2002). Borehole Nqr-137.5 has a total length of 800 m, with the Badenian drilled at approximately 590 m and the Sarmatian at 480 m. The overlying Upper Miocene (Pannonian) interval is marked by thick lignite deposits. In a clearly defined tectonic sub-basin not far from Radljevo, the Pannonian lignite seam is portioned to differently subsided blocks which can be found at a maximum depth of 450 m. In contrast, the maximum subsidence in the central part of the Kolubara Basin is about 280 m (Rundić, 2000). The sampled interval from the Radljevo well (800 m thick) consists of gray marls bearing accumulations of pteropods and bivalve shells. Core samples

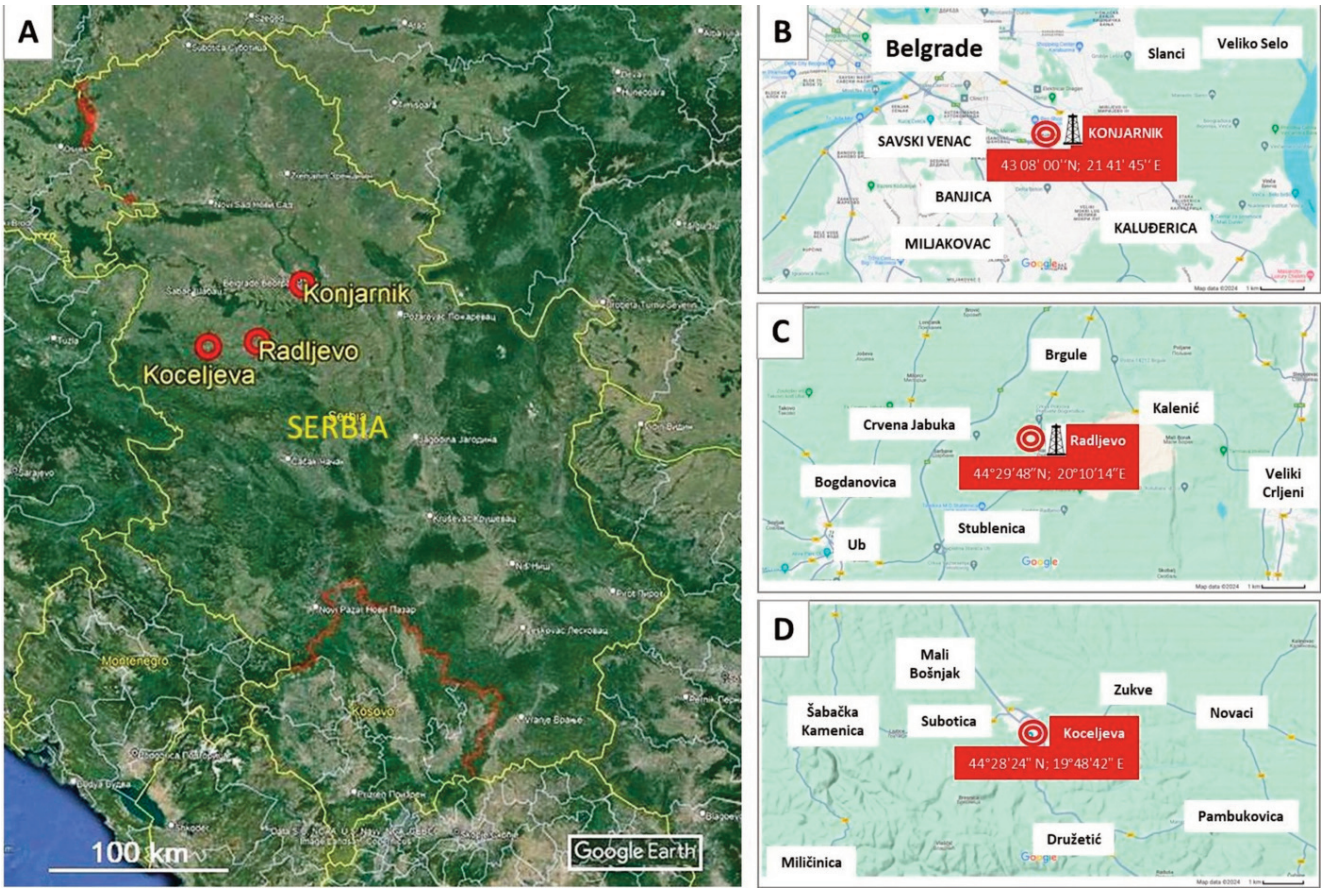

Fig. 1. *Geographical position of investigated localities with pteropod findings.* ***A)*** *Marked positions of the localities: Konjarnik, Radljevo and Koceljeva in Serbia (Google Earth);* ***B)*** *Location of Konjarnik borehole;* ***C)*** *Radljevo borehole;* ***D)*** *Koceljeva (Sumijevac stream). GPS coordinates are provided in figures:* ***B****,* ***C****, and* ***D****.*

with pteropoda were analyzed at 651.2 m and 660.8 m depth.

