Геолошки анали Балканскога полуострва Annales Géologiques de la Péninsule Balkanique	71	95–108	Београд, децембар 2010 Belgrade, December 2010

DOI: 10.2298/GABP1071095G

The Upper Miocene Lake Pannon marl from the Filijala Open Pit (Beočin, northern Serbia): new geological and paleomagnetic data

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Abstract: This work presents major lithological, structural, paleontological and paleomagnetic characteristics of the Upper Miocene Pannonian marl in the Filijala Open Pit of the La Farge Cement Plant near Beočin, northern Serbia. Pannonian marl lies between the underlying heterogeneous Sarmatian deposits and the overlying set of Pontian sand beds and Quaternary sediments. The open pit is located on the NE range of Fruška Gora, a horst structure with a core of Paleozoic, Mesozoic and Paleogene rocks in a complex structural pattern. Pannonian sediments, which are part of a younger structural stage, deposited on the horst limbs. The Pannonian marl strata dip at angles from 12° to 26° (to the NNW), forming a monocline. The strata deformations are a consequence of radial tectonics and are a potential source of landslides. The many mollusks (7 gastropod and 9 bivalve species) and ostracodes (27 species) and their biostratigraphical position indicate marl deposition throughout the Pannonian age. A paleomagnetic investigation established that the marl has inconsistent remanent magnetization (with bad statistical parameters), which originates from neoformed magnetite.

Key words: Upper Miocene, Lake Pannon, cement marls, lithology, stratigraphy, paleomagnetism, Beočin, Fruška Gora.

Апстракт: У раду су приказане главне литолошке, структурне, палеонтолошке и палеомагнетне карактеристике горњомиоценских, панонских лапораца са површинског копа Филијала у Беочину (северна Србија). У подини панонских лапораца су хетерогени сарматски седименти док им повлату чине понтски пескови и квартарне наслаге. Површински коп је лоциран на североисточним падинама Фрушке горе која представља једну хорст структуру изграђену од различитих палеозојских, мезозојских и палеогених творевина који се налазе у врло сложеним тектонским односима. Панонски седименти који представљају део млађе структурне етаже депоновани су по ободима хорста. Панонски лапорци граде једну моноклиналу у којој се падни угао креће од 12° до 26° (пад према С–СЗ). Такве деформације слојева су последица радијалне тектонике и често представљају извор потенцијалних клизишта на копу. Бројни мекушци (7 врста пужева и 9 врста шкољки) и 27 врста остракода као и њихов биостратиграфски положај, указују да се депозиција одиграла током целог панонског ката. Палеомагнетна истраживања су показала да лапорци имају неконзистентну реманентну магнетизацију која потиче од трансформације примарног магнетита у секундарни.

Кључне речи: горњи миоцен, језеро Панон, цементни лапорци, литологија, стратиграфија, палеомагнетизам, Беочин, Фрушка Гора.

Introduction

The area of the Fruška Gora Mountain represents an inselberg in the southern part of the Pannonian Basin, which extends between the Alps, Dinarides, and the Carpatho-Balkanides. 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). Late Early Miocene subsidence and sedimentation was an effect of the syn-rift extension phase that resulted in the formation of various grabens filled by

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thin sin-rift marine and brackish deposits (HORVÁTH & ROYDEN 1981). The Pre-Pannonian (Late Miocene) unconformity is an effect of the first early post-rift phase of basin inversion that occurred during the Sarmatian (HORVÁTH & TARI 1999). Later, a quiet and slow thermal subsidence occurred combined with an uplift and erosion of the neighboring mountains (HORVÁTH & ROYDEN 1981; HORVÁTH *et al*. 2006; SCHMID *et al*. 2008). This post-rift sinking was compensated by intensive sedimentation in the caspi-brackish Lake Pannon during the Late Miocene (FODOR *et al*. 2005; CLOETHING *et al.* 2006; HARZHAUSER & PILLER 2007). The tectonic events that formed the Pannonian Basin also affected the structure of the Neogene deposits on the northern range of Fruška Gora, which were deformed mainly by radial tectonics (MAROVIĆ *et al*. 2007). 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 Fruška Gora horst from the southern Bačka depression (MAROVIĆ *et al*. 2007). Examples of strong deformations are located above the right bank of the Danube River and in the northern part of the Filijala Northern Field, which, at present, is the main worked deposit of the Beočin Cement Plant. This resource has been known since 1838 and worked from 1869. It is located on the northern Fruška Gora range near the piedmont, above the Danube. The marl deposit is worked in three fields unequal in size and degree of exhaustion: (1) the Northern Field, the largest, oldest and most exploited field, (2) the Middle Field or Interfield and (3) the Southern Field (Fig. 1).

The Fruška Gora Mountain was the focus of geological interest in the second half of the 19th century. Information on the initial geological prospecting of Fruška Gora was given by LENZ (1874), KOCH (1876, 1896 and 1902), who gave the first integral descrip-

