GEOLOŠKI ANALI BALKANSKOGA POLUOSTRVA
Volume 81 (1), July 2020, 11–30

https://doi.org/10.2298/GABP200213005J
Original scientific paper
Оригинални научни рад

Stratigraphy revision of Upper Badenian of Rakovica stream near Belgrade (Central Paratethys, Serbia)

Gordana Jovanović[1], Sejfudin Vrabac[2] & Stjepan Ćorić[3]

Abstract. Belgrade area is a region of high paleobiodiversity, being ranked among the best known in Serbia. The prominent position among a number of middle Miocene (Badenian) fossiliferous sites in the vicinity of Belgrade (southern Pannonian Basin, Centrale Paratethys) are occupied with sediments of Rakovica stream, also known as "Rakovica sands". Here, the integrated evidence based on new fossil findings of calcareous nannoplankton, foraminifera and molluscs assemblages, allows the stratigraphic revision of the clastic facies of the Rakovica succession. Based on the studies of lithological composition, high paleodiversity molluscs fauna and local palaeogeographical setting, it can be concluded with reasonable certainty that deposits of Rakovica stream entitled "Rakovica sand" represents a sandstone of the shallow marine (littoral) environment during lower Badenian time. Large benthic foraminifera *Ammonia viennensis* (d'Orbigny), and *Borelis haueri* (d'Orbigny) as well as zone marker NN5 *Sphaenolithus heteromorphus* Deflandre correspond to this biostratigraphic level. During the late Early Miocene and Middle Miocene (Badenian), the climate in the Central Paratehys was mainly subtropical. This is supported at its southern margin by the presence of thermophilous mollusc taxa, as well as the Conidae, Strombidae, Xenophoridae, Pleurotomidae, Turridae, Muricidae, etc. Consequently, the investigated deposit can be ascribed to the Early Badenian which biostratigraphically corresponds to the NN5 nannozone by correlation with successions in theirs type-areas to the Central Paratethys, and defines preciously the time of the marine transgression in this area.

Key words:
Stratigraphy, Middle Miocene (Badenian), nannoplankton, foraminifera, molluscs, Rakovica stream (Belgrade).

Апстракт. Околина Београда је регион високог палеобиодиверзитета који се сврстава међу најпознатије у Србији. Истакнуто место међу бројним средњомиоценским (баденским) фосилним налазиштима у близини Београда (јужни обод Панонског басена, Централни Паратетис)

[1] Natural History Museum, Njegoševa 51, 11 000 Belgrade, Serbia, e-mail: gordana.j@nhmbeo.rs;

[2] University of Tuzla, Faculty of mining, geology and civil engineering, Geology department Univerzitetska 2, 75000 Tuzla, Bosnia and Hercegovina, e-mail: sejfudin.vrabac@untz.ba;

[3] Geological Survey of Austria, Neulinggasse 38, A-1030 Vienna, Austria, e-mail stjepan.coric@geologie.ac.at

заузимају седименти у Раковичком потоку, такозвани "Раковички пескови". Овде обједињени докази засновани на новим фосилним налазима заједница кречњачког нанопланктона, фораминифера и мекушаца омогућавају стратиграфску ревизију кластичних фација из Раковице. На основу проучавања литолошког састава, високог палеодиверзитета фауне мекушаца и локалне палеогеографске средине, може се поуздано закључити да седименти потока Раковица, такозвани "Раковички пескови" представљају пешчаре плитководне морске (приобалне) средине из времена раног бадена. Крупни бентоски фораминифери *Ammonia viennensis* (d'Orbigny), *Borelis haueri* (d'Orbigny), као и маркер за нанопланктонску зону НН5, *Sphaenolithus heteromorphus* Deflandre одговарају овом биостратиграфском нивоу. Током касног раног миоцена и средњег миоцена (бадена) клима је у Централним Паратетису била углавном супторпска. На основу присуства бројних термофилних врста мекушаца, као што су Conidae, Strombidae, Xenophoridae, Pleurotomidae, Turridae, Muricidae, итд., закључујемо да су слични услови владали и на његовом јужном ободу. Сходно томе, проучавани седименти се могу приписати раном бадену, што биостратиграфски одговара нанозони НН5, корелацијом са сукцесијама у њиховим типичним областима Централног Паратетиса и на тај начин прецизно је дефинисано време морске трансгресије на овом подручју.

Кључие речи:
стратиграфија, средњи миоцен (баден), нанопланктон, фораминифери, мекушци, Раковички поток (Београд).

Introduction

The shallow marine deposits are famous for a long time for their highly diverse and excellently preserved foraminifers and mollusc assemblages. In Serbia, the largest spatial distribution of Badenian sediments exposed on the surface can be found in Belgrade and its vicinity, where they have been best studied due to the rich mollusc fauna. Also, the bryozoa, spongia, corals, ostracods, along with the crabs and fish remains are present. Since the first discovery of fossils fauna at Rakovica stream (Žujović, 1886; Pavlović, 1890) and later on, this site have been the subject of interest of many researchers (Luković, 1922; Petrović, 1962; Eremija, 1977; Ganić et al. 2016, etc.). The chronostratigraphical framework of the sedimentary succession from Rakovica stream (the Upper Badenian age, *Ammonia beccarii* Zone) was based on studies of the foraminifera assemblages (Petrović, 1962; 1985), however, these important microfauna collections are not available. As a consequence, it often happens that many localities are assumed to belong to the Upper Badenian age (Jovanović, 2018), pointing to the need to reassess the age of some classical Badenian localities. Later, Rundić et al. (2019) published a summary review of several Miocene sites near Belgrade, but they did not add new stratigraphic records for so-called "Rakovica sand".

For the southern margin of Central Paratethys, some independent age constraints were established by working in the last decade (Ćorić et al. 2009; Pezelj et al. 2013; Sant et al. 2018; Jovanović et al. 2019a, Jovanović et al. 2019a; Mandic et al. 2019). These regions of the Pannonian basin were flooded later than the northern and western regions during the early Badenian (Ćorić et al. 2009; Sant et al. 2017; Jovanović, 2018). However, the chronostratigraphic correlations of marine Middle Miocene deposits of the Serbian Neogene are still considered problematic. The facies distribution, stratigraphy, and tectonic structure of the Belgrade area which comprises early and middle Miocene sediments have not been studied in great detail. The precise

chronological analysis was largely improved for the several sites in Serbia (Sant et al. 2018; Mandic et al. 2019), but chronology of the oldest units of the Belgrade area are still largely speculative. The outcropping rocks exposed on the Rakovica valley are part of the Upper Badenian with most authors (Ganić et al. 2016, Mandic et al. 2019, Rundić et al. 2019). Recently, the latest discovery in Serbia (Jovanović et al. 2019a) modified previous biostratigraphical results of some localities and indicated the necessity of stratigraphic revision of Rakovica and some other localities in the region.

In order to check the stratigraphic position of sediments from the Rakovica stream, several samples have been analysed in respect to nannoplankton, foraminifers, and molluscs. The research was based on these fossil assemblages in order to revise the Upper Badenian deposits of Rakovica stream, and in order to provide a thorough scientific background for future study. New research clarified the stratigraphic position of the deposits of the so-called "Rakovica sand". Micropaleontological and macropaleontological studies on the outcropping rocks exposed on the Rakovica valley showed the existence of a rich fauna, foraminifera and molluscs being the most important component of assembly of the fossil invertebrate. The combination of biostratigraphic analyses based on studies of some rare calcareous nannoplankton, foraminifera and rich molluscs assemblages, allows the revision of the clastic facies of the Rakovica succession. The studied outcrop is located on the left bank of Rakovica stream, on the southern flanks of Torlak Hill near Belgrade (Fig. 1).

Methods and materials

New bulk samples were taken in 2018 for analyses of fossil materials. Authors have collected stratigraphically and taxonomically important microfossils and macrofossils. A total of 12 samples for the analysis were analysed, collected from two outcrops and from one well. Also, old collections of the Natural History Museum in Belgrade, comprising 3000 specimens from the Rakovica deposits, were investigated. For stratigraphic revision of these deposits and for explaining the real vertical ranges of studied fossil assemblages, we used calcareous nannoplankton, benthic foraminifera and some termophilic molluscs, in particular those considered of stratigraphic importance to the Badenian. Sediment samples were processed by using standard micropaleontological and palaeontological methods of preparation technique. A total of 3 samples for the analysis of nannoplankton assemblages were prepared partly at the Vienna Smear slides, following standard procedure described by Perch-Nielsen (1985).

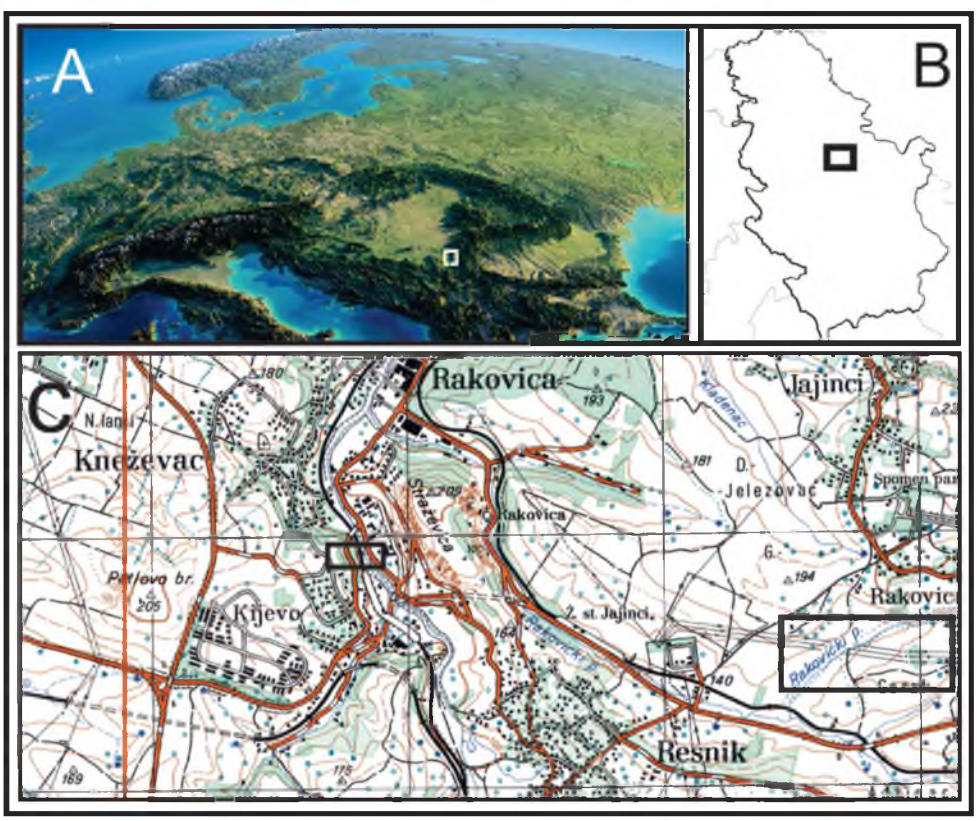

***Fig. 1**: A. Geographical position of Rakovica stream locality in Europe (Google Earth); B. Location of the studied area in Serbia; C. Toporaphic map 1: 50 000, Sheet Belgrade 4 showing the location of the studied successions (squares).*

For the foraminifera and small mollusc extraction, 9 samples were prepared and washed at the laboratory and allowed to dry. Laboratory methods were employed for disintegrating soft sandstone using hydrogen peroxide. Samples were washed and the foraminifera and molluscs were recovered from the over a 0,1 mm fraction-sieve and picked under the microscope. The stratigraphical analysis of the nannoplankton zonation is based on Martini (1971), while the foraminifera zonation is based on Grill (1943). The photos of the molluscs were made with PANASONIC DMC-FZ50.

