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Depth geological relations in the Timok Krajina, between Kladovo and Zaječar (eastern Serbia): based on surface, borehole and geophysical data

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Abstract. The titled topic refers to the area from the great meander of the Danube River in the north, to Zagrađe, south of Zaječar and, to the west, it mainly along the length of the mountain edge of the Carpathians, additionally with the intramountain trough of Borska Slatina. To the east of the state border, segments of the transborder area of Romania and Bulgaria are included. The total area of the amoeboid contour is about 2,500 km^2, within the orthogonally wider framed map. In geological sense, it includes the westernmost margin of the Dacian Neogene Basin, unconformably formed above the crease belt of the Krajina Pre-Carpathians which was affected by Laramyian-Pyrenean deformations; in the trough of Borska Slatina above the Intra-Carpathian magmatic-volcanic formation, and from the curved route east of the Peri-Carpathian contact as the whole cover of consolidated and block-shaped the Moesian Platform. A part of the abundant content of surface, field and cabinet paleontological-stratigraphic, primarily Neogene studies, resulting from the long-term research of recognized authors is displayed in an appropriate manner. Besides, individual representation and intervals from the sites of shallower drilling of different purposes were added. For the first time, the data related to the Neogene and older geological units from the deep boreholes are highlighted, and by well log interpretation and correlation positioned on the attached tables and illustrated with figures. For the first time, the geometry of indented base of the Cenozoic of the entire territory is presented, that is compatible with the geophysical primarily harmonized gravimetric and reflective-seismic indicators. In the Negotin - Zaječar area, we publish the first complex interpretation of the discontinuity of foothills formed as a result of the Alpine orogeny, by depth, above the paleomorphologically formed the Paleozoic Caledonian-Hercynian basement. The greatest thickness of Cenozoic deposits near Velika Vrbica, in the meander of the Danube River, has been interpreted up to 2,300 m, proved near Mala Vrbica (borehole Vb-1, 1,990 m) and, terminates in the Upper Cretaceus of the Carpathian foothills at a depth of 2,497.7 m . The oldest well-defined stratigraphic unit is the Ordovician in the Bukovče-1 borehole near Negotin, with a bottom of 1,982 m on the Krajina part of the Pre-Carboniferous to Sub-Jurassic interval of platform. The deepest borehole in the studied area is 55 Chilia 7, completed in the late Silurian of the Moesian Platform at a depth of 3,203.5 m.

Key words: *Paleontological findings, stratigraphic delimitations, correlation of wells, depth configurations, structural-tectonic interpretation, paleogeography, basinal Neogene, Carpathian foothills, Moesian Platform.*

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Апстракт. Насловљена тема односи се на простор од Великог меандра Дунава на северу, до Заграђа, јужно од Зајечара, а на западу начелно по дужини планинског руба Карпата, додатно са интрагорним ровом Борске Слатине. Источније од државне границе укључени су сегменти пограничних територија Румуније и Бугарске. Укупна површина амебоидне контуре износи око 2.500 km^2, унутар ортогонално шире урамљене карте. У геолошком смислу, обухваћен је најзападнији обод Дакијског неогеног басена, несагласно формираног изнад укљештеног појаса ларамијско-пиринејски тектонизованих Крајинских предкарпата; у рову Борске Слатине изнад интракарпатске магмато-вулканогене формације, а од закривљене трасе источно од перикарпатског контакта, као укупан покров консолидоване и блоковски обликоване Мезијске платформе. Прикладним поступком изложен је део обилног садржаја површинско-теренских и кабинетских палеонтолошко-стратиграфских, првенствено неогених проучавања, проистекао дугогодишњим ангажовањем признатих аутора, уз појединачну заступљеност и интервала са локалитета плићих бушења различитих намена. Овом референцом премијерно су истакнути подаци из дубоких бушотина неогене и старије геологије, који су каротажном корелацијом позиционирани на приложеним табелама и илустрованим сликама. Први пут се јасно конкретизује геометрија разуђене подине неогена укупне територије, компатибилно геофизичким, првенствено усаглашеним гравиметријским и рефлективно-сеизмичким показатељима. На простору Неготин-Зајечар објављује се и прва комплексна интерпретација дисконтинуитета предгорја Алпске тектонизације, дубински покровно изнад палеоморфолошки обликоване палеозојске каледонско-херцинске основе. Највећа дебљина кенозојских наслага код Велике Врбице у меандру Дунава интерпретирана је до 2.300 m, а доказана код Мале Врбице бушотином Vb-1 (1.990 m), завршеној у горњој креди Карпатског предгорја при дубини 2.497,7 m. Најстарији, бушотински одређен стратиграфски члан је ордовицијум у бушотини Буковче (Bu-1, са дном 1.982 m) на Крајинском делу подјурско-прекарбонске платформе. Најдубља бушотина на обухваћеном простору је 55 Chilia 7, завршена у млађем силуру Мезијске платформе у дубини 3.203,5 m.

Кључне речи: *Палеонтолошки налази, стратиграфска разграничења, корелација бушотина, дубинске конфигурације, структурно-тектонска интерпретација, палеогеографија, басенски неоген, Карпатско предгорје, Мезијска платформа*

Introduction

Timok Krajina covers the area of eastern Serbia located south of Kladovo, the Serbian part of the lower Danube and its hilly and mountainous hinterland, Negotin, Zaječar and its surroundings, bordering Romania in the north and Bulgaria in the east. Thus defined the square area is aprox. more than 2,500 km^2 (Fig. 1). It got its name from Timok, the largest river that drains the southern part of the area, all the way to the confluence with the Danube, south of Negotin. Mountainous terrain surrounds this area from the west, south and southeast (Kučaj, Deli Jovan, Miroč, Tupižnica, etc.). In the east, between Kladovo and the confluence of the Timok and the Danube rivers, the alluvial plain and terraces of the Danube (Cvijić, 1921; Petković, 1948; Dragišić & Polomčić, 1998) mark a large lowland known as the Dacian Basin. The lowest point in relief, and at the same time the lowest point in the whole of Serbia, is located at the confluence of the Great Timok and the Danube rivers (28 m.a.s.l.).

The study of the geological structure of the terrain of eastern Serbia has a tradition of over one hundred and fifty years. Special attention has been paid to the relationships of geological units on the surface, especially within and along the edge of the tectonized Carpathians. However, since the discovery of the Paratethys, a large epicontinental sea

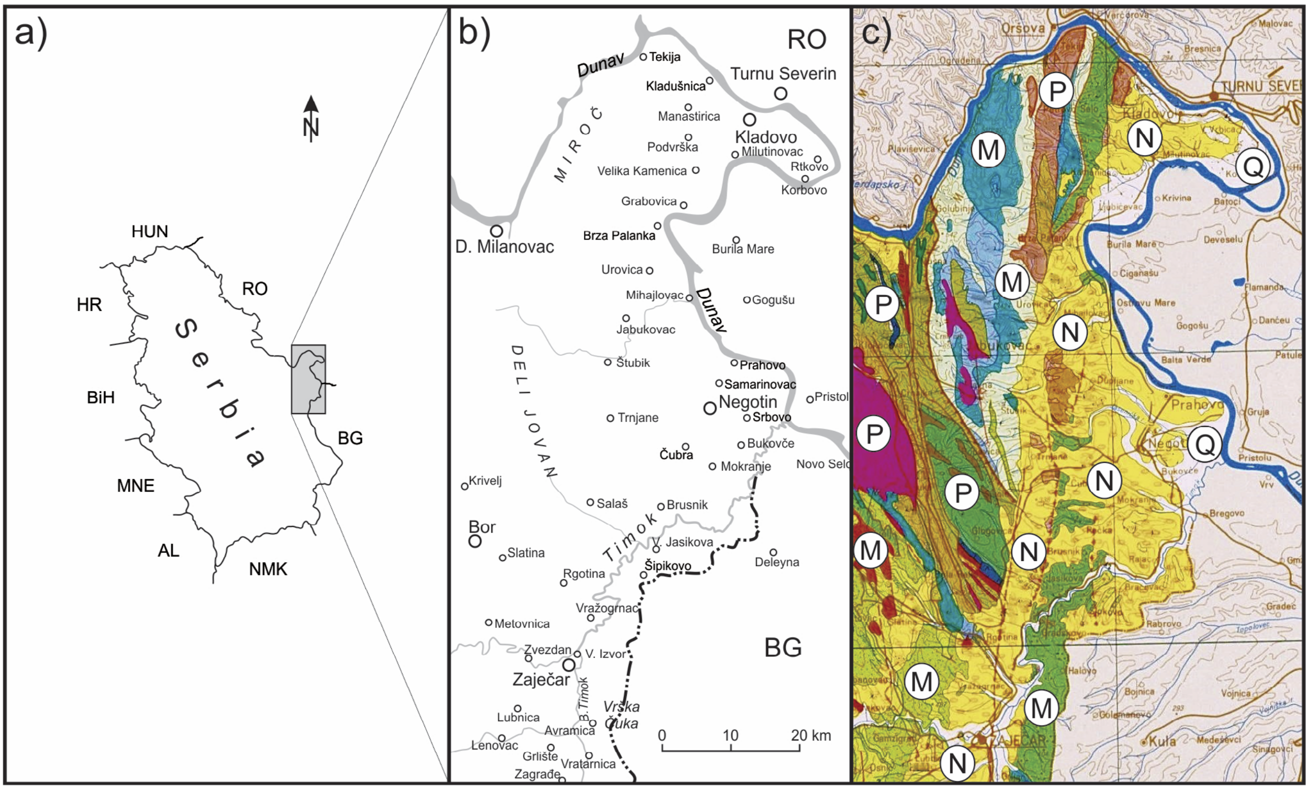

*Fig. 1. **a)** Geographical position of the studied area, **b)** Toponimic map, and **c)** The geological map of SFRY 1: 500 000, sheet 4 Belgrade, 1970). Key (modified and simplified): Q – Quaternary, N – Neogene, M – Mesozoic (flysch, andesites, carbonates and other sedimentary rocks), and P – Paleozoic (granite, gneiss).*

existed in the central and SE Europe (LASKAREV, 1924), interest in studying the younger, basin-like deposits of the Dacian Basin has grown. Much later, the development of geophysical methods and deep drilling has led to new and previously unknown data.

Recently, the most widely used tectonic division of the area of Serbia and beyond (SCHMIDT et al., 2020) includes the studied area of the Timok Krajina. Herein, the tectono-stratigraphic contents of several large entities collide: from Romania, parts of the rigid and stable the Moesian plate (European plate) are "drawn" under the southern Carpathians, which is laterally in "conflict" with the Carpathian-Balkan autochthon (Danubicum) and allochthonous units (Getic and Supra-Getic thrusts). They are extremely tectonized and represent the paleorelief and basement units for young, basin-based deposits in the Timok Krajina, i.e. western margin of the Dacian Basin (e.g. SCHMIDT et al., 2020; KRSTEKANIĆ et al., 2022). Keeping in mind the complexity of the Carpathian orogen as well as well-diverse the Miocene basinal units, the authors gave a simplified legend to mark only general relationships on the attached geological map (Fig. 1c), without distinct stratigraphic affiliation. Still, more details will be shown in the chapter of stratigraphy.

This study has an emphasized in-depth dimension of data interpretation, which distinguishes it from most previous studies in the research area. Earlier references refer mainly to the surface stratigraphy of the Neogene, in places and to the contact with the immediate basement (e.g. STEVANOVIĆ, 1977, 1989 and references therein). By combining geological and geophysical data based on own and partly previously published data, we drawn the thickness maps and subsurface geological models that were not previously available. Firts of all, it refers to the presentation of depth geometry of the Neogene basement and the configuration of the paleogeographic unconformity between the base of the Moesian Platform and the Alpine tectonized Pre-Carpathian cover. Therefore, this study contributes to better knowledge of the geological evolution of the Serbian part of Pre-Carpathians and the westernmost margin of the Dacian Basin.

Review of the earlier researches

The first geological data between the Danube and Timok Rivers were published by Toula (1877). Radovanović (1888, 1891) studied the Neogene rocks in contact with the basement along the length of the basin margin. Additionally, Radovanović & Pavlović (1891, 1893), Pavlović (1893, 1903), and Živković (1893) reported on abundant macro- and microfauna findings. Žujović (1889) produced the first "geological sketches" of Serbia, including the area of Krajina. Brusina (1902) cataloged fossil specimens outside the Pannonian domain, from the eastern Serbia and the bordering Bulgaria.

After the end of World War I, Cvijić (1921) described the Danube River terraces, and Pavlović (1923) analyzed fossils from the oolitic limestones of Crnomasnica. Laskarev (1924) defined the "Paratethys" as an intracontinental aquatorium that covered the western margin of the Dacian Basin and the Krajina area. Petković (1928) studied the Sarmatian deposits in the Braćevac vicinity. Petković (1930) among others, singled out the Đerdap thrust as a part of the Carpathian orogen, whose parts are partially exposed along the length of the foothill belt. Luković & Petković (1934) considered the existence of "intra-Sarmatian discordance". In same year, Laskarev limited the "Buglovian strata" to the basal part of Sarmatian (Laskarev, 1934). During 1932-1937, Pavlović M. significantly expanded Neogene paleontological studies, especially by engaging in the making of the Booklets for geological maps of Kladovo and Negotin (Pavlović 1932, 1937a, 1937b).

After World War II, the intensity of geological studies increased, along with the expansion of dedicated aspects of research and applied methods. Petković (1948) established the existence of deltaic sedimentation in the Kladovo area. Laskarev(1950) defined the "transitional" Buglovian strata as a zone of the lowest Sarmatian. Stevanović (1950, 1951, 1953, 1955, 1958) mapped Maeotian and Pontian in the vicinity of Kladovo and the Pontian on the Kobišnica plateau near Negotin, as well as the exposed Neogene deposits along the Carpathian foothills from Kladušnica to Brza Palanka. Pavlović (1953) wrote about Badenian deposits in Braćevac, near Negotin. Veselinović-Čičulić & Sikošek (1957) reported on the discovery of macrofauna from the Badenian/Sarmatian boundary, in the export shaft of the Lubnica coal mine near Zaječar. Stratigraphic contributions for the Maeotian and Pontian of eastern Serbia and elements of the Pre-Badenian and Badenian rocks in the Slatina Basin were published by Popović (1958, 1968). She singled out Badenian at the outcrops of the Zaječar surrounding, including Badenian in the well B-25 near Avramica (Popović & Gagić, 1969).

The hidrocarbon exploration began with the compilation of a map at scale 1: 300,000, by Marinović (1955, 1959) (field work at scale 1: 50,000 documented by paleontological findings) for the Sip-Rgotina-State border area, as well as the drilling of Rtkovo-1 borehole. For this purpose, during 1957-1958, the first gravimetric measurements and reflective-seismic profiling were performed. For historiographical reasons, we note here that all the deep exploratory drilling ("Naftagas", Novi Sad) was carried out between 1958 and 1974, and geomagnetic measurements between 1965-1967 ("Geozavod" Fund, Belgrade). The first in-depth stratigraphic evaluations based on well logging records, as a model with paleontological findings, were authorized by Marinović (1971) as the annex no. 5 of reference by Boškov-Štajner & Marinović (1971). A part of the cores from the Bukovče-1 borehole (E-SE of Negotin), regarding the Ordovician-Devonian age, were published by Pantić & Šećerov (1975). The gravimetric map at scale 1: 500,000 was publicly displayed (Arsić et al., 1976). The maps of a densened gravimetric network with different filters and the map of the geomagnetic vertical gradient for a part of the Bor-Zaječar magmatic-volcanic belt were published by Bilibajkić (1986).

In the period 1959-1989, Džodžo-Tomić (1963, 1969, 1970) independently or in co-authorship with Čičulić and Popović R. of the internal report for the Basic Geological Map, sheet Bor (Kalenić et al., 1976) was distinguished the micropaleontological zones of the Badenian and Sarmatian. Marković-Marjanović (1967) treated the Quaternary of the Kladovo area in a manner comparable to the transborder territories. Milovanović & Ćirić (1968) published the "Geological map of SR Serbia" at scale 1: 200,000. Here, its parts of the eastern half-sections of Oršava and Zaječar were partially used for a simplified compilation of the basin margin. Petrović (1961, 1969, 1988) distinguished the Badenian and Sarmatian foraminifer biozones of the Štubik trough, as well as beyond. Ercegovac (1963) determined the fossil flora between Brza Palanka and Negotin. Stevanović (1964) renewed detailed macropaleontological studies in certain areas of the premountain Neogene, including intramountain development near Borska Slatina, and later (1977-1981), individually and in other areas. Dolić (1977) reported on Neogene between Negotin and Zaječar. During 1981 and 1983, in the localities of the Danube belt of the Negotin area, the same author independently or jointly worked in detail on instructive outcrops of the condensed Neogene (Stevanović, 1977; Stevanović & Dolić, 1981). Here, we single out the reference Stevanović (1989) and his engagement as one of co-editor and co-author of the book on Pontian from the well-known edition entitled "Chronostratigraphie und Neostratotypen, bd. VIII". His author's and co-authorized chapters refer to the western margin of the Dacian Basin.

Additionaly, the route of the principal delimitation of the Carpathian foothills with the Moesian platform, textually and graphically with the locations of wells, were shown by Atanasiu & Chiriac (1965), Bâncila (1967), and Barbu & Vasilescu (1967). Important data of the nearest (shallow) transboundary boreholes were given by Bokov et al. (1965), and Kojumdgieva et al. (1982, 1989). Broader geological-paleogeographic, mainly pre-Neogene considerations were published by Bonchev (1980).

After 1990, primarily paleontological-stratigraphic contributions on Neogene of the studied area were published (e.g. Krstić, 1991; Krstić & Milićević, 1995; Mihelčić & Dodiković, 1995; Mihajlović & Krstić, 1995; Tanasković et al., 2014; Đajić et al., 2019; Rundić et al., 2015, 2018, 2019).

Material and Methods

The material and data are the result of the co-authors own research, and are partly taken from previously published works and archive materials of other authors. Localities with selected paleontological findings, primarily from the Neogene period, are briefly presented in the stratigraphic chapter, and additionally with several samples from very shallow boreholes and from one mining shaft. Paleontological-stratigraphic determinations of the basement rocks were taken from other authors (clearly mentioned in the text and figure captions). On the other hand, similar analyses of macro- and microfauna related to Neogene deposits are largely the result of the work of the author's team.

In-depth interpretations come from thirty boreholes, between 30 m and 3,203.5 m. Of these, twenty-six boreholes are from Serbia, and two boreholes each from the border areas of Romania and Bulgaria. Deep boreholes are sparsely cored, but have continuous 5-meter "sieve“ samples, with the depths of their upper intervals recorded on the tables or in the text. For discretionary reasons, the coordinates of the boreholes are not given. Their approximate locations are indicated on the corresponding maps in the text. Important boreholes with the Paleozoic, Mesozoic and Cenozoic paleontological findings, as well as other specific data from the Carpathian foothills and the Moesian Platform, are presented in tables and illustrated in the figures.

