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New data concerning the Early Middle Miocene on the southern slopes of Fruška Gora (northern Serbia): a case study from the Mutalj Quarry

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Abstract. During the last few years, geological research at the southern slopes of Fruška Gora Mt.enabled the discovery of different Miocene units (undivided the Lower Miocene and Middle Miocene Badenian, predominantly). This is primarily thinking of the so-called Leitha limestone (Middle Miocene, Badenian), which is an important component in cement production (La Farge Co., Beočin). The high carbonate content (more than 98 %) allows it to be a very important raw material that is mixed with Pannonian marl in the process of cement manufacture. Continuous exploitation of this rock at the Mutalj Quarry enabled an insight into its structural, stratigraphic, sedimentological and hydrogeological features, as well as its relation to the other underlying/overlying units. Numerous fossils (*i.e.,* red algae, mollusks, corals, bryozoans, and foraminifers) and their biostratigraphic range indicate to Middle Miocene Badenian age. Based on data from different boreholes, structural and sedimentological characteristics, spatial distribution, *etc*., a relatively large rock body was discovered (approx. 0.3 km^2). Within these Leitha limestones, there are frequent cracks and caverns infilled with fine lateritic clays and alevrites. These clays were sampled for a paleomagnetic study. The carrier of the primary remanent magnetization (RM) is magnetite that has a primary origin. Lateritic clays are characterized by significant value of magnetic susceptibility. The degree of anisotropy of the magnetic susceptibility (AMS) is low with the dominant magnetic foliation.

Key words: Lower Middle Miocene, Badenian limestone, post-Badenian lateritic clays, paleomagnetism, Fruška Gora Mt.

Апстракт. Последњих неколико година, геолошка истраживања на јужним падинама Фрушке горе омогућила су увид у постојање различитих миоценских јединица (нерашчлањен доњи миоцен и првенствено, баденски кат средњег миоцена). Овде се говори пре свега о тзв. лајтовачким кречњацима (средњи миоцен, баден), важној компоненти у производњи цемента (Лафарж, Беочин). Висок садржаја карбоната (више од 98%) омогућава им да буду врло значајна сировина, те се додају панонском лапорцу у процесу производње цемента. Непрекидна експлоатација ових кречњака у каменолому Мутаљ, омогућила је увид у њихове структурне, стратиграфске, седиментолошке и хидрогеолошке карактеристике, као и њихов однос према другим, подинским односно повлатним јединицама. Бројни фосили (нпр. црвене алге, мекушци, корали, бриозое и фораминифери) и њихов биостратиграфски опсег упућују на млађе баденску старост. На основу података из различитих бушотина, структурних и седиментолошких карактеристика, као и просторне дистрибуције кречњака, утврђено је да се ради о релативно великој стенској маси (око 0,3 km^2). Унутар те кречњачке масе, честе су пукотине и каверне запуњене финим латеритским глинама и алевритима које су биле и предмет палеомагнетних испитивања. Но-

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силац примарне реманентне магнетизације (РМ) је магнетит који је примарног порекла. Латеритске глине карактерише значајна вредност магнетне сусцептибилности. Степен анизотропије магнетне сусцептибилности (АМС) је мали са доминантном магнетном фолијацијом.

Кључне речи: Старији средњи миоцен, баденски кречњаци, пост-баденске латеритске глине, палеомагнетизам, Фрушка гора.

Introduction

The Pannonian Basin was formed as result of continental collision and subduction of the European Plate under the African Plate during the Late Early to Late Miocene (FODOR *et al*. 2005). The Late Early Miocene subsidence and sedimentation was an effect of the sin-rift extension phase that resulted in the formation of various grabens filled by thin sin-rift marine and brackish deposits (CLOETINGH *et al*. 2006; HORVÁTH *et al*. 2006; DOMBRÁDI *et al*. 2010). The tectonic events that formed the Pannonian Basin also affected the structure of the Neogene deposits of Fruška Gora (FG), which were deformed mainly by radial tectonics. Still, deformations that are more complex have been noted in the Upper Miocene and Pliocene nearer to the Danube, in the influence zone of the regional fault that separated large blocks: the uplifted structures of the FG horst from the southern Bačka depression (MAROVIĆ *et al*. 2007). FG was the focus of geological interest in the second half of the 19^{th} century. LENZ (1874) and KOCH (1876) gave the first and original explanation of the geological record of FG. After the Second World War, ČIČULIĆ (1958), ČIČULIĆ-TRIFUNOVIĆ & RAKIĆ (1971), PETKOVIĆ *et al*. (1976) wrote important contributions to the study of the stratigraphy of FG. In recent times, a few articles include different geological studies of FG (RUNDIĆ *et al*. 2005; GANIĆ *et al*. 2009, 2010; TER BORGH *et al*. 2011). All the mentioned authors noted the absence or minor occurrence of the Miocene at the southern flank of the mountain. Except for the Lower Miocene Vrdnik coal basin sediments and volcanites, which are transgressive over the basement rocks (PETKOVIĆ *et al*. 1976), there are no other significant occurrences of Miocene rocks at the southern slope of FG. Only two occurrences of the Miocene limestone were noted (the Mutalj and Beli Kamen Quarries near the Bešenovo village). The first paleomagnetic studies of lateritic clay from the Mutalj Quarry were performed to define the paleorotation pattern of FG during the Neogene. These investigations gave good results (LESIĆ *et al*. 2007; CVETKOV 2010). Afterwards, the lateritic clays from biogenic limestone were re-examined in detail in terms of their magnetic properties.

This work presents new structural, sedimentological, and paleontological data from Mutalj, the largest Middle Miocene quarry at the southern slope of FG (Fig. 1). Additionally, the post-Badenian clays were checked to determine the carrier of remanent magnetization (RM) and the anisotropy of magnetic susceptibility (AMS).

Materials and Methods

All the presented data were obtained on the surface at the Mutalj Quarry and from twelve boreholes (GB-1/10, GB-2/10, GB-3/10, B-16/05, BGMK-1/10, BGMO-3/10, IBMBK-1/10, IBMBK-2/10, IBMBK-4/10, IBMBK-5/10, IBMBK-6/10, IBMBK-7/10 – see Fig. 1; Table 1). Information was plotted on a geodetic plan on the scale 1:25 000, and three geological cross-sections drawn, to be reduced to the scale and prepared for print (Fig. 2).

A detailed sedimentological investigation was performed at the Mutalj Quarry during 2008. Additionally, different fossils were collected to date. For a more precise stratigraphic position, a few limestone samples were examined as thin-sections. All the mentioned material is stored in the Faculty of Mining and Geology, Belgrade as well as the Hidro-Geo Rad, Belgrade. Paleomagnetic measurements were conducted on the lateritic clays on three occasions. The first two times were to determine the paleodirections and the last one was to determine the carrier of the remanent magnetization (RM) and the anisotropy of the magnetic susceptibility (AMS). Samples of slightly different lithology were taken from two caverns. Clays from the first cavern (Mutalj 1) are reddish-brown, adhesive and compact while the clay from the second cavern (Mutalj 2) has a more sandy component. Paleomagnetic measurements were realized in the Paleomagnetic Laboratory of the Republic Geodetic Authority, Department for Geomagnetism and Aeronomy, Belgrade and the Etvös Lorand Geophysical Institute in Budapest, Hungary. For measurement of the initial magnetic susceptibility and the anisotropy of the susceptibility (AMS) in a low-intensity field (in fifteen positions) MFK1-A and KLY-2 Kappabridges were used. The direction and intensity of the remanent magnetization (RM) were measured using JR-5 and JR-5A spinner magnetometers within the domain of the natural remanent magnetization (NRM). A thermal demagnetizer MMTD80 and the pulse demagnetizer MMPM10 performed thermal demagnetization (TD) and isothermal remanent acquisition (IRM). For thermal demagnetization of specimens within the alternating field, an AFD300 and Schönstedt AF demagnetizers were used (max. field strength up to 0.23 T,