The preservation of the most foraminifera and molluscs specimens is quite good. Collected materials are stored in the collections of Natural History Museum in Belgrade (Serbia). The collectors include: Petar Pavlović, at the end of the 19th century, Petar Stevanović around the mid-20th century, as well as the authors of this paper. As old Museum documentation does not contain all information on the location of some fossils, on the basis of the sediment stored on the fossils, we tried to identify the locality where they came from. The part ofstudied specimens of foraminifera are housed in the University of Tuzla (Bosnia and Herzegovina), while the samples of nannoplankton assemblages are stored in the collection of the Geological Survey of Austria in Vienna.

Geological setting

In the Middle Miocene (Badenian) the investigated area was located in the southeastern margin of the Pannonian Basin (Central Paratethys). The deposition of marine sediments during the Early Badenian of Central Serbia resulted from the transgression of the Central Paratethys Sea, which initiated the development of several basins, subbasins and bays with a corresponding sedimentation (Anđelković et al. 1989). In that time, the surrounding of Belgrade was a complex network of shallow marine basins. The Slovenian Trans-Tethyan corridor probably functioned as the connecting sea strait with Mediterranean Sea, according to Bistrićić & Jenko (1985). Connections are recorded also between the Pannonian and the Transylvanian basins, through the Mureș passageway and Făget Basin in Transylvania (Romania), (Chira & Mărunteanu, 1999; Chaix et al. 2018), (Fig. 2B).

Most of the Belgrade area is covered by mid-Miocene sediments, lying transgressively over well-formed paleo-relief. The Miocene deposition in the Belgrade area begins with continental alluvial and lacustrine sedimentation, which occurred during the Early Miocene time and at the beginning of the Early Badenian, before the first sea transgression. The Belgrade basin is filled with sediments composed of conglomerates, marls, clays, sand, sandstones and limestones of different thickness at different sites, because tectonic movements separated these rocks into distinct blocks (Petković, 1912) lifted or plunged, during the Neoalpine tectonic events (Marović et al. 2007; Toljić et al. 2016). Paleogeography, tectonic movements and connections with other basins and sub-basins across the gulf or open-water channels (Anđelković et al. 1989; Matencko & Radivojević, 2012; Jovanović, 2018) were the main factors influencing the diversity of molluscs in Serbia during the Middle Miocene (Badenian), which resulted in the formation of different facies with diverse fauna.

High diversity and excellent preservation of fossil assemblages are mentioned from a large number of Serbian localities, especially molluscs. The age of these deposits should be considered mainly of Middle Miocene (Badenian) which comprises three parts: Early Badenian (Lagenidae Zone), Middle Badenian (*Spirorutilus carinatus* Zone), and Late Badenian (*Ammonia beccarii* and *Elphidium crispum* Zone) (Petrović, 1962; 1985). According to Harzhauser et al. (2018), the Badenian stage can be correlated with the entire Langhian stage and the lower part of the Serravallian stage of the Standard Global Chronostratigraphic Scale of Gradstein et al. (2012). During the Early Badenian, the first marine ingression reached Central Serbia area (Eremija, 1977; Jovanović, 2018; Sant et al. 2018; Mandic et al. 2019). On the terrains of the center of Belgrade and its surrounding, like in the Vienna basin, a very pronounced facies differentiation is recorded, when the Early Badenian sea-level rise covered older deposits in Rakovica area (Luković, 1922). Obviously, each part of Belgrade basin such as the center of Belgrade, followed by Višnjica, Leštane, Veliki Mokri Lug, Kneževac, Rakovica in the vicinity of Belgrade,

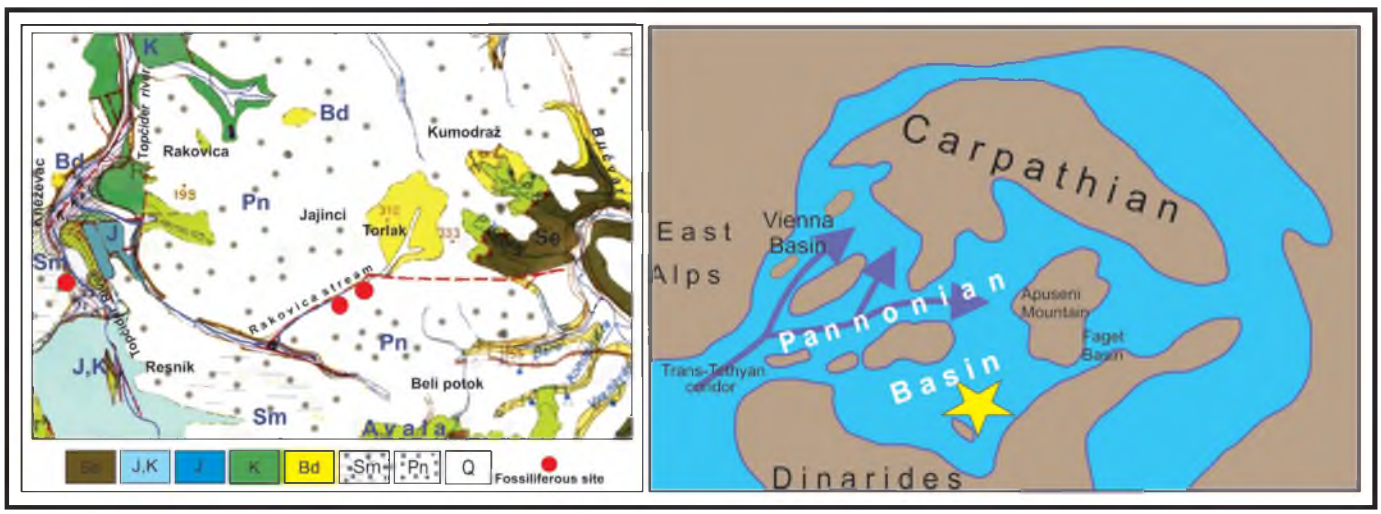

Fig. 2. A. *Geological map of the Rakovica area with marked position of the studied area, after the maps: 1:100 000 of Serbia, sheet Pančevo (according to* Ivković *et al. (1966)), and the map 1:100 000 of Belgrade (according to* Marković *et al. (1985), united and simplified);* ***B.*** *The map of Badenian sea of Central Paratethys (according to* Kovač *et al. (2017);* Chaix *et al. (2018), modified, showing the location of the studied succession (yellow star)).*

had specific development in terms of facies distribution depending on paleorelief configuration and the tectonic reorganisations in the region. During the Early Badenian, when the sea transgression reaches its biggest extent, from the geotectonic point of view, the Rakovica stream belongs to the western Border of Belgrade basin.

Results

The biostratigraphic analysis is based on the Museum collections and new field research, along with collected materials. The fauna originate from several sites, here described under the names: Rakovica stream section, Rakovica stream - old locality situated at a very short distance (about 100 m), and well cores belonging to the estate of Mr. Šujica. Some specimens from the Petar Stevanović collection originates from other localities: *Clavatula schreibersi* (Hoernes) from Rakovica town and *Aporrhais dactylifera* (Boettger) from Jelen Hill.

Rakovica stream section

The described section of Rakovica stream, with a maximum thickness of 3 m, consists of yellowish and grey, fine-grained, poorly cemented sandstone and irregularly distributed hard yellowish sandstone lenses. The sediments are composed of a single relatively uniform deposit. A lower part is mainly dominated by the yellow sandstone, Fig. 3 (A a, B a) whereas the central part shows intermixing of grey and yellowish colored sandstone with hard sandstone lenses, Fig. 3 (A b). The contact surfaces between sediments of different color are uneven, Fig. 3 (B).

In its upper part, they are sometimes replaced by yellowish sandstone with hard sandstone lenses. The latest 1.5 m thick unit, Fig. 3 (A c, C), passing into thin and hard layer cemented Leitha sandstone towards top (Fig. 3 d), with poorly preserved nannofossils and well preserved Ascidien spiculae, has been observed. Both are dominated by quartz grains, while the cement is calcite. On their southern side, laterally, two thin wedge-shaped of the grey sandstone layers are exposed (Fig 3 e). Fossils foraminifera come from both yellowish and grey samples, Fig. 3 (A a, b), while fossil molluscs come from three samples, Fig. 3 (A a, b, c).

Yellowish sandstone

Calcareous nannofossils have low abundance and diversity because very shallow sandstones of

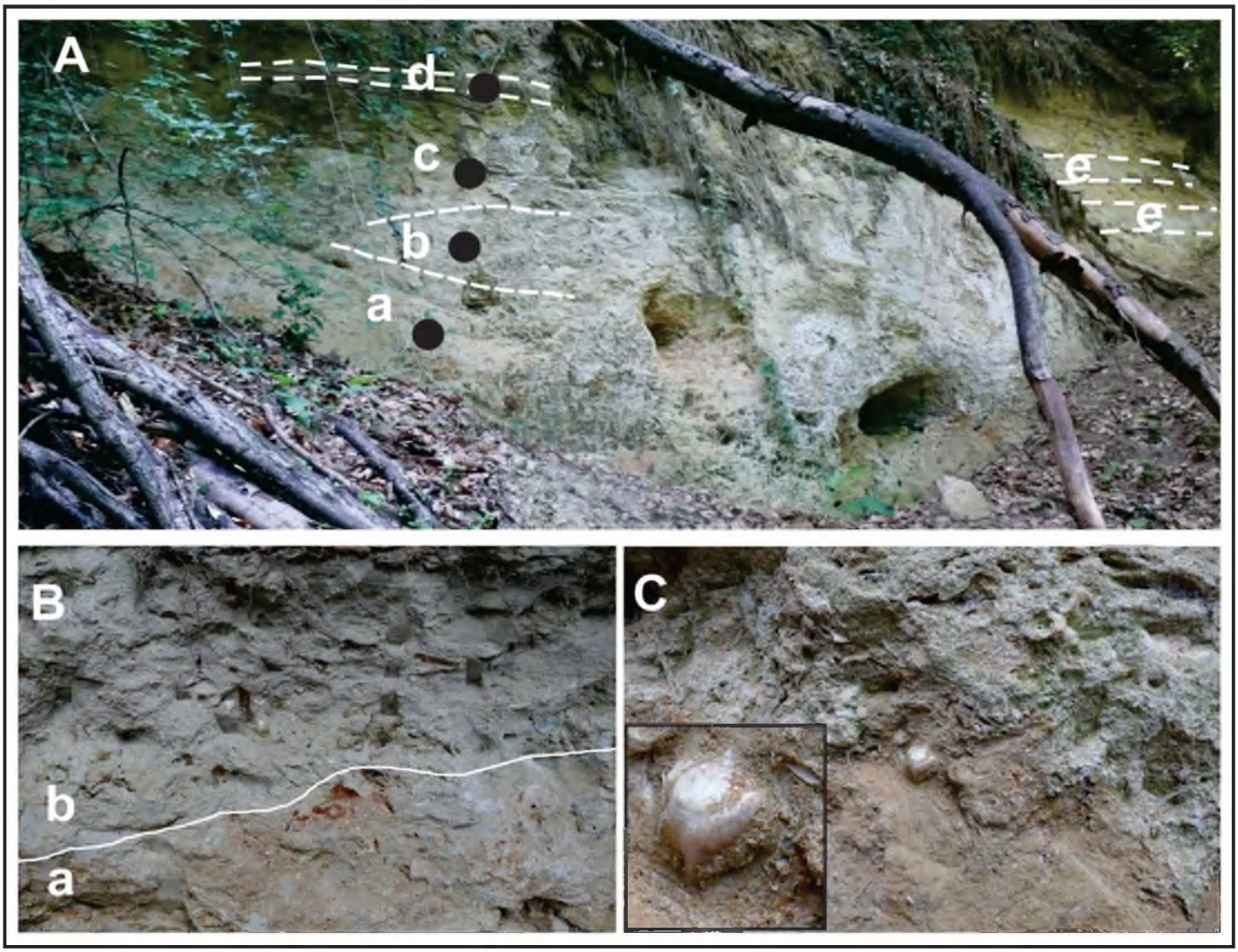

Fig. 3. A (a-e). *The Lower Badenian sandstone in Rakovica stream;* ***B.*** *Transition between yellowish and grey sandstone; C. Yellowish sandstone with sandstone lense;* ***C (a).*** *detail of the picture C – Persististrombus.*