The intervals with established (sensu stricto) paleontological elements were vertically extended in both directions according to the petrological composition on the registered electronic records of well log diagrams. Stratigraphic delimitation by well logging is an original work by the first author. Extended intervals of stratigraphic delimitations are correlatively connected and written on the figures and tables. The well log measurements included all deep boreholes in the Kladovo foothill area and the Negotin platform area, and (for technical reasons) from the bottom of the "introductory column" continuously to the bottom of each borehole. The subsurface models and depth relations defined in this way were supplemented with a new data from the Borska Slatina and Zaječar boreholes, as well as from the terrain surface. All of this is documented with appropriate figures, photographs and tables. The boreholes of the Zaječar Neogene trough and the Borska Slatina intramountain trough have not logged, but more often to continuously cored. The cored samples were grouped by genetically determined facies using the petrological-sedimentological method. From the top of the package of coal-bearing rocks of swamp facies, the age of zircons grain of 16.9 Ma from the tuff layer was taken from the literature (Karpatian Stage of the Lower Miocene).

Among the geophysical disciplines, apart from the already mentioned well log measurements, gravimetric and reflective-seismic methods were used. Geomagnetic methods, outside the orogenic area, of uniformly low intensity, were consulted for information purposes only. The cartography of gravimetric method covered the entire study area. Networks of analog seismic surveys were reproduced in depth in the area of Kladovo and the Negotin platform segment, while the area between Negotin and Zaječar was networked using the CDP method of digital reproduction.

On the basis of integrated surface and subsurface data applying the above-mentinoned methods, for the first time, the map of configurations of the base of Neogene of the Kladovo - Negotin area, extended with the Zaječar and Borska Slatina troughes, as well as a map of the sub-Mesozoic discordance i.e. Paleozoic/Mesozoic boundary in the Negotin - Zaječar area were compiled.

Stratigraphic settings

Paleozoic

Paleozoic rocks were confirmed by boreholes only in the area of the Moesian Platform. The oldest stratigraphic member in the Bu-1 borehole (Bukovče, east of Negotin) is Ordovician (Fig. 2). In addition to polimictic quartz sandstones, there are a lot of arkose-subarkose clastites and laminated siltstones, which at a depth of 1,971–1,979 m contain tissues of primitive plankton and Laminatites algae of a wider stratigraphic range (Pantić & Šećerov, 1975). Silurian predominantly fine-grained dark clastites and pelites of the interval 1,597-1,604 m are characterized by well-preserved acritarch plankton (Pantić & Šećerov,1975). Dark gray biomicrites interlayered with fine-grained clastites, in the core 1,318-1,325 m, contain small brachiopods and mollusks (det. by D. Urošević). Devonian assigment of dark gray to black siltstones and laminites of the core 1,192-1,198 m, were based mainly by triletes spores (Pantić & Šećerov, 1975 – see Fig. 2). In this work, the Devonian is vertically extended by logging to the unconformable the Upper Jurassic cover, down to 1,070 m. The upper limit of the more complete Devonian of the 55 Chilia 7 borehole is determined at a depth of 1,714 m (Bâncila, 1967), below the undivided Upper Jurassic-Lower Cretaceous cover (Fig. 3).

Mesozoic

In the Prahovo-1 borehole (Naftagas, 1959), in the "sieved" sample at 1,580 m, and in the core at 1,403.3 m, bryozoan and brachiopod marly sandstones with *Rynchonella* sp. and fragments of bivalves were recorded (Fig. 4). From the sandstone-limestone deposits at 1,352.5–1,355.9 m, the Middle „Liassic“ brachiopods were determined: *Spiriferina verucosa*, *S. deslongchampsi*, *Konincina* sp., fragments of crinoids and mollusks (Veselinović D., In: Boškov-Štajner & Marinović, 1971). It is discordantly overlain by limestones of synsedimentery conglo-breccia structure with algae *Clypeina jurassica*, *Pianella* sp., larger foraminifers *Coskinolinopsis* sp., hydrozoans and bivalves detritus (Čanović, 1974) which are delimited in depth from 1,235–1,319 m by well logging (Fig. 4).

Comparable limestones are found in the Bu-1 borehole, which are delimited by the logging from 928 to 1,070 m (Fig. 2). The interval 920-927 m contains gymnosperm pollen in the Upper Jurassic-Lower Cretaceous range: benetites ginkgoacea and brachyphyllum (det. by S. Pantić). The sediments at a depth of 750-759 m with algae such as *Bacinella irregularis*, *Salginporella jonsoni*, *Cayeuxia anae*, *Actinoporella* sp., foraminifera, mollusk detritus, urchins, etc. confirmed the Lower Cretaceous age. From the core 406-415 m, similar algae and small foraminifera of the late Lower Cretaceous were determined (Čanović, 1974). From the cored intervals of 310-319 m, marly, basinal sediments of the early Cretaceous contain an microassociation with

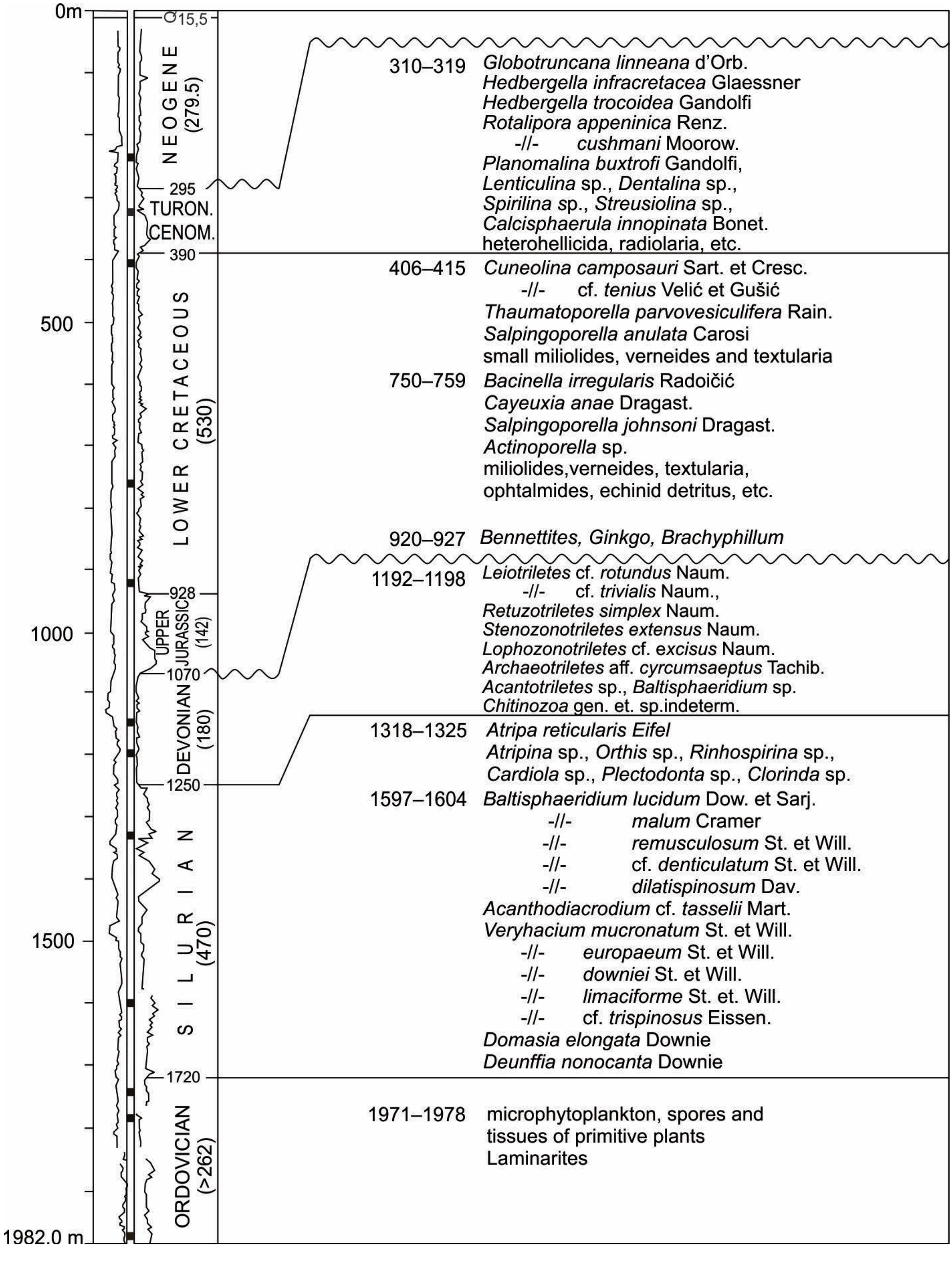

Fig. 2. *The Negotin area. Borehole Bu-1 (Bukovče). Findings of fossils in the Pre-Neogene formations. Paleontological determinations by M. Čanović, D. Urošević, N. Pantić, and P. Šećerov. Stratigraphic delimitation according to well logging by ĐM.*

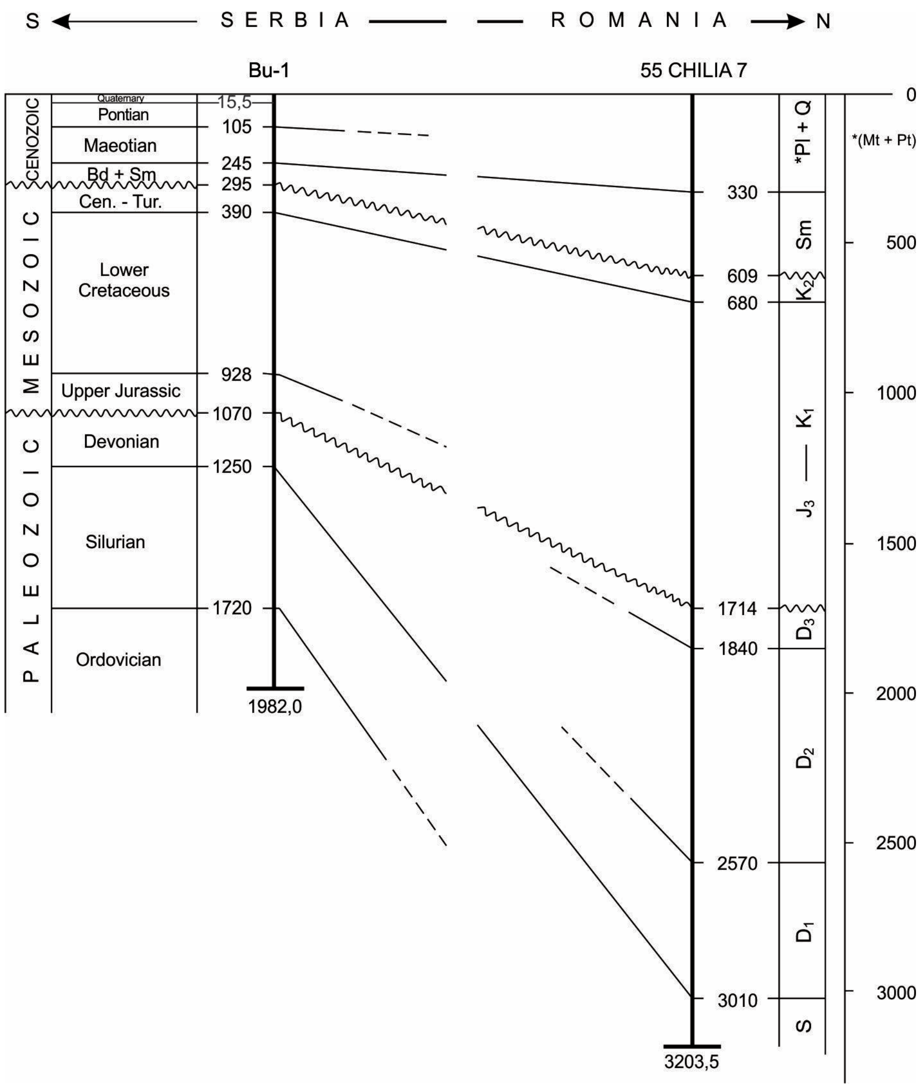

Fig. 3. *A schematic depth-stratigraphic correlation between Bukovče–Chilia.*

Globotruncana lapparenti lapparenti, *Gl. tricarinata*, *Hedbergella tricoidea*, etc.) was determined (Tab. 4). The „Senonian“ segment in the Vu-1 well was cored at depths of 1,735; 1,800; 1,901, and 2,021 m; in borehole Vb-2 at depths 1,915; 1,958; 2,044; 2,117, and 2,190 m and in bo-rehole Vb-1 at depths 2,171; 2,273, and 2,430 m. In those samples, foraminifers such as *Globotruncana lapparenti lapparenti*, *G. linneiana*, *G.* cf. *appenninica*, *G.* cf. *fornicata*, *Marsonella oxigena*, *Verneulina bronni*, *Glan-doyina bavariana*, etc. were recorded (det. by M. Čanović – Tab. 4). The total, by logging delimited "Senonian" has the greatest thickness in the area of the Vb-1 well, at a depth of 1,990-2,450 m (460 m) (Fig. 5).

Globotruncana linneiana, *Hedbergella infracretacea*, *H. trocoidea*, *Rotalipora appenninica*, *R. cushmani*, etc. (Čanović, 1974). The total uneroded interval in the Neogene basement of the Bu-1 well is delimited from the Badenian base at 295 m to the logging determined cover of the Lower Cretaceous, at a depth of 390 m (Fig. 2).

In the belt of crowded tectonization of the Carpathian foothills the Cenomanian-Turonian and "Senonian" segments of the Upper Cretaceous flysch development are distinguished (Tabs. 1, 4). The Cenomanian-Turonian segment in the Vajuga-1 borehole was determined (here in the upper intervals) in cores 2,021 and 2,085 m, and in the core of the Vrbica-1 borehole from a depth of 2,497 m with small Inoceramus bivalves. Numerous microfauna (e.g. *Praeglobotruncana delrioensis*, *Praeglobotruncana* sp.,

In addition to clastic-carbonate deposits, the Upper Cretaceous magmatic-volcanogenic rocks of so-called the Timok magmatic complex in the area of the Borska Slatina intra-mountain trough and the Zaječar trough was also noted (Fig. 6).

As a rule, the well-known Upper Cretaceous Timok andesites with Cu-Au mineralization are found in the deepest part of that complex (e.g. 534-1,680 m, abbr.name 1; 432 -798 m, abbr.name 6, and 591- 600 m, abbr.name 8 - see Tab. 2). Variously altered andesitic epiclastites (Metovnica Fm.) occur above different varieties of andesite (Rundić et al., 2015; Banješević et al., 2019). Fine-grained sandstones, marls and siltstones of the Upper Cretaceous Oštrelj Formation are often deposited over them. Stratigraphically, the youngest part of the pre-Neogene rocks is represented by the so-called the

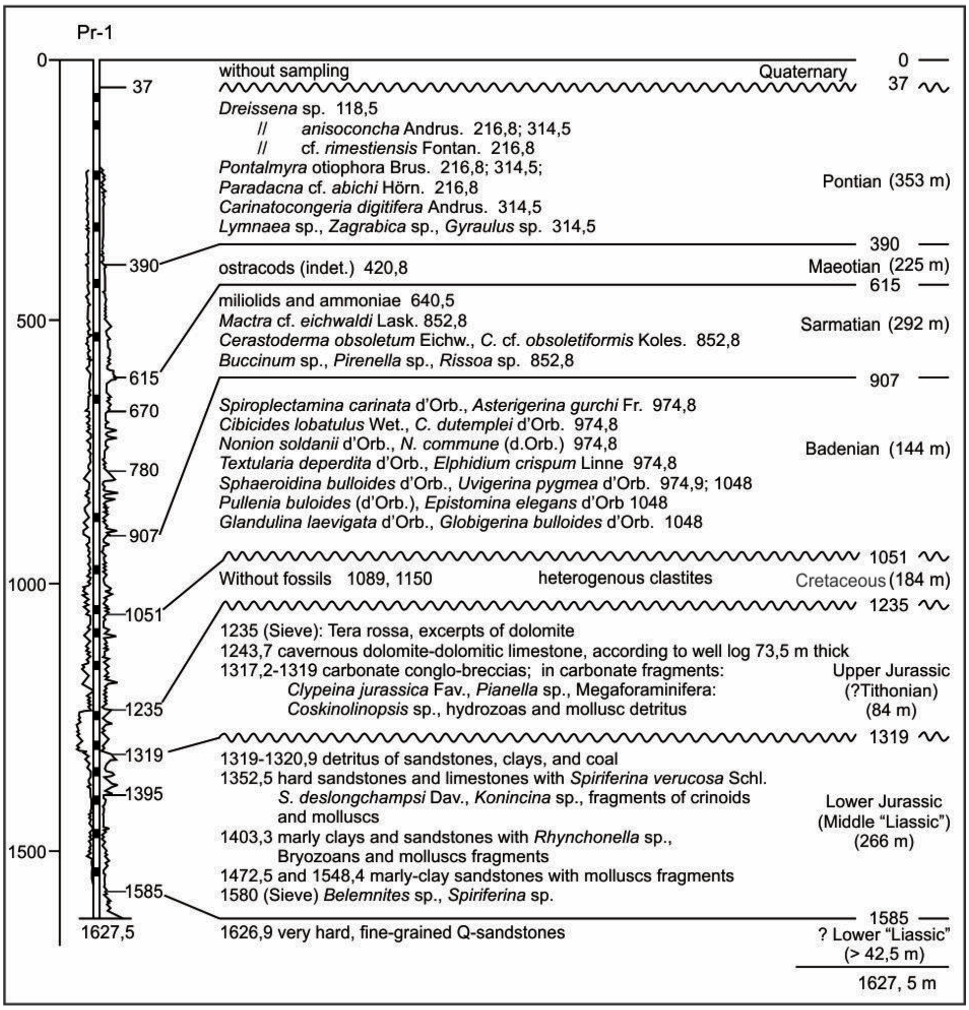

Fig. 4. *The Negotin area, borehole Pr-1 (Prahovo). Extracts of fossil findings. The depths of the upper core interval. The base of Neogene with lithological features. Paleontological determinations: P. Janković, V. Marković, M. Čanović and D. Veselinović. Stratigraphic delimitations according to the well logging by ĐM.*

Cenozoic

The presence of Cenozoic sedimentary rocks has been confirmed in the mentioned exploration boreholes, as well as in numerous surface outcrops and profiles.

Pre-Badenian (Uppermost Oligocene? - Lower Miocene)

At Kladovo, with this reference, the sediments of colluvial-torrent genesis, with no fossils found in boreholes Vu-1, Vb-1 and Vb-2, were singled out as the pre-Badenian (Uppermost Paleogene - Lower Miocene). These clastites sourced from the Carpathian barrier overlie the flysch of the Upper Cretaceous (Fig. 5, Tab. 3).