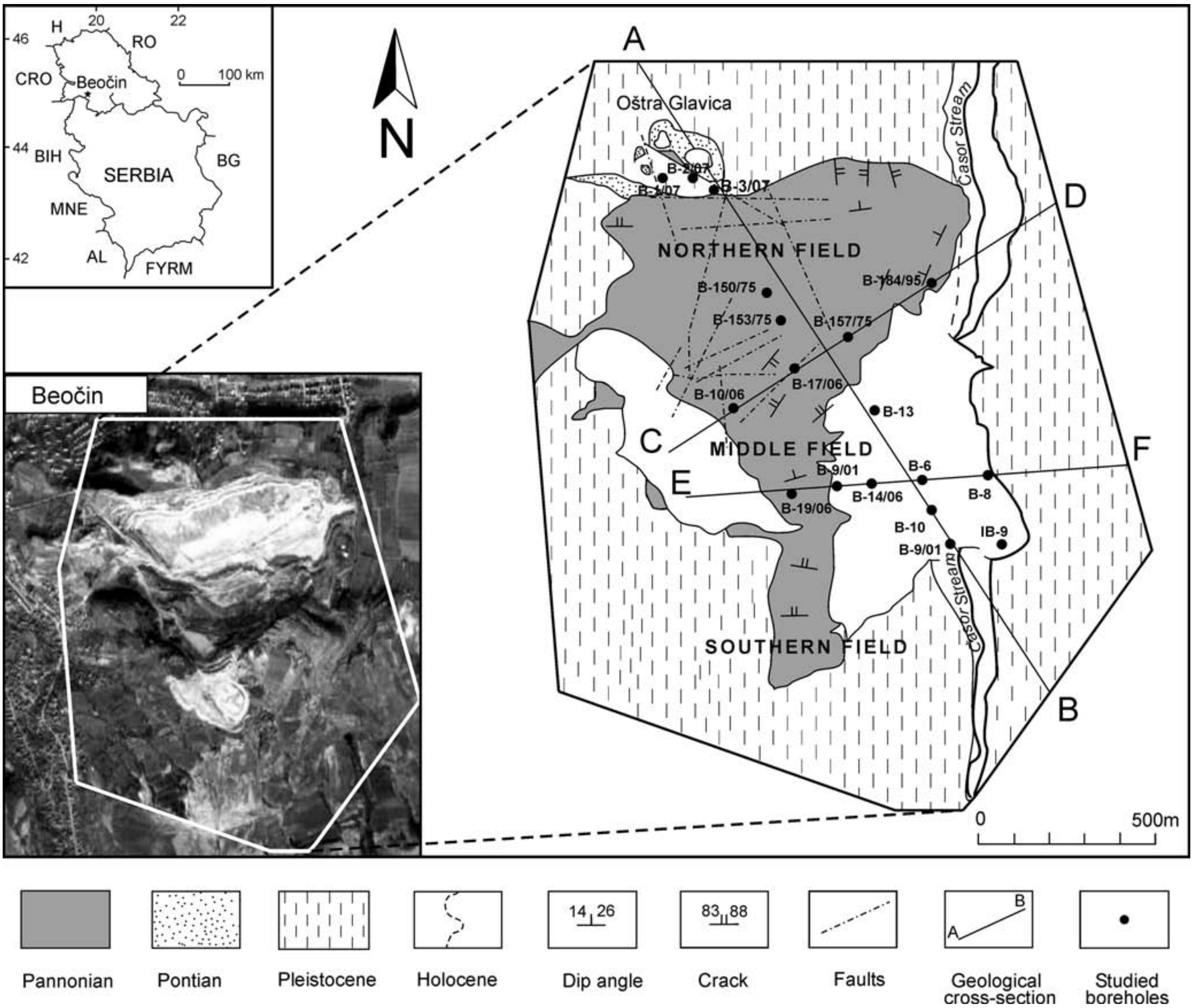

Fig. 1. The geological sketch map of the Beočin town area, with position of the geological cross-section and the studied boreholes.

tion of the geology of Fruška Gora and the first geological map on the scale 1:100000. R. Hörnes (1874) studied mollusks from cement marl near Beočin. Much later, Čičulić (1957, 1977), Čičulić-Trifunović & Rakić (1971), Petković *et al.* (1976), Stevanović & Papp (1985) wrote important contributions to the study of the stratigraphy of Fruška Gora. More recently, geology, stratigraphy, marl resource and quality of the Filijala property, and the chronostratigraphy of the Pannonian, were studied by Draško *et al.* (1998), Đurić (2005), Rundić *et al.* (2005), Simić (2005), Ganić *et al.* (2009) and Borgh *et al.* (2010).

This work presents new structural and stratigraphic–paleontological data for the Filijala property based on observations in the field and on drill-core analysis, as well as paleomagnetic measurements and interpretation.

Materials and methods

Data presented on the geological map and structural cross-sections were collected in all three fields of the Filijala Open Pit, where azimuths and dip angles, and fracture and fault positions were successively measured. Data from boreholes B-150/75, B-153/75, B-157/75, B-184/95, B-9/01, B-10/06, B-14/06, B-17/06, B-19/06, B-1/07, B-2/07, B-3/07, B-6, B-8, B-10, B-13 and IB-9 were used. Information was plotted on a geodetic plan on the scale 1:25 000, and cross-sections drawn, to be reduced to the scale and prepared for print.

Mollusks were identified from 18 samples and collected from the all three Filijala Pit fields, and from boreholes B-8 and IB-9. For a more precise stratigraphic position and biostratigraphic control, five marl samples were examined on ostracodes. Paleomagnetic measurements were conducted in Pannonian marls on the northern and southern margins of the Filijala Northern Field (BCP Lafarge, Beočin).

Twenty two fresh cores, light-grey in color, were drilled in four sections inclined about 10º to the north. The cores were oriented by means of a geological compass. Several samples cut from each core were examined in detail in the laboratory. For measurement of the initial magnetic susceptibility and the anisotropy of the susceptibility (AMS) in the low-intensity field (in fifteen positions) KLY-2 kappabridges was used with relevant software support. The line, direction and intensity of the remanent magnetization (RM) were measured using a JR-5 spinner magnetometer (in four positions) within the domain of the natural remanent magnetization (NRM) and after each step of demagnetization. A Schönstedt thermal demagnetizer was used for thermal demagnetization of the specimens, and an AFD300, Schönstedt AF and an LDA 3A demagnetizer were employed for the alternating field demagnetization. Magnetic minerals, the bearers of characteristic RM, were identified using KLY-2 kappabridges complete with a Curie temperature measuring device, pulse magnetizer and spinner magnetometers JR-4 and JR-5A. The demagnetization data were processed statistically following standard paleomagnetic procedures (Kirschvink 1980; Fisher 1953).