the Rakovica stream are not very favorable to provide abundant and rich associations of nannofossils. The most analysed samples from the yellow sandstone were barren in calcareous nannofossils. The rarity of nanofossils made it difficult to establish a biostratigraphic framework. Nevertheless, in two specimens, the few identified species are rather informative and show that NN5 zone of the Middle Miocene is present in the sampled succession. The first manifestation of nannoplankton is noted at the top of section Rakovica stream, Fig. 3 (A d), where assemblages mainly consist of *Braarudosphaera bigelowii* (Gran & Braarud, 1935) Deflandre, 1947; *Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930; *Coronosphaera mediterranea* (Lohmann, 1902) Gaarder, in Gaarder & Heimdal, 1977; *Cyclicargolithus floridanus* (Roth & Hay, in Hay et al. 1967) Bukry, 1971; *Helicosphaera carteri* (Wallich, 1877) Kamptner, 1954; *Micrantholithus vesper* Deflandre 1950; *Micrantholithus* sp., *Pontosphaera multipora* (Kamptner, 1948 ex Deflandre in Deflandre & Fert, 1954) Roth, 1970; *Reticulofenestra gelida* (Geitzenauer, 1972) Backman, 1978; *Reticulofenestra haqii* Backman, 1978; *Reticulofenestra minuta*, Roth, 1970; *Reticulofenestra pseudoumbilicus* (Gartner, 1967) Gartner, 1969.

Stratigraphically very important species *Sphenolithus heteromorphus* Deflandre, 1953 is absent from the samples of section Rakovica stream, however the occurrences of *Sphenolithus heteromorphus* Deflandre, 1953 in the sample from an old collection of Museum enabled the attribution into NN5

(nannoplankton zonation of MARTINI, 1971). The nannofossil assemblage is composed of *Sphenolithus moriformis* (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967 and *Syracosphaera pulchra* LOHMANN, 1902 and some species of the reworked nannofossils from Cretacaeous deposits: *Micula staurophora* (GARDET, 1955) STRADNER, 1963; *Vatznaueria barnesiae* (BLACK in BLACK & BARNES, 1959) PERCH-NIELSEN, 1968). The age of these deposits corresponds to the zone of calcareous nannoplankton zone NN5 (nannoplankton zonation of MARTINI, 1971 was used). The zone is dated Middle Miocene based on the presence of benthic forms, and corresponds to the M5 zone of BERGGREN et al. (1995), on the regional scale (Paratethys).

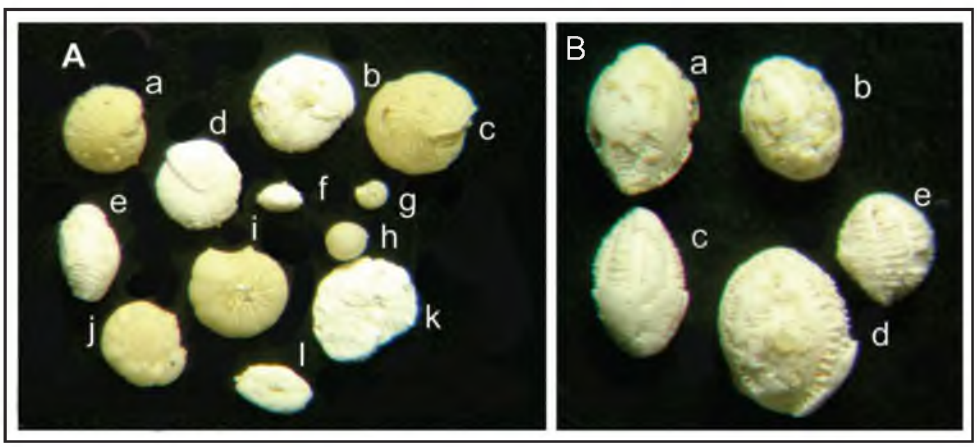

Fig. 4. A. 1, 3, *Elphidium crispum (LINNAEUS);* ***2, 11,*** *Dendritina haueri (D'ORBIGNY);* ***4,*** *Borelis melomelo (FICHTELI & MOLL);* ***5,*** *Borelis haueri (D'ORBIGNY);* ***6, 12,*** *Quinqueloculina sp.;* ***7, 9, 10,*** *Ammonia viennensis (D'ORBIGNY);* ***8,*** *Orbulina suturalis BRÖNNIMANN;* ***4 B. (1–5),*** *Borelis haueri (D'ORBIGNY).*

Foraminifers are unequally distributed in the yellowish sediment and almost exclusively represented by benthic forms, only two planktonic forms of genus *Orbulina* were found. Foraminifers are more numerous and diverse than those of the sample of grey sandstone. The following foraminifera were determined: *Ammonia viennensis* (D'ORBIGNY, 1846), *Elphidium crispum* (LINNAEUS, 1758), *Elphidium* sp., *Borelis haueri* (D'ORBIGNY, 1846), *Borelis melo melo* (FICHTEL & MOOL, 1798), *Dendritina haueri* D'ORBIGNY, 1846, *Triloculina* sp., *Spirolina austriaca* D'ORBIGNY, 1846, *Asterigerinata planorbis* (D'ORBIGNY, 1846), *Glandulina ovula* D'ORBIGNY, 1846 and *Orbulina suturalis* BRÖNNIMANN, 1951.

The mollusc assemblages were already known in the 19th century, when ŽUJOVIĆ (1886) and PAVLOVIĆ (1890) made the list of mollusc species from the Rakovica stream. However, the majority of identified molluscs have a wide chronostratigraphic distribution, making it difficult to divide the Badenian, using them as a basis. Current investigation of the fossil assemblages and recent morphological studies (ATANACKOVIĆ, 1985; BALUK, 2006; HARZHAUSER & KRONENBERG, 2013; HARZHAUSER & LANDAU, 2016; KOVÁCS & VICIÁN, 2014; KOVÁCS & BALÁZS, 2015; KOVÁCS, 2018; LA PERNA et al. 2017; LANDAU et al. 2013; MANGANELLI et al. 2004; NIEGRI & CORSELLI, 2016; POPA et al. 2014; STUDENCKA, 1986; STUDENCKA et al. 1998), led to a significant increase in the number of mollusc species (Fig. 5, 6, 7). Our results show approximately 150 mollusc species occurring in the studied section. However, our estimates of paleobiodiversity are still incomplete as yet and much work remains to be done. Gastropods are dominating. The following taxa are identified: *Dentalium* sp., *Athleta ficulina* LAMARCK, 1811, *Persististrombus inflexus* (EICHWALD, 1830), *Semicassis laevigata* (DEFRANCE, 1817), *Babylonia eburnoides* (MATHERON, 1843), *Lautoconus* sp., *Varioconus pelagicus* (BROCCHI, 1814), *Phasmoconus fuscocingulatus* (HÖRNES, 1856), *Lautoconus kovacsi* HARZHAUSER & LANDAU, 2016; *Plagioconus extensus* (HOERNES, 1856), *Jujubinus* (*Strigosella*) *vexans* (BOETTGER, 1907), *Paroxystelle orientale* (COSSMANN & PEYROT, 1917), *Caecum* (*Caecum*) *trachea* (MONTAGU, 1803), *Gibbula* (*Colliculus*) *pseudangulata* BOETTGER, 1907, *Truncatella* (*Truncatella*) *subcylindrica* (LINNAEUS, 1767), *Nassarius serraticosta* (HÖRNES, 1852), *Microloripes dentatus* (DEFRANCE, 1823), *Bittium reticulatum* (DA COSTA, 1778), *Granulolabium bicinctum* (BROCCHI, 1814), *Pyramistomia* sp., *Megacardita hoernesi* LA PERNA, MANDIC & HARZHAUSER, 2017; *Discors spondyloides* (HAUER, 1847), *Flabellipecten besseri* (ANDRZEJOWSKI, 1830), *Europicardium multi-*