The Lower Miocene of lacustrine character was discovered near Brza Palanka (Stevanović, 1964, 1977). In the streams of Selište and Prlitur, a clastites series (sands, gravels) with interlayers of clay and a thin layer of coal appears under the Badenian clays with *Nucula nucleus* (Linne). The abandoned lacustrine pre-Badenian coal mine is in the isolated Aliksar hollow.

In the area of Zaječar, in the Zvezdan and Lubnica mines, the lacustrine series, in the base of marine Lower Badenian consists of clay, marly clay, marl and sandstone with coal, in which freshwater taxa such as Planorbis, Hydrobia, Prososthenia, Pisidium, Unio, etc. have been found (Veselinović-Čičulić & Sikošek, 1957).

In the area of Zaječar (Tab. 2), Lower Miocene sediments were determined in the following boreholes near Kraljevica, in boreholes abbreviated

Bor clastites (rolls and fragments of limestone, marl, andesite, etc.) which is considered to belong to the uppermost Paleogene, in addition to the Upper Cretaceous (Fig. 6, Tab. 2). In the Zaječar trough, apart from the mentioned carbonate-clastic rocks and andesites and their altered varieties, in the boreholes N-1 (? 630-690 m) and R-1 (585-635 m), the lower Cretaceous deposits represented by Valanginian limestones and/ or Albian glauconitic sandstones (Rundić et al., 2019).

Except in the boreholes, the basement rocks can be seen and on the surface, that is shown on the corresponding maps of the depth configuration (Figs. 11-13 – given in the chapter Structural-Tectonic and Paleogeographic Interpretation).

***Table 1.** The Kladovo area. Lithology of the base of Neogene with tectonic elements.*

Borehole, and depth interval (m)	Lithology of the sample	Dip angle (°) and Harnisch (h)	
	Flysch of the South Carpathian Foredeep (Upper Cretaceous)		
Vb-1			
2013,3-2016,7	Gray marly siltstone, fine-grained sandstone	80	(h)
2088,7-2092,0	Gray siltstone marl, marly sandstone	85-90	–
2171,6-2175,3	Gray-black-dark gray laminated clayey-sandy siltstone	90	(h)
2273,3-2279,0	Dark gray laminated claystone, marly siltstone		
2347,0-2343,0	Dark greyish-brown laminated siltstone. Claystone, gray fine-grained sandstone	10-50 80	– (h)
2420,0-2423,3	Brownish-red sandy crushed claystone (? mylonite)	Undefined	
2497,0-2497,7	Gray-red marl interlayered with fine-grained sandstone and marly limestone; small *Inoceramus* shells	10-15	–
Vb-2			
1915,9-1918,4	Layered gray marly sandstone, siltstone, claystone.	5	–
1958,5-1963,9	The same composition	45-90	(h)
2044,3-2050,3	Laminated fine-grained pelites and claystone.	5	–
2088,7-2092,0	The same composition	Ø	Ø
2117,3-2122,0	Gray fine-grained clayey-marly sandstone interlayered with claystone.	60	(h)
2190,02196,0	Limestone to carbonate sandstone with reddish-brown claystone and gray siltstone interbeds	30-40	(h)
Vu-1			
1679,7-1682,3	Gray marly siltstone and sandy marl	80	–
1682,6-1684,6	The same composition	Ø	–
1735,3-1737,2	Darkish siltstone and fine-grained marly sandstone	Ø	–
1800,5-1805,2	Gray argillaceous siltstone with transitions to reddish clay and marly sandstone	10-40	–
1901,3-1903,9	Gray to reddish marly siltstone and marly limestone	10	–
2021,8-2024,3	Greyish-brown cracked limestone with brown-reddish clay	90	(h)
2086,6-2088,1	Greyish-brown hard sandstone with transitions to marly limestone	45	–
	The platform (Upper Jurassic - Lower Cretaceous)		
Rt-1			
1863,0-1868,8	Whitish cavernous limestone	Unexpressed	
1919,8-1923,0	Fragment of whitish limestone	Ø	Ø
1968,0-1973,4	Whitish cracked limestone	Ø	Ø
2038,0-2042,5	Saccharoidal dolomitic limestone	Massive	
Kor-1			
1632,3-1636,3	Whitish cryptocrystalline limestone with microfauna (heterochelicids, textulariids, spicules)	Ø	Ø
1707,0-1713,0	Whitish dolomitic limestone with shell fragments (indeterm.)	Undefined	

index R -1 (at a depth of 320 - 585 m), R – 2A (395 - 530 m) and R – 3 (from ?100 - 188 m) (VASIĆ et al. 2018, RUNDIĆ et al. 2019) and near Zvezdan in borehole N-2 (0-165 m) (VASIĆ et al., 2018, RUNDIĆ et al. 2019). In these depth intervals, sandy-pebble clastites, limestones and marls with coal occurrences and coaly clays of alluvial-lacustrine and swampy character prevail. Rare shells and snails were found among the macrofauna: *Gyraulus* sp., *Planorbarius* sp., *Planorbis* sp., *Prososthenia* sp., *Fossarulus* sp., and from the ostracod fauna the genera *Candona* sp., *Fabaeformiscandona* sp., *Ilyocypris* sp., ?*Dinarocythere* sp., *Candonopsis* sp., ?*Cypria* sp. The bedrock distribution of the mentioned clastites is shown on Table 2. Radiometric dating of zircon grains from tuff interlayers of the coal series (sample from borehole index N-2, depth 34 m), was found the age of 16.9 Ma, which corresponds to the Lower Miocene, i.e. the Carpatian stage (RUNDIĆ et al. 2019).

Middle Miocene

Middle Miocene sedimentary successions are divided into Badenian, primarily marine genesis, and Sarmatian, brackish one. On the surface of the studied area and in boreholes, these rocks are the most widespread Miocene units.

Badenian Stage

The Badenian sediments on the surface are mainly distributed along the western, southwestern and southern rim of the Dacian basin in steep bays, sections and stream banks that appear from Sip and Davidovac in the Danube meander (STEVANOVIĆ, 1958),

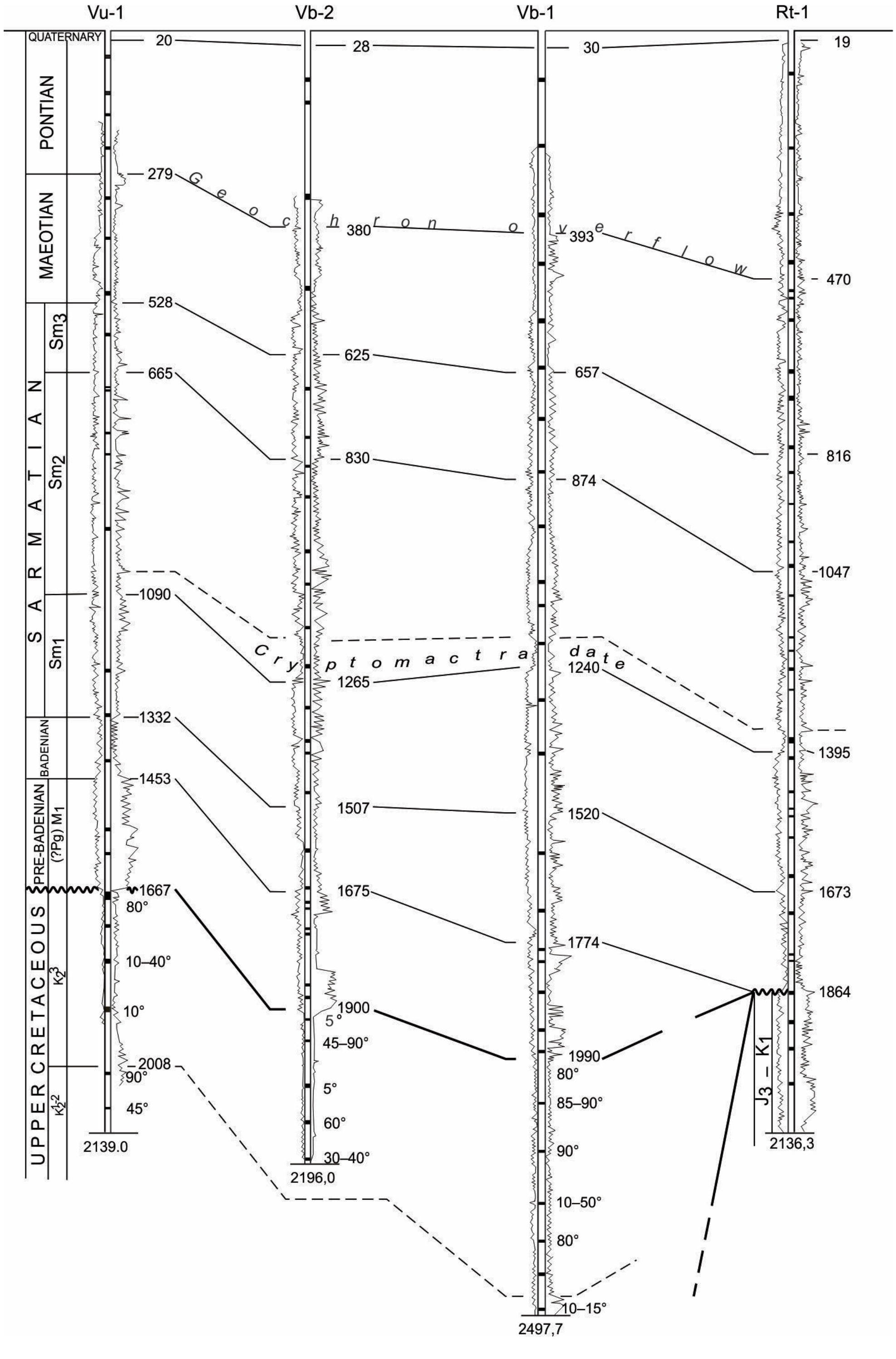

Fig. 5. The Kladovo area. Stratigraphic delimitations according to the well logging, additionally Quaternary cover; in the Neogene basement with dip angles.

of smaller oases. In the middle area, they transgressively include "zones of exhumed paleo-relief" (STEVANOVIĆ, 1964).

The oldest Lower Badenian rocks were found in the Štubik trough, in the centre of the village of Malajnica. According to the mentioned references, they correspond to the lowest part of the Lagenidae zone. The blue, "fat" clays, contain the foraminifers such as *Dentalina adolphina*, *D. semicostata*, *Nodosaria radicula*, *N. rudis*, *Uvigerina macrocarinata*, *U. auberina*, *Nonion pompiloides*, *Cibicides badenensis*, *Siphonodosaria adolphina*, *S. verneuili*, *Textularia mayeriana*, *Pyrgo bulloides*, *Elphidium flexuosum*, etc. The upper level of the Lower Badenian is represented by the *Orbulina suturalis* and *Globigerinoides trilobus* zones (PETROVIĆ, 1967, 1969).

In the Zaječar area, in borehole B-25 of 8-24 m, marly sandstones and sandy clays have mollusks *Loripes dentatus*, *Venus multilamella*, *Anadara diluvii* and foraminifers of the lower Lagenidae zone *Robulus rotulatus*, *R. calcar*, *Nonion pompiloides*, etc. (POPOVIĆ & GAGIĆ, 1969). The mentioned clastites lie transgressively over the Lower Miocene lacustrine deposits.

In Samarinovac, a borehole with the abbreviated index S-1 (Fig. 11) revealed sandy-clays and sand-

via Urovica, Jabukovac, Štubik, Salaš, Braćevac, Koprivnica, Rgotina, Nikoličevo and Veliki Izvor to Vratarnica in the south. Badenian is widely distributed in the southern part of the studied area, while in the northern parts is discovered in the form

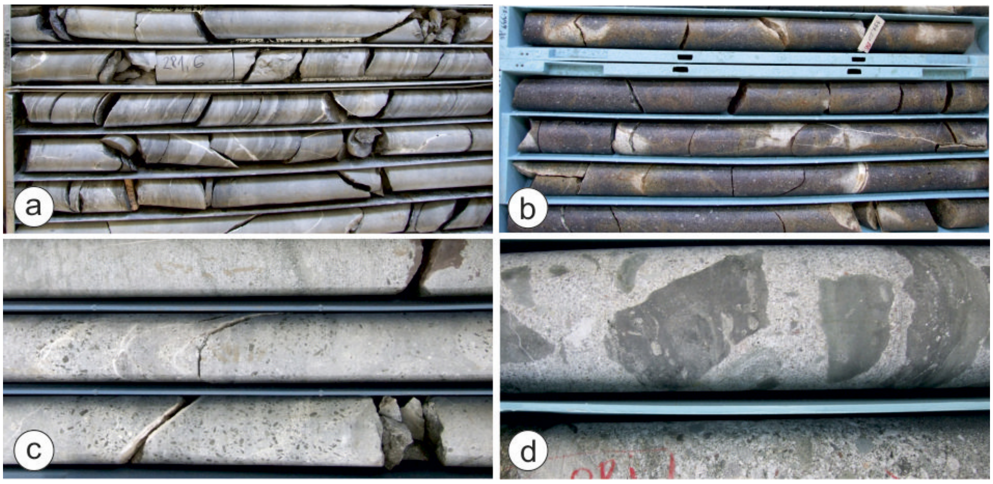

Fig. 6. Different pre-Neogene basement rocks in some of the Borska Slatina boreholes; ***a)*** *The Upper Cretaceous tectonized marls (abbr.name 2; 284-288 m),* ***b)*** *Andesitic epiclastites (abbr.name 7; 398-403 m),* ***c)*** *Andesites (abbr.name 5; 592-595 m), and* ***d)*** *Bor clastites (abbr.name 5; 235–236 m).*

stones in the interval 325-350 m. The foraminiferal association is represented by the species: *Orbulina suturalis*, *O. bilobata*, *Praeorbulina glomerosa*, *Globigerina bulloides*, *G. quinqueloba*, *Quinqueloculina akneriana*, *Q. consobrina*, etc. Based on the identified microfauna of foraminifera and ostracods *Henryhowella asperrima*, *Cytheridea hungarica*, *Heterocythereis mehesi*, *Pokornyella deformis*, etc. as well as remnants of macrofauna, these clastites correspond to the upper level of the Lower Badenian.

Besides, in a few localities the Upper Badenian has been proven. In the deep stream of Trnjane, gray-green clays were discovered at the bottom of the profile, and sands and gravels with macrofauna above: *Glycimeris pilosus*, *Venus multilamella*, *Cardita partschi*, *Spondyllus crassicosta*, *Corbula carinata*, *Murex hoernesi*, *Ancilla glandiformis*, *Volutha rarispina*, etc. These mollusks are age correlative with the microfaunistic association of foraminifera that corresponds to the Bulimina-Bolivina zone (det. V. Marković): *Asterigerina planorbis*, *Quinqueloculina hauerina*, *Q. seminulum*, *Bolivina punctata*, etc. (Stevanović, 1981).

In the village of Veliki Izvor, the outcrops built of weakly bound conglomerates, sandy conglomerates and siltstones with coral nests have been found (Ganić, 2019). By our new research, among macrofauna, a few corals species were identified: *Heliastrea defrancei*, *H. reussiana*, *Favites* sp. *Favia* sp. *Stilopora* sp. (Fig. 7); scaphopods: *Dentalium bade-nensis*; bivalves: *Pecten aduncus*, *P. besseri*, *Ostrea digitalina*, *O. lamellosa*, *Spondylus* sp.; gastropods: *Conus dujardini*, *Nassa notterbecki*, *Clavatula laevigata*, *Turritella erronea*, *Terebralia bidentata lignitarum*, etc. Among the microfauna, the most abundant foraminifera species are *Ammonia beccarii*, *A. viennensis*, *Asterigerinata planorbis*, *Martinottiella communis*, *Bolivina digitalis*, *Cibicides boueanus*, *Amphistegina hauerina*, *Dentalina boueana*, *Nonion commune*, etc.

Within the Borska Slatina intramountain trough, the most instructive sections in the Dosluj and Kusak streams were found (Popović, 1968). The various clastites contain mollusks such as *Divaricella* (*Lucinella*) *ornata*, *Donax* (*Paradonax*) *intermedia*, *Anadara diluvii*, *Ostrea digitalina*, *Pirenella picta mitralis*, *P. picta bicostata*, *Conus* (*Conolithus*) *dujardini*, etc. The new collected microfaunistic assemblages with dominance of *Ammonia beccarii*, *Cibicides dutemplei*, *Rotalia viennensis*, *Elphidium crispum*, *Borelis melo*, etc. corresponds to the *Ammonia beccarii* Zone.

Transitional Badenian/Sarmatian sedimentary succession was found above 87,1 m, and it overlie the freshwater lacustrine series of the "Zvezdan" coal mine. It contains mollusks such as *Lucina ornata*, *L. dentata*, *Arca diluvii*, *Chama gryphoides*, *Terebra transilvanica*, *Pectunculus*, sp., *Cerastoderma* ex gr. *vindobonense*, *Pirenella picta*, *P. disjuncta*, *Cerithium rubiginosum*, *Buccinum shöni* and others.

Badenian sediments were also determined in the boreholes: near Borska Slatina (abbr. indexes 3, 9, 10) (Rundić et al., 2015), then in the Zaječar trough at Kraljevica in boreholes (abbr. indexes R-1, R-2A, R-3) and, near Zvezdan (abbr. indexes N-1), which are transgressive over the freshwater series (Vasić et al., 2018, Rundić et al., 2019 – Tab. 2). Herein, the determined mollusks and foraminifers in a clastic series corresponding to the Upper Badenian, i.e. the Bolivina - Bulimina Zone. By exploratory drilling around Kladovo, Badenian rocks were isolated in the

***Table 2.** The Bor–Zaječar area. Excerpts of borehole data of the base of Neogene.*

Abbr. name (Fig. 12)	Original name of borehole	Depth intervals of the pre-Neogene formations (m), lithology and stratigraphic level	Reference
		Borska Slatina trough	
1	FMTC-1335	23- 345 Bor clastites, Upper Cretaceous-Paleogene 345-480 Siltstones & Marls, Upper Cretaceous (Oštrelj Fm.) 480-534 Andesitic epiclastites, Upper Cretaceous (Metovnica Fm.) 534-1680 Timok andesite with Cu-Au, Upper Cretaceous	Rundić et a. 2015, Banješević et al., 2019
2	FMTC-1210	131-284 Bor clastites, Upper Cretaceous-Paleogene 284-450 Marls, Upper Cretaceous	Rundić et al. 2015
3	FMTC-1332	Non-drilled	ibid.
4	FMTC-1107	52,5-78 Bor clastites, Upper Cretaceous-Paleogene 78-94 Marls, Upper Cretaceous	ibid.
5	FMTC-1346	178-447 Bor clastites, Cretaceous-Paleogene 447-592 Marls, Upper Cretaceous 592-600 Andesites, Upper Cretaceous	ibid.
6	FMTC- 1213	269-416 Marls and siltstones, Upper Cretaceous (Oštrelj Fm.) 416-432 Andesitic epiclastites, Upper Cretaceous (Metovnica Fm.) 432-798 Timok andesites with Cu-Au, Upper Cretaceous	Rundić et al. 2015, Banješević et al., 2019
7	FMTC- 1216	215-337 Marls, Upper Cretaceous 337-403 Andesites and its clastites Upper Cretaceous	Rundić et al. 2015
8	FMTC-1339	316-442 Bor clastites, Upper Cretaceous-Paleogene 442-591 Siltstones & Marls, Upper Cretaceous (Oštrelj Fm.) 591-600 Andesites, Upper Cretaceous	ibid.
9	FMTC-1331	360-368 Bor clastites, Upper Cretaceous-Paleogene	ibid.
10	FMTC-1109	437-525 Bor clastites, Upper Cretaceous-Paleogene 525-560 Marls, Upper Cretaceous (Oštrelj Fm.) 560-562 Andesites and its clastites, Upper Cretaceous	ibid.
		Zaječar trough	
N-2	NRKR-17002	165-900 Upper Cretaceous-Paleogene Metovnica Fm.	Vasić et al., 2018, Rundić et al., 2019
R-3	RTK-1503	188-930? Upper Cretaceous-Paleogene Metovnica Fm.	ibid.
R-2A	RTK-1502A	530-560 Andesite clastites, Upper Cretaceous-Paleogene Metovnica Fm	ibid.
R-1	RTK-1501	585-635 Limestones, Lower Cretaceous (Valanginian)	ibid.
N-1	NRKR-17001	128-585 Upper Cretaceous-Paleogene Metovnica Fm. ?585-?630 Fine-grained clastites, Upper Cretaceous (Cenomanian) ?630-?690 Glauconitic sandstones, Lower Cretaceous (Albian)	ibid.
		Avramica hollow (informative)	
	B-25	136-454 Lower Cretaceous, 454-713 Upper Jurassic, 713-1023 Middle Jurassic, 1023-1025 Lower Jurassic	Geological Survey Found
	B-26	0-468 Lower Cretaceous, 468-544 Upper Jurassic, 544-689 Middle Jurassic, 689-799 Lower Jurassic, 799-815? Paleozoic	ibid.