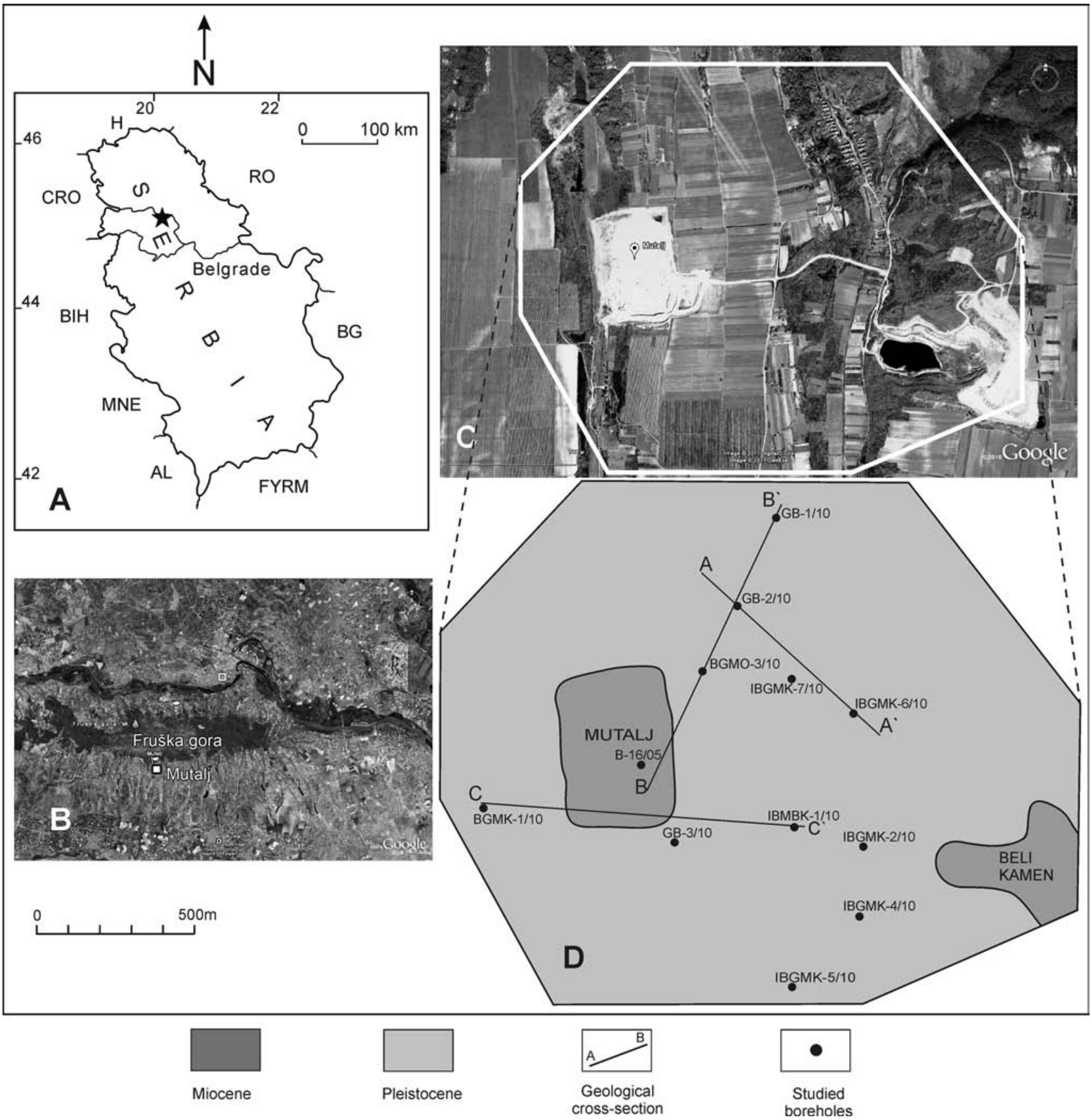

Fig. 1. Geographic position (A), satellite image of southern part of Fruška Gora Mt. (B) and satellite image of the Mutalj Quarry and its simplified geological map (C, D).

Technical University of Budapest). The demagnetization data were processed statistically following standard paleomagnetic procedures (Kirschvink 1980; Fisher 1953).

Geology of the Mutalj Quarry

The Mutalj Quarry belongs to the village of Bešenovo on the southern slope of FG (N 45°6'29.24"; E 19°41'40.46" – Fig. 1). It is the largest open pit in this part of FG (approx. 295 000 m^2). Herein, Triassic and Jurassic rocks make the basement for the Neogene sediments that cover them on the southern side. Generally, the clastic–carbonate sediments of the Lower Triassic, the carbonate facies of the Middle Triassic and the igneous–sedimentary complex of the Middle and Upper Triassic represent the Triassic formations in FG. Tithonian-Berriasian sediments as well as an ophiolite complex represent the Jurassic age (Fig. 2, B–B'). The basement rocks form a very complex structural pattern with features of most diverse folding and radial deformation. In total, twelve exploration boreholes were investigated (Table 1).

Table 1. Geographic position of the investigated boreholes (WGS84).

No.	Borehole	North	East
1	IBMBK-1/10	45° 6' 22.25"	19° 42' 6.75"
2	IBMBK-2/10	45° 6' 20.36"	19° 42' 16.94"
3	IBMBK-4/10	45° 6' 12.94"	19° 42' 16.61"
4	IBMBK-5/10	45° 6' 5.44"	19° 42' 6.72"
5	IBMBK-6/10	45° 6' 34.21"	19° 42' 15.22"
6	IBMBK-7/10	45° 6' 37.73"	19° 42' 5.99"
7	BGMK - 1/10	45° 6' 23.69"	19° 41' 19.82"
8	BGMO -3/10	45° 6' 38.45"	19° 41' 52.74"
9	GB - 1/10	45° 6' 54.77"	19° 42' 3.45"
10	GB - 2/10	45° 6' 45.38"	19° 41' 57.62"
11	GB - 3/10	45° 6' 20.59"	19° 41' 48.90"
12	B-16/05	45° 6' 29.25"	19° 41' 44.35"

In the area of Bešenovo, the Miocene deposits are distributed along a narrow, discontinuous belt of E–W direction. The best exposure of these sediments is located at the Mutalj Quarry where Middle Miocene Badenian limestone appears. However, based on the exploratory drilling, it was determined that the basis of the Badenian sediments is composed of different rocks from an older Miocene continental series (Fig. 2. B–B', C–C'). It consists of multi-colored pebbly clays, sands, quartzites, older rock fragments, and conglomerates. Stratigraphically, these rocks correspond to the undivided Lower Miocene (Fig. 2). These sediments were best studied on the southern slopes of FG, near Vrdnik (the Vrdnik Coal-Bearing Basin); hence, they are known as "the Vrdnik Series" or the Vrdnik Formation (PETKOVIĆ *et al.* 1976; RUNDIĆ *et al.* 2005). They are transgressive and discordant over the various members of the basement rocks (Fig. 2. B–B'). In certain places, the relationship with the different older fragmented and reworked rocks is probably sharp (Fig. 2, A–A). Based on earlier data (RUNDIĆ *et al.* 2005), three litho-stratigraphic members within the Vrdnik Series are distinguished: a) at the base, there are various breccias, conglomerates and sandstones, rarely clays, 5–30 m thick; b) above the basis, there is a coal-bearing horizon. It is composed of 4–6 coal layers, 0.6–2.5 m thick, represented by intercalated layers of montmorionite clay (bentonite); c) the overburden of the coal layer is composed of a lower and upper overburden. However, based on the facts from the investigated boreholes, there are no coal seams at the Mutalj Quarry. Only a part of that lithological succession is determined. The varicolored terrigenous series contains brown clay, reddish sandy clay, grayish sand, and pebbles of different rocks (serpentinites, quartzites, diabases, different schist, *etc*.). It has a great distribution and makes the base for the different younger rocks (see cross-sections in Fig. 2). According to this, it can be supposed that the Lower Miocene sediments have a thickness of more than 100 m.

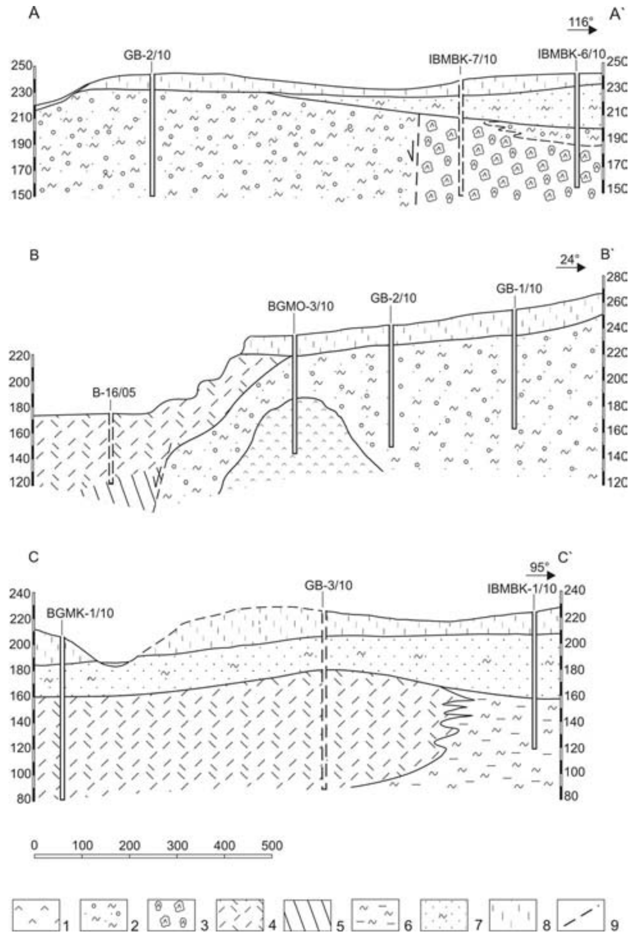

Fig. 2. Geological cross-sections across the Mutalj Quarry: A–A′, B–B′, and C–C′. Key: **1,** Jurassic diabases (only in cross section and boreholes); **2, 3,** Lower Miocene lacustrine deposits and volcanites (only in cross section and boreholes); **4,** Middle Miocene (Badenian) reef limestone; **5, 6,** Middle Miocene (Badenian) sandy marl and sandy clay; **7,** Pleistocene red beds – the Srem Formation; **8,** Pleistocene loess–paleosoil sequences; **9,** Fault.