The third site, Koceljeva (Sumijevac stream, 44°28'24" N; 19°48'42" E; Fig. 1A,D) belongs to the Koceljeva Graben, which occupies the southwestern edge of the Kolubara–Tamnava Basin and is narrowed between the horsts of Vlašić–Blizonj in the south and Jazovnik in the north (Marović et al., 2007). Here, a 4 meter-high outcrop of conglomerate and sandstone yields a rich fossil assemblage mainly represented by a diverse shallow marine fauna (Jovanović et al., 2019). The succession starts with conglomerates (about 0.5 m thick) containing calcareous nannoplankton, foraminifera and abundant well-preserved shells of juvenile mollusks, fragments of some adult mollusks, disarticulated shells of adult bivalves, echinoid spines, ostracods, and otoliths. Among other mollusks, the gastropods *Semicassis* sp. indet. and *Kalloconus* sp. indet., and the bivalve *Procardium* sp. indet. have been recorded. The conglomerate is overlain by a layer of grey, poorly cemented sandstone with similar association of calcareous nannofossils and foraminifera as well as a more diverse and better-preserved mollusk fauna. The top of the succession is composed of grey, whitish to yellowish, very fine-grained, poorly cemented sandstone with nannofossils, foraminifers and mollusks. Microfossil assemblage contains the calcareous nannofosil *Sphaenolithus heteromorphus* Deflandre, 1953 and the benthic foraminifera *Lenticulina clypeiformis* (d'Orbigny, 1846), *Ammonia viennensis* (d'Orbigny, 1846) and *Nonion commune* (d'Orbigny, 1846) (after Jovanović et al., 2019).

Materials and Methods

About 50 poorly preserved pteropod shells were recorded from the boreholes in Konjarnik (20 shells) and Radljevo (30 shells) and two specimens from Koceljeva. The analyzed specimens are housed in the Natural History Museum in Belgrade (Serbia) in the Cenozoic invertebrate collection and in the Paleontological collection of Petar Stevanović (coll. 1969). Pteropods were analyzed under the stereomicroscope BIO-OPTICA Type: 1000, and photographs were taken by OPTIKA C-H4K micro-camera and PANASONIC DMC-FZ50 camera.

Micropaleontological analyses of the calcareous nannofossils and foraminifera were performed on the core samples, partly at the laboratory of the GeoSphere Austria (calcareous nannofossils) and partly at the University of Tuzla, Faculty of Mining, Geology and Civil Engineering (foraminifera).

Results

Pteropoda systematic part

Order: Pteropoda
Suborder: Euthecosomata
Family: Cavoliniidae Gray, 1850 (1815)
Genus: *Vaginella* Daudin, 1800

***Vaginella austriaca* Kittl, 1886**
Figs. 2 A, B

*1886 *Vaginella austriaca* Kittl n.f. – Kittl, p. 54, pl. 2, figs. 8–12.
1984 *Vaginella austriaca* Kittl, 1886 – Janssen, p. 73, pl. 4, figs. 1–8.
1991 *Vaginella austriaca* Kittl, 1886 – Zorn, p. 120, pl. 6, figs. 1–6, pl. 7, figs. 1–9, pl. 12, figs. 4, 5, pl. 14, figs. 1–8, pl. 16, figs. 1–4.
1993 *Vaginella austriaca* Kittl, 1886 – Janssen & Zorn, p. 203, pl. 6, figs. 8–15, pl. 10, figs. 1–5, pl. 11, figs. 1–6.
1999 *Vaginella austriaca* Kittl, 1886 – Zorn, p. 732, pl. 4, figs. 1–3, pl. 5, figs. 1, 2.
2017 *Vaginella austriaca* Kittl, 1886 – Bošnjak et al., p. 339, text-fig. 10.

Material: Koceljeva - one well-preserved shell (inv. no. 7337), and one shell fragment (inv. no. 7338).

Dimensions: inv. no. 7337 (Fig. 2A) - height: 6.5 mm, length: 2.4 mm, apical angle: 27°; inv. no. 7338 (Fig. 2B), fragment - height: 4.5 mm, length: 2.5 mm.

Description: Elongated, lance-like shell, dorsoventrally flattened, with an acute angle. Shell widens towards the aperture, where it is the widest. Protoconch not preserved.

Remarks: The shell morphology corresponds to the descriptions referred to in the synonymy. Several species of *Vaginella* have similarly shaped shells, and one of the distinguishing criteria between them is the apical angle. According to the apical angle ranges given in Cahuzac & Janssen (2010) specimens from Koceljeva are in the range of the species *Vaginella austriaca*.