Vajuga, Vu-1 (1,332-1,453 m), Vrbica, Vb-2 (1,507-1,675 m), Vb-1 (1,520- 1,774 m) and Rtkovo, Rt-1 (1,673-1,864 m) (Tab. 3).

In the area of Negotin, according to the fossil content, Badenian was proved in the borehole Pr-1 (Prahovo), correlatively separated (in the interval of 907-1,051 m - Fig. 4), and from the marls of the borehole Bu-1 (Bukovče) at 268-295 m. Identified Badenian foraminifera are listed in Table 5. The Badenian transgression proceeded unevenly. A large facies diversity has been seen as result of littoral deposition, with a scattered coastline and changing seabed. The occurrence of corals stands for specify in relation to the southern Pannonian basin in Serbia, where algal ridges dominate.

Sarmatian Stage

The Sarmatian around Kladovo, Negotin and Zaječar is the most widespread stratigraphic unit

Table 3. The Kladovo area. Depths of correlative stratigraphic delimitations with thicknesses of inscribed members.

Borehole	Vu-1	Vb-2	Vb-1	Rt-1	Kor-1	
(Quaternary)	(20)	(28)	(30)	(19)	(28)	Cenozoic
Q/Pt	20	28	30	19	28	
(Pontian)	(259)	(352)	(363)	(461)	(442)	
Pt/Mt	279	380	393	480	470	
(Maeotian)	(249)	(245)	(264)	(336)	(308)	
Mt/Sm_3	528	625	657	816	778	
(Khersonian)	(137)	(205)	(217)	(231)	(195)	
Sm_3/Sm_2	665	830	874	1047	973	
(Bessarabian)	(425)	(435)	(366)	(348)	(337)	
Sm_2/Sm_1	1090	1265	1240	1395	1310	
(Volhynian)	(242)	(242)	(280)	(278)	(150)	
Sm_1/Bd	1332	1507	1520	1673	1460	
(Badenian)	(121)	(168)	(254)	(191)	(169)	
Bd/Pg?-M_1	1453	1675	1774	1864	1629	
(pre-Badenian)	(214)	(225)	(216)	(0)	(0)	
K_2^3	1667	1900	1990	Ø	Ø	Sub-basinal Mesozoic
("Senonian")	(341)	(>296)	(460)	(0)	(0)	
K_2^{1-2}	2008	>2196	2450	Ø	Ø	
(Cen/Tur)	(>131)	Ø	(>47.7)	(0)	(0)	
J_3-K_1	Ø	Ø	Ø	1864	1629	
				(>272.3)	(>116)	
The boreholes bottom	2139	2196	2497.7	2136.3	1745	
Sub-basinal tectonized Fore-Carpathians				Sub-basinal platform		

discovered on surface. The marine-brackish deposits are made of sandy clays, gravels, sands, siltstones, and carbonates of various genesis. The Volhynian, Bessarabian and Khersonian substages were singled out. They lie continuously over the marine Badenian or are transgressive over the pre-Neogene paleorelief.

In the area of Kladovo, they proved between Sip, Kladušnica and Podvrška, then in Brza Palanka, and the surrounding area such as the Suvaja stream and the Rečka river (Stevanović, 1977, 1981, 1985).

In the area of Negotin, the Sarmatian is spread over surface of the terrain from Urovica in the north to Šipikovo in the south. Several localities with basic lithological and paleontological characteristics will be presented here, as well as data on Sarmatian in boreholes.

A. Volhynian substage

In the Štubik trough, the transitional level between Badenian and Sarmatian, known as "the Buglovian layers" (Laskarev, 1934, 1950) is discovered. In the Skočka river, west of Jabukovac, sandy clays with *Pirenella nympha*, *Nassa eichwaldi* are found over the Badenian clays and sands, and above them, the rhizoidhydrobyians sands (Stevanović, 1964).

On the southwestern slopes of Bordešica, NE of Jabukovac, from the clayey sediments *Ervilia podolica*, *Pirenella nympha*, *Psammobia labordei*, *Modiola sarmatica* were found. Above, marly clays with *Abra reflexa*, *Ervilia podolica*, *Cardium vindobonense*, *Mohrensternia inflata*, *M. angulata*, *Natica helicina* and others are found. The foraminiferal association (determ. by M. Petrović) is represented by large forms of *Elphidium macellum*, then *El. advenum*, *Nonion granosus*, *Quinqueloculina haidingeri*, etc., from the Large elphidiums Zone (Stevanović, 1964).

In the valley of Jagnjilski stream, gray-blue clays, and sands, contain *Quinqueloculina reussi*, *Q. akneriana*, *Q. akneriana var. akneriana*, *Elphidium crispum*, *El. macellum*, *El. fichtelianum*, *El. reginum*, *Articulina sarmatica*, *Cyteridea hungarica*, etc. which correspond to the *Quinqueloculina reussi* Zone.

South of Braćevac, near the confluence of the Beoka and Selski streams, from siltstone and gravelly sand the following mollusks were collected: *Mactra* (*Sarmatimactra*) *eichwaldi*, *Mactra* (*Sarmatimactra*) *vitaliana*, *Cerastoderma obsoletum vindobonense*, *C.* cf. *inflata*, *C. plicatum latisulcum*, *Irus gregarius dissitus*, *I. gregarius gregarius*, *Ervilia dissita dissita*, *E. dissita andrussovi* and others. Microfauna foraminifera were also found: *Elphidium macellum*, *El. reginum*, *El. aculeatum*, *Porosononion subgranosum*, *P. bogdanowiczi*, *Ammonia beccarii*, *Sarmatiella moldawiensis*, and others (Ganić, 2005). Here, because of increased freshening of marine water, abundant finding of *Porosononion granosum* suggest to *P. granosum* Zone, which is the lateral equivalent of the *Quinqueloculina reussi* Zone.

Fig. 7. *Various corals from the Veliki Izvor outcrops. Scale bar - 1cm.*

In the Borska Slatina trough, data on the finding of Sarmatian sediments from boreholes abbreviated indexes 2, 3, 4, 5, 7, 8, 9, and 10 (Fig. 8). In the Zaječar trough in boreholes N-1, R-1, R-2A and R-3, Sarmatian sediments above a depth of 230 m contain mollusks: *Granulolabium bicinctum*, *Acteocina lajonkeriana*, *Mohrensternia* cf. *pseudoangulata*, *Ervilia* cf. *dissitta*, *Irus* cf. *gregarius*, which confirm the Volhynian substage i.e., the rhizoid-hydrobyans layers (similar conclusion was given by Vasić et al., 2018; Rundić et al., 2019).

B. Bessarabian substage

By this reference, the base of the Bessarabian substage in the Kladovo area is determined by the lower limit of the lagoonal sandy-marly interval with cryptomactras (*Cryptomactra pesanseris* - Fig. 5, Tab. 4), which illustrates in depth the interruption of communication between the Dacian and Pannonian basins.

Near Mihajlovac, on the right bank of the Arau Jankuli stream near the confluence with Ogaša stream, conglomerates, gravels, and fine-grained sands were discovered. Based on mollusk fauna such as *Sarmatigibbula* (*Barbotella*) *hoernesi* (Fig. 9), *Mactra fabreana*, *Cerastoderma desperatum*, *Paphia crenulata* and *Solen subfragilis*, foraminifers and ostracodes as *Elphidium macellum*, *El*. *macellum aculeatum*, *El*. *rugosum*, *Porosononium subgranosum*, *P*. *martkobi*, *Quinqueloculina consobrina*, *Euxinocythere multicristata*, *Loxoconcha quadrituberculata* and others the middle Sarmatian – Bessarabian substage is documented. The similar observation regarding the Bessarabian was defined by Stevanović (1981).

At Čubra, in the carbonate-sandstone facies, the numerous foraminifers were determined: *Spirolina pseudosteligera*, *S. subgrandis*, *Articulina problema*, *Nonion* cf. *bogdanowiczi*, *Quinqueloculina* cf. *fasset*, etc. and some ostracods as well. The association belongs to the *Spirulina pseudosteligera* Zone which matches to the upper part of the Middle Sarmatian (Džodžo-Tomić, 1970). To the west of Bučum, foraminifer's species *Spirolina subgrandis*, *Peneroplis* sp., *Triloculina acrainica* var. *sarmatica*, *Triloculina* cf. *cubanica*, *Elphidium* sp., *Rotalia* sp. were extracted from sandy limestones. Oolitic lumpy limestones, discovered west of Kornjet, with identified foraminifera *Peneroplis* cf. *orbicularis*, *Rotalia* sp., *Elphidium* sp., *Eponides* sp. and *Discorbis* sp. also correspond to the Middle Sarmatian (Džodžo-Tomić, 1970).

At the Kovilovo locality, a mollusk fauna of the Sarmatian age was collected from the sands, siltstones and oolitic limestones (*Irus naviculatus*, *I*. *vitalianus mediosarmatica*, *Irus* sp., *Cerastoderma* sp., *Mactra naviculata*, *Gibbula homairei homairei*, *G*. *podolica issperata*, *Calliostoma carasiense*, *Trochus sulcatopodolicus*, etc.). Among microfauna, the following foraminifera and ostracods were found: *Porosononion subgranosum*, *Elphidium reginum*, *El*. *macellum*, *El*. *hauerinum*, *El*. *fichtelianum*, *El*. *crispum*, *Heterocythereis mehesi*, etc.

At Rajac, transgressively over the Cretaceous flysch deposits, the sands, siltstones and limestones with following macro- and microfauna have been determined: *Mactra* cf. *tapesoides*, *M.* cf. *vitaliana*, *Cerastoderma fittoni*, *C*. cf. *michailowi*, *Modiola incrasata*, *disjuncta disjuncta*, *Porosononion subgranosum subgranosum*, *Elphidium aculeatum*, *El*. *crispum*, *Ammonia beccarii*, *Quinqueloculina* sp., *Miocyprideis sarmatica*, *Cyprideis* sp., *Loxoconcha* sp., and others (Ganić, 2005).

C. Khersonian substage

The Upper Sarmatian in this area are significantly less widespread than the Volhynian and

Table 4. *The Kladovo area. Extract of paleontological findings by depth (m) from the indexed boreholes (depths of the upper core intervals). Paleontological determinations: macrofauna - Đ. Marinović and P. Janković; microfauna - V. Marković and M. Čanović.*

Pontian	*Dreissena anisoconcha*, 46 Vu-1; 91 Vb-2; 80 Rt-1, *Carinatocongeria digitifera*, 91, 135Vb-2; 227 Rt-1 *Pontalmyra otiophora*, 46 Vu-1; 135 Vb-2; 224Vb-1; 227-Rt-1, *Moodacna* sp., 80 Rt-1 *Paradacna abichi*, 80 Rt-1; 135 Vb-2; 224 Vb-1, *Limnocardium* sp., 91 Vb-2; 110 Kor-1; 135 Vb-2 *Pseudocatillus pseudocatillus*, 276 Kor-1, *Valenciennius* sp., 227 Rt-1, *Neritodonta* sp., 227, 355 Rt-1 *Hydrobia* sp., 46 Vu-1; 355 Rt-1
Maeotian	*Congeria panticapea*, 504 Rt-1; 561 Vb-1, *C. novorosica*, 504 Rt-1, *Theodoxus stefanescui*, 561, 648 Vb-1 *Theodoxus* sp., 504 Rt-1; 509 Vu-1, *Hydrobia kelterborni*, 504 Rt-1, *Hydrobia* sp. 504, 707 Rt-1 *Pyrgula* sp. 504 Rt-1
Sarmatian/Khersonian	*Ammonia beccarii*, 630 (sieve) Vb-2; 876 Kor-1; 917,982,1035 Rt-1, miliole (indet.) 858 Vb-1; 917, 982, 1035 Rt-1, *Elphidium* sp., 917 Rt-1, *Porosononion granosum*, 1035 Rt-1, *Mactra* sp. (*M.* aff. *micula*), 852,917, 1035 Rt-1; 931, 967 Kor-1, *Cerastoderma* sp., 876 Kor-1, *Hydrobia* sp., 787 Vb-2, *Neritodonta* sp. 787 Vb-2
Sarmatian/Bessarabian	*Ammonia beccarii*, 903 Vb-2; 1089 Rt-1; 991, 1062, 1071 Kor-1, *A. heidingeri*, 903 Vb-2, miliole (indet.), 903 Vb-2; 1202, 1376 Rt-1, *Elphidium crispum*, 1232 Vb-2, *Elphidium* sp., 1016 Kor-1, 1376 Rt-1, *Porosononion granosum*, 1376 Rt-1, *Mactra* sp. (*M.* aff. *fabreana*), 903, 953, 1010 Vb-2; 998 Kor-1; 1089 Rt-1, *Ervilia* sp. (*E.* aff. *dissita*), 1202 Rt-1, *Cryptomactra pesanseris*, 1190 Vb-1; 1232 Vb-2
Sarmatian/Volhynian	*Elphidium aculeatum*, 1377 Vb-2, *Elphidium* sp. 1474 Rt-1
Badenian	*Cibicides dutemplei*, 1589 Vb-2, *Gyroidina soldani*, 1589 Vb-2, *Nonion soldani* ,1589 Vb-2 *Valvulineria complanata*, 1589 Vb-2, *Elphidium crispum*, 1589 Vb-2, *Globigerina triloba*, 1589 Vb-2, *G. bulloides*, 1589 Vb-2; 1708 Rt-1, *G. bilobata*, 1797 Rt-1, *Orbulina universa*, 1589 Vb-2, 1797 Rt-1
(?Pg) - M_1(pre-Badenian)	No fossils (Rock falls and torrent deposits) 1472, 1545, 1595 Vu-1; 1689, 1700, 1741, 1749, 1848, 1874 Vb-2; 1778, 1801, 1861, 1932, 1974 Vb-1
"Senonian"	*Globotruncana lapparenti*, 1735, 1800, 1901 Vu-1; 1958, 2117, 2190 Vb-2; 2420 Vb-1, *G. linneiana*, 1800 Vu-1; 1958, 2190 Vb-2, *G.* cf. *appeninica*, 1958 Vb-2, *G.* cf. *formicata*, 2021 Vu-1, *Globotruncana* sp., 1915, 2044 Vb-2, 2420 Vb-1, *Marsonella oxigona*, 1915, 2190 Vb-2, *Verneulina bronui*, 1915 Vb-2; 1958 Vb-1, *Gandoyina bavariana*, 2190 Vb-2, *Pseudoclavulina amorpha*, 2190 Vb-2, *Epistomina partschiana* 2171, 2273 Vb-1, *Lenticulina* cf. *crepidulus*, 1915 Vb-2, *Cristelaria* sp. 2171 Vb-1, *Textularia* sp. 2273 Vb-1, *Cenosphaera* sp., *Dictiomitra* sp., *Theocampe* sp., *Pithonella* sp., 1901 Vu-1
Cenomanian-Turonian	*Praeglobotruncana delrioensis*, 2085 Vu-1, *Praeglobotruncana* sp., 2021, 2085 Vu-1, 2497 Vb-1, *Hedbergella tricoidea*, 2021, 2085 Vu-1; 2497 Vb-1, *H. infracretacea*, 2497 Vb-1, *Globotruncana lapparenti lapparenti*, 2021, 2085 Vu-1, *G. lapparenti tricarinata*, 2021 Vu-1, *G. lapparenti inflata*, 2085 Vu-1, *Calcisphaerula inopinata* 2497 Vb-1, *Ticinella* sp., *Spirolina* sp., 2497 Vb-1

Bessarabian because of epirogenic activities in the late Sarmatian, which caused additional uplift and retreat of the sea. The sediments are found on outcrops in very narrow belts, most often connected to steep stream valleys, ravines, and road cuts from Ključ in the north to Negotin in the south. They are in contact with Bessarabian or Maeotian clastites (Stevanović & Paramonova, 1983).

In the northern part of the Štubik trough, the Khersonian limestones were discovered on Mećeriz hill (elevation 312), west-southwest of Kupusište. Among the macrofauna, *Mactra crassicolis*, *M. bulgarica*, *Cerastoderma* cf. *disjunctoides* have been found (Stevanović, 1964).

North of Mihajlovac, on the right bank of the Arau-Jankuli stream and over the Bessarabian rocks, the mixed coarse- and fine-grained clastites with bivalves *Mactra balcica*, *M. bulgarica*, *M. caspia*, *Congeria sarmatica*, *C.* cf. *panticapea* and rare foraminifera as *Elphidium rugosum* have been identified (Stevanović, 1981).

South of Mihajlovac, on the road between Dušanovac and Miloševo, in a road cut under the Strana hill, a long section made of sandy siltstone, laminite and calcarenite was discovered. From the sandy siltstone, the mollusks such as *Mactra* cf. *caspia*, *Hydrobia elongata*, *H. turricaspia*, *Pirenella disjuncta disjuncta*, *Theodoxus* sp., *Congeria panticapea* were collected. In addition, frequent foraminifers and ostracods have been recorded (e.g. *Ammonia beccarii*, *Quinqueloculina akneriana rotunda*, *Quinqueloculina* sp., *Cyprideis* sp., etc.