The marine Badenian sediments have a relatively small distribution at the Mutalj Quarry. If compared to the northern parts of the mountain, there is a clear difference (PETKOVIĆ *et al.* 1976; RUNDIĆ *et al.* 2005). The Badenian sediments are present as an elongated, discontinuous rock body with E–W direction and they have much wider distribution on the northern slopes of FG. They are characterized by large diversity of the facies, which is a consequence of various conditions in the coastal area of the former island in the Paratethys Sea (conglomerates, sandstones, sandy marls and tuff-sandstones, clays and clayey marls, limestones, *etc*.). However, the Mutalj Quarry includes three lithostratigraphic members (Fig. 2. B–B'). Very rare grayish-green clay and sandy marl and the wider distributed biogenic limestones (the so-called Leitha limestone). They contain numerous fossils and several types of limestones could be distinguished: lithotamnian, amphistegin, bryozoan, *etc*. The limestone is massive, reefy, developed by the life activities of the red algae *Lithotamnion*, foraminifers and bryozoans, and including numerous fossil remains of mollusks, as well as scarce findings of sea urchins, corals and other organisms. Analyses of the sediment determined the dominance of algal and algal–foraminifer biomicsparite and biomicrudite (Figs. 3, 4). On the lateral sides, toward the E–NE periphery of the exploitation area, the limestones turn into marly limestones, sandy marl, and clay (Fig. 2. B–B', C–C').

The Badenian sediments at Mutalj Quarry are overlaid by Pleistocene red beds. Finally, Pleistocene loess–paleosoil sequences cover both of them (Fig. 2. B–B', C–C').

Based on data from the above-mentioned boreholes and from field observations, it can be concluded that there is no rock connection between the active Mutalj Open Pit and the abandoned one (the Beli Kamen Open Pit). This means that there are two independent limestone bodies, which belong to a narrow belt on the southern slope of FG.

Lithostratigraphy and sedimentology

A lithostratigraphic column of the Badenian limestone with a total thickness of more than 30 meters (2009) was recorded in the Mutalj Quarry (N 45°06'21.1", E 19°41'43.1"). Including the Pleistocene sediments of the Srem Formation and the loess–paleosoil sequences, the overall thickness of the whole section reaches up to 48 meters (Figs. 3, 4.). These are white biogenic limestones, very porous and poorly cemented. They have a general appearance of chalky carbonate and contain various fauna of mollusks (clams, snails), algae, and other reef builders. The thirty meters of the column appeared homogeneous without a clearly visible internal stratification or other structural features. At the top of the limestone, there are many emphasized cracks of meter dimensions that are filled by red clays and alevrites. The limestones are permeable and there is an accumulation in the deepest floor of the quarry (see Fig. 3A, B). The dark green water has a high content of carbonate. A typical example of Badenian biogenic limestone – biomicrudite is shown in Fig. 7.

The allochem contains primarily large algal remains. The fragments are rudites. Large pelagic and benthic foraminifers make a small percent of the allochem. Biogenic detritus is minimized. Ortochem is a micrite calcite. The Leitha limestone has an intergranular and intragranular porosity. The pores sporadically contain a sparite calcite. Non-carbonate ingredients are clay minerals that are either adhered to algal fragments or mixed with micrite. The total content of calcite ($CaCO_3$) is about 98 %.

Over the Badenian bioclastic limestone, there are breccias up to 2 meters thick (Fig. 3). One local phenomenon was noted, even in the realm of the quarry, which, regardless of their limited occurrence, we think consider very interesting. The phenomenon is constructed of a variety, both in size and form, of fragments that originated from the Badenian rocks (Fig. 5). The fragments can be observed macroscopically and they contain algal debris and large foraminifers (Fig. 7D). In some parts of the breccias, there was a significant transport of fragments, while in other parts, there was none at all. It is evident that there are polyphases of its making (Fig. 5). Vertically as well as laterally, there is black scree of black pebbles with centimeter dimensions. The cement of the breccias is carbonate, without fossil remains, painted in different shades of red. Given that, these breccias lie over "karstified" Badenian limestone and under the Srem Formation, their stratigraphic position for the time being, outstanding issues. A sample of the carbonate breccias (No. 33, Fig. 3), which overlies the Badenian biogenic limestone, is built from various, primarily in size, angular fragments. Smaller fragments may have rounded and dark brown to black membranes. These fragments may correspond to grain-type black pebbles. The Badenian algal limestone represents the source rock for the fragments. Each fragment represents the different microfacies. Most of the rudites contain algal fragments and other biogenic allochem similar to that of the Badenian limestone. In addition, as smaller fragments, independent algal grains are embedded in the matrix. The cement is a micrite pigmented with iron oxides. The terrigenous component is evenly distributed throughout the rock. Its content is up to 5 %. These are mainly angular quartz grains and fragments of metamorphic rocks. Present in the micrite matrix, there are an irregular cavities filled by sparite calcite which, together with micrite, correspond to a type of dismicrite.

A slightly different example is a sample of limestone breccias (No. 34, Fig. 3). A feature of the fragments is that they all have brown, ferrous membranes (black grains). The fragments do not touch; they are embedded in the matrix. The cement is a micrite pigmented with iron oxides. Within it, the terrigenous component reaches up to 2–3 %. The total content of calcite ($CaCO_3$) is about 97 %.

An important characteristic of the Leitha limestone is its high $CaCO_3$ content, which in certain samples reaches over 98 %. Therefore, it is used to enrich the main raw material (Pannonian marl) with carbonates

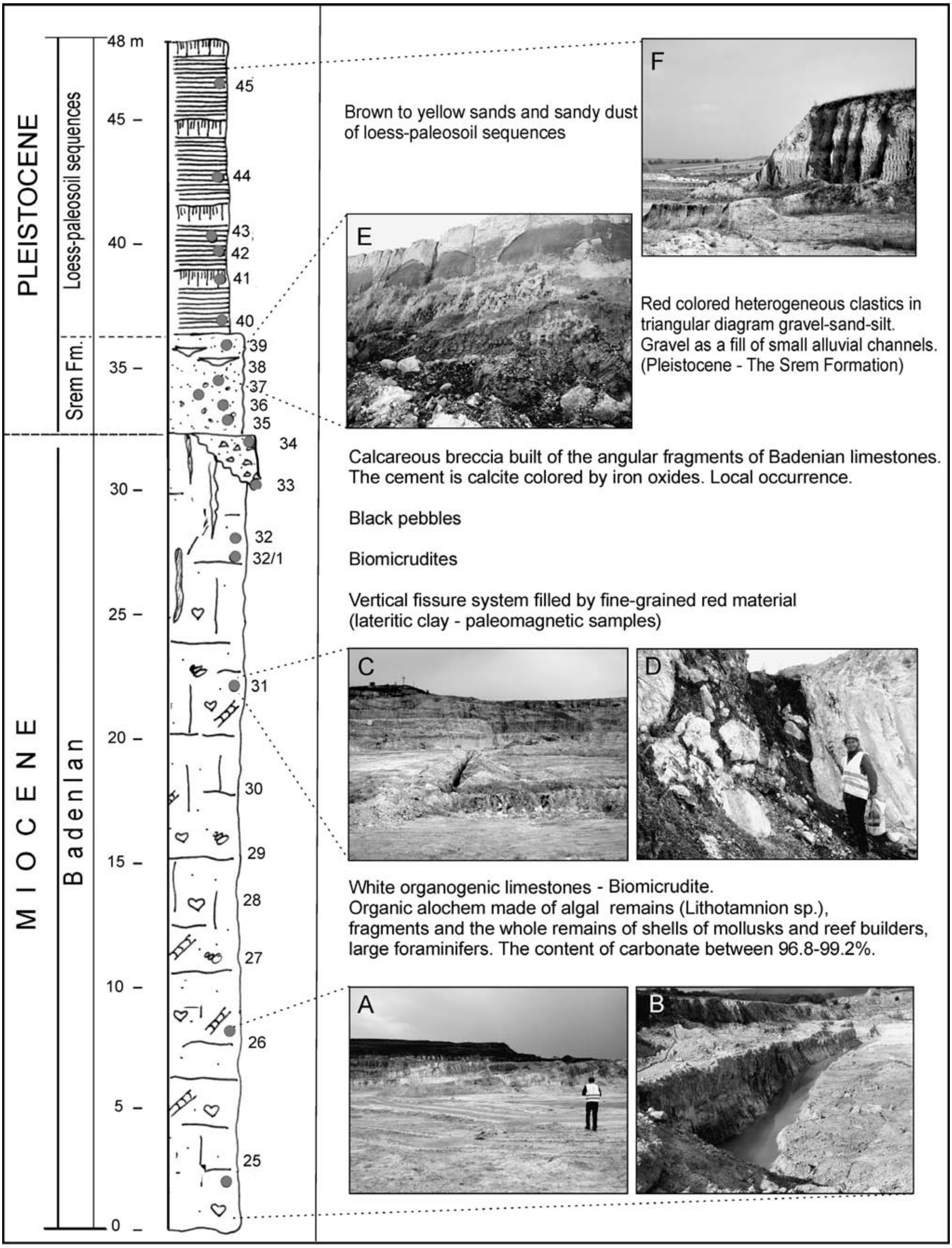

Fig. 3. Lithostratigraphic succession at the Mutalj Quarry and the main sedimentological features. The numbers from 25 to 45 show the position of the taken samples.