Stratigraphic distribution: Paratethys – Austria (Karpatian and Badenian deposits, e.g., Janssen 1984; Bohn-Havas & Zorn 1993, 1994; Janssen & Zorn, 1993; Zorn, 1991, 1999), Poland (Lower and Middle Badenian, e.g., Zorn, 1991, 1999; Bohn-Havas & Zorn, 1993, 1994; Janssen & Zorn, 1993), Hungary (Lower Badenian, e.g. Zorn, 1991; Bohn-Havas & Zorn 1993, 1994; Bohn-Havas et al. 2004; NN5 nannozone after Bohn-Havas & Zorn 1993, Bohn-Havas et al., 2004, and Selmeczi et al., 2012), Czech Republic (Karpatian and Lower Badenian, e.g. Zorn, 1991, 1999), Slovenia (Badenian, e.g. Mikuž et al., 2012 and references therein), Serbia (Badenian, e.g. Stevanović, 1970, Jovanović et al., 2019), Bosnia and Herzegovina (Badenian, Vrabac et al., 2013; Gašparič et al., 2019; Mandic et al., 2019a); Romania (Lower Badenian, e.g., Zorn, 1991, 1999; Janssen & Zorn, 1993; Bohn-Havas & Zorn, 1994), and Bulgaria (Badenian, e.g. Zorn, 1999; Nikolov, 2010). Outside Paratethys: Middle Miocene deposits of the Mediterranean (e.g. Zorn 1991, 1999 and references therein; Bohn-Havas & Zorn, 2002; Janssen & Little, 2010; Janssen, 2012), Miocene deposits of the North Sea Basin (e.g. Zorn, 1991, 1999 and references therein; Bohn-Havas & Zorn, 2002; Cahuzac & Janssen, 2010; Janssen & Little, 2010; Janssen, 2012), and the Aquitaine Basin (Cahuzac & Janssen, 2010; Janssen & Little, 2010; Janssen, 2012).

***Vaginella* sp. indet.**
Figs. 2 C, D

Material: Konjarnik locality: three imprints, inv. nos. AS 3 – 50, AS 3 – 51, AS 3 – 52.

Dimensions: inv. no. AS 3 – 51 (Fig. 2.C) – height: 3.9 mm, length: 0.8 mm, apical angle: 15°; inv. no. AS 3 – 51 (Fig. 2D) – height: 1.7 mm, length: 0.4 mm, apical angle: 16°.

Description: lance-like shell imprint, widening towards aperture area, narrower than in fig. 2A, with lower apical angle. No protoconch visible.

Remarks: Three imprints from Konjarnik are not very well preserved, and all the diagnostic elements are not visible. One of the determination criteria, apical angle, is on these specimens lower than the one usually typical for the species *Vaginella austriaca* (e.g., Cahusac & Janssen, 2010), possibly pointing to other *Vaginella* species. Due to the poor preservation and therefore uncertainty of the specific species determination, specimens are determinated as *Vaginella s*p. indet.

Family: Cliidae Jeffreys, 1869
Genus: *Clio* Linnaeus, 1767

***Clio*? sp. indet.**
Fig. 2E

Material: Konjarnik locality: one imprint (inv. no. AS 3 – 53).

Dimensions: height: 5.9 mm, length: 4 mm, apical angle: 39°.

Description: One specimen showing the elongated, triangular shell, which widens towards the aperture. Indication of the dorsoventral flattening of the shell. Visible traces of shell surface ornamentation by curved and narrow transversal ribs. Between the ribs is a wide and flat surface. Protoconch not preserved.

Remarks: The preserved imprint resembles to the genus *Clio* based on the described shell morphology. This specimen represents the first record of the possible presence of the genus *Clio* in Serbia, and no comparative material is available from this area. Since the preservation state is poor and partial, determination was possible on the genus level.

Family: Limacinidae Gray, 1847
Genus: *Limacina* Bosc, 1817

***Limacina valvatina* (Reuss, 1867)?**
Figs. 2 F-J

?*1867 *Sp*[*irialis*]. *valvatina* Rss. – Reuss, p. 146, pl. 6, fig. 11.
?1886 *Spirialis valvatina* Reuss – Kittl, p. 69, pl. 2, fig. 38.
?1984 *Spirialis valvatina* Reuss, 1867 – Janssen, p. 72.
?1991 *Limacina valvatina* (Reuss, 1867) – Zorn, p. 97, pl. 1, figs. 1–6, pl. 10, figs. 1, 2, pl. 11, figs. 4, 5.
?1993 *Limacina valvatina* (Reuss, 1867) – Janssen & Zorn, p. 179, pl. 1, figs. 4–11, pl. 2, figs. 1–11, pl. 3, figs. 1–12.
?1999 *Limacina valvatina* (Reuss, 1867) – Zorn, p. 728, pl. 1, figs. 4, 6–10.
?2010 *Limacina valvatina* (Reuss, 1867) – Cahuzac & Janssen, p. 47, pl. 12, figs. 6–12.
?2017 *Limacina valvatina* (Reuss, 1867) – Bošnjak et al., p. 332, text-figs. 3, 5.

Material: Konjarnik locality: inv. no. AS 3 – 54; Radljevo locality: inv. nos. AS 3 – 55, AS 3 – 56.

Dimensions: Inv. no. AS 3 – 54 (Fig. 2F) - width: 0.8 mm; inv. no. AS 3 – 55 (Fig. 2G) – width: 2.1 mm; inv. no. AS 3 – 56 (Fig. 2H) – width: 1 mm.

Description: Preserved spiral shell imprints and fragments in the core, not available for measurement. Whorls are not visible. Basic characteristics of the species, i.e. shell shape, shell height and width ratio, elevated spire, shape of the whorls, umbilicus and aperture are not visible or are quite damaged. Only on rare specimens can one recognize three to four whorls that suddenly widen.