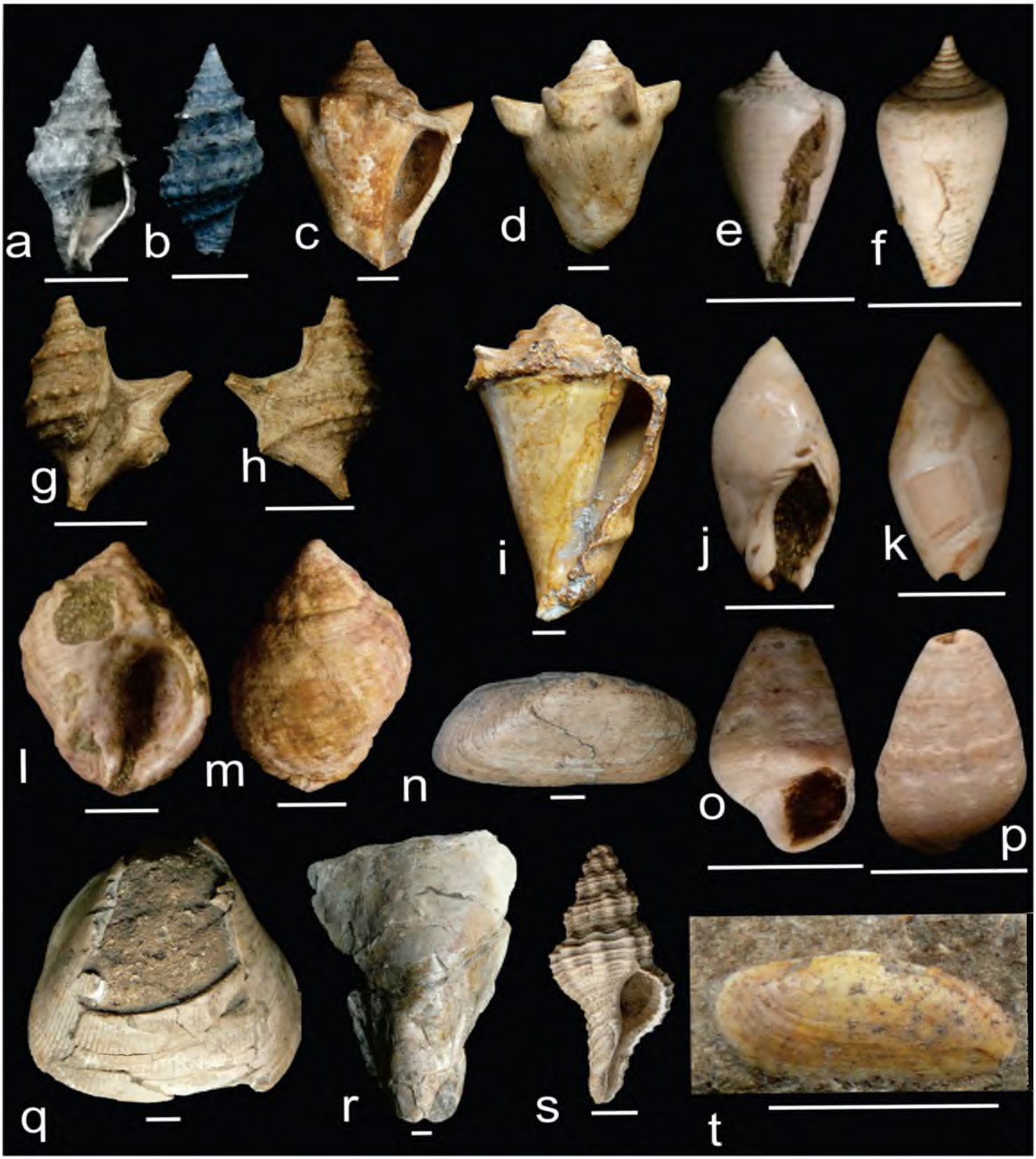

Fig. 5. *Detailed view of molluscs assemblage; Scale bar 0,5cm (Fig. 5a, b) and 1cm (Fig. 5, c–t):* ***a,b,*** *Clavatula schreibersi (Hoernes);* ***c, d,*** *Persistis trombusinflexus (Eichwald);* ***e,f,*** *Plagioconus extensus (Hoernes);* ***g, h,*** *Aporrhais dactyloides (Boettger);* ***i,*** *Persistis trombus cf lapugyensis (Sacco);* ***j,k,*** *Amaldaglandıformis, (Lamarck);* ***l, m ,*** *Cathymorulaexilis (Hörnes);* ***n,*** *Serratina sp.;* ***o, p,*** *Pyramistomia sp.;* ***q,*** *Discorsspondyloides (Hauer);* ***p, q,*** *Pyramistomia sp.;* ***r,*** *Atrina pectinata (Brocch);* ***s,*** *Streptochetusornatus (d'Orbigny);* ***t,*** *Azorinuschamasolen (da Costa).*

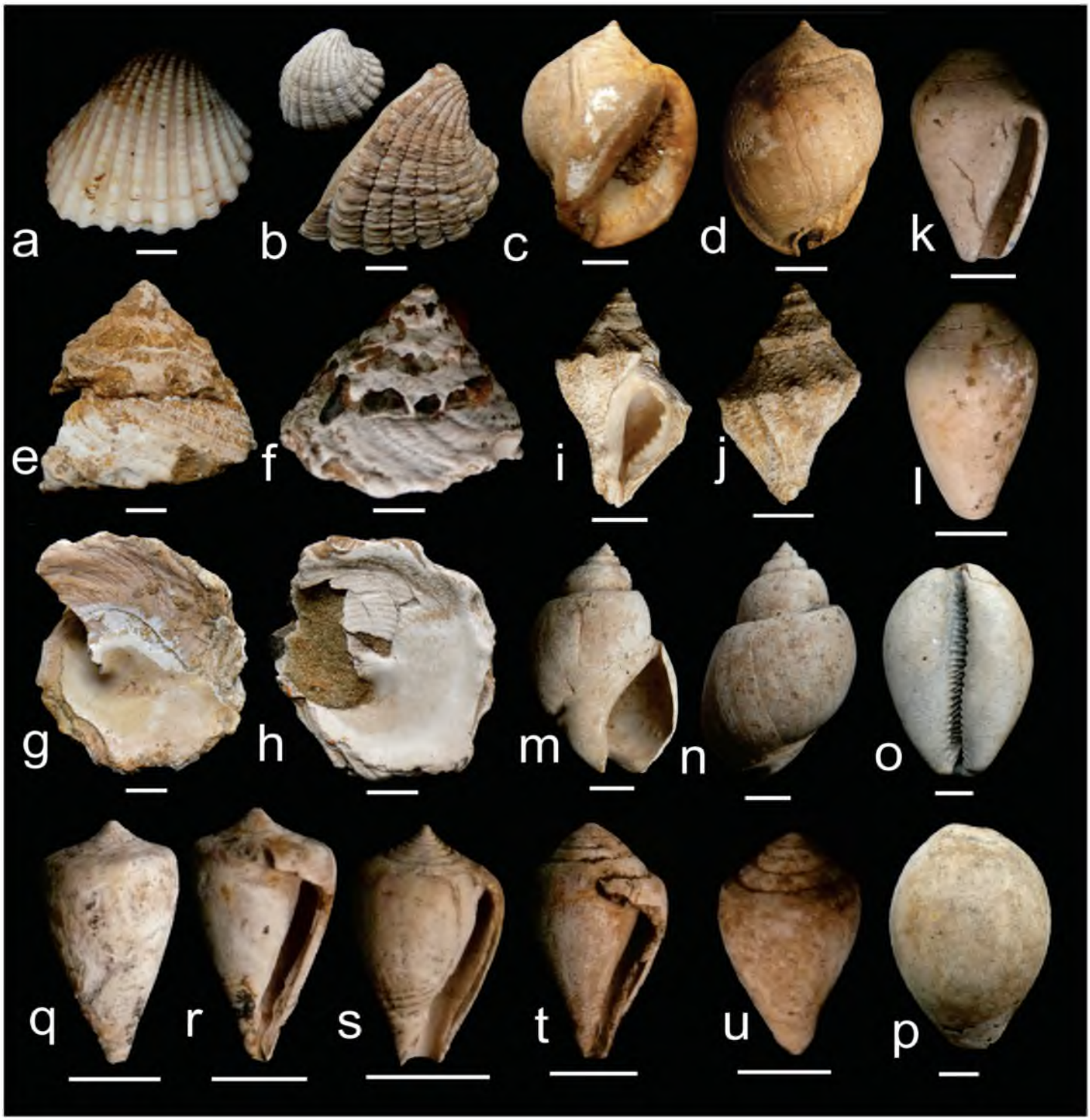

***Fig. 6**. Detailed view of molluscs assemblage; Scale bar 0,5cm (Fig. 6 a) and 1cm (Fig. 6 b-u). Cardites partschi (Münster in Goldfuss); **b,** Megacardita hoernesi La Perna, Mandic & Harzhauser; **c, d,** Semicassislaevigata (Defrance); **e, f,** Xenopohora deshayesi Michelotti; **g, h,** Xenophora sp.; **i, j,** Vitularia linguabovis (Basterot); **k, l,** Lautoconus subraristriatus (Pereirada Costa, 1866); **m, n,** Babylonia eburnoides (Matheron); **o, p,** Zonarina phyletica (Schilder); **q, r,** Kalloconus ponderoaustriacus (Sacco); **s,** Phasmoconus cf schroeckingeri (Hoernes & Auinger); **t, u,** Varioconus sp.*

costatum (Brocchi, 1814), *Pirenella* sp., *Rissoina* (*Rissoina*) *pusilla* (Brocchi, 1814), *Modiolula phaseolina* (Philippi, 1844), *Acteocina lajonkaireana* (de Basterot, 1825), *Hydrobia* sp.,etc.

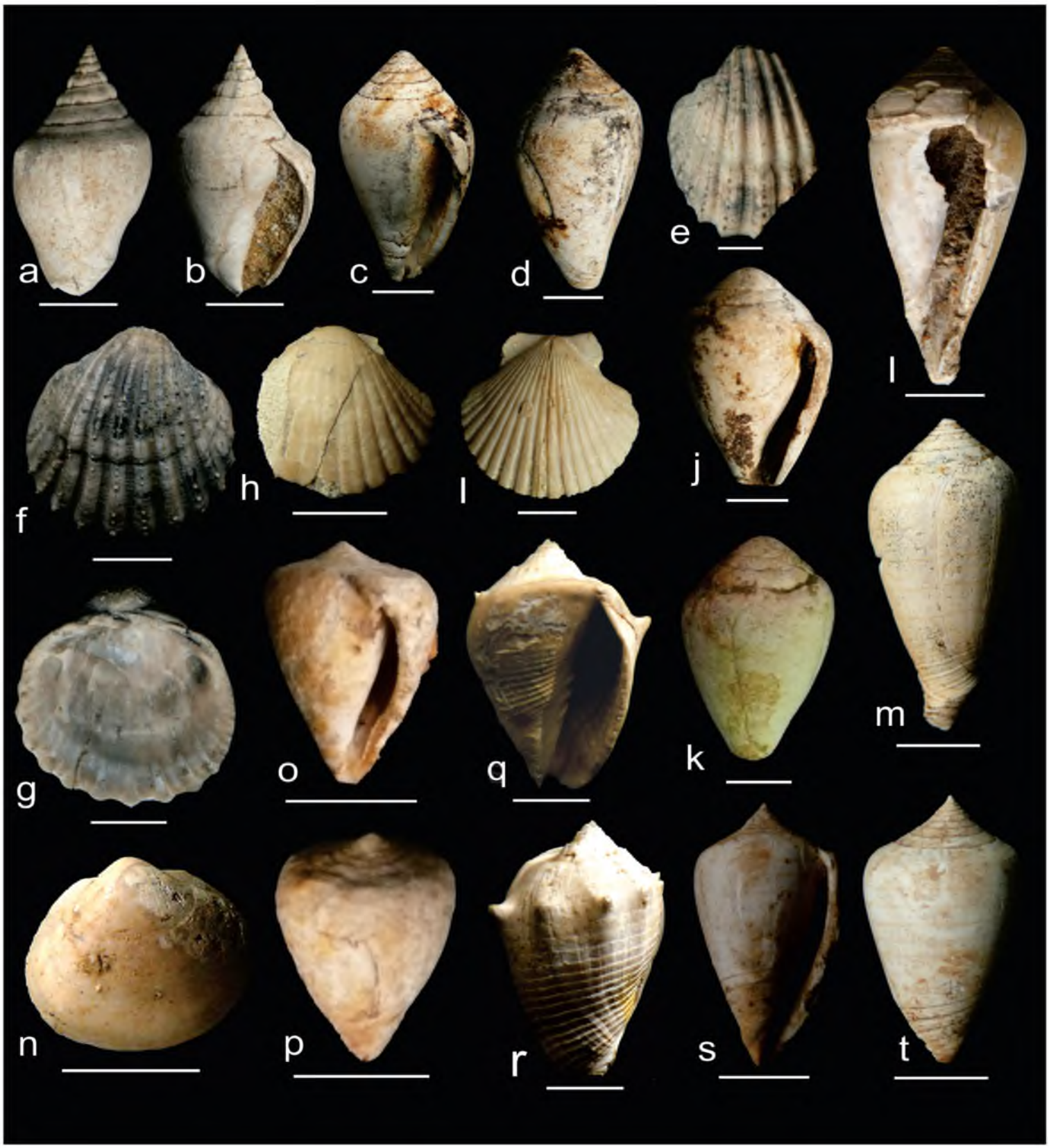

Fig. 7. *Detailed view of molluscs assemblage; Scale bar 1cm.* ***a, b,*** *Persistis trombusexbonellii (Sacco);* ***c, d,*** *Lautoconus ponderosus (Brocchi);e –Acanthocardia sp.;* ***f, g,*** *Acanthocardia paucicostata (Sowerby);* ***h,*** *Pectenaduncus (Eichwald);* ***i,*** *Flabellipecten besseri (Andrzejowski);* ***j, k,*** *Lautoconus kovacsi Harzhauser & Landau;* ***l, m,*** *Varioconus pelagicus (Brocch);* ***n,*** *Glycymeris pilosa (Linnaeus);* ***o, p,*** *Kalloconus letkesensis Harzhauser & Landau;* ***q, r,*** *Athletaficulina Lamarck;* ***s, t ,*** *Phasmoconus fuscocingulatus (Hörnes).*