Fig. 4. Contact between Badenian limestones (A) and Pleistocene clastic sediments (B).

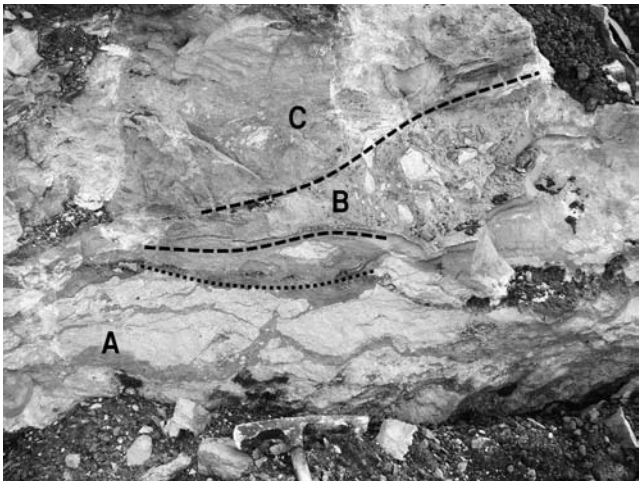

Fig. 5. Several stages in the creation of breccias. **A,** Fragmentation of the Badenian limestone without movement; **B,** Finer limestone fragments are transported; **C,** Large limestone fragments.

during cement production. In the paleogeographical sense, they were deposited during the Badenian, along the southern shore of the former Fruška Gora Island. Due to good insulation, the conditions needed for the development of red algae and other reef-forming organisms were more suitable here than on the northern coast; hence, the Badenian limestones on the southern slopes are richer in $CaCO_3$.

During the first phase of the limestone exploitation at the Mutalj Quarry, their total thickness was more than 100 meters.

Fossils in the Leitha limestone

The fossil macrofauna often contains large forms, such as: *Pecten aduncus*, *P. haueri*, *Chlamys latisimuss*, *Chlamys* sp., *Flabellipecten besseri*, *Glycimeris pilosus*, *Panopea menardi*, *Ostrea lamelosa*, *O. digitalina*, *Isocardia cor*, *Conus mercati*, *etc*. (Fig. 6). Foraminifers, ostracodes, as well as different algae and bryozoans, have also been recorded. Among the foraminifers, the genus *Amphistegina* is of particular importance and makes the microfacies specific. Following species were recognized: *Amphistegina haueri*, *Globigerina bulloides*, *G. bilobata*, *Asterigerina planorbis*, *Cibicides lobatulus*, *Ammonia ex gr. beccari*, *Elphidium crispum*, *Elphidium* sp., *Bolivina* sp., *Lithotamnion* sp. and *Lithophyllum* sp. Similarly, there are other types of these rocks based on the prevailing microfossils (Fig. 7). All the mentioned fossil species suggest the Upper Badenian, which is consistent with field observations and the position of similar sediments on the northern slope of the FG. However, a precise biostratigraphic determination will be realized later.

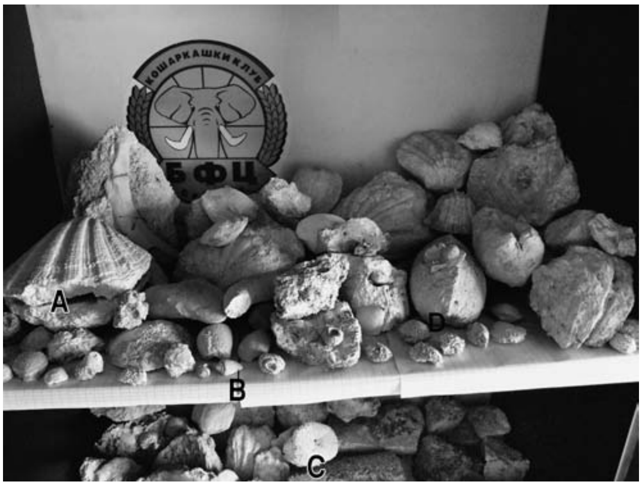

Fig. 6. Association of fossil mollusks extracted from the Leitha limestone: **A,** *Chlamys latissimus* Brocco.; **B,** *Conus* sp.; **C,** A fossil coral; and **D,** Shell molds of *Panopea* sp.

Hydrogeological features

From the hydrogeological point of view, the Middle Miocene Badenian limestones provide a good environment for the formation of karst aquifers. This was confirmed by geological exploration drilling and installation of piezometers, as well as other hydrogeological studies.

Analyses of hydrogeological mapping in the wider area of the Mutalj Open Pit, the bored cores and the infiltration tests determined the large permeability potential of this limestone as well as the overlying beds composed of loess sequences and different pebbly and sandy clay deposits of so-called the Srem Formation (Pleistocene). The results of the infiltration tests (*in situ*) showed that the coefficient of filtration in the Mutalj Open Pit limestone is about $K = 10^{-2}$ cm/s. Ac-

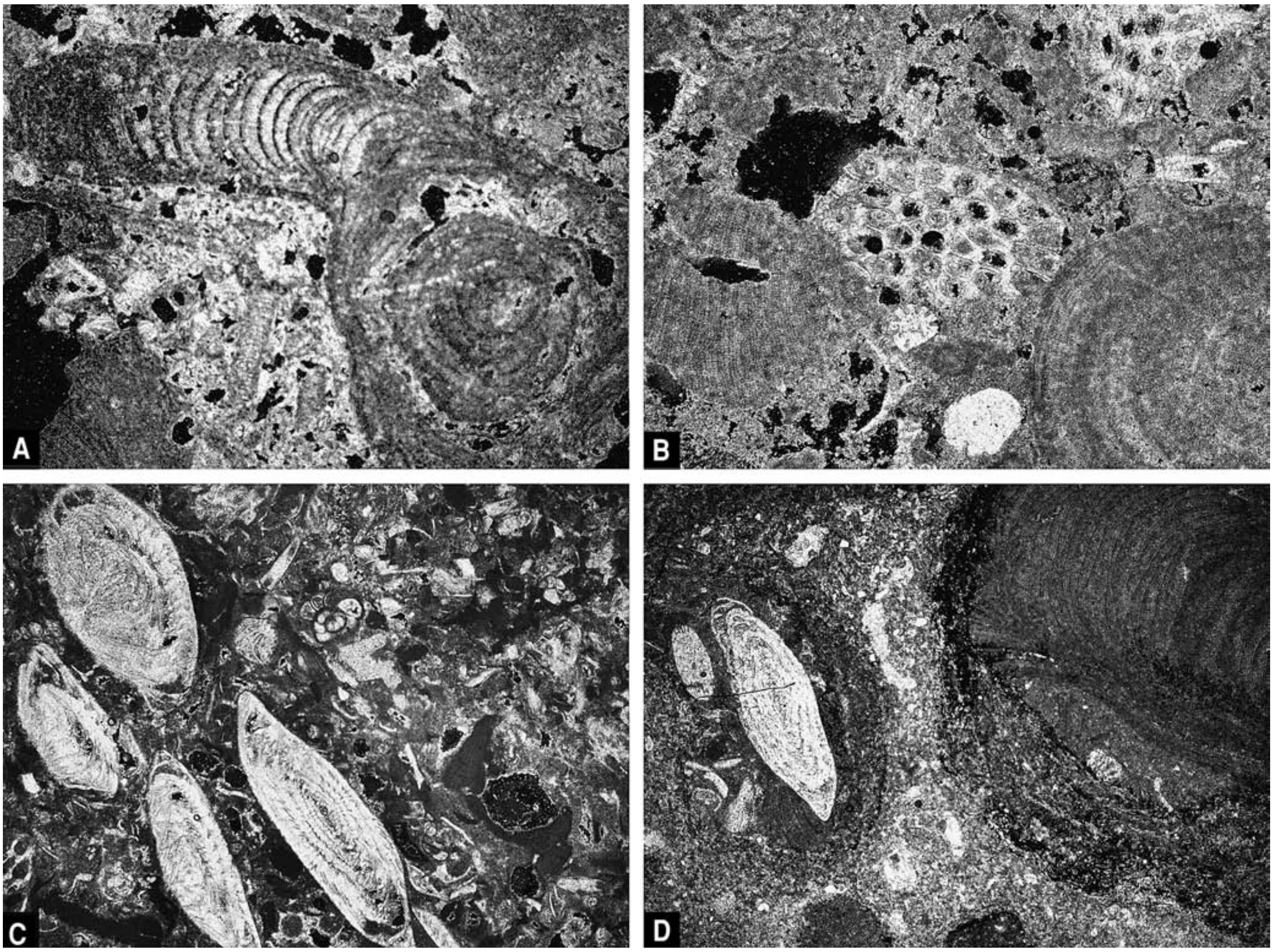

Fig. 7. Different microfacies of Badenian limestone: **A,** Lithotamnian limestone (Sample 32); **B,** Algal–bryozoan limestone (sample 32/1); **C,** Amphistegin limestone (sample 34/1); **D,** Algal and foraminifer fragments within the breccias (sample 34/2). Scale: length of pictures is 4 mm.

cording to these results, they belong to the highly permeable sediments. The coefficient of filtration for the overlying sediments is less than $K = 10^{-4}$ cm/s and they belong to the middle-permeable sediments. Based on these results, it can be concluded that the infiltration of atmospheric precipitation into the underground occurred very quickly and recharged the karst aquifer formed in the Badenian limestones. Drainage of the karst aquifer is towards the southwest, which is compatible with the dip direction of the Vrdnik Formation. This was concluded from the results of numerous measurements that were performed in the network of piezometers formed around the Mutalj Open Pit. During 2005, the limestone exploitation reached the ground water level at an elevation of from 175 m to 177 m and opened the karst aquifer within it.