Geology of the Filijala Pit property

The area of the Filijala Pit property occupies a segment of the northern Fruška Gora horst. Paleozoic and Mesozoic rocks and Paleogene igneous rocks that form the basement constitute the horst body with Neogene sediments on its lateral sides. The basement rocks of Fruška Gora form a very complex structural pattern with features of most diverse folding and radial deformation.

Neogene sediments form a younger structural stage and are distributed on the slopes and piedmont of the Fruška Gora horst. In the Beočin area, the Neogene is part of a large range and foothill belt of northern Fruška Gora (Fig. 1). While the older Miocene beds are nearer to the Pre-Tertiary core of Fruška Gora in the south, younger stratigraphic members of the Neogene extend northward to the Danube River. Sarmatian sediments were identified in boreholes SE in the Filijala and exposed on a hill above the Filijala Southern Field in Beočin Village, in the Čerević Stream valley (between Veliki Komesarovac and Mali Komesarovac heights) and elsewhere (Fig. 2). The Sarmatian consists of het-

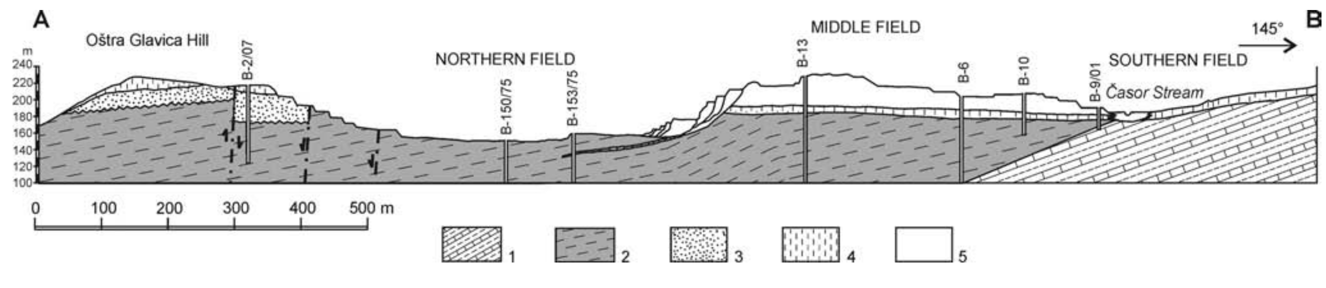

Fig. 2. Geological cross-section A–B through the Miocene sediments on the Filijala Open Pit near Beočin. Legend: **1,** Sarmatian (only in cross section) laminated marl, sandy marl, banded silty marl and siltstone, marly sandstone, stratified sandy limestone, lenses of conglomeratic marl, coaly clay, *etc.*; **2,** Pannonian marl; **3,** Pontian sand; **4,** Pleistocene loess; **5,** Holocene alluvial–prolluvial deposits, recent delluvial deposits and artificial deposits.

erogeneous strata, a succession of commonly laminated intrabasinal marl, banded marl, sand-conglomeratic marl, limestone and stratified sandy limestones.

Pannonian sediments are apparently conformable over the Sarmatian, developed in marly facies, associated with cement marl in the Filijala property (only at borehole B-9/01 in the Southern Field). At the contact, the Pannonian strata consist of compact sandy marl. Upward follows bedded or thick marl in a total thickness of 200 meters (Figs. 2 and 3).

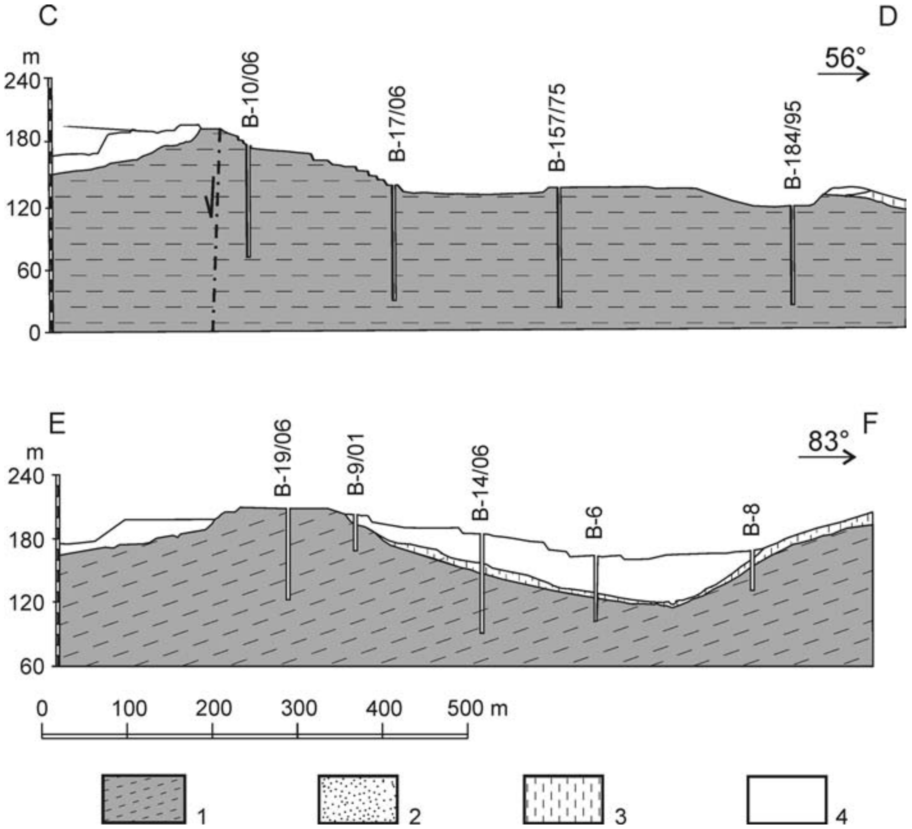

Fig. 3. Geological cross-sections C–D and E–F through the Miocene sediments on the Filijala Open Pit near Beočin. Legend: **1,** Pannonian marl; **2,** Pontian sand; **3,** Pleistocene loess; **4,** Holocene alluvial–prolluvial deposits, recent delluvial deposits and artificial deposits.