The grey sandsone

The grey sandstone contains only foraminifera fauna and mollusc shells. Nannoplankton is absent. Foraminifers are represented almost exclusively by benthic forms while the planktonic forms are scarce, only one specimen of *Orbulina* have been recorded. The following foraminifera were determined: *Ammonia viennensis* (D'ORBIGNY, 1846), *Elphidium crispum* (LINNAEUS, 1758), *Borelis haueri* (D'ORBIGNY, 1846), *Dendritina haueri* D'ORBIGNY, 1846, *Quinqueloculina* sp. and *Orbulina suturalis* BRÖNNIMANN, 1951. (Fig. 4 A). Among molluscs, the following species are identified: *Antalis vulgaris* (DA COSTA, 1778); *Antalis* cf. *mutabilis* (HÖRNES, 1856); *Phasmoconus* cf. *schroeckingeri* (HOERNES & AUINGER, 1879); *Varioconus pelagicus* (BROCCHI); *Kalloconus letkesensis* HARZHAUSER & LANDAU, 2016; *Babylonia eburnoides* (MATHERON, 1843); *Athleta ficulina* (LAMARCK, 1811); *Zonarina phyletica* (SCHILDER); *Oligodia spirata* (BROCCHI, 1814); *Cathymorula exilis* (HÖRNES, 1856); *Finella perpusilla* (GRATELOUP, 1827); *Odostomia* sp.; *Ocinebrina* sp.; *Crepidula* sp.; *Pyramidella* sp.; *Potamides disjunctus* SOWERBY, 1831; *Alvania oceani* (D'ORBIGNY, 1852); *Gibborissoa varicosa* (BASTEROT, 1825); *Paroxystele orientale* (Cossmann & Peyrot, 1917); *Retusa umbilicata* (MONTAGU, 1803); *Tritia* cf. *longitesta* (BEERBISTRICKÝ, 1958); *Gibbula angulata* (EICHWALD, 1829); *Flabellipecten besseri* ANDRZEJOWSKI, 1931; *Pecten aduncus* EICHWALD, 1930; *Venus nux* GMELIN, 1791; *Glycymeris* (*Glycymeris*) *deshayesi* (MAYER, 1868); *Glycymeris* sp.; *Microloripes dentatus* (DEFRANCE, 1823), etc.

Rakovica stream – old locality

This section is not longer available for fossil sampling, but it might be possible to correlate it to the beds 4, 5, 6 of the section described by EREMIJA (1977). We represent it by museum collections. The sample of yellowish sand from fossils was taken in 1995. The section's length was 10 m, and the yellowish sand and small lense of sandstone could have been recognized. Foraminifera, bryozoa, corals, ostracod shells, echinoid spines, remains of crabs, and rich mollusc communities are also present. These marine assemblages from a highly energetic, normally saline environment were characterized by excellent preservation of foraminiferal tests and mollusc shells.

Foraminifers are relatively common. Foraminifers are dominated by ammonia, elphidium and milliolides. As for planktonic forms, only two specimens *Orbulina* were found. The following foraminifera were determined: *Ammonia viennensis* (D'ORBIGNY, 1846); *Elphidium crispum* (LINNAEUS, 1758); *Elphidium* sp.; *Borelis melo melo* (FICHTEL & MOLL, 1798);, *Dendritina haueri* D'ORBIGNY, 1846; *Quinqueloculina* sp.; *Triloculina* sp.; *Pyrgo simplex* (D'ORBIGNY, 1846); *Spirolina austriaca* D'ORBIGNY, 1846; *Asterigerinata planorbis* (D'ORBIGNY, 1846); *Glandulina ovula* D'ORBIGNY, 1846; *Orbulina suturalis* BRÖNNIMANN, 1951; *Dentalina* sp.; *Peneroplis planatus* (FICHTEL & MOLL, 1798) and *Ortomorphina* cf. *columella* (KARRER, 1877). Among molluscs, the following were recognized: *Athleta ficulina* LAMARCK, 1831; *Amalda glandiformis* (LAMARCK, 1810); *Streptochetus ornatus* (D'ORBIGNY, 1852); *Xenophora deshayesi* MICHELOTTI, 1847; *Xenophora* sp.; *Vitularia linguabovis* (BASTEROT, 1825); *Cathymorula exilis* (HÖRNES, 1852); *Persististrombus exbonellii* (SACCO, 1893); *Persististrombus inflexus* (EICHWALD, 1830); *Zonarina phyletica* (SCHILDER, 1923); *Babylonia eburnoides* (MATHERON, 1843); *Varioconus* sp.; *Phasmoconus fuscocingulatus* (HÖRNES, 1851); *Paroxystelle orientale* (COSSMANN & PEYROT, 1917); *Flabellipecten besseri* (ANDRZEJOWSKI, 1831); *Anadara* sp.; *Polinices redemptus* (MICHELOTTI, 1847), etc.

Well of the estate of Mr. Šujica

In the West, meaning in Topčider river area, sedimentation took place in a shallow marine environment, and lagoonal environment was formed, resulting in deposition of coal-bearing clay. At a depth of 12 m, blue clay with coal and fossils were recovered from core well of Mr. Šujica's estate (STEVANOVIĆ & STEPANOVIĆ, 1939; STEVANOVIĆ, 1970). This fauna probably belongs to the Upper Badenian because it contains sarmatoid forms. Additionaly, Sarmatian deposits are situated above these sediments. Also, termophille taxa such Conidae FLEMING, 1822; Strombidae RAFINESQUE, 1815; Muricidae RAFINESQUE, 1815; Cypraeidae, etc, are missing. Among foraminifera *Dendritina haueri* D'ORBIGNY, planispiral porcelaneous species *Spirolina austriaca*

d'Orbigny, *Quinqueloculina* sp., *Pseudotriloculina consobrina* (d'Orbigny) and *Ammonia viennensis* (d'Orbigny) are identified. *Acanthocardia paucicostata* (Sowerby, 1841), *Acanthocardia turonica* (Mayer, 1861), *Arca rollei* Hörnes, 1864, *Tellina donacina* Linnaeus, *Modiolus* sp., *Microloripes dujardini* (Deshayes, 1850), *Crepidula cochlear* Basterot, 1825, *Calyptrea chinensis* (Linnaeus, 1758), *Venus* sp., *Ringicula minor* (Grateloup, 1838). About 500 m south, on the left bank of Topčider River, in another well, similar fauna was identified: *Anadara diluvii* (Lamarck, 1805), *Cubitostrea digitalina* (Eichwald, 1830), *Nassarius edlaueri* (Beer-Bistricky, 1958); *Granulolabium nodosoplicatum* (Hörnes, 1856) *G. rubiginosum* (Eichwald, 1853), *Venus* sp. (Stevanović & Stepanović, 1939).

Discussion and Interpretation

In Serbia and some other regions of Central Paratethys, the temporal span and boundaries of the Badenian regional stage remain unclear. Generally, in Paratethys area, other biostratigraphic problems were noticed (Kovač et al. 2018). In recent works, Badenian transgression is well documented from Serbia (Sant et al., 2018; Jovanović et al., 2019a; Mandic et al., 2019; Rundić et al., 2019), but the base of the Badenian has not yet been precisely defined. The intense efforts directed at resolving stratigraphic problems have not yet been matched with the latest researches of Badenian sediment of Central Paratethys. As pointed out by Jovanović et al. (2019a), a biostratigraphic revision is required for some Badenian localities. In order to check the stratigraphic position of sediments from the Rakovica stream, several samples have been analysed in respect to nannoplankton, foraminifers and molluscs. The existing information of the Middle Miocene calcareous nannofossil species from the Serbia sites: Višnjica (near Belgrade) and Koceljeva (Western Serbia) have been published by Mihajlović & Knežević (1989), and Jovanović et al. (2019a). Age of these deposits corresponds to the calcareous nannoplankton *Sphenolithus heteromorphus* (NN5) zone. A similarity is registered between the nannofossil assemblages of Lower Badenian deposits in Serbia, Transylvania, Slovenia, Bosnia, as reported by several authors (Bartol, 2009; Chira & Vulc (2003); Mihajlović & Knežević (1989), or between the other fauna (Jovanović et al., 2019a; Chaix et al., 2018).

Both Rakovica stream and Rakovica stream – old locality are not significantly different because they contain almost the same rich fossil assemblages, though the old locality seems somewhat more diverse in terms of gastropods. Chronologically, the section Rakovica stream – old locality is stratigraphically slightly older, taking into account the falling angle of the sediments, 30-40° (Petković, 1912; Eremija, 1977). In the investigated area, the identification of the nannoplankton zone NN5 (Martini, 1971), was made based on the presence of *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta*. *Sphenolithus heteromorphus* was recorded in the sample of the old museum collection. Its LO (Last Occurrence) in the Mediterranean was dated at ~ 13.4 Ma (Abdul Aziz et al., 2008), which points to the fact that these sediments must have been older than 13.4 Ma. This means that these Rakovica sediments correspond to the NN5 calcareous nannoplankton zone (Martini, 1971).

The foraminifera associations from the analysed sandstones of the Rakovica stream belong to the lower Badenian, namely the older zone *A. viennensis* and *E. crispum*. This finding is supported by several facts. The first is that in the sandstones a species of *B. haueri* has been designated, which in Central Paratethys is exclusively associated with the Lower Badenian (Cicha et al., 1998). Additionaly, the sandstones contain a rich association of fossils, which is not a feature of the uppermost zone of Upper Badenian in Central Paratethys. Due to the few fossil communities, this zone is also referred to as the "Impoverishment Zone" in the Vienna Basin (Papp & Schmid, 1985). The cause of "Impoverished fauna" is probably the decrease in salinity of the seawater at the end of Badenian. Also, this "Impoverishment Zone" is characteristic of the uppermost zone of Upper Badenian in the area of Northern Bosnia (Vrabac, 1999). Very important difference between the Upper Badenian and Lower-Badenian zones of *Ammonia viennensis* is that the Upper Badenian zone was formed during the regression, while the Lower Badenian zone is related to the transgression of Central Paratethys. Basal conglomerates and fossiliferous sandstones of the Rakovica stream were de-

posited during the transgression of the lower Badenian Sea, which is a feature of the lower Badenian sediments of the *A. viennensis* Zone, both in Serbia (Jovanović et al., 2019a) and in Northern Bosnia (Ćorić et al., 2018). Upper Badenian zone sediments are highly regressive in the Vienna Basin (Papp & Schmid, 1985). This was stated in numerous sites of the southern margin of Central Paratethys (Vrabac et al., 2015). In the Višnjica locality near Belgrade (according to Krstić &Mitrović, 1993), sediments of the upper Badenian with *Ammonia beccarii* (= *Ammonia viennensis*) lying over the older ones (zone with *Spiroplectamina carinata*) were drilled in the V-26 well. Biostratigraphically, they correspond to the *Bolivina dilatata* Zone, and their total thickness is about 40 m.