***Table 5.** The Negotin area, borehole Bu-1 (Bukovče) – the Neogene base (Upper Cretaceous) and Cenozoic part. The upper depths of species from the drilling mud samples. Determination of microfauna by V. Marković. Stratigraphic delimitations and unconformity by Đ. Marinović (+/– species transported by drilling mud into deeper stratigraphic member).*

Q		0.0 – 15.5	Aeolian cover, terrace sand and gravel
PONTIAN 89,5 m	15,5 m	15.5 – 30	Yellow-gray pelites without findings of microfauna
		30 – (85)	*Thaminocypris negotini* Krstić
		30 – (85)	*Bakunella dorsoarcuata* Zal.
		30 – (105)	*Camptocypria ossoine* Krstić
		35 – (45)	*Leptocythere palimpsesta* Liven.
		40 – (105$^+$)	*Zalanyella venusta* Zal.
		45 – 75	*Serbiella hastata* Krstić
		50 – 85	*Leptocythere bosqueti* Livent.
		50 – (105$^+$)	-//- *andrusovi* Livent.
		50 – (105$^+$)	*Pontoniella acuminata* Zal.
		55 – 60	*Caspiolla balcanica* Zal.
		55 – 60	*Reticulocypris orientalis* Krstić
		55 – (105$^+$)	*Loxoconcha schweyeri* Susin
		65 – (105$^+$)	*Xestoleberis multituberculata* Zal
		65 – (105$^+$)	-//- cf. *castis* Mandelstam
MAEOTIAN 140 m	105 m	105	*Candona fagiolata* Stančeva
		-//-	-//- *ricca* Stanč.
		-//-	*Loxoconcha ancilla* Stanč.
		-//-	*Caspiolla arcuata* Stanč.
		110	*Candona massiccia* Stanč.
		-//-	*Caspiolla acuelata* Stanč.
		-//-	*Lineocypris vidinensis* Stanč.
		115	*Candona tschorlevensis* Stanč.
		125	*Leptocythere* aff. *propinqua* Liven.
		140	*Loxoconcha venticulata* Stanč.
		200	*Stanchevia gajtanensis* Stanč.
		-//-	*Hemicytheria strabella* Stanč.
		205	-//- *bella* Stanč.
		210	*Loxoconcha faveolata* Malz.
		220	*Xestoleberis mariposa* Stanč.
SARMATIAN 23 m	245 m	245	*Ammonia beccari* Linn.
		-//-	*Quiqueloculina akneriana* d'Orb.
		-//-	*Elphidium minutum* d'Orb.
		-//-	-//- *josephinum* d'Orb.
		-//-	-//- *hauerinum* d'Orb.
		-//-	*Nonion granosum* d'Orb.
		250	*Elphidium antonium* d'Orb.
		255	*Porosononion subgranosum* Eger.
		-//-	*Elphidium crispum* Linn.
		260	-//- *macellum* Fich/Moll.
		265	*Porosononion martkobi* Bogd.
		-//-	*Nonion bogdanoviczi* Volsch.
BADENIAN 27 m	268 m	270	*Globorotalia obesa* Bolli.
		-//-	*Orbulina universa* d'Orb.
		-//-	*Globogerinoides bulloides* d'Orb.
		-//-	-//- *trilobus* d'Orb.
		-//-	-//- -//- *immaturus* Roy.
		275	*Orbulina suturalis* Bronn.
		-//-	*Uvigerina pygmea* d'Orb.
		285	*Dentalina pauperata* d'Orb.
		-//-	-//- *consobrina* d'Orb.
		-//-	-//- *verneuilli* d'Orb.
		290	*Globigerinoides conglobatus* Brady.
		-//-	*Globigerina cincina*
		-//-	*Uvigerina semiornata* d'Orb.
		-//-	*Cibicides pseudoungerianus* Cush.
		-//-	*Sphaeroidina bulloides* d'Orb.
		-//-	*Nonion soldani* d'Orb.
CEN.-TURON. (Basement)	295 m	310 - 319 (core)	*Globotruncana linneanna* d'Orb. *Hedbergella infracretacea* Glaessner, etc.

The sands and clays near Bratujevac (Bratujevac Pimnice) are horizontal over a length of about 200 m (Stevanović & Dolić, 1981). In the lower part of the section, *Mactra bulgarica*, *M. caspia* were found. In the higher parts, congerians are dominant: *Congeria sarmatica*, *C. exigua*, *C.* cf. *panticapea*, foraminifera: *Quinqueloculina consobrina*, *Q. acneriana*, *Q. seminulum*, *Q. au-striaca*, *Q. hauerina*, *Porosononion subgranosum*, *Ammonia* ex gr. *bec-carii* and ostracods *Euxinocythere pseudonaviculata*, *Leptocythere modesta*, *Cyprideis* sp., *Candona* sp., *Xestoleberis* sp. (det. Marković V. and Krstić N.) (Krstić et al., 1998).

The section in the Bukovo stream, west of Negotin, builds in the lower part from coarse-grained, cross-stratified sands and conglomerates bound by carbonate cement in the higher parts. In the sandy part of the section, abundant mollusks with transported shells and its fragments were found: *Mactra bulgarica* (Fig. 10), *M. balcica*, *M. caspia*, *Pirenella disjuncta*, *Hydrobia* sp. and others. The sediments were deposited in the delta zone, with a large yield of the coarse-grained rounded clastites.

In the area of Kladovo, Sarmatian paleontological data according to the upper depths of the cored intervals of wells Vb-1, Vb-2, Rt-1 and Kor-1 are specified in Table 4. Well-log correlated stratigraphic delimitations into the substages and total thicknesses by wells Vu-1, Vb-1, Vb-2, Rt-1 and Kor-1 are shown in Figure 5 and Table 3.

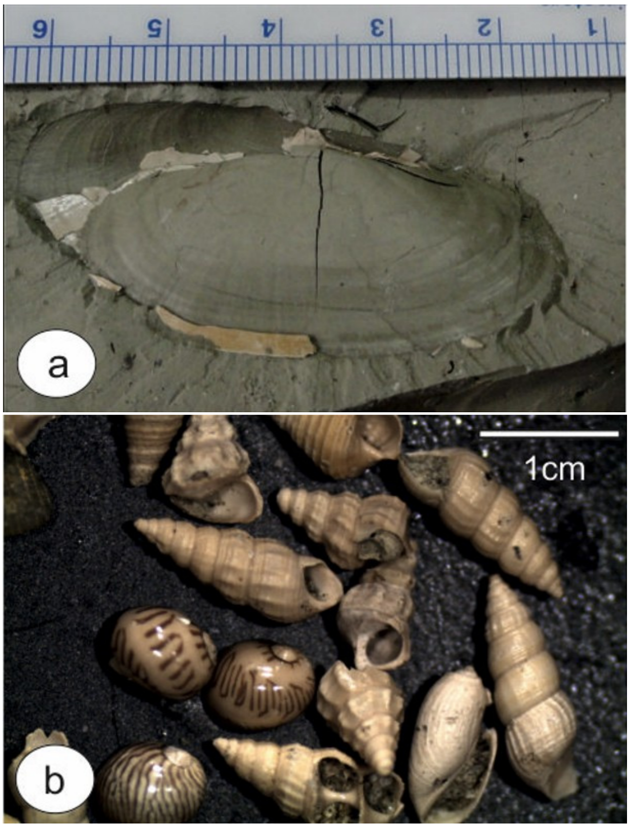

Fig. 8. Lower Sarmatian macrofauna from the borehole abbr. name 9 (B. Slatina). ***a)*** *A destroyed exterior and preserved mold of Psamobia labordei sarmatica Papp (262.70-263.50 m),* ***b)*** *Association of small gastropods (Mohrensternia inflata (Andzejkowski), M. sarmatica Friedberg, Clithon pictus pictus Ferussac, Gibulla sp., Calliostoma sp. (263.60-264.00 m).*

Fig. 9. Sarmatigibbula (Barbotella) hoernesi (Barb. De Marny) from the vicinity of Mihajlovac. Scale bar - 1cm.

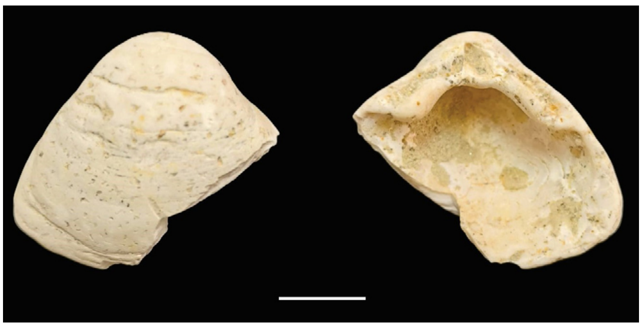

Fig. 10. Mactra bulgarica (Toula) (damaged shell) west of Negotin, the Bukovo stream. Scale bar - 1 cm.

Upper Miocene

Maeotian Stage

The Maeotian rocks around Kladovo were found between Kladušnica and Brza Palanka, and further south in the vicinity of Mihajlovac, Mala Kamenica, Dušanovac, Miloševo, Vidrovac, Badnjevo and the Bukovo Monastery (e.g. Stevanović, 1980). These deposits consist of sands with interlayers of pebbles, marly sands and marls, and sandy limestones occur much less often. In most cases, they conformably overlie the Khersonian or Bessarabian deposits, but there is an angular unconformity between them. The older part builds of clay, sandy clay and sand has a brackish-marine nature with *Dosinia meotica* and *Modiola minor*, and the younger one builds of caspibrackish clay, carbonate sands and sands with small gastropods and bivalves of the genus Congeria.

Near Mala Kamenica, in the right cut of the Parareče and Podišor streams, a section built of clay, sand and siltstone was found (Stevanović, 1980; Stevanović & Krstić, 1981). The mollusks separated from the fine-grained clastites: *Dosinia maeotica*, *Modiolus incrassatus*, *Dreissenomya nevesskae*, *Pirenella disjuncta disjunctoides*, *Viviparus moldavicus*, *Pseudamnicola atava*, *Theodoxus stefanescui*, *Dreissena polymorpha* and others. The association belongs the Lower Maeotian, i.e., corresponds to the Oltenian Substage. The ostracod microfauna is also numerous: *Cyprideis sarmatica*, *Euxinocythere rudis*, *Candona* (*Pontoniella*) *bulgarica*, *Loxoconcha ancila*, which corresponds to the *Candona* (*Pontoniella*) *bulgarica* Zone. Rare foraminifers were represented only by the species of *Ammonia* ex gr. *beccarii*.

The Upper Maeotian gray clays were proven on the section of the right side of the Valja Mare river in the vicinity of Kladušnica (Stevanović & Dolić, 1981). They contain the mollusks such as *Hydrobia* sp., *Radix* sp., *Pseudamnicola* sp., *Theodoxus* sp., *Congeria novorossica*, and the ostracods *Candona* (*Caspiocypris*) *ovalis*, *Loxoconcha graciella*, *Maeotocythere* sp.

South of the village of Mihajlovac, in a gully by the road, an outcrop built of sandy siltstone was discovered. The Upper Maeotian mollusks were found such as *Psilounio* sp., *Congeria panticapea bulgarica*, *Dreissena polymorpha*, *Theodoxus stefanescui*, *Brotia escheri auingeri*, *Pseudamnicola wenzi*, etc. (Ganić, 2005). Ostracods such as *Cyprideis* cf. *ventroundulata*, *Aurila* cf. *notata*, *Euxinocythere immutata*, *Euxinocythere* sp., etc. are also recorded.

A clay section with sand interlayers was discovered in Badnjevo near Negotin (Stevanović et al., 1981). The remains of flora found in the clayey layers, while the mollusks *Pseudamnicola*, *Hydrobia*, *Pyrgula*, *Theodoxus*, *Dreissenomya*, etc. as well as numerous ostracods: *Stanchevia gajtanensis*, *Candona* (*Candona*) *fagiolata*, *C.* (*Syrmiella*) *arcuata*, *C.* (*Candona*) *misiensis*, *Gethocytheria parvula* and others. *Stanchevia gajtanense* Zone corresponds to the Upper Maeotian, i.e. the Moldavian Substage (Stancheva, 1990).

In the area of Kladovo, the Maeotian sediments were delimited in boreholes Vu-1 (Vajuga) in the interval of 279-528 m, Vb-1 and Vb-2 (Vrbica) in the intervals of 393-657 and 380-625 m and Rt-1 (Rtkovo) at a depth of 480-816 m (Fig. 5; Tab. 3).

In the area of Negotin, deposits of Maeotian age were confirmed by boreholes near Prahovo (Pr-1) and on the Kobišnica plateau, borehole Bu-1 (Bukovče). In borehole Pr-1, the Maeotian was demarcated at a depth of 390-615 m (Fig. 4), and in borehole Bu-1, in the interval from 105-245 m, it was proved by ostracod microfauna (Tab. 5).

Pontian Stage

Caspibrackish Pontian sediments on the surface were discovered southwest and south of Kladovo, under the aeolian cover and river terraces, and across the Maeotian in the narrow belt between Brza Palanka and Dušanovac, as well as on the Kobišnica plateau in the vicinity of Negotin. Based on lithostratigraphic and biostratigraphic data, the lower Novorossian substage and the upper - Portaferrian substage were authorized (Stevanović, 1951, 1953).

Lithologically, Novorossian substage is general with two facies: the first is marl and clayey-siltstone-sandy with *Paradacna abichi*, *Congeria digitifera*, *Dreissensia anisoconcha*, etc. The second one is sandy to sandy-clayey with *Prosodacna littoralis*, *Pseudocatillus pseudocatillus*, *Congeria turgida*, etc.

In the area of Kladovo, from the northern edge of the village of Vajuga in the streambed of Valea Satului, gray blue siltstone and clay contain brackish species: *Carinatocongeria digitifera*, *Dreissena anisoconcha*, *Prosodacna* (*Eupatarina*) *litoralis*, *Caladacna steindanchneri*, etc. On the northern flank of Golo brdo, above Mala Vrbica, from the siltstone clays of the transitional level (lower/upper Pontian), the following were determined: *Paradacna abichi*, *Carinatocongeria digittifera*, *Osoinia planicostata*, *Parvidacna planicostata*, *Plagiodacna carinata*, *Limnocardium novorosicum*, *Congeria rumana*, *Pseudocatillus pseudocatillus*, *Valenciennesius* sp., etc. (Stevanović, 1989). Pontian mollusks from the Vrbica, Vajuga, Rtkovo and Korbovo boreholes are specified in Table 4.

In the area of Negotin, along the northern length of the Kobišnica plateau, in platy siltstones and laminites, there is an association of brackish mollusks close to the contact of the Pontian substages with: *Paradacna abichi*, *Caladacna steindacheri*, *Limnocardium otiophorum orientale*, *L.* (*Arpadicardium*) *mayeri*, *Congeria rumana*, *C. rhomboidea*, *Dreissena anisoconcha*, *Pisidium krambergeri*, *Valenciennesius geticus*, etc. (Stevanović, 1989).

In the Bu - 1 borehole, on the Kobišnica plateau, the range of depths of the specifically contained ostracod species found between 105 and 30 m. The boundary with the Quaternary is lithologically at a depth of 15.5 m (Tab. 5). The borehole VI-2 east of Srbovo, at a depth of 138.5 m, revealed only the sediments of the Lower Pontian. In gray-blue silty clays and clays from 7 m to the bottom, a fauna of gastropods and bivalves was determined, among which are: *Carinatocongeria digitifera*, *Congeria rumana*, *Dreissena anisoconcha*, *Paradacna abichi*, *Limnocardium mayeri*, *Paradacna retowskii ossoine*, *Pseudocatillus simplex*, *Valenciennius geticus*, *Zagrabica cyclostomopsis*, *Radix* cf. *kobelti*, *Melanopsis esperoides*, *Hydrobia vitrella* and others. Below 110 m, instead of *Paradacna abichi*, *Paradacna* sp. numerous *Zagrabica* ex. gr. *cyclostomopsis* appear in the clays (Stevanović, 1989).

The Portaferrian substage is typically developed only around Kladovo. Lithologically, it is built of sands and sandy clays with *Monodacna laticostata*, *Arcicardium primigenium*, *Paradacna retowskii ossoinae*, *Didacna otiophora orientalis* and *Parvidacna planicostata* (Stevanović, 1951, 1955, 1977). The Portaferrian substage of Osojna (*s. lato*) and the Golo brdo hill with sand and sandstone alternations contains (in excerpt): *Osoina laticostata*, *Paradacna retowsky ossoine*, *Parvidacna planicostata*, *Arcicardium primigenium*, *Limnocardium* (*Bosphoricardium*) *emarginatum*, *L. petersi*, *L.* (*Tauricardium*) *subsquamulosum*, *Congeria rhomboidea*, etc. (Stevanović, 1989).

There are no Pliocene layers in the entire studied area.

Quaternary

Quaternary deposits are represented by different genetic types of sediments created during the Pleistocene and Holocene.

The high river terraces, river-lake deposits, loessoids, river terraces and proluvium are of Pleistocene age (Dolić & Rakić, 1976; Bogdanović & Rakić, 1980).

The high river terraces are fragmentarily fortified at a height of 150-170 m above the Danube River between Sip and Davidovac. They are built from heterogeneous pebbles. Based on the relationship with the substrate and cover soil, they are of Lower Pleistocene age.

River-lake sediments - terraces of the Ključ (90-120 m above the Danube), are the most widespread in the Great Danube meander. Outside of it, they were found south of the Podvrška river in Brza Palanka, Mihajlovac and Mala Kamenica. These sediments are represented by medium- to coarse-grained, poorly sorted gravels and sandy clays. At Brza Palanka, mollusks *Corbicula fluminalis*, *Unio atavus*, *Pisidium amnicum*, *Melanopsis acicularis*, *M. esperi*, *Lithogliphus naticoides* and ostracod *Cyclocypris triebelli* were found in the sandy clays, which indicates the lower part of the Middle Pleistocene (Bogdanović & Rakić, 1980).

The loessoid clays, sands and sub-sands were found SE of Kladovo, around the villages of Vajuga, Velika Vrbica, Mala Vrbica, and SE of Mala Kamenica. These sediments lie over the river-lake gravels of the Ključ terrace, and two parts can be distinguished on the outcrops. In the lower part, oblique and horizontal stratification of the deposits is noticeable, and near Mala Vrbica and Mala Kamenica, mollusks *Punctum pygmaeum*, *Pisidium obtusalelapponicum*, *Valonia excentrica* and ostracods *Candona neglecta*, *Iliocypris gibba*, *I. brady*, *Cyprinotus salinus* and others were found. The mentioned fauna extracted from silty sand and sandy siltstone corresponds to the upper part of the Middle Pleistocene. The dust composition shows that the loess-like habitus was created by the modification of the former alluvial plain by deluvial, proluvial and aeolian agents (Bogdanović & Rakić, 1980).