Near Beočin, the Pannonian marls are also located west of the Filijala. In addition, these deposits are present at the surface or under the Pontian on the local heights of Tancoš, Mali Komesarovac and Belo Brdo, designated as cement marl prospects.

Near Beočin, the Upper Pontian/Portaferrian beds unconformably and transgressively lie over the Upper Pannonian marls. They consist of sand, interbeds and lenses of sandy siltstone and gravelly sand, in small "oases" on the Filijala northern border (Figs. 1 and 2) and in larger areas on the Tancoš and Belo Brdo hills west of Beočin. The Pontian deposits are highly variable in thickness, more than fifty meters thick near Čerević, west of Beočin.

Lithostratigraphy

The whole Filijala Pit, all three worked fields, is formed of Upper Miocene and Quaternary deposits. Before the mining began, almost the entire terrain of the property had a Quaternary cover, but the long exploitation has uncovered the Neogene sediments, especially the units containing the mined raw material for the cement plant. The Sarmatian deposits under the productive strata, they themselves being gangue in the cement production, are not exposed on the surface anywhere within the borders of the property. They were found only in exploratory boreholes (IB-9 and B-9/01) located SE of the property, in the Časor Stream valley. It was inferred based on borehole sections, observations and mapping that the Sarmatian deposits underlie the Quaternary in a narrow tract on either side of the Časor Stream, SE of the delineated area. Further WNW, the Sarmatian sediments lie under the Pannonian marl. Beds of the Sarmatian and Lower Pannonian sediments, being provisionally conformable or without visible angular discordance, dip in almost the same direction (Fig. 2). As the Lower Pannonian exposures in the Southern Field have dip angles of about 20° to the NNW, the older Sarmatian layers presumably have the same dip direction. Tracing the inclination of the Neogene deposits, or the SSE-NNW azimuth, the Sarmatian layers dip in the same direction. Hence, even the deepest borehole did not enter Sarmatian rocks in the Northern Field. The measured section of borehole IB-9 and of the exposed deposits in the bordering areas indicated heterogeneous lithology of the Sarmatian (Fig. 4). Lithologically, it consists of laminated marl, sandy marl, banded silty marl and siltstone, marly sandstone, stratified sandy limestone, sand-gravelly marl lenses, coal clay, *etc*. The coal clay lies at the bottom of IB-9, between 14 m and 15 m deep, on the right bank of the Časor Stream (Fig. 4). The identified fossil fauna were *Pirenella picta* (DEFRANCE), *Ervilia* cf. *dissita* (EICHWALD), *Cerastoderma* sp.

Pannonian deposits have the largest distribution in the Filijala property, particularly in the largest mined

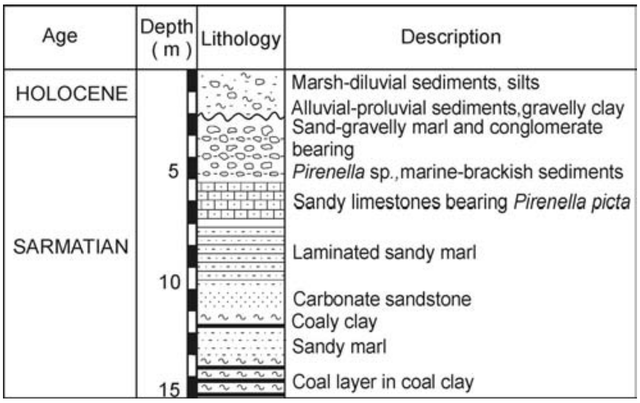

Fig. 4. Measured section of borehole IB 9 in the Časor Stream (near Southern Field of the Filijala Open Pit).

Northern Field. Unlike the heterogeneous Sarmatian sediments that frequently vary in both the horizontal and vertical directions, the Pannonian deposits are uniform in composition, represented by marl facies. They are sandy, hard at the boundary with the Sarmatian. The rest of the sequence consists of true marls to the boundary with the Pontian sandy beds.

The lower level of marls (Slavonian, sensu STEVANOVIĆ) is located in the mined Southern Field and probably is covered in the transitional area from the Southern Field to the Northern Field. It is marked by fossil fauna of scarce small gastropods, bivalves and ostracodes. These marls in the Southern Field are platy, then bedded and relatively hard, locally sandy with the occurrences of beds of indurated carbonate sandstone and marly siltstone. The average amount of $CaCO_3$ in the lower Pannonian marls of the Southern Field is 62.55 %.