The Badenian fauna from Rakovica is thought to contain a large proportion of molluscs (Žujović, 1886; Pavlović, 1890; Eremija, 1977, 1987; Ganić et al. 2016) but understanding the age and general spatiotemporal processes that shaped their distribution are yet unclear, and they are probably older than the Upper Badenian (Jovanović, 2018). In previous literature, the chronostratigraphical framework of the sedimentary succession was based on the foraminifera assemblages and the entire succession is dated as Upper Badenian. In recent years, the Middle Miocene deposits of the Rakovica area have been studied, as well as the Badenian fauna. However, most of these papers refer to the outdated biostratigraphy (Ganić et al., 2016; Rundić et al., 2017) or misidentification of foraminifera (Rundić et al. 2019). For example, in the Fig. 5 (p. 114) according to Rundić et al. (2019), we can clearly identify *Borelis haueri*.

Our results show approximately 150 mollusc species occurring in the studied sections, thermophile molluscs are common. Gastropods dominated in the samples. Molluscan assemblages represent elements common in Early Miocene or early Middle Miocene (Badenian) of the Central Paratethys. The Early Badenian is characterized by a rich fauna that prefers warm water (Harzhauser & Piller, 2007). Many marine molluscs display a peak in diversity during the warm Early Badenian. The high diversity reflects the warm temperature and indicated Middle Miocene Climatic Optimum, which allowed numerous thermophilic proto-Mediterranean elements to migrate into the Paratethys (Harzhauser et al. 2003). Despite the fact that thermophile taxa play an important role in establishing biostratigraphic and biogeographic correlations (Harzhauser & Piller, 2007), they were poorly used for biostratigraphy of Serbian deposits. Molluscs such as *Xenophora deshayesi*, *Babylonia eburnoides*, *Semicassis laevigata*, *Vitularia linguabovis, Persististrombus exbonellii*, *Persististrombus* cf. *lapugyensis*, *Aporrhais dactylifera* and *Megacardita hoernesi*, belong to the Early Miocene or appear at the beginning of the Badenian transgression. Stenohaline, thermophilic species from the investigated area are followed by numerous gastropod cerithiids (over 500 specimens) and *Rissoina* (over 100), indicative of the occurrence of sea-grass meadows in a predominantly shallow water environement. Therefore, the investigated sections correspond to Early Badenian age (nannoplankton zone NN5) and to TB 2.4, the Badenian sequence within the NN5 nannozone.

The investigated fauna has been frequently used as reference fauna for the comparison with other famed Paratethyan Early Badenian mollusc fauna from Lower Austria (Gainfarn and Vöslau), Poland (Korytnica) and Romania (Lapugiu de Sus, Costei), and can be correlated with the Lagenidae Zone (Grill, 1941) of the Badenian, as well as with some classic Badenian fossiliferous sites of Serbia. From the Rakovica near Belgrade, the rich mollusc fossils presented here can be compared with that of the Golubac (Notheastern Serbia), (Mikinčić, 1932; Spajić, 1975; Jovanović, 2018). Both localities show high diversity with numerous common termophile taxas (*Persististrombus*, *Xenophora*, *Lautoconus*, *Varioconus*, *Phasmoconus*, *Kalloconus*, *Terebra*, *Clavatula*, *Babylonia*, etc), but Golubac site is much more abundant in the number of species and specimens (Jovanović, 1996). The numerous identified molluscs from Rakovica sites have a wide geographic distribution in Central Paratethys such as *Flabellipecten besseri*, *Pecten aduncus*, *Microloripes dentatus* (Defrance), *Cardites partschi*, *Athleta rarispina*, *Paroxystele orientale*, *Xenophora deschayesi* etc (Studencka, 1986; Landau et al., 2013; Chaix et al., 2018). In comparison with other localities in Central Paratethys (Baluk, 2003, 2006; Mikuž, 1998) etc, quite the "im-

poverished" conoidean fauna from the Rakovica stream is observed. Turrids are important marine carnivorous gastropods that are highly diversified in shallow as well as deep water. Among Turridae and Pleurotomidae, only seven species are identified, thermophile genus *Clavatula* with three species and more than 110 specimens indicated to warm climate (*Clavatula granulatocincta*, *C. sophiae*, *C. schreibersi*). Some rare gastropods as well as representatives of family Architectonidae (= Solariidae), etc are noticed. The architectonicids known as "sundials," are a group of worldwide distribution, mainly in subtropical and tropical waters which have an extended veliger stage enabling larvae to live in the plankton for relatively long periods and thus to cover great distances with the ocean currents, ensuring wide distributional ranges (Mauro-Pietro & Cesare, 2016). *Heliacus monilifera* and *Psilaxis* cf. *simplex* have a wide chronostratigraphic distribution (Landau et al., 2013).

A frequent alternation of different facies is the result of inflows into the shallow sea and the characteristic of sea shore. In addition, the Rakovica stream sediments were deposited in a fairly shallow marine embayment in which the material was occasionally brought in by streams or rivers. *Coccolithus pelagicus* is common in close to river mouths (Ćorić, 2003). This type of deposition is indicated by the nature of the layers, such as wedge-shaped sedimentary deposits, gradual transitions between sediments of different colours and small differences in grain size. All data indicated that the communications with a deeper sea were established as early as in Lower Badenian. The Badenian molluscan biodiversity was shaped by a series of events connected with the geodynamic and climatic evolution of the southern margin of Central Paratethys during the early Middle Miocene (Badenian). Palaeogeography, tectonic movements and connections via bayways or canals with open sea (Anđelković et al. 1989; Matenco & Radivojević, 2012) present the main factors within the mollusc community, making Serbian diversity during Middle Miocene (Badenian), (Jovanović, 2018).

The lithofacial and biofacial characteristics of the studied deposits of the Rakovica stream indicate that they were deposited in a very shallow, coastal part of the infralittoral sea with normal salinity. The cosmopolitan nanofossil indicates shallowing of the sea. The small reticulofenestrids such as *R. minuta* or *R. haqii* have a wide ecological tolerance and indicate a nutrient-rich, eutrophic, near-shore environment (Auer et al. 2015). The abundant and varied molluscan assemblage signifies subtropical conditions, favorable substrates, and abundant food supply. Large benthic forms are suggesting a shallow water high-energy environment. Therefore, the mollusc assemblage clearly indicates the infralittoral zone and, thus, the euphotic zone. Shallow marine environments are also documented by the numerous trace bioerosion on shell of molluscs (Ganić et al. 2016), as well as in the investigated materials presented here. In southern Topčider river area, sedimentation took place in shallow marine settings, resulting in deposition of coal-bearing clay, probably corresponding to Upper Badenian. This probably documents shallow or estuarine environments and coast vicinity.

During the late Early Miocene and Middle Miocene (Badenian), the climate in the Central Paratehys was mainly subtropical (Kovač et al., 2007). This is supported at the southern margin by the abundance of thermophilous mollusc taxa as well as in the same interpretations made by other authors engaged in the same fieldwork (Jovanović et al., 2019c; Mandic et al., 2019). The studied mollusc fauna indicates the influence of the period of global warming, so called Middle Miocene Climatic Optimum (MMCO initial warming beginning ca. 18 Ma and with peak warming ca. 17–14.75 Ma, according to Zachos et al. (2001, 2008), that preceded the Middle Miocene Climatic Transition (global cooling during the interval ~15–13 Ma). MMCO event initiated many ecological changes, including the influence on the development of mollusc fauna and their distribution. Literature data from around the world suggest that during the MMCO, many localities were characterized by rich invertebrate remains, containing an abundance of predominant foraminifers, gastropods and bivalves. Numerous taxa are very sensitive to temperature and salinity change. The presence of typical warm-water indicators (e.g., Conidae, Clavatulidae, Strombidae, Xenophoridae, Cypraeidae) within the studied Museum collections, supports the interpretation that studied fauna excisted during the late phase of the Middle Miocene Climatic Optimum. Based on these criteria, we conclude that it is necessary to continue the revision of the Upper Badenian in Serbia, Bosnia and Herzegovina,

and Croatia, on the localities where the Upper Badenian has been determined only based on the *Rotalia beccarii* zone (= *Ammonia viennensis*).

Conclusion

This paper presents the results of biostratigraphic studies of Badenian (early Middle Miocene) sediments of the Rakovica stream near Belgrade (Central Serbia). The Badenian sediments, rich in various fossils, have a widespread distribution in the area of Belgrade. A review of past works on the early Middle Miocene sediments of the Rakovica stream (Petrović, 1962, 1985; Ganić et al., 2016; Rundić et al., 2019), together with new fieldwork in that area and the latest research of the vicinity of Koceljeva (Jovanović et al., 2019a), have indicated the necessity of stratigraphic revision of those beds. Micropaleontological and macropaleontological studies of the sediments of Rakovica stream herein attributed to the Lower Badenian showed the existence of a rich fauna where molluscs and foraminifera, as well as some rare nannofossils, allowed accurate dating the age of the researched sediments. The biostratigraphic analysis is based on the old Museum collections and new ressearches. The conducted investigation resulted in defining middle Miocene (lower Badenain, Lagenidae NN5 Zone) age of these sediments.

Our conclusions about the fossil records give new light on the stratigraphy of Rakovica sediments for further studies, providing a useful resource to the future study of fossil assemblage diversity. The results show approximately 150 molluscs species, occurring in the studied sections and Museum collections. Many Middle Miocene species belonging to extinct or extant genera have been recorded in the Paratethyan region. Further research might increase the total number of mollusc taxa indicated above for the Badenian of Rakovica.

During the late Early Miocene and Middle Miocene (Badenian), the climate in the Central Paratehys was mainly subtropical. This is supported at its southern margin by the abundance of thermophilous mollusc taxa as well as Conidae, Strombidae, Cypraeidae, Xenophoridae, Muricidae, Pleurotomidae, etc. Based on the studies of lithological composition, nannofossils, foraminifers and high paleodiversity mollusc fauna and local palaeogeographical setting, it can be concluded with reasonable certainty that the Rakovica deposits represented a shallow marine (sublittoral) environment during Lower Badenian time. The abundant and varied molluscan assemblage and other fossil assemblages indicate favorable substrates, abundant food supply, and warm-temperate to subtropical conditions. Current investigation of the fossil assemblages that are here dated as Lower Badenian will contribute to clarify more accurately the biogeographic pattern of Badenian fauna of the region, and fill in the gaps in the biostratigraphical division of the Badenian sediments of Serbia. It should also contribute to a better knowledge of the paleoecological conditions during early Middle Miocene (Badenian), when the warm climate zone was much wider than today. We conclude that it is necessary to continue the revision of the Upper Badenian in Serbia, Bosnia and Herzegovina, and Croatia, in the localities where it is determined solely based on the *Rotalia beccarii* zone (= *Ammonia viennensis*).

Acknowledgements

The authors are grateful to Dr Zoltán Kovács (Eötvös University, Budapest), and Dr Dan Mircea Tămaș (Babeș-Bolyai University, Kogălniceanu). This study was realized through the cooperation between Natural History Museum (Belgrade), University of Tuzla and Geological Survey of Austria (Vienna).

References

Abdul Aziz, H., Di Stefano, LM., Foresi, FJ, Hilgen, SM., Iaccarino, KF., Kuiper, F., Lirer, G., Salvatorini, A., & Turco, E. 2008. Integrated stratigraphy and 40Ar/39Ar chronology of early Middle Miocene sediments from DSDP Leg 42A, Site 372 (Western Mediterranean). *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 257: 123–138.