Within the terrace sediments in the valleys of the Danube, Timok, Mokranjska rivers and other larger streams, the four levels can be distinguished. The oldest level corresponds to Mindel and is the "Kovilovo" terrace, with a relative height of 75-90 m and a thickness of 5-15 m. The next level is Riss 1 a "Strana" terrace, with a relative height of 60-71 m and a thickness of 2-12 m. "Buban" is a terrace that corresponds to the Riss 2 level, with a relative height of 30-35 m and a thickness of 6-12 m. Finally, and the "Gradska" terrace belongs to the Würm, with a relative height of 10-15 m and a thick-ness of 8-15 m (Dolić & Rakić, 1976; Bogdanović & Rakić, 1980).

Holocene deposits are represented by quicksand, proluvium, deluvium, alluvium, travertine and technogenic deposits. All these types of sediments were formed from the end of the Pleistocene to the present day. Accumulations of "quicksand" were found east of Kladovo in the vicinity of Kostol, Mala Vrbica and SW of Velesnica, and near Negotin on the Kobišnica plateau and in the vicinity of Radujevac. They are represented by sand dunes and barhans with a NNW-SSE direction, which coincide with the directions of modern air currents (Dolić & Rakić, 1976; Bogdanović & Rakić, 1980).

Structural-Tectonic and Paleogeographic Interpretation

In accordance with the title of the current reference, the interpretation is based on unified indicators of surface geology, shallow and deep boreholes and the geophysical methods used, primarily gravimetry, well logging and reflective seismics specific to study area.

In the area of Kladovo, a slightly bent gravimetric configuration of relatively uniform negative increment (Ivković, 1957), is expressed from the immediate Carpathian foothills, towards Kladovo and Velesnica. The negative values of isogams are more intense east of Kladovo, and the lowest from Kostol (Mala Vrbica) towards Romania. Based on a network of seismic profiles (Petrović, 1959), reflections are steeper east of Kladovo and Milutinovac. To the west of these geophysical indicators, the indented paleobase of the Carpathian foothills between Kladušnica and Brza Palanka is heterochronously covered by mixed Miocene clastites, concluding with the Maeotian and Pontian (Stevanović, 1951, 1955, 1958). At the site of Cladova-2, west of Turn Severin (Romania), the "Sinai bedrock" at a depth of 600 - 620 m has direct contact with the Lower Sarmatian (Băncila, 1967). To the east of the morphostructural saddle Kladovo – Rečica – Velesnica, the Neogene base sank to the formation of a trough, at Velika Vrbica, 2,300 m deep. On the eastern flank of the "seismic minimum", the continuity of reflections is disturbed, indicative of the providing of a longitudinal sub-Neogene barrier.

By making exploratory boreholes ("Naftagas" 1959-1962), it was established that in the foothills of Vrbica - Vajuga, east of Kladovo, basement of the Cenozioc succession is made up of Upper Cretaceous flysch which was affected by Alpine deformations (Fig. 5; Tabs. 1, 4). The fractured flysch base is discordantly covered by Pre-Badenian angular clastites and variably large pebbles of various petrological composition in an unsorted sandy-gravelly matrix, in borehole Vb-2, determined to be 225 m thick (Tab. 3). However, the sub-Neogene morpho-horst Rtkovo-Korbovo is built by completely different massive Tithonian - Neocomian limestones that are directly covered by marine Badenian deposits (Fig. 5; Tab. 3). From the geophysical and borehole-geological factometry, it follows that the southern extension of the contact of tectonized Pre-Carpathians and the Moesian Platform (Băncila, 1967) is located below the apostrophized troughes of Velika Vrbica and Burila Mare in Romania. This also resolved the issue (Stevanović, 1964) of "locating the longitudinal pre-mountainous sag further from the morphological Carpathian hills". A structural saddle is formed from the longitudinal intra-trough pass, and to the west of the morpho-horst of borehole 55 Chilia 7, from which a wider morphostructural nose rises towards Ljubičevo. To the west of the Burila Mare trough-unit with a conditionally maximum depth of about 1200 m, an ascending trough was formed towards Brza Palanka, which ends at the edge of the Carpathian orogen in the lacustrine-coaly wally of Aliksar (Fig. 11).

In the depressed part of the Kladovo area above the marine Badenian, with the 254 m thick borehole Vb-1, sedimentation of the Lower Sarmatian up to 280 m thick continues. The paleogeographical connection with the Pannonian Basin is stable and essentially of the same biostratigraphic evolution. Interruption of mutual communication caused by the critical uplift of the Carpathians, with this reference is precisely positioned and graphically illustrated by the base of the Bessarabian lagoonal interval with cryptomactras (Fig. 5; Tab. 4).

Continuous descending during the Middle Sarmatian is more pronounced in the central part of the Danube River meander with a significant yield of the fine-grained clastites of interval progradational sedimentation. Along the length of the western marginal area, along the shallowed shelf of Podvrška, a limestone-reef rock is interlayered (Stevanović, 1951, 1977). The greatest thickness of the Bessarabian Substage reaches 435 m (Tab. 3).

The Upper Sarmatian in latent regression was sweetened until the extinction of the stunted Khersonian mactras and the disappearance of the resistant ammonias in the basin area, as a biostratigraphic indicator of the depth delimitation toward the Maeotian (Fig. 5; Tab. 4).

The absence of genus Dosinia in the material from the boreholes is not the reason for the elimination of the Lower Maeotian, both for paleoecological reasons, and because of the rarefied coring in the lower part of the Maeotian sedimentary column. Along the length of the western paleogeographic near coast, mainly the younger parts of the Maeotian are locally overflow (Manastirica, Podvrška, Brza Palanka) above the indented foothills (Marinović, 1959; Stevanović, 1951, 1977 and others). In the northeastern part of the Danube meander, the brackish sandy-marly Maeotian is more than 336 m thick, correlative to borehole Rt-1. The re-establishment of the connection of the Pan-

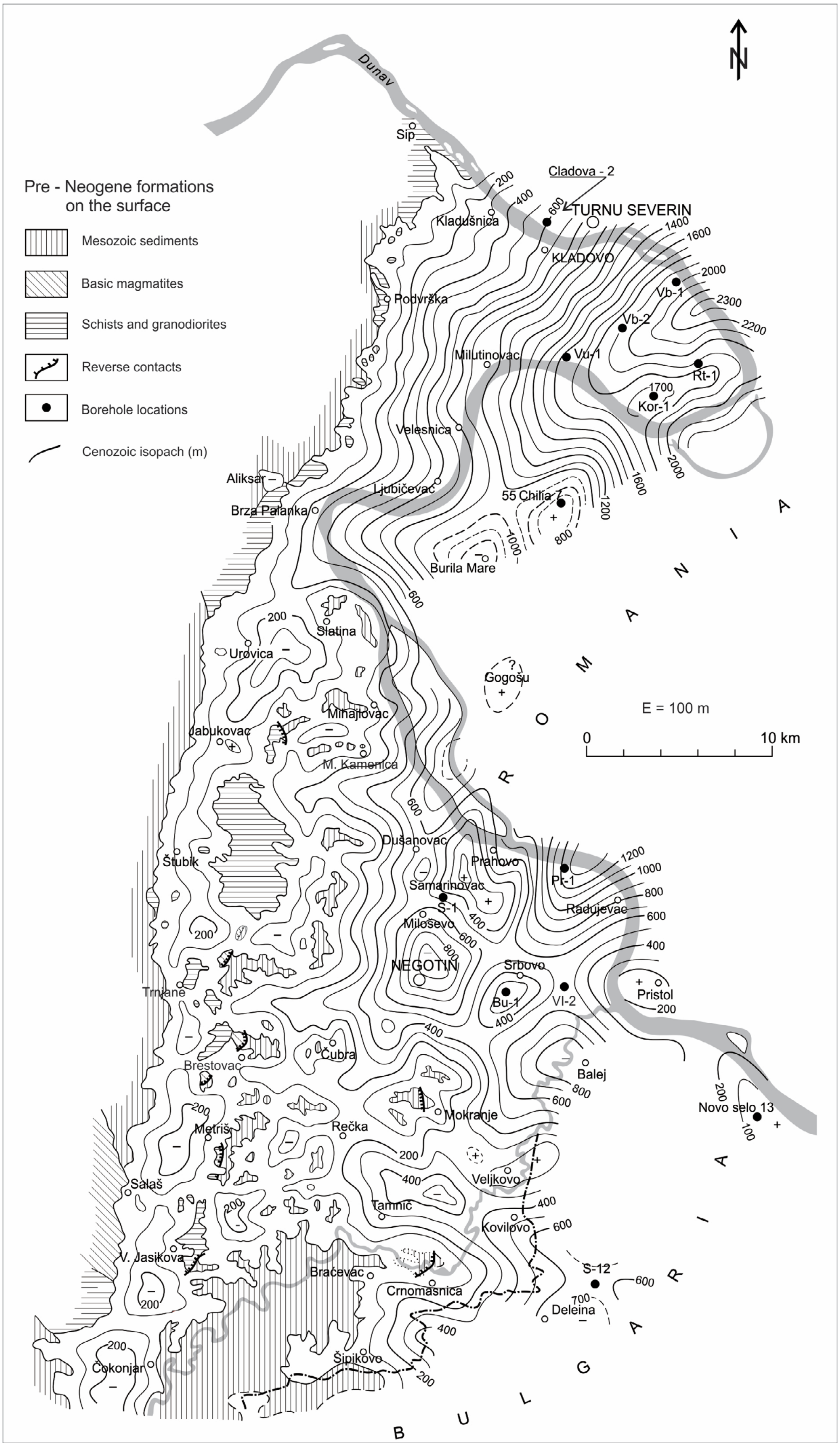

Fig. 11. *The Kladovo-Negotin area. The thickness map of configuration of the Cenozoic basement.*

nonian basin with the Dacian basin by overflowing the Carpathian barrier, was marked by the mixing of Lower Pontian lacustrine mutants of the Central Paratethys and the autochthonous brackish-freshwater Euxine-Dacian biogenic associations. That geochron of delimitation, in the meander of the Danube, is found at depths of up to 470 m (Fig. 5; Tabs. 3, 4). Regressive Pontian sediments, as indicated in the stratigraphic chapter, were discovered on the surface in several localities, and there are no Pliocene deposits. The entire area has been subjected to compact subsidence of the entire Neogene column. The post-Pontian indented in relief alluvial and aeolian multiphase cover is of variable thick-ness (Cvijić, 1921; Marković – Marjanović, 1967; Dolić & Rakić, 1976; Bogdanović & Rakić, 1980; Dragišić & Polomčić, 1998) averagely 20 – 30 m max. to 40 m.

In the Negotin-Zaječar area between the Carpathian orogen and the State border, neotectonic and morphostructural entities are generally historiographically apostrophized:

• The Štubik Neogene trough extending with the Zaječar trough; and the intramountain trough of Borska Slatina.

• An area of Neogene sedimentation with partially exposed bedrock of the Alpine tectonized foothills, and

• An area of sunken geological structures, mostly under the Quaternary cover.

The Štubik Neogene trough along its entire western length is closed by a system of Laramiyan-Pyrenean faults towards the Carpathian orogen, while the eastern side of the trough is paleo-archipelagoically open. The trough's wider communication is from Urovica towards Brza Palanka and Podunavska Slatina, while further south the connections around the island massifs are more complex. From Kupuzište near Brza Palanka and the transverse sub-Neogene threshold Jelašnica – Čokonjar, determined by this reference, the length of the trough is about 45 km. The width of the trough is variable, at most 10 km. Longitudinal intra-trough sink were formed within the mentioned dimensions: Urovica, South Štubik, West Meteriš and Koprivnica, individual thickness of 200-350 m (Fig. 11). The mixed-clastic shallow-water marine to semimarine composition of the trough is of a highly variable order. From the Danube River towards Jabukovac, the sedimentary column is more complete, while further south, only the Badenian and Lower Sarmatian rocks have been established. The bedrock of the trough is built by extensions of the formations of the sunken Carpathian foothills - a thrust and fold system of the Alpine tectonization with general NNW-SSE and N-S direction, conditionaly without larger basic- and ultrabasic masses, which are geophysically marked in the direction to the south (Bilibajkić, 1986).

The Zaječar part of the trough is a morphotectonic extension of the Štubik trough south of the Jelašnica-Čokonjar depth treshold established here, which is also the hub of west-rotating torsion towards the Borska Slatina intramountain trough. To the demarcation with the lacustrine trough-depression of Minićevo - Kneževac, near Zagrađe in the south, it is about 30 km long, and in the transverse direction of Lubnica - Grljan, the maximum width is up to 12 km. The outer contour of the trough was compiled, mainly according to the regional map of Milovanović & Ćirić (1968), then segments of the Basic geological map (Veselinović et al., 1967, 1975), in accordance with the flows of gravimetric anomalies (Bilibajkić, 1986). The eastern flank of the trough is sharply faulted and essentially closed paleogeographically, while the western flank has an outflow trend. A significant part of the trough is filled with the lacustrine Lower Miocene stratified coals, and the total thickness of the sediments is 3,3 times greater, which is all reversed compared to the Štubik part of the trough (Fig. 12). At the location of borehole R-1 (abbreviated index), with a total thickness of the Neogene column of 585 m (Tab. 2), the Badenian and Sarmatian boundary is located between 320 and 270 m in depth (Vasić et al., 2018). That "Paratethys's development" disapper south of Vratarnica (Fig. 12). A sample from the borehole N-2, 34 m deep, of the lacustrine sedimentary column, was isotopically dated to 16.9 Ma, corresponding to the Karpatian Stage (Rundić et al., 2019).

The paleogeographic connections with the intramountain trough of Borska Slatina are indicative on prolongation sandy outcrops of the Rgotina vineyards and mostly eroded remains of marly limestones above the Crna Reka (Popović, 1968) and certainly the banks of the Magurska Kosa, according to with which the configuration of the basement of the northern part of the trough is oriented (Fig. 12). The direct basement of the northwestern part of the trough is predicted to be built by the extension of the tectonically narrowed Bela Reka - Rgotina structures; the central part of the "magmatogeno-volcanogenic mixed formation" (Vasić et al., 2018) and older Cretaceous clastites (Rundić et al., 2019), (Tab. 2). Under the southwestern part of the trough, the Tupižnica - Grlište Lower Cretaceous possibly lies. The southeastern part of the basement is generally composed of Jurassic-Cretaceous formations of tectonized the Stara Planina perianticlinorium, overlie by the Upper Cretaceous carbonate and volcano-sedimentary rocks of the Vratarnica complex.

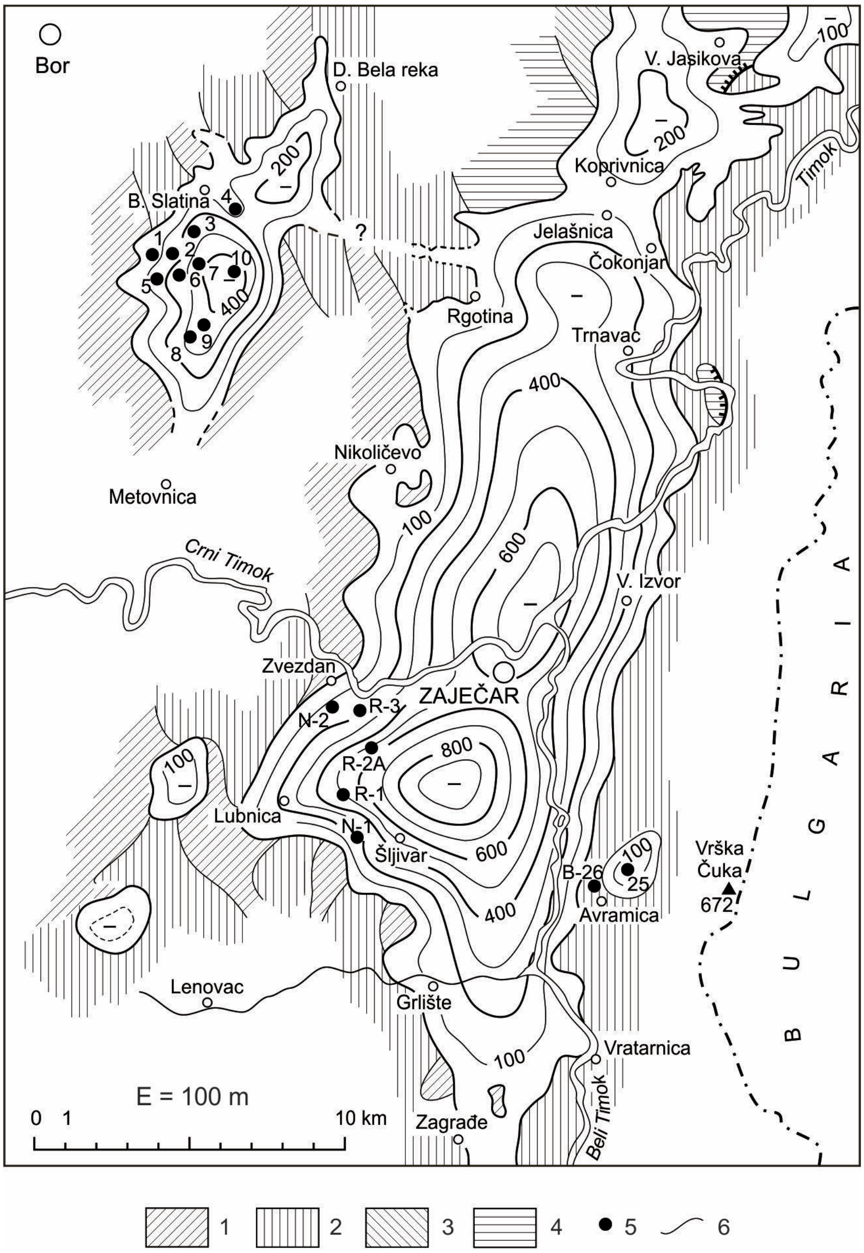

__Fig. 12.__ The Bor–Zaječar area. Depth interpretation of the Zaječar trough and Borska Slatina intramountain trough with isolated hollow units (according to Table 2). Pre-Neogene formations on the surface: __1.__ Magmatic-volcanogenic complex (U. Cretaceous–Paleogene), __2.__ Tectonized Paleozoic and Mesozoic, __3.__ Basic magma-tites and serpentinites, and __4.__ Heterogeneous schists and granitoids, __5.__ location of wells (source indexes abbreviated), and 6. isopachs.

The Borska Slatina intramountain trough as well as the Zaječar trough was formed oblique (NNE-SSW) in relation to the basement extension (NNW-SSE) of the Laramiyan structures of Alpine tectonics. According to the map at Figure 12, in the direction Donja Bela Reka - Banjska Reka, the length of the trough is about 13 km, and the width between Maljenik in the west, and Zagrađe in Donja Bela Reka is 8 km. South-west of the flow of the Banjska river, the trough is semi-closed by an interdepression sill towards the Šarbanovac-Sumrakovac intramountain limnic depression, which is not covered by this reference. The supposed Intra-Carpathian eroded paleo-communication between Borska Slatina and the Central Paratethys enclave of Donji Milanovac (Stevanović, 1964) is also outside this reference.