The upper set of the Beočin marl beds (Serbian, sensu STEVANOVIĆ) is developed in the northern part of the Middle Field and in the Northern Field. The marl deposits of the Upper Pannonian form thick beds, or rather groups of beds, rarely partly massive and less indurated on average than the lower Pannonian marl. The average $CaCO_3$ in the Northern Field marls is 64.42 %. Upper Pannonian marls of the Northern Field include interbeds and lenses entirely different from the enclosing rocks. In exposures of the Northern Field, the interbeds of ferruginous silty sand are 10 cm or thinner, for example in observation points determined by the coordinates 45º12'12" N, 19º44'40" E and 45º12'08" N, 19º44'38" E (eastern border of the worked field). Sand or even gravel interbeds in massive marl deposit are found in some boreholes of the Northern Field. For example, a layer of sand-marl conglomerate, depth interval from 60 m to 61.1 m in borehole B-6, included pebbles of quartz, chert, serpentinite, Cretaceous sandstone, *etc*.; in borehole B-8 depth interval from 51.2 m to 53 m, a layer of marly sand succeeds gravelly-sandy marl. Note that these beds, as do the common Pannonian deposits, have a dip direction to the NNW. Minor local sand/gravel interbeds are wedges in marlstones, which deserve consideration because, being permeable, they may contain water and under certain conditions may disturb the stability of slopes. The landslide uncovered marl beds, which were the parting plane, with the dip elements 340/18 (45º11'51" N, 19º44'20" E, altitude 204 m).

In respect to granularity, sediments in the Filijala Open Pit property are classified as clay-silt deposits based on petrographic examination of samples from different parts of the marl deposit. The sand constituent is negligible, except in the mentioned lowest horizons and in small local interbeds and lenses. Consequently, Pannonian marl from the Filijala property should be taken for fine silt-clay material, micrite, or mudstone. Microcrystalline calcite is the essential mineral constituent varying between 60 % and 67 % on average. The non-carbonate proportion of the marl consists of quartz, hydromica, montmorillonite, feldspar kaolinite, limonite goethite and organic matter.

The Pannonian deposits generally have a dip direction from SSE to NNW at a gradually changing angle: about 20° in the Southern Field, 18° in the centre of the Interfield to 26° at the northern border of the Interfield. Following the azimuth, the marl dip angle in the Northern Field lessens to 12° or 14° in the northern pit slope. Within the confines of the marl deposit, Pannonian marls continuously dip to NNW from the southern border of the Southern Field, increasing in thickness to about 200 meters at the Oštra Glavica Hill. However, long excavation of marl in a large area of the Northern Field has reduced its natural thickness to the base bench level at an altitude of 110 m. The greatest thickness of about 109 m was measured in borehole B-19/06, which ended in Pannonian marl (Fig. 3).

While seemingly monotonous over a wide area, Pannonian marls vary upward in the lithostratigraphical section. Pontian sediments are the youngest Miocene stratigraphic unit in the Filijala property, which once covered it completely, but have naturally eroded and remained only in the north of the Northern Field. Through its mining history, however, most of Pontian deposits have been removed as mine waste, with only "oases" of Pontian left on the Oštra Glavica Hill and on the northernmost border of the property.

The Upper Pontian deposits of the Portaferrian substage (STEVANOVIĆ 1990) in the Filijala are transgressive and unconformable over the Upper Pannonian marl. These deposits have deep angle between 5° and 8°. The Upper Pontian strata consist entirely of sandy sediments, distinctly different in lithology from the older Pannonian marls. Pontian deposits begin with a layer of ferruginous silty sandstone, abounding in characteristic Portaferrian fossil fauna, over Pannonian marl. Upward follow cross-laminated grey-brown sand, lenses of gravelly sand and silty sand to the Quaternary loessoid (loess-like) deposits.