Anđelković, M., Pavlović, M., Eremija, M., & Anđelković, J. 1989. Paleogeografija [Paleogeography]. In: Anđelković, M. (Ed.). Geologija šire okoline

Beograda [*Geology of the surroundings of Belgrade*– in Serbo-Croatian], IV, University of Belgrade, 282 pp.

Atanacković, M. A. 1985. Mekušci morskog miocena Bosne [*Miocene marine mollusks of Bosnia* – in Serbo-Croatian]. Geoinženjering, 1: 1–305.

Auer, G., Piller, W.E., & Harzhauser, M. 2015. Two distinct decada land centennial cyclicities forced marine upwelling intensity and precipitation during the late early Miocene in Central Europe. *Clim. Past*, 11: 283–303.

Bałuk, W. 2003. Middle Miocene (Badenian) gastropods from Korytnica, Poland; part IV-Turridae. *Acta Geologica Polonica*, 53: 29–78.

Bałuk, W. 2006. Middle Miocene (Badenian) gastropods from Korytnica, Poland; Part V. Addenda et Corrigenda ad Prosobranchia. *Acta Geologica Polonica*, 56: 177–220.

Bartol, M. 2009. *Middle Miocene calcareous nannoplankton of NE Slovenia (Western Central Paratethys)*. Paleontološki Institut Ivana Rakovca ZRC SAZU, 1–136.

Berggren, W.A., Kent, D.V., Swisher, III, C.C., & Aubry, M.-P. 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Aubry, M.-P. & Hardenbol, J. (Eds.). *Geochronology, Timescales and Global Stratigraphic Correlation*. SEPM Special Publication, 54: 129–212.

Bistričić, A. & Jenko, K. 1985. Area No. 224 b1: Transtethyan Trench "Corridor", YU. In: Steininger, F. F., Senes, J., Kleemann, K. & Rögl, F. (Eds.). *Neogene of the Mediterranean Tethys and Paratethys. Stratigraphic correlation tables and sediment distribution maps*. University of Vienna, 1: 72–73.

Chaix, C., Saint, Martin, J.-P., Merle, D., Saint Martin, S. & Caze, B. 2018. Biodiversité des coraux scléractiniaires du Langhien (Badénien, Miocène moyen) de Lăpugiu de Sus (Roumanie). *Geodiversitas*, 40 (14): 321–353.

Chira, C. & Mărunteanu, M. 1999. Middle Miocene (Lower Badenian) calcareous nannofossils from the Mureş passage way and Făget basin, Romania. *Acta Palaeontologica Romaniae*, 2: 73–82.

Cicha, I., Rögl F., Rupp. C. & Ctyroka, I. 1998. Oligocene – Miocene foraminifera of the Central Paratethys. *Abh. senckenberg. naturforsch. Ges.*, 549:1–325.

Chira, C. & Vulc, A.M. 2003. The Miocene calcareous nannofossils from Bistriţa area (Transylvania, Romania). *Studia Universitatis Babeş-Bolyai, Geologia*, 48: 67–80.

Ćorić, S. 2003. Calcareous nannofossil biostratigraphy of the Mühlbach section (Gaindorf Formation, Early Badenian), Lower Austria. *Ann. Naturhist. Mus. Wien*, 104 (A): 15–21.

Ćorić, S., Pavelić, D., Rögl, F., Mandic, O., Vrabac, S., Avanić, R., Jerković, L. & Vranjković, A. 2009. Revised initial datum for the initial marine flooding of North Croatian basin (Pannonian Basin System, Central Paratethys). *Geologica Croatica,* 62 (1): 31–43.

Ćorić, S., Vrabac, S., Đulović, I. & Babajić, E. 2018. Donji miocen i donji baden na profilu Čaklovići u Tuzlanskom bazenu [Lower Miocene and Lower Baden in the Caklovici profile in the Tuzla basin – in Croatian]. *Book of abstracts of the 17th Congress of Geologists of Serbia, Vrnjačka Banja*, 115–120.

Eremija, M. 1977. Miocen u oblasti ekshumiranog mezozojsko-serpentinskog paleoreljefa, od Rakovice do Ripnja. [Miocene in the exhumed Mesozoicserpentine area of palaeorelief, from Rakovica to Ripanj – in Serbian]. In: Petković, K. (Ed.). *Geologija Srbije*, 3: 145–154.

Eremija, M. 1987. Badenski kat [Badenian stage – in Serbian]. In: Andjelković, M. (Ed.). *Geologija šire okoline Beograda*. Zavod za Regionalnu geologiju i paleontologiju Rudarsko-geološkog fakulteta Univerziteta u Beogradu. I: 151–194.

Ganić, M., Radović, P., Rundić, LJ., Bradić, K. & Knežević, S. 2016. Traces of drilling predation in the Upper Badenian (Middle Miocene) molluscs from The Rakovica stream (Belgrade). *Geologia Croatica*, 69 (2): 173–180.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. 2012: *The Geologic Time Scale 2012*. Elsevier, 2: 1–114.

Grill, R. 1941. Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen. *Oel und Kohle*, 37: 595–602.

Grill, R. 1943. Über mikropaläontologische Gliderungsmöglichkeiten im Miozän des Wiener Beckens. *Mitt. Reichsanst. Bodenforschung*, 6: 33–44.

Harzhauser, M., Mandić, O. & Zuschin, M. 2003. Changes in Paratethyan marine molluscs at the Early/Middle Miocene transition: diversity, palaeogeography and palaeoclimate. *Acta Geologica Polonica*, 53 (4): 323–339.

Harzhauser, M. & Piller, WE. 2007. Benchmark data of a changing sea — Palaeogeography, Palaeobiogeography and events in the Central Paratethys during the Miocene. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 253: 8–31.

Harzhauser, M. & Kronenberg, G. 2013. The Neogene strombid gastropod Persististrombus in the Paratethys Sea. *Acta Palaeontologica Polonica*, 58: 785–802.

Harzhauser, M. & Landau, B. 2016. A revision of the Neogene Conidae and Conorbidae (Gastropoda) of the Paratethys Sea. *Zootaxa*, 4210 (1):1–178.

Harzhuaser, M., Grunert, P., Mandic, O., Lukeneder, P., García, G. A., Neubauer, T.A., Carnevale, G., Landau, B.M., Sauer, R. & Strauss, P. 2018. Middle and late Badenian palaeoenvironments in the northern Vienna Basin and their potential link to the Badenian Salinity Crisis. *Geologica Carpathica*, 69 (2): 149–168.

Ivković, A., Vuković, A., Nikolić, J., Kovaćević, D., Palavestrić, LJ., Petrović, LJ., Jovanović, O., Trifunović., I, & Sebinović, LJ. 1966. Osnovna geološka karta SFRJ 1:100 000 – list Pančevo [Basic Geologic Map of Former Yugoslavia 1: 100 000, Sheet Pančevo – in Serbian]. Savezni geološki zavod, Beograd.

Jovanović, G. 1996. The Badenian of the Golubac. In: Krstić, N. (Ed.). *Neogene of Central Serbia*. IGCP Project 329, Neogene of Paratethys, Special Publication, Geoinstitute, 19: 95–96.

Jovanović, G. 2018. Badenske školjke jugoistočnog oboda Panonskog basena [Badenian bivalves of the southeastern margin of Panonian Basin Systems (Central Paratethys) – in Serbian]. *Bulletin of Natural History Museum,* Special editions, 44: 1–136.

Jovanović, G., Ćorić, S. & Vrabac, S. 2019a. First evidence of the marine Badenian transgression Badenian near Koceljeva (western Serbia). *Geološki anali Balkanskoga poluostrva*, 80 (1): 1–15.

Jovanović, G., Vrabac, S. & Ćorić, S. 2019b. Stratigrafska revizija gornjeg badena Rakovičkog potoka kod Beograda (Centralni Paratetis, Srbija) [Stratigraphy revision of Upper Badenian of Rakovica stream near Belgrade (Central Paratethys, Serbia) – in Serbian]. *Proceedings of the 2nd Geological Congress of Bosnia and Herzegovina, October 2nd–4th, 2019*, 76–79.

Jovanović, G., Trif, N., Codrea, V. & Đurić, D. 2019c. Middle Miocene shark teeth from the southern margin of the Pannonian Basin System (Serbia, Central Paratethys). *Geološki anali Balkanskoga poluostrva*, 80 (1): 29–43.

Kovács, Z. 2018. Muricidae (Neogastropoda) assemblages from the Middle Miocene of the Făget Basin (Romania) in the collection of the Hungarian Natural History Museum, Budapest. *Fragmenta Palaeontologica Hungarica*, 35: 111–142.

Kovács, Z. & Vicián, Z. 2014: Badenian (Middle Miocene) Conoidean (Neogastropoda) fauna from Letkés (N Hungary). *Fragmenta Palaeontologica Hungarica*, 30: 53–100.

Kovács, Z. & Balázs, P. 2015. Conidae (Neogastropoda) assemblage from the Middle Miocene of the Făget Basin (Romania) in the collection of the Hungarian Natural History Museum, Budapest. *Fragmenta Paleontologica Hungarica*, 32: 11–48.

Kováč, M., Andreyeva-Grigorovich, A., Barjaktarević, Z., Brzobohatý, R., Filipescu, S., Fodor, L., Harzhauser, M., Nagymarosy, A., Oszypko, N., Pavelić, D., Rögl, F., Saftić, B., Sliva, L. & Studencka, B. 2007. Badenian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sea-level changes. *Geologica Carpathica,* 58 (6): 579–606.

Kováč, M., Hudáčková, N., Halásová, E., Kováčová, M., Holcová, K., Oszczypko-Clowee, M., Báldi, K., Less, G., Nagymarosy, Ruman, A., Klučiar, T. & Jamrich, M. 2017. The Central Paratethys palaeoceanography: a water circulation model based on microfossil proxies, climate, and changes of depositional environment. *Acta Geologica Slovaca*, 9 (2): 75–11.

Kováč, M., Halásová, E., Hudačková, N., Holcová, K., Hyžný, M., Jamrich, M. & Ruman, A. 2018. Towards better correlation of the Central Paratethys regional time scale with the standard geological time scale of the Miocene Epoch. *Geologica Carpathica*, 69 (3): 283–300.

Krstić, N. & Mitrović, S. 1993. Badenski sedimenti Beogradskog Dunavskog Ključa [Badenian sediments of Danube meander near Belgrade in Serbo-Croatian]. *Radovi Geoinstituta*, 28: 43–62.

La Perna, R., Mandić, O. & Harzhauser, M. 2017. Systematics and palaeobiogeography of Megacardita Sacco in the Neogene of Europe (Bivalvia, Carditidae). *Papers in Paleontology*, 3 (1): 111–150.

Landau, B., Harzhauser, M. & Beu, A.G. 2009. A Revision of the Tonnoidea (Caenogastropoda, Gastropoda) from the Miocene Paratethys and their Palaeobiogeographic Implications. *Jahrbuch der Geologischen Bundesanstalt*, 149 (1):61–109.

Landau, B.M., Harzhauser, M., İslamoğlu, Y. & Marques da Silva, C. 2013. Systematics and paleobiogeography of the gastropods of the middle Miocene (Serravallian) Karaman Basin, Turkey. *Cainozoic research*, 11–13: 3–576.

Luković, M. 1922. Drugomediternakse facije iz okoline Beograda [Second Mediterranean facies from Belgrade surroundings – in Serbian]. *Geološki anali Balkanskoga poluostrva*, 7 (1): 22–41.