The hydrogeological conditions and the relation between the Mutalj Open Pit and the abandoned neighboring limestone of the Beli Kamen Open Pit were the objects of detailed investigations during 2010. Main goal of these studies was to explain the geological conditions as well as their hydrogeological relations. Namely, during the past decades, it was not possible to determine whether there is a unique aquifer between these limestone quarries. In addition, there was doubt whether the karst aquifer in the Beli Kamen limestone and the artificial lake formed therein could affect the aquifer recharge in the Mutalj Open Pit. Finally, it could lead to an increased inflow of groundwater from this direction. However, further exploitation of the limestone from the Mutalj Open Pit, as well as its continual dewatering resulted in a lowering of the ground water level; the mirror of the water at level is now at 158.76 m (Table 2).

Table 2. Recent measurements of the elevation of the water mirror.

Open pit	Elevation	Date
Mutalj	158.76 m	19.11.2010.
Beli Kamen	173.10 m	17.01.2011.

All the mentioned geological and hydrogeological data obtained during 2010 show that the space between the pits is not constructed of marine limestone rock. It consists of Lower Miocene lacustrine deposits, dark, grayish-green siltstones, reworked blocks and fragments of diabases and schists, minor pebbles of carbonates, *etc*. (IBMBK-6/10, IBMBK/7/10). The exploration borehole BGMO-3/10, which was drilled with the purpose of determining of the absence of limestone, showed that there is a diabases block below the mentioned lacustrine sediments. From the hydrogeological point of view, the diabases are impermeable. These formations alternate with low-permeable sediments, such as gray–yellow marly clay, marly sandstone, poorly consolidated sandstone, gravel with lenses of sand, *etc*. These sediments represent a lateral facies of Badenian limestone (IBMBK-1/10, IBMBK-2/10). Similar geological successions were observed in boreholes IBMBK-4 and IBMBK-5. Different loess and paleosoil sequences form the cover of the mentioned Miocene sediments.

Paleomagnetic data

All samples in the NRM domain have measured values of initial magnetic susceptibility in the range 1.9–3.4 10^{-3} SI and remanent magnetization in the range 29.1–78.4 mA/m. The degree of AMS is low with the dominant magnetic foliation indicating remanent magnetization formed during compaction (Fig. 8). Correction for tectonics caused a slight change in the position of the anisotropy axis of the magnetic susceptibility (Fig. 9). Based on the acquisition of isothermal remanent magnetization experiment by the method of step-by-step thermal demagnetization three-component IRM (LOWRIE 1990) and the CISOWSKI test (1981), it was found that the primary carrier of natural remanent magnetization is magnetite (Fig. 10). To avoid cracking and loss of the samples during heating, it is planned to perform alternating field demagnetization. However, the presence of a "resistant" RM to the effect of an alternating field (AF) would require the use of thermal demagnetization (Fig. 11). The direction of the high-stability PRM component was determined by principal-component analysis (KIRSCHVINK 1980) and Fisher statistics (FISHER 1953). The isolated paleomagnetic directions are consistent not only within a cavern, but also between the cavities (Fig. 12).

Interpretation and Discussion

The Miocene epoch on the southern slope of FG is relatively unknown. Poor data were derived from the BGM 1: 100 000 sheet Novi Sad (ČIČULIĆ-TRIFUNOVIĆ & RAKIĆ 1971). Therein, only a few "patches" indicate the presence of Miocene rocks. However, continual investment in the cement industry and the demand for good raw material resulted in numerous drilling in this area. Consequently, a completely different distribution pattern of the Miocene on the southern slope of FG to that on the northern slopes was established.

Lower Miocene undivided heterogeneous rocks have a relatively small distribution. Practically, they are confirmed only in the studied boreholes (see Fig. 2). However, based on core data, there is a clear signal for the continental development of the Lower Miocene there. The main characteristics of these deposits are as follows: variegated beds, lack of fauna, domination of coarse-grained clastics, very fast vertical and lateral alternation of facies, noticeable variations in grain size, *etc*. According to the early known facts regarding the geology of the Vrdnik coal-bearing basin (PETKOVIĆ *et al*. 1976; RUNDIĆ *et al*. 2005), these rocks correspond to the upper part of the Lower Miocene Vrdnik Formation. Up to the present, the age of these sediments is not clear. Comparable data comes from the neighboring Požeška Mt. (northern Croatia), where Lower Miocene alluvial deposits were discovered (PAVELIĆ & KOVAČIĆ 1999).

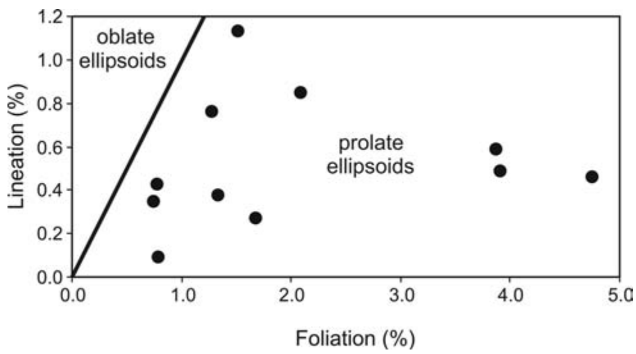

Fig. 8. Lineation *versus* Foliation (Flinn diagram), showing oblate shape for the AMS measurements, with the foliation coinciding with the bedding plane.

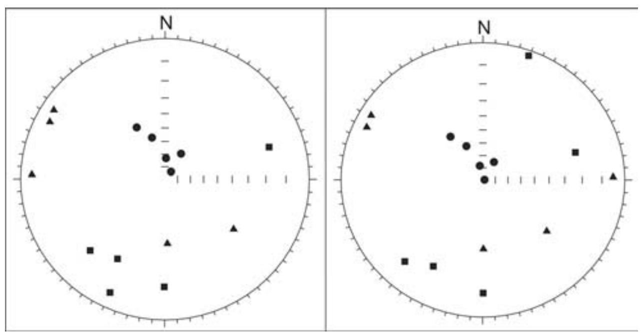

Fig. 9. Equatorial projection (on the lower hemisphere) k_{max} (square), k_{int} (triangle) and k_{min} (circle) of AMS ellipsoid axes for individual clay samples from the Mutalj Open Pit. Left: before correction for tectonics; right: after correction for tectonics.