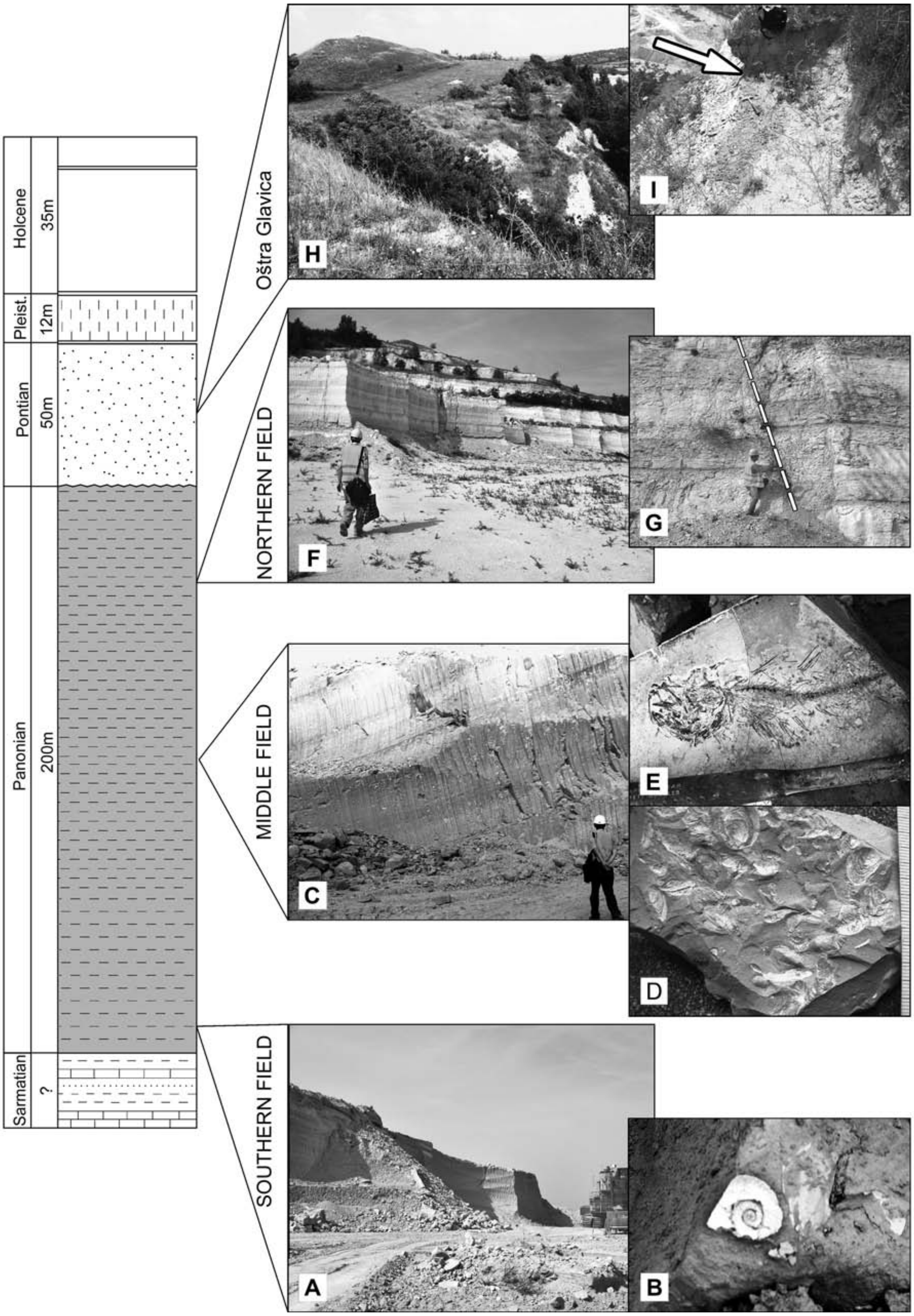

Fig. 5. Synthetic column of the Miocene sediments of the Filijala Open Pit. **A**, Outcrops at the Southern field; **B,** Lower Pannonian marls with *Gyraulus praeponticus;* **C**, Outcrops at the Middle field; **D,** Marls with *Congeria banatica;* **E**, Fossil fish at bedding surface; **F,** Outcrops at the Northern field of the Upper Pannonian marl; **G**, Fault in the Northern field; **H**, The peak Oštra glavica (Northern field) where there is a fault on the last layer that separates Pontian sand (left) and Pannonian marl (right); **I,** Contact between Pontian sand and Pannonian marl in the fault zone near the peak Oštra glavica – the Northern field.

The Pontian deposits lie over the Upper Pannonian marls on the Oštra Glavica Hill at altitudes over 175 m. Here, Pontian sands build up the last bench in the northern slope and continue upward to the Pleistocene boundary in a thickness of some 15 meters. In a small depression between the two tops of the hill, Pontian deposits fill a trench to the Pannonian marls (altitude 125 m) behind the highest bench above the northern pit slope.

The Northern Field has several identified faults that influence the morphostructural pattern. A fault in the strike direction ENE–WSW is at present in the base bench in the northern slope face and a similar minor fault in the northern slope (Fig. 5G). Open sections near the northern slope and in the new boreholes indicate a number of faults. A fault closes a small but relatively deep trough that is closed in the south by a fault of ENE–WSW trend (Fig. 6). The fault is located in a high bench where, along the same elevation, it separates the zone of Pannonian marl development in the south from the zone of the younger Pontian sand. The trough is closed by faults striking NNW–SSE (western) and ESE–WNW (eastern), which on the plan give the trough the shape of an elongated inequilateral triangle.

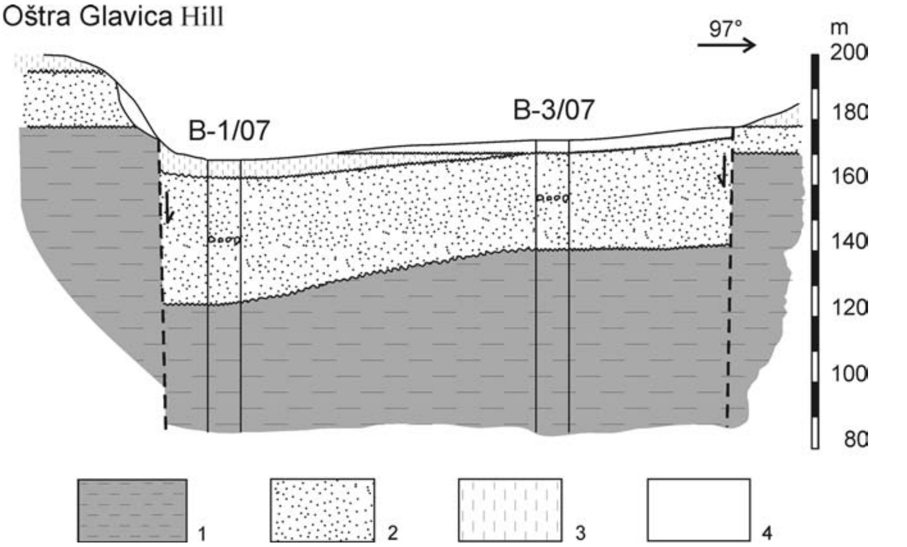

Fig. 6. Geological cross section in Oštra Glavica, northern border of the Filijala Open Pit. Legend: **1,** Pannonian marl; **2,** Pontian sand; **3,** Pleistocene loess; **4,** Holocene alluvial–prolluvial deposits, recent delluvial deposits and artificial deposits.

Fossils in cement marls

Marl samples collected for examination contained a relative abundance of mollusks (gastropods and bivalves), a few fish and floral remains and numerous ostracodes. Fossil fish and fossil turtle are known from previous excavations in the pit (ĐURIĆ 2005). The remains of a fossil proboscidean were excavated some years earlier, but, unfortunately, they have been lost. A very well-preserved fossil fish (Fig. 5E) was recently discovered in a landslide scar north in the Middle Field.

Fossil mollusks and ostracodes may be used in dating the Lower Pannonian, the so-called Slavonian substage (Slavonian, *sensu* STEVANOVIĆ), and the Upper Pannonian (Serbian, *sensu* STEVANOVIĆ).