Remarks: All general species characteristics are not visible. Nevertheless, based on the visible part of the shell morphology, comparison with the descriptions referred to in the synonymy these findings are presumed as *Limacina valvatina* species. Records of mass occurrence of *Limacina* in Paratethys correspond to the NN6 nannozone, and the wide distribution of the *"Spirialis* beds" (old name for the genus *Limacina*). Species *Limacina valvatina* is one of the most distributed species in the Badenian deposits of the Central Paratethys (e.g., Janssen & Zorn, 1993; Zorn, 1991, 1999; Bohn-Havas & Zorn, 1993, 2002; Bohn-Havas et al., 2004).

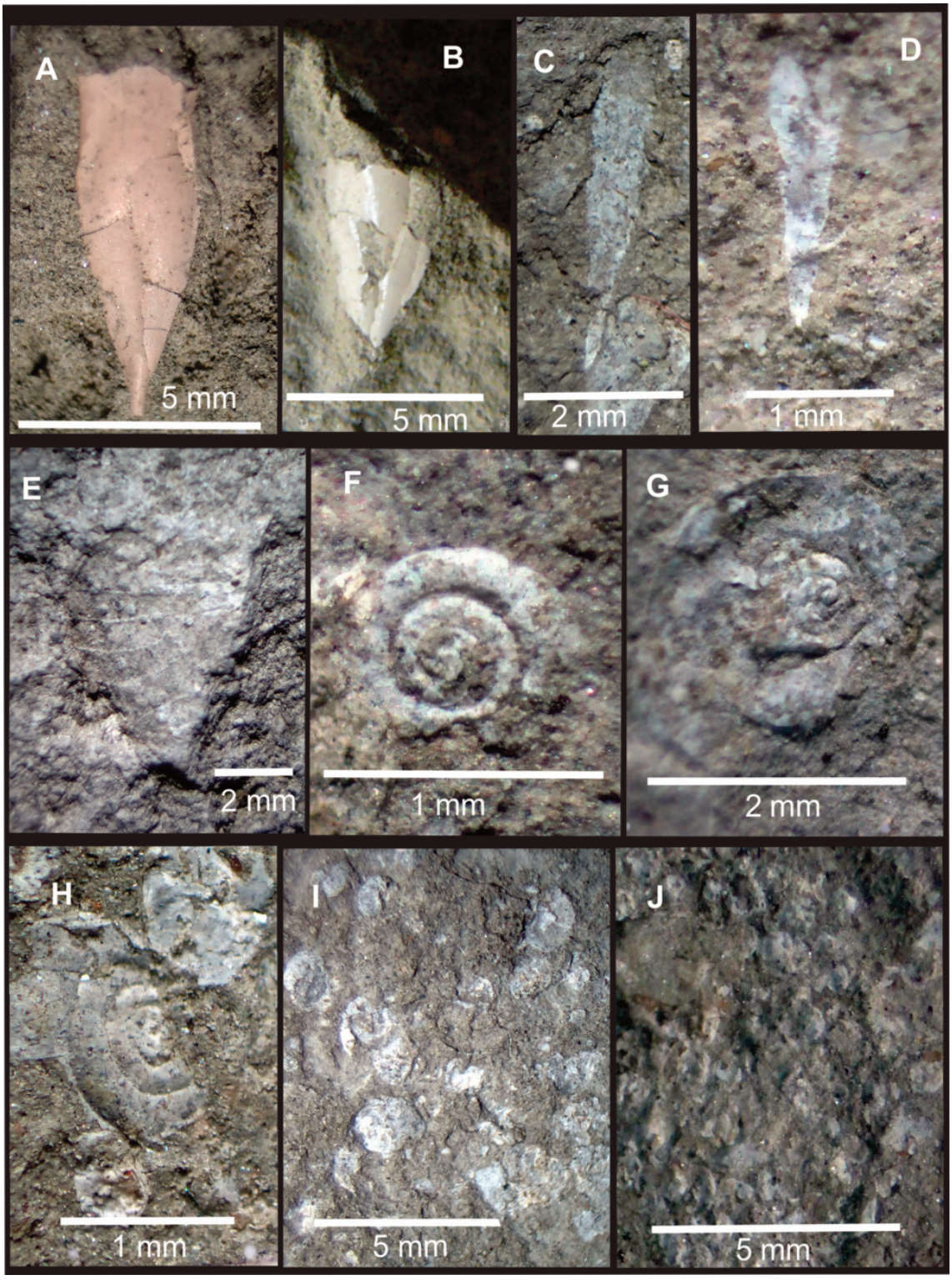

Fig. 2. *Cavoliniidae, Cliidae and Limacinidae.* ***A–B:*** *pteropods from Koceljeva;* ***A.*** Vaginella austriaca *Kittl, 1886, inv. no. 7337;* ***B.*** *fragment of* Vaginella austriaca *Kittl, 1886, inv. no. 7338;* ***C-F:*** *Pteropods from Konjarnik;* ***C.*** Vaginella *sp. indet., inv. no. AS 3 – 50;* ***D.*** Vaginella *sp. indet., inv. no. AS 3 – 51. AS 3;* ***E.*** Clio*? sp. indet., inv. no. AS 3 – 53;* ***F.*** Limacina valvatina *(Reuss, 1867)?, inv. no. AS 3 – 54.* ***G-H:*** *Pteropods from Radljevo;* ***G.*** Limacina valvatina *(Reuss, 1867)? (660.8 m-depth), inv. no. AS 3 – 55;* ***H.*** Limacina valvatina *(Reuss, 1867)?, (651.2 m- depth), inv. no. AS 3 – 56.* ***I.*** *The accumulation of shells* Limacina valvatina *(Reuss, 1867)? from Konjarnik.* ***J.*** *The accumulation of* Limacina valvatina *(Reuss, 1867)? from Radljevo.*