Between Borska Slatina and Bela Reka, the trough is built by lacustrine Miocene clastites. The marine fossil-bearing Badenian was discovered south of B. Slatina along the edges of the trough in the upper parts of the Maljenik, Kusak and Dosluj streams (Stevanović, 1964; Popović, 1968). The lower limits of the Neogene sediments were determined by drilling for coal exploration at a depth between 23 m (borehole abbr.

index 1) and 437 m (R-10), as well as the formation composition of their magmatic-volcanic Upper Cretaceous basement (Tab. 2) (Rundić et al., 2015; Banješević et al., 2019). The eastern side of the trough is steeper than the western one. From B. Slatina, along the NNW- SSE internal threshold, the trough is differentiated into a northern segment up to 250 m thick and a southern, stratigraphically more complex segment (with Badenian and Sarmatian) with a total thickness up to 450 m. According to the last mentioned authors, in the center of the trough (borehole 10, abbrev. index), the thickness of the Badenian is less than 200 m, and the reduced marine (almost fresh-watered) Sarmatian up to 312 m. Due to the steep centripetal dip, the sediments are angularly disturbed on the surface between 15° (Popović, 1968) and 20° (Stevanović, 1977). Since the Post-Volhynian time, the area is continuously exposed to erosional destruction and topographic shaping, ending with the Quaternary overcovering.

The area of Neogene sedimentation with a partially exposed base of the Alpine tectonized foothills has various literature aspects of structural-tectonic, zonal facies and other geological concepts, mostly with scarce geophysical support. The regional gravimetric map (Arsić et al., 1976) was segmentally reproduced in larger scales and parameters on the basis of which two developmental rows of elevated isogamic values were established.

Along the length of the western row of stronger intensity, there are staggered mutually obliquely closed (NNE-SSW) maxima of Grinda Raduluj – Malajnica – Korbulovo, then shorter (N-S) Trnjanska Glavica, then more spacious (NW-SE) Lepa Glavica – Metriš and semi-closed Velika Jasikova, which pericline towards Gradskovo. The mentioned anomalies geologically include the Malajnica massif (*sensu lato*) of heterogeneous schists with granitoids and other rocks, and further south with crowded small masses of ultrabasites, or without them, which on east reversely overlie the Cretaceous flysch. The fronts of these scale-thrusts from north to south are mapped on the outcrops: Jabukovac east (the Zamna riverbed); Kolibine, Trnjane northeast (the Trnjanska river), Brestovac (the Čubarska river); Lepa Glavica; Metriš south; Velika Jasikova and possible Trnavac east, in the Timok gorge (Fig. 11). The depth condition according to this lineament will be presented in the further text of the chapter.

The eastern row of the Bouguer gravimetric values, but of lower intensity than the previous one, stretches north from the bank of Podunavska Slatina towards Mihajlovac. From Mihajlovac, the intensity of anomalies is increased and closed along the Dupljane - Bukovo axis and separated on the Balej hill. (Fig. 11). Along that route, the Alpined tectonized Cretaceous flysch is partly on surface, and under the Neogene cover, it is of higher density compared to the synmorphically formed, conditionally the younger flysch of Čubra - Klenovac - Braćevac. From Mihajlovac, through Vidrovac to the "Negotin mud", the flow of the lateral isogams of the negative accretion is thickened, indicative on subsidence of the eastern wing. The reverse fault line near Mokranje and further south, in Kremenjača near Crnomasnica, with Tithonian-Neocomian limestones overlie the Cretaceous flysch, has been emphasized differently in the literature, including with a repeated quote by Petković (1948).

Above the sunken contact of the Carpathian foreland with the platform, the Neogene trough in the Danube River meander, as previously explained, has a southern prolongation. From Veliko Ostrovo, at a depth of ±700 m, the trough narrows between the flysch massifs towards Dupljanske pivnice in the west. The main trough from Dušanovac (±500 m) via Milosevo, expands further south into the asymmetric - centripetal depression of Negotin (±950 m). North and south of Čubra, the depression shallower around the exposed flysch base, especially towards Štubik trough and Rečka (Fig. 11). Across the Mid-Neogene structural saddle north of Srbovo, the Negotin depression is connected to the Prahovo trough with very steep flanks. On the border with Romania, the Neogene base sank to depths 1100 m. Above the southern morphostructural threshold of Bukovče, at a depth of ±450 m, the Negotin depression is morphostructurally related to the Balej depression (±800 m) in Bulgaria. The Veljkovo border antiform is oriented diagonally in relation to the Tamnič trough-depression (500 m), which is open to the east. Borehole S-12 (Bulgaria), at a depth of 641,9 m, established the Lower Cretaceous/Badenian contact (Kojumdgieva et al. ,1982).

The most prominent Samarinovac morphohorst, ±250 m, bi-apically extending in SE-NW direction near Kusjak, sub-Neogene periclinally sink towards Gogoš in Romania. The flanks of the horst are steep, especially the eastern one. The southwestern foothill of the horst is deeper than 400 m. Borehole IEBS-1 (indexed as S-1), at a depth of 350 m was completed in an older Badenian (Mitrović et al. 1996). In the deep borehole Bukovče-1, the base of the Neogene, i.e. Badenian/Turonian boundary was determined at a depth of 295 m (Fig. 2 – entire borehole, and Tab. 5 – Neogene segment). Finally, the Pristol block-horst (interpolated 200 m) in Romania extends towards the sub-Neogene southern Novoselsky "vault" ±30 m, in Bulgaria, where the Upper Cretaceous/ Bessarabian - Khersonian contact was established (Bokov et al., 1966).

The characteristics of the sediments of the unique Neogene basin area above the Carpathian foreland and the Moesian platform, between Brza Palanka, Šipikovo and the state border, are sufficiently presented in the stratigraphic chapter, for which reason it is omitted here.

In the area of sunken sub-Neogene geological structure, in-depth interpretations of the boreholes resulted from the combined insights of the lithological composition from "sieve" samples and cored intervals, including paleontological analyzes and special determinants, framed by log-stratigraphic delimitations. Spatial relationships accounted for by interdependent geophysical indicators are complemented by specific considerations and original assumptions emphasized in the text.

With the Bu-1 borehole, the Proterozoic - Cambrian Baikal basement was not reached up to a depth of 1,982 m. In the Ordovician segment, layered clastites are represented, among which quartz sandstones with especially arkoses and subarkoses. Their frequency suggests the presence of metamorphosed potassium para- or ortho-granulites. Above the Ordovician in the Paleozoic succession of unexpressed tangential disturbance, during the older Silurian in a relatively calm marine environment, mostly unmetamorphosed siltstones, laminites and fine-grained quartz sandstones alternate. Volcanic rocks were not recorded, which determines the miosynclinal character of the sedimentation. In the late Silurian, the clastic sediments (above 1,425 m) pass into intervals with biomicrites and other carbonates (Fig. 3).

During the early Devonian, dark gray to black clays and siltstones were predominantly deposited. In the younger part of the Devonian column, greenish glauconitic sandstones are layered, certainly synchronous with the intrusions of basites in the Carpathian depression and the serpentinized, later overthrusted schists of the foreland. The increased participation of the dolomite-carbonate component in the late Devonian is indicative of the beginning of the vertical enlargments of the platform. By the end of the Devonian, the process of elevation caused a trend of regression and an interruption of sedimentation, and according to the Bu-1 borehole, above 1,070 m, deposits of the complete Carboniferous, Permian and Triassic are completely missing. In borehole 55 Chilia 7, on the Romanian part, above the Devonian microcrystalline dolomites and limestones, the break corresponds to a depth of 1,714 m (Fig. 3). From the above, it follows that in the border part of Krajina, the beginning of emersion occurred synchronously with the Bretonian phase, in contrast to „eugeosynclinal“ areas, where emersion is intra-Carboniferous, i.e. corresponds to the Sudetian tectonic phase. Referring to the post-Ordovician "Strehaj uplift" in western Wallachia (Atanasiu & Chiriak, 1965; Bonchev, 1980) the trend of emersion movement by time is from NE to SW. It is not unnnecesary to add that the mentioned direction also has the mega-vault of the Moho-discontinuity of western Wallachia, 30-28 km deep (Aljinović, 1986) and others.

The Prahovo-1 borehole was completed in the Lower Jurassic hard quartz sandstones, which are covered by marine mixed-terrestrial and carbonate fossil-bearing sediments of the middle part of the Lower Jurassic. Existence of (undrilled) the lower part of the Lower Jurassic (developed in the wider environs, Romania and Bulgaria) is very certain. There is a relatively short-term hiatus above the middle Lower Jurassic that is marked by coal-seams and a terrestrial crust, at 1,319 m deep (Fig. 4). The regionally transgressive Upper Jurassic calcarenites contain synsedimentary deposits (e.g. conglomerate-breccia calcarenites) indicative of intraformational oscillations at the end of the Tithonian with pronounced elements of local paleokarstification (1,235 m). The overlying the Cretaceous deposits are variable, containing mostly terrestrial content, 184 m thick. In relation to the Bu-1 well, the Prahovo block sank 756 m.

The sub-Mesozoic depth configuration was constructed by cross-linked seismological-correlative transfer of the established discordance Pz/Mz (1,070 m) of the Bukovče-1 borehole to the surrounding area (Fig. 13). According to that seismoreflector, SW of Mokranje and Rečka, and below the lineament (traced in the previous text) visible on the surface of Jabukovac - Velika Jasikova and beyond, the three sub-Mesozoic blocks - antiforms are differentiated: Metriš SE, Brestovac south and an extrapolated Brestovac north. With relatively flattened amplitudes, they are separated from each other and briefly elongated S-N and SE-NW, at a depth of -1,500 m. Their western flanks, between -1,700 and -2,000 m, are diagonally directed under the Alpine - Carpathian orogen. South of the Trnavac gorge, the sub-Mesozoic trough (-2,200 m) is crowded between sub-Mezozoic troughs of the burried formes of Veliki Izvor (-1,800 m) and Halovo (-1,500 m). In the belt of foothill Alpine thrusts, below which there are no organized seismic reflections, or the area is outside the CDP seismic network, the deep morphotectonic interpretation is an omitted (Fig. 13).

From the Paleozoic/Mesozoic delimitation of the Bukovče-1 well, the sub-Mesozoic configuration, seismo-correlatively, the antiforms of apically approximate depths are: Mokranje (-1,500 m), Veljkovo (-1,700 m), Jasenovac (-1,300 m) and Braćevac East (-1,200 m). Discordantly, the overlying rocks on the Paleozoic is intra- or extrapolated interpreted at depth between -2,500 m (Rogljevo) and -1,300 m (Zlokuće) with an objectively reduced geological-depth accuracy.

A brief discussion

This paper give a comprehensive, and in same time, detail view of the depth geological relations in the studied area. It implies that the authors processed a lot of available data, including own collected over many years of work. Although some general relationships were known before (e.g. Stevanović, 1977, 1989), their concretization in the form of spatial boundary lines and the thickness of individual stages is completely autenthic. Although the large regional syntheses and correlations did not considered here (e.g. Schmidt et al., 2020), some specific geological morhostructures on the attached maps are correlative with such, regional schemes. Based on that structural-stratigraphic elements, the zone of Alpine tectonics of the Carpathian foothills and the contact with the Moesia Platform are demarcated. The configuration of the basement is emphasized by the Velika Vrbica Trough and the Rtkovo-Korbovo Morphohorst, extending to Chilia in the border area of Romania. The complete sedimentary column is delimited by correlated well logging. Geochronology of post-Volhynian inter-basinal isolation and Lower Pontian recommunication is based on biostratigraphic constrains (Fig. 5) and shows good potential for the future paleogeographic studies.

South of Brza Palanka, between the Carpathian orogen and the State border, there are elaborately shaped outcrops and huge masses of Pre-Cenozoic formations. A longitudinal, partially visible scale-thrust lineament of Alpine tectonics is positioned, and the reach of the reverse thrust to the contact with the platform. A very complex configuration of the sub-basin units is built over the entire area. Within the Štubik Trough, longitudinal paleo-bays are differentiated and nominated. The Veliko Ostrovo - Miloševo trough-synform belt is shown for the first time, which in the Negotin area expands into a scattered paleo-depression. The sub-Neogene Rečka plateau, in the south, is connected to the Tamnič Trough, directed towards Kladovo (Fig. 11). An analogue could be find in Bulgaria (borehole S-12) where at a depth of 641,9 m, the Lower Cretaceous/Badenian boundary was recorded (Kojumdgieva et al., 1982). On the geologically completely covered area of the platform, sharply fractured the Prahovo Trough, open to the north, is highlighted. It is laterally bounded by the bi-apical Samarinovac horst and the Radujevac – Pristol plateau horst (Romania), and is closed on the south by the sub-

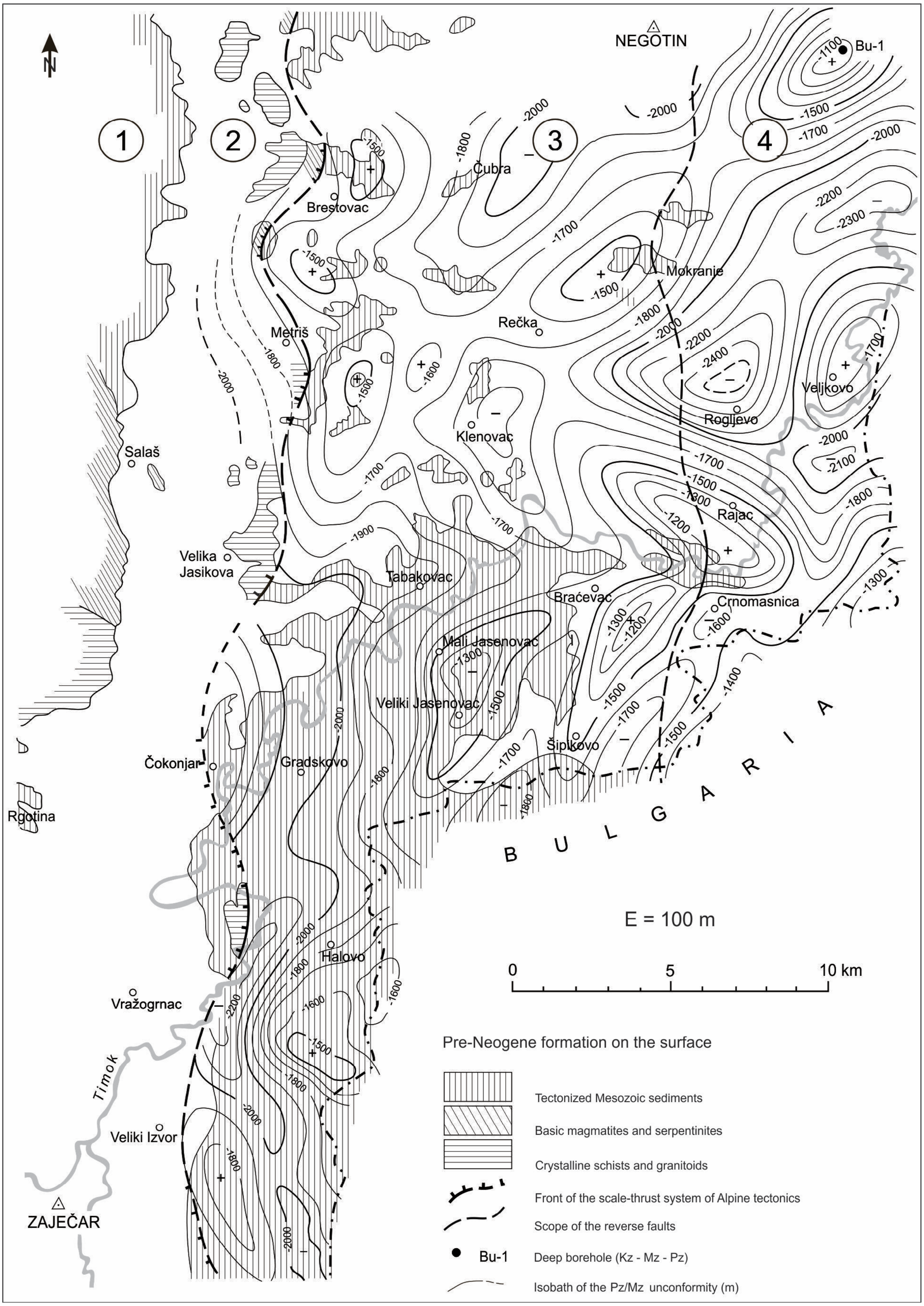

Fig. 13. *The Negotin–Zaječar area. The Sub-Mesozoic depth configuration (synthesis interpretation). The seismic CDP base "by horizon A", partially modified, intra and extrapolated. ❶ The Carpathian orogen; ❷ Forelandly scale-thrust belt; ❸ The belt of crowded tectonization; ❹ Platform.*

Neogene Bukovče "arch". All the plotted structural details on the tickness map of configuration of the Cenozoic basement represent a good base for the further cross-border depth correlation.

The Zaječar trough was formed above the submerged, „eugeosynclinal" Alpine tectonized basement, south of the deeply cramped the Jelašnica treshold promoted here (Fig. 12). The eastern side is steeper than the western side, which is more scattered and has a trend of overflow. The greatest thickness is up to about 950 m, of which approximately the older half consists of limnic deposits, partly coal and tuff. The younger part of the sedimentary column is represented by an ingressive marine Badenian with the southern oval reach to the Grliška River. The thickness of the freshwatered Sarmatian near Zaječar reaches 300 m. The paleoconnection with the Borska Slatina trough was fundamentally disrupted by post-Volhynian emersion. Since this area is very interesting in terms of future exploitation of metallic and non-metallic raw materials, these data can serve as a guide for future exploration planning and drilling.

The Borska Slatina intramountain trough was formed during the Cretaceous-Paleogene magmatogenic fracturing in the direction of Donja Bela Reka - Metovnica. The northern part of the trough contains only limnic-terrestrial deposits up to 250 m thick. The southern part, with a total thickness of 450 m, contains basal terrigenous deposits overlain by marine Badenian up to 150 m thick, and atypical very freshwatered to oligohaline Sarmatian deposits of steep, centro-directed sedimentation. As we mentioned in the text, these structural interpretations partly based on recent sedimentological-biostratigraphic analyzes based on boreholes data (Vasić et al., 2018; Rundić et al., 2018, 2019). After the Volhynian, the content of the trough is exposed to permanent erosional destruction. On the other words, good knowing of the depth structural setting and sub-basinal configuration of the mentioned trough make a very important precondition on the future projects of Cu, Au explorations.

Between Negotin and Zaječar, and east of the longitudinal Alpine scale-thrust lineament, the Pz/Mz depth delimitation in the Bu-1 borehole, within the limits of seismo-correlativity has been transferred to the surrounding area. During the long-term post-Devonian hiatus, the Palaeozoic basement was remodelled, to a predominantly crossed morphostructural configuration. Shaped antiforms have approximate dimensions of 3-7 x 2-4 kilometers, while synforms with inflexional folds are more spacious (Fig. 11). It is not possible to determine the sunken fractured and deformed morphostructures below the scale-thrust belt of the immediate foothills. Accordingly, it can be said that although the plotted depth morphostructures are realistic, there are still an unknown and this shows how important it is to monitor drilling, especially those related to deeper wells on both sides of the state border.