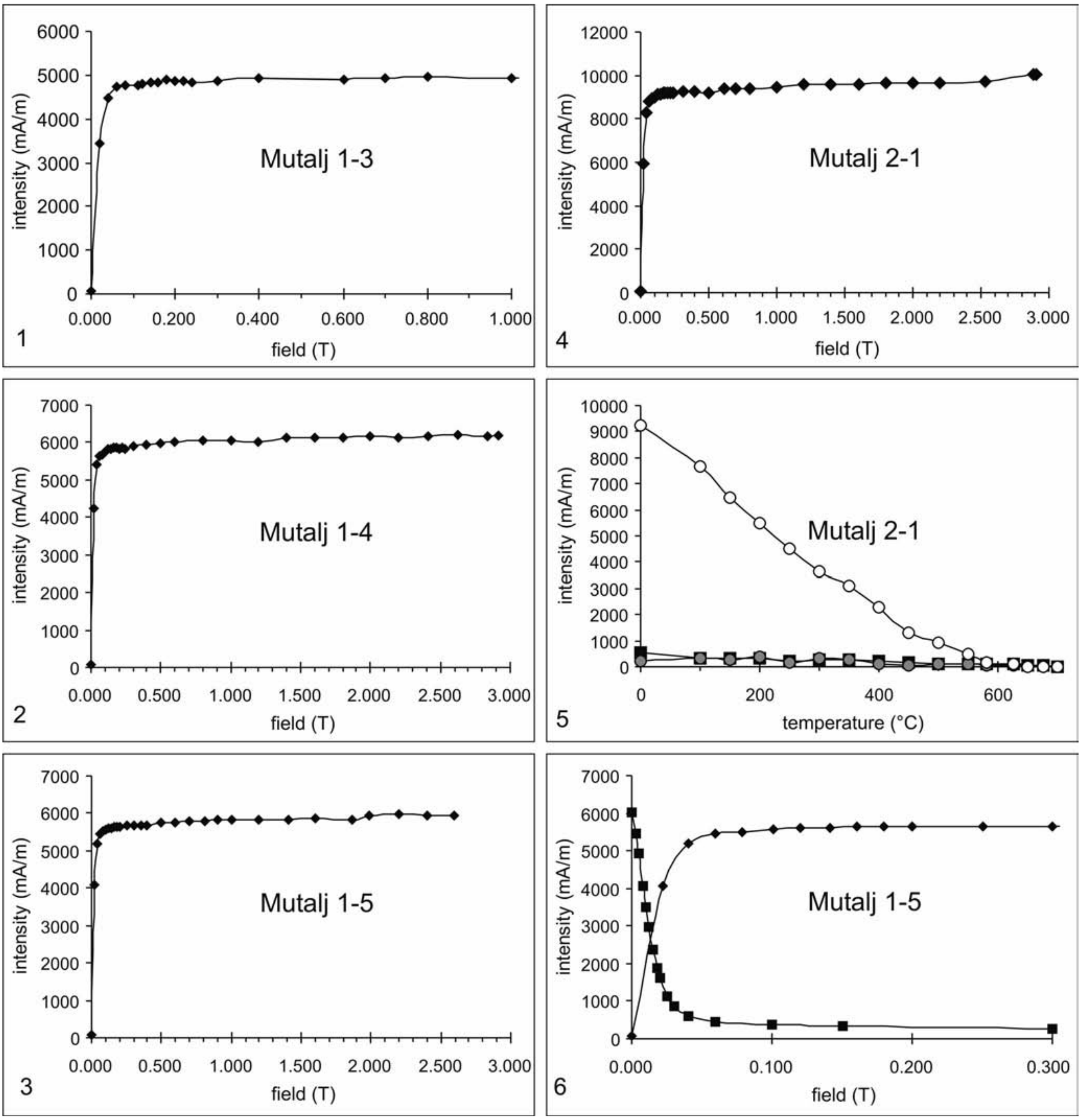

Fig. 10. Magnetic mineralogy. Diagrams of the behavior of the magnetization-bearing mineral during the magnetic field control and heating in the laboratory. Key: **1–4,** IRM acquisition behavior; **5,** The three-component IRM (LOWRIE 1990) behavior on thermal demagnetization. The hard (square), the medium hard (dots) and soft (circle) components of the composite IRM were acquired in fields of 2.91 T, 0.4 T and 0.121 T, respectively; **6,** Acquisition and AF demagnetization of IRM (CISOWSKI test, 1981).

A well-known fact is that the beginning of the Badenian age (Early Langhian, *ca*. 16.3 Ma) coincides with a marine transgression in the domain of the Central Paratethys (ĆORIĆ & RÖGL 2004; ĆORIĆ *et al*. 2004, 2009; HARZHAUSER & PILLER 2007; HOHENEGGER *et al*. 2009; PILLER *et al*. 2007; RÖGL *et al*. 2008). Such records, coupled with different tectonic, seismic and sequence stratigraphy data, indicate to a very powerful and important event (HORVÁTH *et al*. 2006; KOVÁČ *et al*. 2007; SCHMID *et al*. 2008). Generally, the Lower Badenian deposits discordantly overlie the older Miocene strata or the pre-Tertiary basement (e.g., the Vienna Basin, the Styrian Basin, the southern margin of the Pannonian Basin in Croatia, Bosnia,

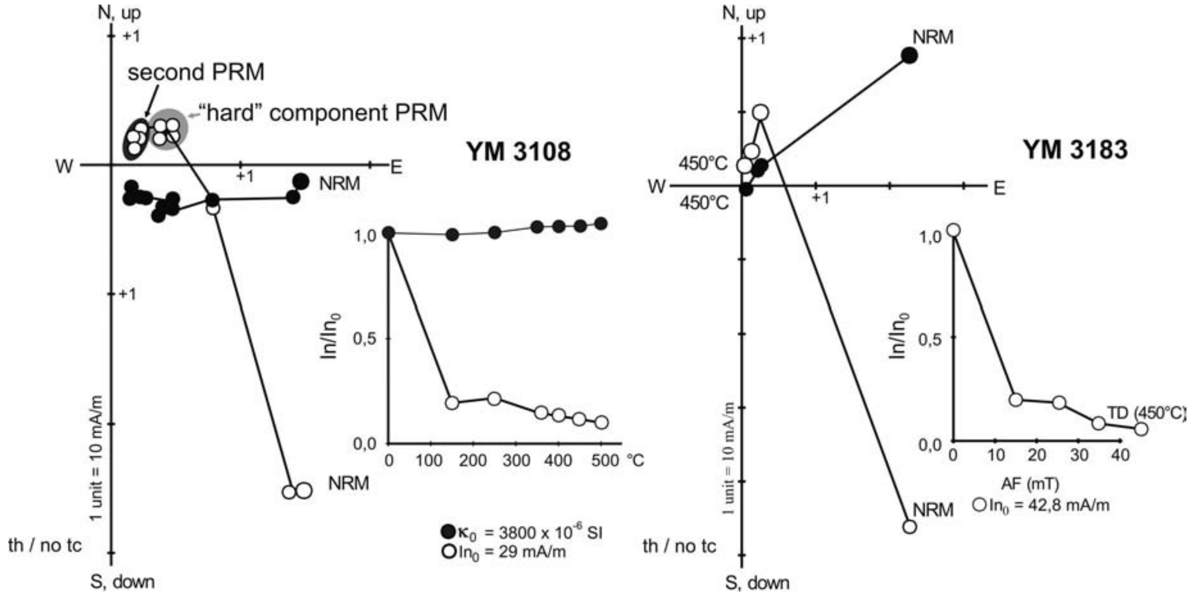

Fig. 11. Typical demagnetization curves for clay. Key: Zijderveld diagrams and intensity/susceptibility *versus* temperature curves. During thermal demagnetization, the remaining intensity of the NRM was measured after heating the specimen to a given temperature and cooling back to ambient. In the Zijderveld diagrams full/open circle: projection of the NRM in the horizontal/vertical plane; in the others susceptibility: dots, NRM intensity: circles. In_0 - initial intensity of the NRM, k_0 - initial susceptibility.

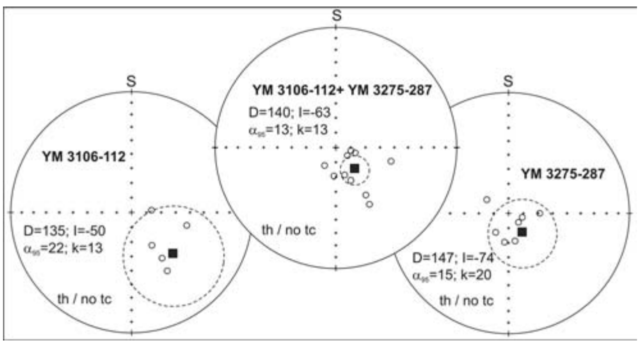

Fig. 12. Mutalj Open Pit, limestone with paleokarst. Paleomagnetic directions (open circles), locality mean paleomagnetic directions (squares) with statistical parameters a_{95} (interrupted line). Stereographic projection. Key: open circles - negative inclination.

Serbia – see ĆORIĆ *et al*. 2009). All the collected facts from the Vojvodina Province and Fruška Gora Mt. indicate to a similar time event (PETKOVIĆ *et al*. 1976; RADIVOJEVIĆ *et al*. 2010). It is considered that the marine transgression engulfed the Fruška Gora Island surrounded by the Central Paratethys Sea. On the southern flank of FG, there are no Lower Badenian rocks on the surface. The only evidence for them was found in borehole B-16/05, where sandy marl was drilled at a depth of 53 meters under the surface (see Fig. 2, B–B'). On the other hand, Lower Badenian marine deposits on the northern slopes of FG have a wider distribution (PETKOVIĆ *et al*. 1976). Nevertheless, younger Badenian sediments have a much wider distribution on FG. During the Late Badenian (Early Serravallian, *ca*. 13.6–12.7 Ma), algal–bryozoans, and coralline reefs built a distinct belt along both sides of the mountain (Erdelj, Ležimir, Mutalj, *etc*.). The main sedimentological feature is the enhanced carbonate production controlled by strong volcanism (tuffs, dacites, andesites, *etc*.). These Badenian limestones are not only high-quality raw materials, but also contain extremely fine association of fossil mollusks, algae, coral, bryozoans, foraminifers, ostracodes and other fauna. For example, warm-temperature pectinids and ostreids suggest a shallow-marine, sublittoral to littoral environment (SCHMID *et al*. 2001). The mentioned biomicrudites with abundant reef-builders could be a part of a small carbonate platform that is existed in the area of FG. Similar records come from northern Croatia and Austria (SCHMID *et al*. 2001; VRSALJKO *et al*. 2006). Temperature estimates for the Central Paratethys Miocene mostly rely on a comparison of the biota characteristic for a certain time interval with their present-day relatives. Additionally, a number of isotope and trace element studies are also available for the period considered (BÁLDI 2006; KOVÁČOVÁ *et al*. 2009). However, a direct interpretation of these records in terms of paleo-temperature without a consistent control based on faunal records is unsafe (LATAL *et al*. 2006). The reason is that relatively small epicontinental seas, such as the Paratethys, can be strongly influenced by regional differences in seawater isotope composition (LATAL *et al.* 2006; HARZHAUSER *et al.* 2007). For this reason, some authors try to calculate the Paratethyan temperature record based on the open/closure position of the main gateways between the Mediterranean, the Indian Ocean, the Atlantic Ocean, and the Paratethys (KARAMI *et al.* 2011). They applied an oceanic 4-box model to determine the temperature, salinity and exchange flows for the Paratethys and the Mediterranean Sea before and after closure of the Indian Ocean gateways. They concluded that closure of the gateways connecting Paratethys and the Mediterranean to the Indian Ocean had a great impact on the temperature of the basin's temperature as well as on its salinity. Following this model, it seems that the Badenian predominantly algal and bryozoan limestone suggests warm-temperature conditions (17–21°C) in this period (KOVÁČ *et al.* 2007).