Fossil distribution

Three pteropod taxa are recognized in Konjarnik: *Limacina valvatina* (Reuss, 1867)?, *Vaginella* sp. indet., and *Clio*? sp. indet. The analyzed sediment contains calcareous nannofossils (Table 1), foraminifera, one unrecognizable fish fragment and mollusks: bivalves *Nucula nucleus* (Linnaeus, 1758) and *Corbula*? sp. indet., and gastropod *Rissoina podolica* Cossmann, 1921. The analyzed calcareous nannoplankton assemblage shows the stratigraphic range from NN4 to NN6 nannozone according to Martini (1971). The foraminifera are represented exclusively by benthic forms, with a pronounced dominance of bolivines. The following foraminifera were determined: *Bolivina dilatata maxima* Cicha & Zapletalova 1963, *Ammonia viennensis* (d'Orbigny, 1864) and *Bulimina* sp., indicating the late Badenian age (*Bolivina dilatata maxima* zone - the equivalent to the *Bulimina-Bolivina* zone of the Vienna Basin) (Grill, 1943) (this study).

From Koceljeva, two well-preserved specimens of *Vaginella austriaca* are recorded; the first one mentioned in Jovanović et al., (2019), and the second one collected by one of the present authors (GJ) in 2020. The Koceljeva associated fossil assemblage points to the early Badenian age (Jovanović et al., 2019).

At Radljevo, pteropods are represented by shell fragments and molds of *Limacin*a *valvatina* (Reuss, 1867)?. Additionally, fragments of echinoid spines, bivalves and fish scale were found. At a depth of 651.2 m, rare findings of *Limacina valvatina* (Reuss, 1867)? are associated with the bivalve *Varicorbula gibba* (Olivi, 1792). Between 660 and 680 m depth, *Limacina* shows higher abundances. Calcareous nannoplankton analyses indicate the NN6 nannozone, i.e. the uppermost part of the Badenian, above the common *Cibicides floridanus* around 13.40 Ma (after Raffi et al., 2020) (Table 3). Foraminifera are rarely present, and the recorded species *Bolivina dilatata maxima* Cicha & Zapletalova, 1963 and *Bulimina elongata elongata* d'Orbigny 1846, also indicate the late Badenian age. In the *Bolivina dilatata maxima* Zone numerous remains of the pteropod *Limacina* sp. were recorded (this study) (Table 2).

***Table 1**. Calcareous nannofossils from the Konjarnik locality with marked stratigraphic range.*

KONJARNIK	PARATETHYS STRATIGRAPHY AND BIOZONATION				
	KARPATIAN	BADENIAN		SARMATIAN	
	OLDER	NN4	NN5	NN6	YOUNGER
NANNOSPECIES					
Braarudosphaera bigelowii					
Calcidiscus premacintyrei					
Coccolithus pelagicus					
Coronocyclus nitescens					
Helicosphaera carteri					
Helicosphaera euphratis					
Helicosphaera wallichii					
Pontosphaera discopora					
Pontosphaera multipora					
Reticulofenestra pseudoumbilicus					
Rhabdosphaera clavigera					
Sphenolithus abies					
Sphenolithus moriformis					

***Table 2**. Calcareous nannofossils assemblage from the Koceljeva locality (after Jovanović et al., 2019).*

KOCELJEVA	PARATETHYS STRATIGRAPHY AND BIOZONATION				
	KARPATIAN	BADENIAN		SARMATIAN	
	OLDER	NN4	NN5	NN6	YOUNGER
NANNOSPECIES					
Braarudosphaera bigelowii					
Coccolithus pelagicus					
Coronocyclus nitescens					
Helicosphaera carteri					
Helicosphaera mediterranea					
Reticulofenestra minuta					
Rhabdosphaera clavigera					
Sphenolithus heteromorphus					
Sphenolithus moriformis					
Thoracosphaera saxea					

***Table 3**. Calcareous nannofossils from the Radljevo locality with marked stratigraphic range.*

RADLJEVO	PARATETHYS STRATIGRAPHY AND BIOZONATION				
	KARPATIAN	BADENIAN		SARMATIAN	
	OLDER	NN4	NN5	NN6	YOUNGER
NANNOSPECIES					
Acanthoica cohenii					
Braarudosphaera bigelowii					
Calcidiscus pataecus					
Coccolithus pelagicus					
Coronocyclus nitescens					
Helicosphaera carteri					
Helicosphaera walbersdorfensis					
Helicosphaera wallichii					
Holodiscolithus macroporus					
Micrantholithus vesper					
Pontosphaera multipora					
Reticulofenestra haqii					
Reticulofenestra perplexa					
Reticulofenestra pseudoumbilicus					
Rhabdosphaera clavigera					
Sphenolithus moriformis					
Syracosphaera pulchra					
Umbilicosphaera rotula					

Discussion

The Badenian pteropod records presented here provide the most complete information on the so far recorded Middle Miocene pteropods in Serbia. Four pteropod taxa were found at three localities, one of which (Radljevo, Fig. 1 A,C) represents a new pteropod record in Serbia.