Mandic, O., Rundić, LJ., Ćorić, S., Pezelj, Đ., Theobalt, D., Sant, K. & Krijgsman, W. 2019a. Age and mode of the middle Miocene marine flooding of the Pannonian Basin–constraints from Central Serbia. *Palaios*, 34:71–95.

Manganelli, G., Spadini, V. & Cianfanelli, S. 2004. The xenophorid gastropod of the Mediterranean Pliocene: the record of the Siena Basin. *Bollettino della Societa Paleontologica Italiana*, 43: 409–45.

Marković, B., Obradinović, Z., Veselinović, M., Anđelković, J., Stevanović, P. & Rakić, M. 1985. Osnovna geološka karta SFRJ 1:100 000 – list Beograd [Basic Geologic Map of Former Yugoslavia 1: 100 000, Sheet Beograd – in Serbian]. Savezni geološki zavod, Beograd.

Marović, M., Toljić, M., Rundić, LJ. & Milivojević, J. 2007. *Neoalpine tectonics of Serbia*. Serbian Geological Society, 87 pp.

Martini, E. 1971. Standard Tertiary and Quartenary calcareous nannoplankton zonation. *Proceedings of the 2nd Planktonic Conference, Ed. Tecnoscienza, Roma*, 739–785.

Matenco, L. & Radivojević, D. 2012. On the formation and evolution of the Pannonian Basin: Constraints derived from the structure of the junction area between the Carpathians and Dinarides. *Tectonics*, 31: TC6007. 10.1029/2012TC003206.

Mauro Pietro, N. & Cesare, C. 2016. Bathyal Mollusca from the cold-water coral biotope of Santa Maria di Leuca (Apulian margin, southern Italy), *Zootaxa*, 4186 (1): 1–97.

Mihajlović, Đ. & Knežević, S. 1989. Krečnjački nanoplankton iz badenskih i sarmatskih sedimenata Višnjice i Karaburme kod Beograda [Calcareous nannoplankton from Badenian and Sarmatian deposits at Višnjica and Karaburma in Belgrade – in Serbo-Croatian]. *Geološki anali Balkanskoga poluostrva,* 53: 342–366.

Mikinčić, V. 1932. Kenozojski sedimenti između Golupca, Vukotića i V. Gradišta [Cenozoic deposits between Golubac, Vukotić and V. Gradište – in Serbo-Croatian]. *Bulletin of the Yugoslavian Royal Geological Institute,* 1 (1): 89–104.

Mikuž, V. 1998. Turrids (Neogastropoda) from Middle Miocene Badenian beds of Slovenia. *Geologija*, 40: 65–101.

Mikuž, V. 2009: Miocenski polži iz okolice Šentjerneja in drugih najdišč v Krški kotlini. [Miocene gastropods from the vicinity of Šentjernej and from other localities in the Krka basin – in Slovenian]. *Folia biologica et geologica*, 50 (2): 5–69.

Niegri, M. P. & Corselli, C. 2016. Bathyal Mollusca from the cold-water coral biotope of Santa Maria di Leuca (Apulian margin, southern Italy). *Zootaxa*, 4186: 1–97.

Papp, A. & Schmid, M. E. 1985. Die fossilen Foraminiferen des tertiären Beckens von Wien. Revision der Monographie von Alcide d' Orbigny (1846). *Abh. Geol. Bundesanst*, Wien, 37: 1–311.

Pavlović, P. 1890. Mediteranska fauna u Rakovici [Mediterranean fauna in Rakovica – in Serbian]. *Geološki anali Balkanskoga poluostrva*, 2: 40–41.

Pavlović, P. 1893: Prinove Geološkog zavoda. [Noveltis from Geological Survey– in Serbian]. *Geološki anali Balkanskoga poluostrva*, 5 (1): 212–223.

Petković, B. 1912. Tektonska skica okoline Beograda [Tectonic sketch of the surroundings of Belgrade – in Serbian]. *Glasnik Geografskog društva,* 1: 47–55.

Petrović, M. 1962. Prilog poznavanju tortonskih foraminifera iz Beograda i bliže okoline [A con-

tribution to the knowledge of torton foraminifera from Belgrade and the surrounding area- in Serbo-Croatian]. *Geološki anali Balkanskoga poluostrva*, 29: 27–38.

Petrović, M. 1985. Foraminiferske zone i loze badenskog kata okoline Beograda [Foraminiferal zone and lineages of the Badenian stage of the surroundings of Belgrade – in Serbo-Croatian]. *Geološki anali Balkanskoga poluostrva*, 49: 271–291.

Pezelj, DJ., Mandic, O. & Ćorić, S. 2013. Paleoenvironmental dynamics in the southern Pannonian Basin during initial Middle Miocene marine flooding. *Geologica Carpathica,* 64 (1): 81–100.

Popa, V.M., Duma, A. & Săplăcan, A. 2014. Badenian gastropods from the collections of the Mureș County Museum. *Seria Geologie*, 60 (2): 5–30.

Rundić, Lj. & Knežević, S. 2017. The Miocene Fossiliferous sites of the Avala Mt. (Belgarde area, Serbia) and their importance. *Bulletin of the Natural History Museum*, 10: 29–41.

Rundić, LJ., Ganić, M., Knežević, S., Radivojević, D. & Radonjić, M. 2019. Stratigraphic implications of the Mio-Pliocene geodynamics in the area of Mt. Avala: new evidence from Torlak Hill and Beli Potok (Belgrade, Serbia). *Geologica Croatica*, 72 (2): 109–128.

Sant, K., Palcu, D., Mandic, O. & Krijgsman, W. 2017. Changing seas in the Early–Middle Miocene of Central Europe: a Mediterranean approach to Paratethyan stratigraphy. *Terra Nova*, 29 (5): 273–281.

Sant, K., Mandic, O., Rundić, LJ., Kuiper, K. & Krijgsman, W. 2018. Age and evolution of the Serbian Lake System: integrated results from Middle Miocene Lake Popovac. *Newsletter on Stratigraphy*, 51 (1): 117–143.

Spajić, O. 1975. Miocen Braničeva (stratigrafski prikaz) [Miocene of Braničevo (stratigraphic review) – in Serbo-Croatian]. *Geološki anali Balkanskoga poluostrva*, 39: 59–75.

Stevanović, P. 1970. Paleogeografsko-ekološke prinove iz tortona okoline Beograda [Paleogeographic-ecological novelties from the Tortonian of Belgrade vicinity – in Serbo-Croatian]. *Bulletin of Serbian Academy of Science and Arts,* 278, Department of Natural Science and Mathematics, 33: 1–26.

Stevanović, P. & Stepanović, B. 1939. Prethodna beleška o drugomediternskim slojevijma na levoj obali Topčiderske reke (var. Rakovica) i o njihovoj fauni [Previous note on the second Mediterranean beds on the left bank of the Topčiderska river (var. Rakovica) and their fauna – in Serbian]. *Geološki anali Balkanskoga poluostrva*, 16:134–136.

Studencka, B. 1986. Bivalves from the Badenian (Middle Miocene) marine sandy facies of southern Poland. *Palaeontologia Polonica*, 47: 3–128.

Studencka, B., Gontsharova, I. A. & Popov, S. 1998. The bivalve faunas as a basis for reconstruction of the Middle Miocene history of the Paratethys. *Acta Geologica Polonica*, 48: 285–342.

Toljić, M. 2016. Tectonic evolution of the European margin and Neotethys suture zone in the region of Belgrade (Northern Šumadija-Serbia). *WSEAS Transactions on Environment and Development*, 12: 268–277.

Vrabac, S. 1999. Facijalne i biostratigrafske odlike badena i sarmata sjeverne Bosne [*Facial and biostratigraphic features of Badenian and Sarmatian of northern Bosnia* – in Bosnian, with an English Abstract]. Unpubl. PhD Thesis University of Tuzla, 107 pp.

Vrabac, S., Ćorić, S., Đulović, I. & Ječmenica, Z. 2015. Diskordancija između badena i sarmata u profilu Spasine kod Ugljevika [Discordance between Baden and Sarmatians in the profile of Spasina near Ugljevik]. *Proceedings of the 1st Congress of Geologists of Bosnia-Herzegovina with International Participation, Tuzla*, 10–15.

Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K. 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science,* 292: 686–93.

Zachos, J.C., Dickens, G.R. & Zeebe, R.E. 2008. An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. *Nature*, 451: 279–283.

Žujović, M.J. 1886. Tertiär formation. Geologische Uebersicht des Königreiches Serbien. *Jahrbuch der k. k. Geologische Eeichsanstalt*, l: 71–127.

Резиме

Стратиграфска ревизија горњег бадена потока Раковице код Београда (Централни Паратетис, Србија)

У овом раду су представљени резултати биостратиграфских проучавања баденских (рани средњи миоцен) седимената Раковичког потока код Београда (централна Србија). На подручју Београда баденски седименти имају широко распрострањење и богати су разноврсним фосилима. Преглед претходних радова о рано средњомиоценским седиментима Раковичког потока (Петровић, 1962, 1985; Гаић и др., 2016; Рундић и др., 2019), нова теренска истраживања као и најновија истраживања околине Коцељеве (Јовановић и др., 2019а), указали су на неопходност стратиграфске ревизије ових седимената. Микропалеонтолошка и макропалеонтолошка испитивања која су у овом раду седименте Раковичког потока приписала доњем бадену, показала су постојање богате фауне, међу којом су мекушци и фораминифери, као и неки ретки нанофосили који су омогућили прецизно дефинисање старости истраживаних седимената. Биостратиграфска анализа се заснива и на подацима добијеним на основу старих музејских колекција. Као резултат ових истраживања утврђена је средњомиоценска (доњобаденска, НН5 Лагенидна Зона).

Наши закључци о фосилном запису бацају ново светло на стратиграфију раковичких седимената за даље студије и пружају користан ресурс за проучавање разноврсности фосилних заједница. Резултати показују око 150 врста мекушаца које се јављају на проученим профилима и у музејским збиркама. Многе врсте средњег миоцена које припадају изумрлим или постојећим врстама или родовима, забележене су и у региону Паратетиса. Поред тога, будућим истраживањима могао би се још повећати горе наведени укупни број мекушаца из бадена Раковице.

Током касног раног миоцена и средњег миоцена (бадена), у Централном Паратетису клима је била углавном супторпска. То се може закључити и за његов јужни обод на основу обиља термофилних врста мекушаца, као што су Conidae, Strombidae, Cypraeidae, Xenophoridae, Muricidae, Pleurotomidae etc. На основу проучавања литолошког састава, нанофосила, фораминифера и високог палеодиверзитета фауне мекушаца као и палеогеографског положаја, може се са сигурношћу закључити да су седименти Раковице настали у веома плиткој морској (сублиторалној) средини, током раног бадена. Богат и разнолик скуп мекушаца и других фосилних заједница указује на повољну подлогу, обиље хране и топло умерене до суптропске услове. Проучавања фосилних заједница које су овде датиране као доњобаденске, допринеће тачнијем разјашњавању биогеографске дистрибуције баденске фауне у региону и попуњавању празнина у биостратиграфској подели баденских седимената Србије. Такође би требало да допринесе бољем познавању палеоеколошких услова током раног средњег миоцена (бадена), када је зона топле климе била шира него данас. Закључујемо да је потребно наставити с ревизијом горњег бадена у Србији, Босни и Херцеговини и Хрватској, на локалитетима где је старост одређена само на основу зоне *Rotalia beccarii* zone (= *Ammonia viennensis*).

Manuscript received February 13, 2020
Revised manuscript accepted May 25, 2020