Based on the lithological succession, the geological and hydrogeological cross-sections and the results of the infiltration tests, it can be asserted with confidence that there is no hydraulic connection between the Mutalj and Beli Kamen Quarries that could have a significant impact on aquifer recharge.

The paleomagnetic study of the post-Badenian lateritic clays shows that biogenic limestones and their products should not be rejected *a priori* as unsuitable for paleomagnetism but should be viewed as potential carriers of the primary RM. The carrier of remanent magnetization in these clays is magnetite, which occurs in significant concentrations and probably has a primary origin. In relation to the Badenian sediments on the northern slope of FG, which have a positive RM polarity, they have the opposite RM polarity and, practically, same values of inclination (CVETKOV 2010; LESIĆ *et al.* 2007). The declination of the RM is counter-clockwise rotated, which is typical for Badenian deposits on FG (LESIĆ *et al.* 2007), as well as for other rock masses of the southern part of the Pannonian Basin (MARTON 2005). On the other hand, the extracted paleodirection is limited by the Late Pliocene rotation and the Badenian limestone underlying the Pontian sediments, hence, it can be concluded that the mentioned clays formed during the Middle–Late Miocene. This is contrary to common opinion that they belongs to the Pleistocene (the Srem Formation, see PETKOVIĆ *et al.* 1976)

Conclusions

The Mutalj Quarry is located on the southern slope of Fruška Gora. It is the largest Miocene quarry in this part of the mountain. It occupies of 0.3 square kilometer of a more or less rectangular area and the mean thickness is more than 40 meters (recent data). The high content of carbonate (more than 98 %) in the limestones allows them to be very important raw materials for cement production (La Farge Cement Factory, Beočin).

Core data, structural and stratigraphic measurements show that the whole limestone deposit on the southern slope of FG belongs to a narrow, discontinuous belt of Middle Miocene Badenian sediments with E–W extension. In the Mutalj Quarry, the limestone has the largest distribution and transgressively lies over the Lower Miocene Vrdnik Formation (up to date, there is no confident data regarding the precise stratigraphic position of these rocks). There are no other Miocene units there. This means that the Middle Miocene Sarmatian and the whole Upper Miocene are completely missing. Different Pleistocene sediments including the red continental beds (the Srem Formation) and the loess–paleosoil sequences form the cover of this limestone.

Sedimentological analyses as well as fossil remains from the limestone indicate to favorable conditions needed for development of marine, shallow-water assemblages (mollusks, foraminifers) and reef-forming organisms, such as red algae, bryozoans, corals, *etc.* This indicates to the Badenian marine transgression in this part of the Central Paratethys. The mostly algal and bryozoan limestone suggests warm-temperature conditions (17–21°C). This biogenic, shallow-water carbonate unit on the Mutalj Open Pit represents the best section of Leitha limestone on the investigated area. After the Badenian, a continental regime replaced this marine one. Due to the drier climate, red lateritic beds were formed upwards. Additionally, numerous cracks and caverns within the limestone were formed. Later, fine-grained prolluvial sediments infilled them.

The Middle Miocene Badenian limestone provides a good environment for the formation of karst aquifers. Analyses of hydrogeological mapping in the wider area of the Mutalj Open Pit, and data from boreholes and infiltration tests determined the large permeability potential of this limestone. The coefficient of filtration is about $K = 10^{-2}$ cm/s, thus they belong to the highly permeable sediments.

Based on paleomagnetic investigations, it was determined that the magnetite-bearing sediments deposited during the post-Badenian time mainly do not carry a coherent. In relation to the Badenian sediments on the northern slope of the FG that have a positive RM polarity, they have the opposite RM polarity. The declination of the RM is counter-clockwise rotated, which is a characteristic for Badenian Age (LESIĆ *et al.* 2007). However, the extracted paleodirection is limited by the well known the Late Pliocene rotation. Therefore, it can be concluded that the mentioned clays probably formed during the Middle–Late Miocene.

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Reference

BÁLDI, K. 2006. Paleoceanography and climate of the Badenian (Middle Miocene, 16.4–13.0 Ma) in the Central Paratethys based on foraminifera and stable isotope (δ^{18}O and δ^{13}C) evidence. *International Journal of Earth Science*, 95: 119–142.

CISOWSKI, S. 1981. Interacting *vs*. non-interacting single domain behavior in natural and synthetic samples. *Physics of the Earth and Planetary Interiors*, 26: 56–62.

CLOETINGH, S., BADA, G., MATENCO, L., LANKREIJER, A., HORVÁTH, F. & DINU, C. 2006. Modes of basin (de)formation, lithospheric strength and vertical motions in the Pannonian–Carpathian system: inferences from thermomechanical modeling. *Geological Society of London*, 32: 207–221.

CVETKOV, V. 2010. Paleomagnetism of Fruška gora. 139 pp. Unpublished PhD Thesis, University of Belgrade, Faculty of Mining and Geology.

DOMBRÁDI, E., SOKOUTIS, D., BADA, G., CLOETINGH, S. & HORVÁTH, F. 2010. Modelling recent deformation of the Pannonian lithosphere: Lithospheric folding and tectonic topography. *Tectonophysics*, 484: 103–118.

ĆORIĆ, S. & RÖGL, F., 2004. Roggendorf-1 borehole, a key-section for Lower Badenian transgressions and the stratigraphic position of the Grund Formation (Molasse Basin, Lower Austria). *Geologica Carpathica*, 55 (2): 165–178.

ĆORIĆ, S., HARZHAUSER M., HOHENEGGER, J., MANDIC, O., PERVESLER, P., ROETZEL, R., RÖGL, F., SCHOLGER, R., SPEZZAFERRI, S., STINGL, K., ŠVÁBENICKÁ, L., ZORN, I. & ZUSCHIN, M. 2004. Stratigraphy and correlation of the Grund Formation in the Molasse Basin, northeastern Austria (Middle Miocene, Lower Badenian). *Geologica Carpathica*, 55 (2): 207–215.

ĆORIĆ, S., PAVELIĆ, D., RÖGL, F., MANDIC, O., VRABAC, S., AVANIĆ, R., JERKOVIĆ, L. & VRANJKOVIĆ, A. 2009. Revised Middle Miocene datum for initial marine flooding of North Croatian Basins (Pannonian Basin System, Central Paratethys). *Geologica Croatica*, 62: 31–43.

ČIČULIĆ, M. 1958. Oligocene and Miocene of Fruška Gora (Syrmien). *Bulletine Scientifiques*, Zagreb, 4 (2): 48–49 (in German).

ČIČULIĆ-TRIFUNOVIĆ, M. & RAKIĆ, M. 1971. Basic geological map 1:100,000, Sheet Novi Sad, with Explanatory book. 52 pp. *Savezni geološki zavod*, Beograd (in Serbian)

FISHER, R.A. 1953. Dispersion on a sphere. *Proceedings of the Royal Society of London, Series A*, 217: 295–305.

FODOR. L., BADA G., CSILLAG G., HORVÁT, E., RUSZKICZAY-RÜDIGER, Z., PALOTÁS, K., SÍKHEGYI, F., TIMÁR, G., CLOETING S. & HORVÁT, F. 2005. An outline of neotectonic structures and morphotectonics of the western and central Pannonian Basin. *Tectonophysics,* 410: 15–41

GANIĆ, M., RUNDIĆ, LJ., KNEŽEVIĆ, S., VASIĆ, N. & RADONJIĆ, M. 2009. Northern slopes of Fruska Gora Mountain, Beočin vicinity (southern part of the Central Paratethys) – a representative example of the Neogene succession. *3rd International Workshop Neogene of Central and South-Eastern Europe, Abstract volume*, 33–34, Cluj-Napoca.

GANIĆ M., RUNDIĆ LJ., KNEŽEVIĆ S. & CVETKOV V. 2010: Late Miocene Pannon marls from the Filijala Open Pit (Beocin, northern Serbia): new geological and paleomagnetic data. *Geološki anali Balkanskoga poluostrva,* 71: 95–108

HARZHAUSER, M. & PILLER, W.E. 2007. Benchmark data of a changing sea – Palaeogeography, Palaeobiogeography and events in the Central Paratethys during the Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 253: 8–31.

HARZHAUSER, M., PILLER, W. E. & LATAL, C. 2007. Geodynamic impact on the stable isotope signatures in a shallow epicontinental sea. *Terra Nova*, 19: 324–330.

HOHENEGGER, J., RÖGL, F., ĆORIĆ, S., PERVESLER, P., LIRER, F., ROETZEL, R., SCHOLGER, R. & STINGL, K. 2009. The Styrian Basin: A key to the Middle Miocene (Badenian/Langhian) Central Paratethys transgressions. *Austrian Journal of Earth Science,* 102: 102–132.

HORVÁTH, F., BADA, G., SZAFIÁN, P., TARI, G., ÁDÁM, A. & CLOETINGH, S. 2006. Formation and deformation of the Pannonian Basin. *In*: GEE, D.G. & STEPHENSON, R.A. (eds.), European lithosphere dynamics. *Geological Society of London,* 32: 191–207.