Species *Vaginella austriaca*, unlike in the rest of the Paratethys Sea, is not abundantly present in Serbia and only occurs at Koceljeva (surface outcrop, Fig. 1 A,D). The drill-core from Konjarnik (Fig. 1A,B) shows a high amount of pteropods *Limacina valvatina*?, imprints of *Vaginella* sp. indet., even comprising juvenile forms, and a representative of the genus *Clio*? sp. indet. which represents the first possible record of this pteropod genus in Serbia (Fig. 2E). In the core from Radljevo (Fig. 1 A,C) pteropod *Limacina valvatina*? predominates. Samples from both analyzed boreholes show an abundant but monotypic pteropod record of *Limacina valvatina*? attributed to the NN6 nannozone after Martini (1971).

There are also differences in the inferred paleoenvironment between the investigated localities. Although all localities represent the record from a muddy seafloor, the water depth apparently was different. The well-preserved fossil pteropod shells of *Vaginella austriaca* are found only in Koceljeva (Figs. 1 A,D, 2A,B). While *Vaginella austriaca* from Koceljeva occurred in a shallow-water, nutrient rich paleoenvironment (Jovanović et al., 2019), the pteropod associations from Konjarnik and Radljevo originate from a slightly deeper marine environment. Lithological composition, scarce macrofauna, and richness of microfauna, presence of pteropods, etc. indicate a deeper water environment and altered conditions such as anoxia at the basin bottom in Konjarnik (Stevanović, 1970). Similar paleoenvironmental conditions probably existed in Radljevo. The bivalves *Varicorbula gibba* (Olivi, 1792) and *Nucula nucleus* (Linnaeus, 1758) represent the opportunistic species that preferentially inhabit unstable habitats with muddy bottoms, frequently characterized by low-oxygen concentrations and organic enrichment (e.g. Fuksi et al., 2016). On the other hand, the warm climate and rapid burial of pteropod shells in clay material undoubtedly enabled the better state of preservation state in the Koceljeva deposits.

Badenian chronostratigraphy used in this paper is after Raffi et al. (2020), where Badenian is divided into the early and late Badenian (Fig. 3). According to some other authors, the Badenian division is threefolded, and the early Badenian comprises the early and middle Badenian as in e.g. Hohenegger et al. (2014).

Pteropod records from the Central Paratethys are the most common in the Middle Miocene deposits corresponding to the peaks of the Badenian transgressive-regressive cycles (e.g. Sremac et al., 2022 and references therein). Here presented results from Serbia can be correlated with the two high-stand episodes. Koceljeva deposits attributed to the NN5 Zone of Martini (1971) can be correlated with the TB 2.4 transgressive-regressive cycle (Hardenbol et al., 1998), and the deposits from the Konjarnik and Radljevo boreholes, as the most probable time-equivalent of the NN6 Zone, to the TB 2.5 transgressive-regressive cycle.

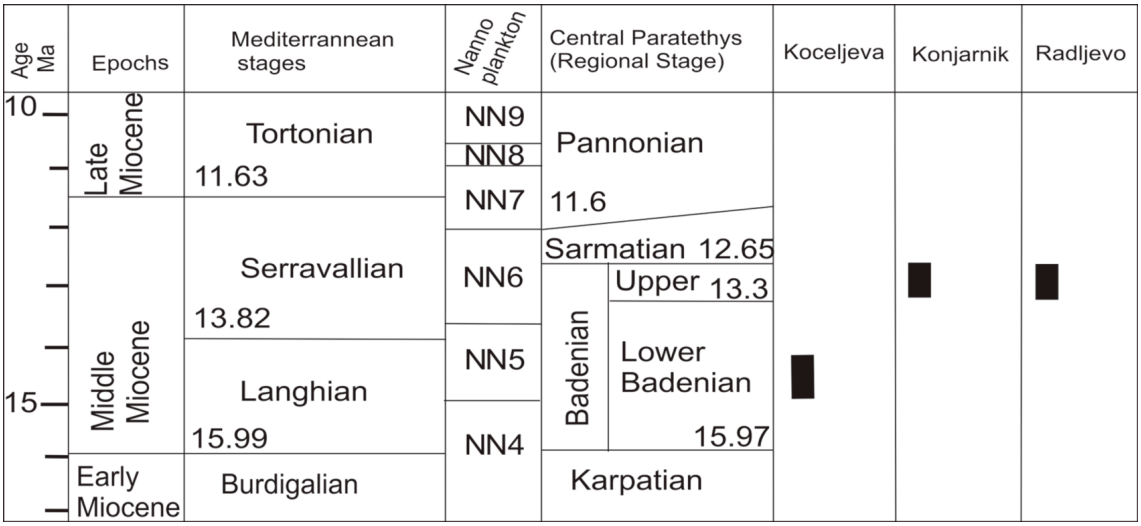

***Fig. 3**. Stratigraphic framework and correlation of the Middle Miocene of the Central Paratethys and Mediterrannean area (after Raffi et al., 2020).*