Conclusions

• Between the eastern edge of the Carpathian orogen and the border territories of Romania and Bulgaria, and under a single Cenozoic cover, the following are delimited: the direct overthrust belt, the belt of fold-reverse tectonization, and the western segment of the Moesian Platform.

• On the segment of the Moesian Platform in Serbia, the Bu-1 (Bukovče) borehole was completed in the Ordovician rocks at a depth of 1,982 m, and the 55 Chilia 7 borehole was completed in the Silurian near the border of Romania with a bottom of 3,203.5 m; depths of the sub-Paleozoic fundament are unknown.

• Ordovician of the borehole Bu-1 is composed of fine-grained subarkose-arkose to laminated clastites with spheres of primitive plankton. Silurian psammites with acritarches above 1,425 m are intercalated by the brachiopod-bearing limestone.

• Devonian pelites to flyschoids of the Bu-1 borehole with abundant trilete spores, in borehole 55 Chilia 7 they terminate with regressively the Upper Devonian carbonates.

• The beginning of the emersion movements of the platform corresponds to the Bretonian uplift, on a paleoarc without Carboniferous, Permian, and complete Triassic deposits.

• On the cratonically sunken Prahovo block, the Devonian basement is not drilled. Above the quartz sandstones of the well (1,617 m), there are limestones of the middle “Lias”. The “Lias”/Upper Jurassic contact is marked by a terrigenous crust with friable coal (1,319 m). Above the unconformity, there are directly overlying synsedimentary conglomerate-breccia calcarenites, which contain elements of paleokarstification under the Cretaceous cover (1,235 m).

• Between Negotin and Zaječar, the Devonian/ Upper Jurassic unconformity of the Bu-1 borehole (1,070 m) is networked in a depth-seismic correlation, in accordance with the possibilities of seismic reflector monitoring. During the long-term post-Devonian hiatus, both on the platform and along the foothills, before the Alpine thrust cover, the basement (Paleozoic) space was destructively reshaped and paleomorphologically modeled into units of different dimensions and orientations, 3-7 x 2-4 km. The constructed configuration of the Paleozoic paleoroof is illustrated by a depth map, for informational reasons also marked with reverses partially visible on the surface.

• On the platform, immediately above the Jurassic-Neocomian base, and towards the Bu-1 borehole, the Lower Cretaceous is of uniform sedimentation. It consists of calcareous algae, foraminifera and accompanying marine detritus, delimited by the well logging to a thickness of 530 m.

• Since the beginning of the Cretaceous Period, within parts of the tectonically unstable Carpathian Depression, differentiated flysch with a thickness of 200-500 m was deposited zonally. With the strengthening of the Laramian orogeny, primary folds of considerable dimensions with differences were formed, which build up the orogen and participate in the structure of the foothills.

• With the activation of the Pyrenean phase, the original deformations were retectonized during the Early Paleogene, as is visible on the surface in numerous incisions of the foothills, especially in the Timok Gorge. A similar phenomenon was registered in the boreholes in the Neogene base of the Kladovo area. The lithological composition with layer inclinations, the paleontological content by cored intervals and the thickness of the Cenomanian-"Senonian" rocks are documented.

• Along the length of the Carpathian foothill, tectonically cut off units are scale-thrust pushed and reverse-faulted to the literature-observed, partially discovered abnormal contacts. Their eastern reach, in the sense of the "Pericarpathian lineament", delimits the foothill and the platform along the route, from north to south: a barrier paleomorpho-horst Rtkovo-Korbovo - a sub-Neogene trough Burila Mare - Gogoš west - Kusjak - bottom of the Negotin depression - reverse-horst Mokranje, and Kremenjača near Crnomasnica, directed toward Rabrovo in Bulgaria.

• From the uppermost Oligocene and the beginning of the Miocene, under the influence of the Sava phase, the process of displacement of the uplifted structures into disjunctively shaped spaces changes. East of Kladovo, in the Vajuga-Mala Vrbica belt, the crowded flysch base is erosively filled with pronouncedly large, angular, and pebbly sediments, of different petrological and genetic origin and a matrix without fossil findings, to 250 m thick. At Velika Vrbica, the terrigenous complex is synformably directed towards the north-east, with a bottom at a depth of 2,300 m. It is unconformably covered by marine Badenian, so it stratigraphically identifies as pre-Badenian s. lato. In the Zaječar trough near Zvezdan, completely different continental terrigenous-carbonaceous sediments with tuffs, have been determined by zircon radiometric dating at 16.9 Ma (Karpatian Stage).

• At the beginning of the Badenian, due to the disruption of the Styrian phase, marine transgression spreads on a super-regional scale. In the Kladovo area, Badenian deposits gradually cover the erosionally dissected pre-Tertiary base and the previously deposited continental coarse-clastic complex. Along the foothills of the Carpathians, especially south of Brza Palanka, a trench is formed that spreads eastward into a dissected coral archipelago. The paleogeographic connection with the Pannonian Basin exists until the end of the Volhynian with continuous oscillations of overflow-outflow episodes accompanied by local changes in biofacies and lithological characteristics. The greatest thickness of the Badenian-Volhynian column in the Danube meander near V. Vrbica is between 500 and 550 m. The southern reach of the indented aquatorium is in the Zaječar trough, up to the middle part of the Vratarnica - Zagrađe line, while the western part is in the south of the intramontane trough Borska Slatina, in which the Sarmatian complex is almost completely freshwatered.

• With the continuation of the Carpathian uplift by the Early Attic tectonization, communication with the Pannonian Basin was interrupted at the boundary of the Early and Middle Sarmatian. This geochron in the Kladovo area is positioned at the base of the biostratigraphic interval with cryptomactras, which was paleontologically determined by coring of the boreholes Vb-1 and Vb-2 at depths of 1,190 and 1,232 m. Stratigraphic findings are bounded by well logging correlation at depths between 1,090 (Bu-1) and 1,395 m (Rt-1). Biogenic development according to the eastern Paratethys type, with *Mactra fabieana*, *M. naviculata*, *Sarmatigibbula* (*Barbotella*) *hoernesi*, etc., continued with frequent ingressive-regressive oscillations. Elevations of the epirogenic rank follow the spread of limestone facies, in contrast to subsidence with more pronounced cross-progradation. In relation to the whole Sarmatian, the Bessarabian deposits have the greatest thickness. In the Kladovo area, i.e., the V. Vrbica trough, they reach more than 400 m.

• Khersonian is regressive and of smaller thickness with scarce fossil associations. The older mixed limestone and terrestrial part of column contains typical species of the eastern Paratethys such as *Mactra bulgarica* and *M. caspia*, while the younger horizons are characterized by brackish congerians of the Sarmatian type with a considerable proportion of freshwater mollusks. In the Negotin area, on surface, they are found at more prominent locations in relief. In the Kladovo area, they are below 528 m (Vu-1) and 816 m (Rt-1), with thicknesses up to 231 m.

• Maeotian is dominantly made by silt-marl to fine-sand deposits and on the surface, it is spread on erosional remains. In the marginal Kladovo part, between Kladušnica and Brza Palanka, Maeotian makes the overflow cover above the heterochronous floor. South of Mihajlovac, incomplete parts of the column, with spatial interruptions, are located near Negotin, and in the boreholes between Bu-1 and Mokranje, following an arc form to Baley in Bulgaria. The older and marginal part of the sedimentary column rarely contains marine relics with Dosinia and Mytilus species. The dominant content is Congerians-brackish and brackish-freshwater type. The greatest thickness of Maeotian deposits is in the NE meander of the Danube and reach up to 350 m.

• On the Maeotian/Pontian boundary, by the overflow of the Carpathian barrier, the connection of the Central and Eastern Paratethys was restored. From Lake Pannon, the caspibrackish fauna of central basinal facies migrates and mutates with the autochthonous species of the Dacian Basin. In the Danube meander, the Pontian is much more exposed along the arc Osojna and Golo Brdo, as well as in the road cuts NW of Vajuga with frequent *Dreissena anusoconcha*, *Congeria turgida*, *Caladacna steindacheri*, and *Osoinia planicostata*. In the boreholes Vu-1, Vb-1, Vb-2, and Rt-1, *Carinatocongeria digitifera*, *Paradacna abichi*, *Pseudocatillus pseudocatillus*, etc. were determined. In that area, the Pontian thickness is delimited from 259 m (Vu-1) up to 461 m (Rt-1). Southly, the regressive Pontian is found on surface of the heights between Mihajlovac and Dušanovac, and on the Kobišnica plateau. It was also determined in the boreholes Bu-1 (Bukovče), VI-2 (Kobišnica), and Pr-1 (Prahovo). In the Pr-1 borehole (Prahovo) the thickness of the Pontian reaches 353 m, and further to south it reaches Balejsko Brdo towards Bulgaria.

•There are no Pliocene deposits in the studied area, and the Quaternary cover has a maximum thickness of 30-40 m.

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Резиме

Дубински геолошки односи у Тимочкој крајини, између Кладова и Зајечара (источна Србија): на основу површинских, бушотинских и геофизичких података

У овој референци изложени су геолошки односи специфичних садржајности, са оригиналним ставовима као и изабраним поставкама ранијих аутора. Палеонтолошки елементи из више десетина неогених изданака и једног рударског окна, сажето су обухваћени стратиграфским текстом, док су укупни бушотински подаци дубински позиционирани на упоредивим сликама и табелама. Уз геофизичку потпору, нарочито је наглашена структурно-тектонска и палеогеографска дубинска интерпретација. Од укупно 30 бушотина, 26 је из Србије, док су по две бушотине из граничног простора Румуније и Бугарске.

Најстарији набушени стратиграфски члан, и то на западном сегменту Мезијске платформе, је ордовицијум. Рифео-камбријски ни старији фундамент бушотински није достигнут. Ордовицијум палеозојске „миогеосинклинале“, према узорцима бушотине Бу-1 (Буковче), је без наглашене поремећености и метаморфизма. Аркозно-субаркозни кластити до ламинирани алевролити садрже ткива примитивног фито-планктона. Силикатни кластити и пелити делимично редукционе генезе са сферама акритархи старијег силура, у млађим нивоима прослојени су карбонатима. Између ордовицијума и силура није констатована угловна разлика. Девонске пелите углавном са трилетним спорама, у горњем делу стуба, смењују флишоидне наслаге почетних вертикалних померања које се у бушотини 55 Chilia 7, регресивно завршавају доломитима и кречњацима горњег девона (слика 3). Емерзиони свод палеоелевације без наслага карбона, перма и тријаса, на платформском подручју Крајине временски одговара бретонској фази док су у Карпато-балканској „еугеосинклинали“ са регресивним карбоном, издизања судетска.

На платформском блоку Буковче, ерозијом делимично разнету девонску подину на дубини 1.070 m, директно покривају горњојурски калкаренити формирани у нестабилним околностима са синседиментационим конгло-кластима, према ЕКД дебљине 142 m. Басенска алевролитично-лапоровита фосилоносна неокомска и млађа доња креда у континуитету седиментације укупно има дебљину од 530 m . Горња креда дубински изнад 390 m, одређена је асоцијацијом глоботрункана из пелашких лапораца који изграђују подину дискордантном неогеном покрову изнад 295 m дубине (слика 3, табела 5).*

На Праховском кратогеном блоку, девонска подина до дубине 1.627,5 m није набушена. Изнад тврдих кварцних пешчара дна бушотине, услојени су хетерозрни пешчари и кречњаци са спириферима и белемнитима средњег лијаса. На својој горњој граници (1.319 m) обележени су „кором палеогеографског детритуса“ – дробљивог пешчара, муљевите глине и мрвљеног угља. Пост-хијатусно покровни горњојурски доломити и бречасти кречњаци са *Clypeina jurassica*, на свом горњем дискордантном контакту (1.235 m) су палеокарстификовани. Мезозојски, наглашено редуковани стуб, завршава се басенским хетерогеним кредним седиментима, који су у дубини 1.051 m подлога трансгресивном средњомиоценском покрову (слика 4).

У појасу Карпатског предгорја између Неготина и Зајечара, дубинска интерпретација је у складу са синтезом геолошких и геофизичких елемената. Стратиграфска дискорданција палео зоик/мезозоик бушотине Буковче – 1 (1.070 m), сеизмо-корелативно је усмерена најдаље до уздужног реверсног контакта утврђеног местимично и на површини. Током споменутог пост-девонског хијатуса, тј. пре регионално-интра-јурског покривања, простор је деструктивно преобликован. Дубинска конфигурација моделованих подмезозојских антиформи осредњених су димензија 3-7 x 2-4 km, док су синформе са инфлексивним прегибима пространије (слика 13).

*Комплетан стуб бушотине суперпозиционо је дефинисан спојем наведених прилога у дубини 295 m.

Од почетка креде, у појасу Карпатског предгорја унутар нестабилних интрабасенских трогова, углавном је депонован полифацијално диференцирани флиш. Пре краја креде, јачањем ларамијске тектонизације, простор је наборно издизан уз сукцесивно источносмерно окопњавање, без присутне најмлађе креде и старијег палеогена. Активирањем пиринејске фазе, сложено издигнуте ларамијске деформације су пре касног олигоцена ретектонизоване, и ширином предгорног појаса краљуштано потиснуте најдаље до чела источно-реверсног линеамента (слике 5, 11).

Од најгорњег олигоцена и почетка миоцена, синхроно деформацијама савске фазе, траје процес снажне континенталне деструкције свеукупно издигнуте геолошке грађе. На Кладовском подручју, петролошки хетерогени крупни облутно-бујични и угласти осулински одломци, кратког континенталног транспорта, у појасу Вајуга – Врбица директно покривају тектонизовану флишну основу у дебљини осредњено 250 m (табела 3). Екстензивним образовањем рова Велике Врбице, формира се суб-акватична седиментација са трендом задебљања према северу односно североистоку (слика 11). У оквирима Зајечарског рова и интрагорног рова Борске Слатине, пребаденски теригени, делимично угљевити кластити прослојени андезитско-дацитским туфовима, такође су дебљине до 250 m. Радиометријским датирањем циркона из туфова зајечарског рубног дела седиментног стуба, у ранијем тексту цитиране ауторизације, утврђена је изотопска старост 16.9 милиона година што одговара карпатском кату.

Поремећајима штајерске фазе, од почетка бадена унутар Паратетиса шири се маринска трансгресија. На Крајинском простору, нарочито јужно од Брзе Паланке, образован је плитак медитерански архипелаг, приобално-коралног повољног биогеног развоја. Веза с Панонским басеном је трајала до краја волинског времена, биостратиграфски упоредивих садржајности. Највећа дебљина целине баденско-волинског стратиграфског стуба на Кладовском подручју код Велике Врбице износи 534 m (табела 3). Јужни домет тог разуђеног, ограничено ослађиваног акваторијума по ободу Зајечарског рова је до средокраће Вратарница - Заграђе, а западни у границама интрагорног рова Борске Слатине (слика 12).

Издизањем Карпатске баријере рано-атичком тектонизацијом, међубасенска комуникација је прекинута на граници волинског и бесарабског времена. Тај геохрон је, овом референцом, на Кладовском подручју дубински илустрован позиционирањем базе лапоровито-алевритског лагунског интервала са криптомактрама (слика 5). Биогени развој настављен је типски за источни Паратетис, и то на рубном и архипелашком простору учестало са ингресивно-преливном или одливном седиментацијом, а у депресионим деловима са променљивим дебљинама у односу на целину седиментног стуба. Активна издизања епирогеног ранга прате локална повијања, повећање карбонатних прослојавања и развој кречњачких биофација, а улегања учестали проградациони сегменти. Највећа дебљина бесарабског потката у Врбичком рову отвореном према Румунији је у неколико већа од 400 m (табела 3).

Херсонско доба карактеришу касноатичка регресивна померања и повећано ослађивање акваторијума са осиромашеним маринским биоценозама. До краја херсона, од фораминифера углавном су опстале амоније, а од милиола првенствено квинкелокулине. Мекушци су заступљени закржљалим мактрама и еуксино-бракичним конгеријама, праћени обиљем хидробија и повећањем бројности остракода. Јужни домет херсона по оси Рајац – Злокуће, отворен је према Делеини у Бугарској где је бушотином С-12 утврђен до дубине 74 m (Kojumdgieva и др. 1982). Источно од Кладова, дебљина херсонских наслага овом референцом дубински је интерпретирана оквирно између 137 и 231 m (слике 5 и 11; табела 3).

Меот је ограничено трансгресиван. На Кладовском подручју уз Карпатско побрђе Кладушница – Подвршка – Брза Паланка, дискордантно покрива хетерогену подлогу. Старији (тањи) део, веома променљивог састава, блиско басенском рубу, садржи маринско-бракичне биогене реликте источног Паратетиса, углавном са досинијама и митилоидним мутантима, мешано са врстама приобално-копненог утицаја. Млађи рубни, и источније укупно задебљали лапоровито-песковити стуб, са бракичним еуксино-конгеријским врстама, променљиво је ослађен. На североисточном делу меандра Дунава дебљина меота је до 350 m (табела 3, слика 5). Јужније, на Карпатском предгорју, или окружује старију палеоморфолошку основу или је покрива. Због епирогеног издизања, има тренд палеогеографског померања према истоку. Од ерозије је боље очуван источније од линије Велико Острово север – Михајловац – Бадњево. Јужни домет меота ограничен је разуђеним рубом Неготинске депресије и дужином Балејског брда, усмерено према Бугарској.

На граничном геохрону меота и понта, преливом Ђердапске баријере, поново је успостављена комуникација између Централног и Источног Паратетиса. Регионална палеохипсометрија Панонског зајезереног простора је већа у односу на тонући руб Дакијског басена. Из западног одливног простора, каспибракична фауна, претежно муљевитог дна, меша се са врстама Дакијског басена. Из тог разлога, понт у Тимочкој Крајини обилује типовима панонског порекла и њиховим мутантима. Седиментни понт је релативно стабилне бракичне засољености, осим у јужном, активно регресивном простору. Дебљина најпотпуније развијеног лапоровито-песковитог стуба у рову Велике Врбице северније од Рткова, достиже скоро 500 m (табела 3, слика 5). Јужније, регресивни понт најбоље је очуван унутар синформне осе Велико Острово – Михајловац – Душановац – унутрашњи овал Неготинске депресије, према Балеју у Бугарској. Испод понтског акваторијума, издваја се палеоострвски низ Самариновац – Пристол (Румунија) – Ново Село (Бугарска).

На целокупном простору обухваћеном овом референцом плиоценских седиментних наслага нема. Квартарне наслаге заступљене су седиментима различитих генетских типова, насталих током плеистоцена и холоцена, укупних дебљина највише 30-40 m.

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