The Lower Pannonian (Slavonian) is developed in the Southern Field. Its fossil content consists of scarce, small gastropods, notably of the Lymnaeidae family: *Radix croatica* (GORJANOVIĆ-KRAMBERGER) and *Radix kobelti* REUSS, then *Gyraulus praeponticus* (GORJANOVIĆ-KRAMBERGER) (Fig. 5B), *Limnocardium praeponticum* (GORJANOVIĆ-KRAMBERGER), *Paradacna cekusi* (GORJANOVIĆ-KRAMBERGER) etc. in the lower horizons, and *Undulotheca pancici* (GORJANOVIĆ-KRAMBERGER), *Undulotheca halavatsi* KOCH, *Gyraulus praeponticus* (GORJANOVIĆ-KRAMBERGER) and others in the upper horizons. The assemblage of ostracodes identified from the Southern Field includes *Amplocypris* ex gr. *acuta* KRSTIĆ, *Herpetocyprella auriculata* (REUSS), *Cypria* sp., *Candona* (*Candona*) sp., *Candona* (*Propontoniella*) sp., *Candona* (*Thaminocypris*) *improba* KRSTIĆ, *Candona* (*Typhlocypris*) *fossulata* (POKORNY) and *Loxoconcha* sp. Younger horizons of the Lower Pannonian are developed in the north of the Southern Field and probably also in the boundary area of the Southern and Middle Fields, presently under the embankment of the old waste dump.

The Upper Pannonian (Serbian) contains abundant mollusks with the specific dominance of *Congeria banatica* R. HÖRNES (Fig. 5D), *Congeria subdigitifera* STEVANOVIĆ, *Paradacna syrmiense* R. HÖRNES, *Provalenciennius pauli* R. HÖRNES, *Provalenciennius* sp. and *Gyraulus* cf. *praeponticus* (GORJANOVIĆ-KRAMBERGER). The ostracodes identified from the Northern Field are *Herpetocyprella hieroglyphica* (MÉHES), *Amplocypris acuta* KRSTIĆ, *A. major* KRSTIĆ, *Cypria* cf. *serbica* KRSTIĆ, *Cypria* sp., *Candona* (*Serbiella*) gr. *kolubarae* KRSTIĆ, *Candona* (*Zalanyiella*) *buchi* KRSTIĆ, *C.* (*Z.*) *rurica* KRSTIĆ, *Candona* (*Caspiolla*) *prebalcanica posterior* KRSTIĆ, *C.* (*C.*) *alasi beocini* KRSTIĆ, *Candona* (*Typhlocypris*) sp. 1, *Candona* (*Typhlocypris*) sp. 2, *Candona* (*Reticulocandona*) *reticulata* (MÉHES), *Candona* (*Typhlocyprella*) cf. *ankae* KRSTIĆ, *Candona* (*Lineocypris*) sp. and *Hemicytheria* sp. A similar association was identified from the Middle field, which additionally includes *Amplocypris sincera* ZALÁNYI and *A.* cf. *marginata* SOKAČ.

Paleomagnetic survey

Paleomagnetic measurements within the domain of the NRM indicate very low magnetic susceptibility and remanent magnetization of the Pannonian marls, a result of the low magnetic strength of minerals (Tab. 1). On a stereographic projection of ellipsoid AMS axes, the k_{min} axes are crowded near the centre of the equatorial projection, in the geographic and structural systems, which indicate a remanent magnetization induced through the process of compaction (Fig. 7, Tab. 2).

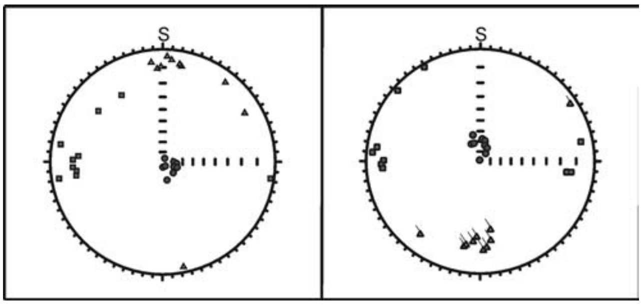

Fig. 7. Equatorial projection (on the lower hemisphere) k_{max} (square), k_{min} (triangle) and k_{int} (circle) of the AMS ellipsoid axes for individual marl samples from the Filijala Open Pit. Left: before correction for tectonics and right: after correction for tectonics.

Table 1. Initial magnetic susceptibility, remanent magnetization and polarity of the Pannonian marls after the process of demagnetization.

Filijala (YM 3044-065)					
Susceptibility (10^{-6} SI)			Intensity(10^{-5} A/m)		Polarity kRM
min	max	int	min	max	
38.07	53.18	44.88	7.32	58.7	N

Table 2. Magnetic properties of the Pannonian marls from the Filijala surface mine. Positions of the AMS ellipsoid axes (k_{max}, k_{int}, k_{min}) are expressed by declination (*D*) and inclination (*I*), anisotropy (*P*), lineation (*L*), foliation (*F*) and measurement reliability parameters (e_{12}, e_{23} and e_{13}).