The Badenian marine transgression, which has been documented in numerous sites in the Pannonian Basin, is not contemporaneous (e.g., Mandić et al., 2019 a,b). Similar pteropod fossils were found in the Ugljevik coal mine in Bosnia and Herzegovina (Vrabac et al. 2013; Mandic et al. 2019a), comprising *Vaginella austriaca* and *Limacina valvatina* from the Upper Lagenid, *Spirorutilus* and *Bulimina-Bolivina* zone, within the interval constrained to ~14.1–12.7 Ma (Pezelj et al., 2013; Mandic et al., 2019a). The marine flooding reached the Ugljevik area at ~14.15 Ma, during the regional Badenian stage (Mandic et al., 2019a). The species *Vaginella austriaca* was also observed in the Prnjavor Basin (Eremija, 1970), suggesting that this basin was well connected to the open sea, during this part of the Badenian. According to Vrabac et al. (2017, 2020), the sediments around the Tuzla Basin also comprise *Vaginella austriaca*, typical for the younger part of the early Badenian. This species was also found in the ventilation shaft "Tušanj-2" north of Tuzla at a depth of 283 m, together with the decapod remains (upper Langhian / early Badenian), the nannoplankton NN5 Zone sensu Martini (1971) (Gašparič et al., 2019).

The distribution of the pteropod genera recorded in Serbia during the Badenian of the Central Paratethys is shown in Fig. 4 B,C. The pteropod fauna from Serbia represents one of the southern-