KARAMI, M.P., DE LEEUW, A., KRIJGSMAN, W., MEIJER, P.Th. & WORTEL, M.J.R. 2011. The role of gateways in the evolution of temperature and salinity of semi-enclosed basins: An oceanic box model for the Miocene Mediterranean Sea and Paratethys. *Global and Planetary Change*, 79: 73–88.

KIRSCHVINK, J.L. 1980. The least-square line and plane and the analysis of paleomagnetic data. *Geophysical Journal of the Royal Astronomical Society*, 62: 699–718.

KOCH, A. 1876. Neue Beiträge zur Geologie der Fruška Gora in Ostslavonien. *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt,* 26: 1–48.

KOVÁČ, M., ANDREYEVA-GRIGOROVICH, A., BARJAKTEREVIĆ, Z., BRZOBOHATY, R., FILIPESCU, S., FODOR, L., HARZHAUSER, M., NAGYMAROSY, A., OSZCZYPKO, N., PAVELIĆ, D., RÖGL, F., SAFTIĆ, B., SLIVA, L. & STUDENCKA, B. 2007. Badenian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sea-level changes. *Geologica Carpathica*, 58 (6): 579–606.

KOVÁČOVÁ, P., EMMANUEL, L., HUDÁČKOVÁ, N. & RENARD, M. 2009. Central Paratethys paleoenvironment during the Badenian (Middle Miocene): evidence from foraminifera and stable isotope (δ^{13}C and δ^{18}O) study in the

Vienna Basin (Slovakia). *International Journal of Earth Science*, 98: 1109–1127.

LATAL, C., PILLER, W. E. & HARZHAUSER, M. 2006. Shifts in oxygen and carbon signals in marine molluscs from the Central Paratethys (Europe) around the Lower/Middle Miocene transition. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 231: 347–360.

LENZ, O. 1874. Beitrage zur Geologie der Fruska Gora in Syrmien. *Jahrbuch der Kaiserlich-Königlichen Geologischen Reichsanstalt,* 24: 325–332.

LESIĆ, V., MARTON, E. & CVETKOV, V. 2007. Paleomagnetic detection of Tertiary rotations in the Southern Pannonian Basin (Fruška Gora). *Geologica Carpathica*, 58 (2): 185–193.

LOWRIE, W. 1990. Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. *Geophysical Research Letters,* 17 (2): 159–162.

MAROVIĆ, M., TOLJIĆ, M., RUNDIĆ, LJ. & MILIVOJEVIĆ, J. 2007. Neoalpine tectonics of Serbia. *Serbian Geological Society*, series Monographs, 87 pp., Belgrade.

MÁRTON, E. 2005. Post-Badenian Horizontal Movements in the Pannonian Basin as Indicated by Paleomagnetic Data. *GeoLines*, 19: 82–84.

PAVELIĆ, D. & KOVAČIĆ, M. 1999. Lower Miocene Alluvial Deposits of the Požeška Mt. (Pannonian Basin, Northern Croatia): Cycles, Megacycles and Tectonic Implications. *Geologica Croatica*, 52 (1): 67–76.

PETKOVIĆ, K., ČIČULIĆ-TRIFUNOVIĆ, M., PAŠIĆ, M. & RAKIĆ, M. 1976. Fruška Gora – Monographic review of geological materials and tectonic assembly. 267 pp. *Matica srpska*, Novi Sad (in Serbian with French summary).

PILLER, W.E., HARZHAUSER, M. & MANDIC, O. 2007. Miocene Central Paratethys stratigraphy – current status and future directions. *Stratigraphy*, 4: 71–88.

RADIVOJEVIĆ, D., RUNDIĆ, Lj. & KNEŽEVIĆ, S. 2010. Geology of the Čoka structure in northern Banat (Central Paratethys, Serbia). *Geologica Carpathica*, 61: 341–352.

RÖGL, F., ĆORIĆ, S., HARZHAUSER, M., JIMENEZ-MORENO, G., KROHN, A., SCHULTZ, O., WESSELY, G. & ZORN, I. 2008. The Middle Miocene Badenian stratotype at Baden-Sooss (Lower Austria). *Geologica Carpathica*., 59: 367–374.

RUNDIĆ, LJ. DULIĆ, I., KNEŽEVIĆ, S., BOGIĆEVIĆ, G., GAJIĆ, V. & CVIJIĆ, P. (eds.). 2005. The First International Workshop on Neogene of Central and South-Eastern Europe, Fruška Gora - Field Guide. *Serbian Geological Society*, 1–31, Novi Sad.

SCHMID, S., BERNOULLI, D., FÜGENSCHUH, B., MATENCO, L., SCHEFER, S., SCHUSTER, R., TISCHLER, M. & USTASZEWSKI, K. 2008. The Alpine–Carpathian–Dinaridic orogenic system: correlation and evolution of tectonic units. *Swiss Journal of Geosciences*, 101: 139–183.

SCHMID, H. P., HARZHAUSER, M. & KROH, A., 2001. Hypoxic Events on a middle Miocene Carbonate Platform of the Central Paratethys (Austria, Badenian, 14 Ma). *Annales Naturhistorische Museum Wien*, 102A: 1–50.

TER BORGH, M., VASILIEV, I., STOICA, M., KNEŽEVIĆ, S., MATENCO, L., KRIJGSMAN, W., RUNDIĆ, Lj. & CLOETINGH, S. 2011: The age of the isolation and evolution of the sedimentary infill of the Pannonian Basin. Geophysical Research Abstracts, vol. 13, EGU 2011-6492.

VRSALJKO, D., PAVELIĆ, D., MIKNIĆ, M., BRKIĆ, M., KOVAČIĆ, M., HEĆIMOVIĆ, I., HAJEK-TADESSE, V., AVANIĆ, R. & KURTANJEK, N. 2006. Middle Miocene (Upper Badenian/Sarmatian) Palaeoecology and Evolution of the Environments in the Area of Medvednica Mt. (North Croatia). *Geologica Croatica*, 59: 51–63.

Резиме

Нови подаци о старијем средњем миоцену на јужним падинама Фрушке Горе (северна Србија): пример каменолома Мутаљ

Током последњих неколико година, истраживања која је на јужним падинама Фрушке горе спровела компанија ЛАФАРЖ, омогућила су откриће значајних наслага средње миоценских кречњака. Ту се пре свега мисли на тзв. баденски лајтовац који представља важну компоненту у производњи цемента. Висок садржај карбоната (преко 98%), омогућује им да буду важна сировина која се додаје лапорцу у процесу стварања цементног клинкера. Стална експлоатација овог камена на каменолому Мутаљ, омогућила је увид у његове структурно-тектонске, стратиграфске и седиментолошке и хидрогеолошке карактеристике. Скоро по правилу, баденски кречњаци леже дискордантно преко различитих кластичних творевина тзв. Врдничке серије (формације). С друге стране, углавном су покривени неколико метара дебелим серијама тзв. Сремске серије и лесно-палеоземљишних секвенци. Бројни фосилни докази (алге, мекушци, корали, бриозое и фораминифере) указују да кречњаци припадају млађим еквивалентима баденског ката. Њихове литолошке и седиментолошке особине указују на плитку, субспрудну морску средину. Бројне истражне бушотине, анализа њихових језгара и интерпретација структурних профила указују на испрекидан појас пружања ових седимената на јужним падинама Фрушке горе (са запада ка истоку). Експанзивна експлоатација кречњака са површине од око 0,3 km^2 брзо мења и њихове техничке карактеристике (сада је просечна дебљина преко 40 m у односу на раније године кад је била преко 100 m).

Са хидрогеолошког аспекта гледано, баденски кречњаци представљају добру средину за формирање карстне издани што је истражним бушењем, уградњом пиезометара и осталим хидрогеолошким испитивањима и потврђено. Коефицијент филтрације баденских кречњака указује на добро пропуст-

љиве седименте (K=10^{-2} cm/s). Новим истраживањима (2010) је утврђено да не постоји хидраулична веза (нема јединствене карстне издани) између Мутаља и напуштеног оближњег каменолома Бели Камен. Висинска разлика између кота водених огледала на та два копа износи око 15 m. Палеомагнетна истраживања пост-баденских латеритских глина показују да се биогени кречњаци не смеју априори одбацити као неподобне стене за палеомагнетна мерења, и треба их посматрати као потенцијалне носиоце примарне магнетизације. Носилац реманентне магнетизације у овим глина је магнетит, који се јавља у великом концентрацијама и вероватно има примарно порекло. У односу на баденске седименте на северним падинама Фрушке Горе који имају позитиван поларитет реманентне магнетизације, ове глине на Мутаљу имају супротан поларитет и практично, исте вредности инклинације (LESIĆ *et al*. 2007; CVETKOV 2010). Деклинација реманентне магнетизације показује ротацију у смеру супротно кретању казаљке на сату што је типично за баден Фрушке горе (LESIĆ *et al*. 2007) као и за остале стене у јужном делу Панонског басена (MARTON 2005). С друге стране, издвојени палеоправац је ограничен млађе плиоценском ротацијом те се може закључити да су поменуте глине формиране у периоду средњи–горњи миоцен.