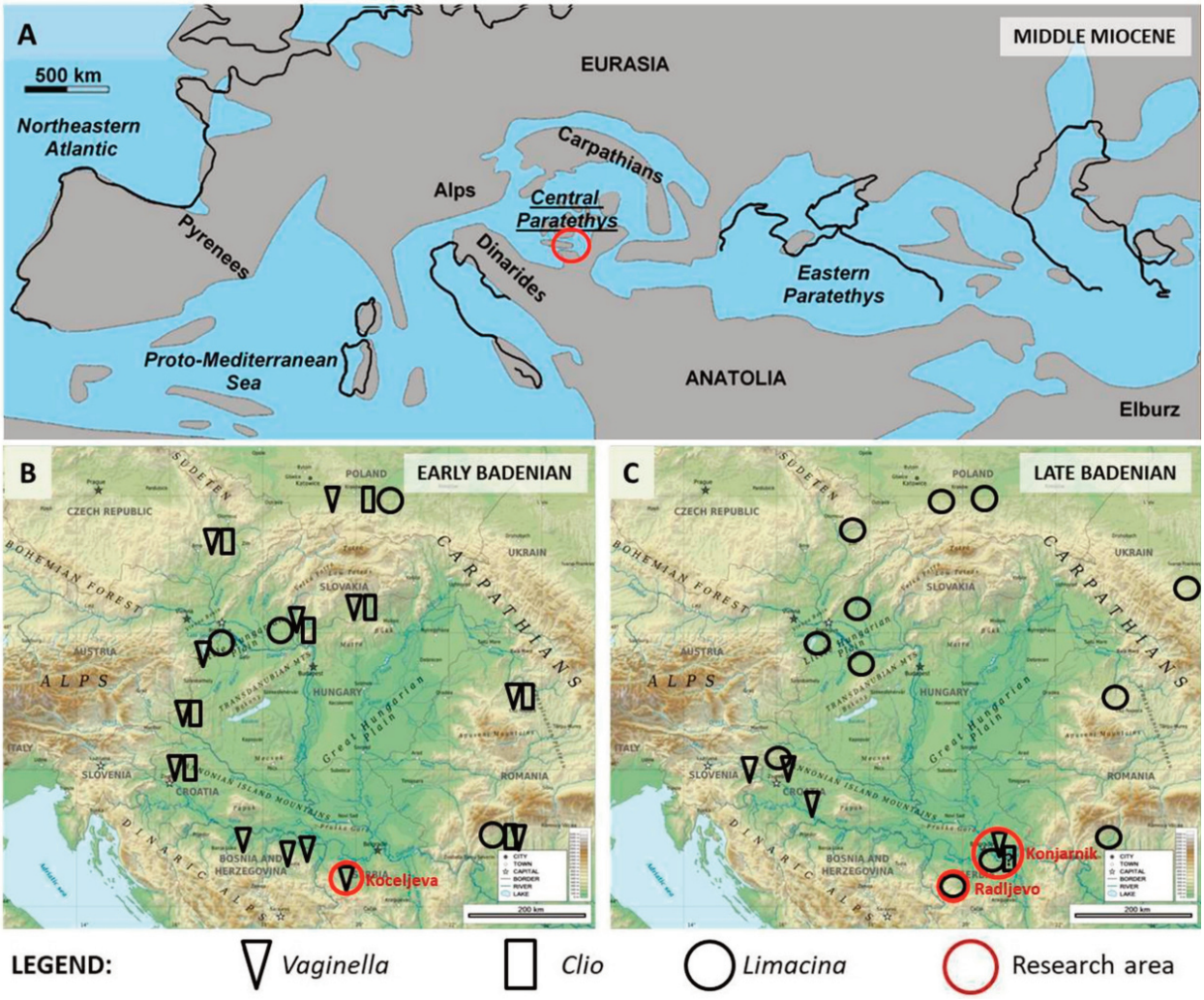

Fig. 4. *Paleogeography of the Paratethys* ***(A, C)****.* ***A.*** *Simplified paleogeography of the Paratethys Sea during the Early to Middle Miocene after Harzhauser et al., 2019) (modified). Serbia was a part of the Central Paratethys;* ***B.*** *Early Badenian pteropod findings (partly after Bošnjak et al., 2017) positioned in the Pannonian Basin System and Carpathian Foredeep geographic map (Wikimedia Commons);* ***C.*** *Late Badenian (map from Wikimedia Commons). Findings from Serbia are shown within a red circle.*

most occurrences of these holoplanktonic mollusks in the Central Paratethys. The species *Vaginella austriaca* is the only pteropod representative occurring in the early Badenian (Langhian, Lagenid Zone) in Serbia, while *Limacina valvatina*? is most numerous in the late Badenian (early Serravallian) of the investigated area. The genera *Vaginella* and *Clio* ? still occurred in the southern part of the Pannonian Basin in the late Badenian (NN6), modifying their paleogeographic distribution (Fig. 4 B,C).

Biostratigraphic value of the associated mollusk assemblages is hard to evaluate because many species were widespread throughout the Karpatian and the Badenian, but the findings at Koceljeva are in concordance with the estimated Langhian (early Badenian) age (NN5 Zone).

Conclusions

The Badenian holoplanktonic mollusk assemblages housed at the Natural History Museum of Belgrade comprise pteropod fossils from three localities, Konjarnik (wider center of Belgrade), Koceljeva (western Serbia) and Radljevo (Kolubara Basin, central Serbia), among which Radljevo represents a new fossil pteropod site in Serbia. The following taxa were determined from the studied sites: *Vaginella austriaca* Kittl, 1886, *Vaginella* sp. indet. *Limacina valvatina* (Reuss, 1867)?, and *Clio*? sp. indet.

The assemblage from the borehole Konjarnik is dominated by *Limacina valvatina*? and accompanied by *Vaginella* sp. indet. and *Clio*? sp. Recorded species at Koceljeva and Radljevo comprise *Vaginella austriaca* and *Limacina valvatina*?, respectively.

In the biostratigraphic context, the foraminifera associations from Radljevo belong to the upper Badenian (*Bolivina dilatata maxima* Zone; NN6 nannozone). Calcareous nannoplankton and foraminiferal studies have shown that the deposits from Koceljeva belong to the Badenian Lagenidae NN5 Zone (Langhian) (after Jovanović et al., 2019), and the ones from Konjarnik to the Badenian nannozone NN6, or *Bolivina dilatata maxima* zone (early Serravallian).

According to our study, Serbian pteropod fauna represents one of the southernmost occurrences of these mollusks in the Central Paratethys during the Badenian, with *Vaginella austriaca* as the most widespread species at the southern rim of the Pannonian basin.

We hope that this pteropod research will contribute to future studies on the biostratigraphy, paleogeography, and paleoclimate of the Middle Miocene at the southern boundary of the Central Paratethys.

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Резиме

Средњомиоценски (баденски) холопланктонски мекушци (Euthecosomata - Pteropoda) Србије, Централни Паратетис

У раду су анализиране баденске холопланктонске заједнице мекушаца из Природњачког музеја у Београду како би се идентификовали сакупљени таксони птеропода и старост седимената у којима су пронађени. Фосили птеропода потичу из три локалитета: Коњарник (шири центар Београда), поток Сумијевац код Коцељева (западна Србија) и Радљево (Колубарски басен, централна Србија), међу којима Радљево представља нови налаз фосилних птеропода у Србији. Идентификовани су следећи таксони: *Vaginella austriaca* Kittl, 1886, *Vaginella* sp. indet. *Limacina valvatina* (Reuss, 1867)? и *Clio*? sp. indet.

У заједници из бушотине на Коњарнику доминира *Limacina valvatina*? и праћена је са *Vaginella* sp. indet. и *Clio*? sp. indet. У Радљеву је пронађена само *Limacina valvatina* ?. У биостратиграфском контексту, асоцијације фораминифера из бушотине у Радљеву припадају горњем бадену (*Bolivina dilatata maxima* зона - еквивалент *Bulimina-Bolivina* зони Бечког басена). Проучавања нанопланктона и фораминифера су показала да коцељевачке наслаге припадају доњем бадену, лангијској нанозони NN5 (Jovanović et al., 2019), док оне са Коњарника припадају каснобаденској (серавалској) нанозони NN6, односно *Bulimina-Bolivina dilatata maxima* зони.

Према нашем истраживању, *Vaginella austriaca* је најраспрострањенија врста на јужном ободу Централног Паратетиса. Примерци *Limacina valvatina*? јављају се само на два локалитета у Србији: Коњарнику и Радљеву.

Надамо се да ће истраживање птеропода допринети будућим студијама које се фокусирају на проучавање биостратиграфије, палеогеографије и палеоклиме средњег миоцена јужне границе Централног Паратетиса.

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