Filijala (geographic orientation)											
k_{max}		k_{int}		k_{min}		*P*	*L*	*F*	*statistical stability*		
D°	*I*°	*D*°	*I*°	*D*°	*I*°	%	%	%	e_{12}(°)	e_{23}(°)	e_{13}(°)
97.6	–8.0	8.7	7.9	142.7	78.7	1.10	0.24	0.86	14.1	2.2	6.7
Filijala (tectonic orientation)											
k_{max}		k_{int}		k_{min}		*P*	*L*	*F*	*statistical stability*		
D°	*I*°	*D*°	*I*°	*D*°	*I*°	%	%	%	e_{12}(°)	e_{23}(°)	e_{13}(°)
97.7	1.5	8.0	–12.2	0.9	77.7	1.09	0.24	0.85	12.6	2.9	6.7

Hematite (Fe_2O_3), determined by mineralogical and petrological tests, was not confirmed by standard magnetic measurements, which was why special experiments for inducing isothermal remanent magnetization (IRM) and thermal demagnetization of the composite IRM were applied. The measured NRM and IRM values and the behavior of the magnetic susceptibility during heating indicated magnetite (Fe_3O_4), whereas the participation of hematite in the total RM of the marls was excluded (Fig. 8).

With the initial NRM measured, it was decided to demagnetize all samples from the southern and five samples from the northern pit borders by means of alternating magnetic field and/or heating. The demagnetization steps were small, 2–3 mT or by 10 °C (Fig. 9), due to the low initial RM intensity. Thermal demagnetization, at temperatures exceeding 400 ºC, caused pyrite oxidation and led to its transformation into magnetite. The newly formed magnetite grains induced chemical remanent magnetization during cooling along the ambient field (Fig. 8.C and Fig. 9).

Statistical processing of the demagnetization data did not give any RM direction sufficiently uniform for a definition of the primary RM. The heterogeneous directions of the RM independent of the cores are due to the transformation of a primary magnetic mineral into a secondary mineral.

Discussion

Pannonian marls on the northern ridges of Fruška Gora Mountain formed during the early phase of evolution of the Lake Pannon (MAGYAR *et al*. 1999; MAGYAR *et al*. 2007), in which a mesohaline/oligohaline lake formed related to the isolation of the Pannonian domain and fresh water inflow. Mollusks and ostracodes carried from the surrounding rivers and lakes into this lake modified to the slightly brackish environment and together with the few adapted marine species formed an endemic community (similar to that of the present-day Caspian Lake). The principal mass of calcium carbonate in the Beočin marl presumably formed through the chemical process of carbonate precipitation in the warm, mildly agitated aquatic environment saturated with bicarbonate solution. The chemogenetic carbonate mud mixed with inflown clay and clay-sand clastic materials (silicates)

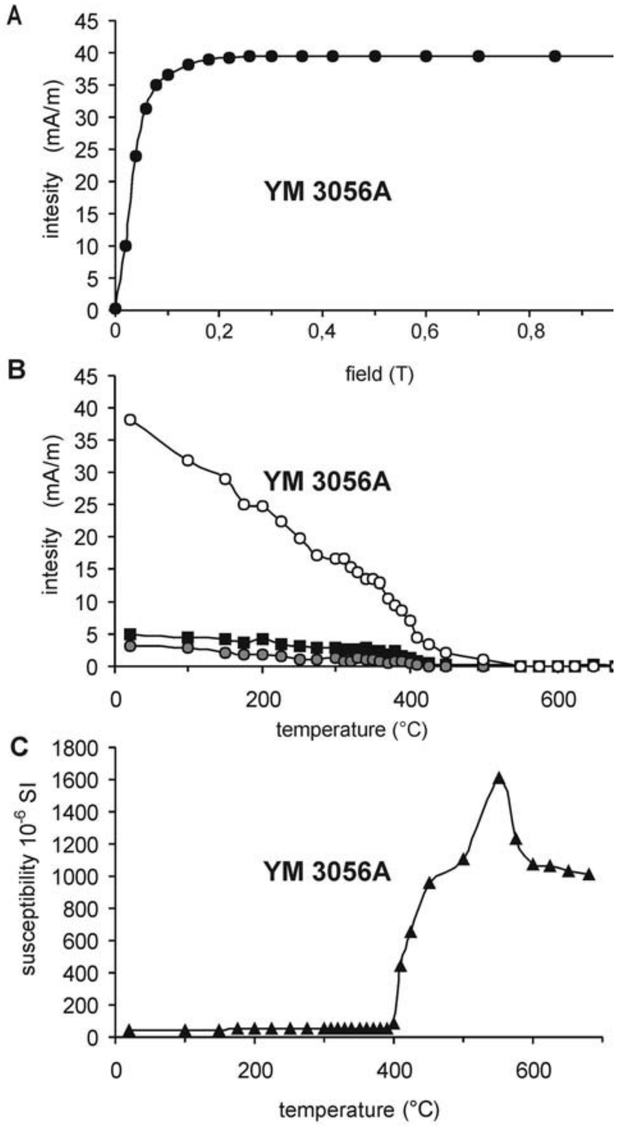

Fig. 8. Magnetic mineralogy. Diagrams of the magnetization-bearing mineral behavior during the magnetic field control and heating in the laboratory. Key: **A**, IRM acquisition behavior; **B**, The three-component IRM (Lowrie, 1990) behavior on thermal demagnetization. The hard (square), the medium hard (dots) and soft (circle) components of the composite IRM were acquired in fields of 1 T, 0.36 T and 0.2 T, respectively; **C**, Susceptibility variation with heating.

produced a carbonate-clay composite that later lithified into marl. The morphologic features of the fossil fauna give evidence of the depositional environment that produced the marls (MAGYAR *et al*. 1999; MAGYAR *et al*. 2007). Ostracodes and other fossils with mostly thin carapaces and their morphology indicate to their existence in calm water (RUNDIĆ 1998, 2006). There was an opinion that the uppermost marl at the contact with the Upper Pontian sand was transitional from the Upper Pannonian to the Lower Pontian (ČIČULIĆ 1977). It was explained that grey marl with *Valenciennius pauli* R. HÖRNES, *Congeria banatica* R. HÖRNES of the Upper Pannonian was succeeded by pale-yellow marl with *Congeria banatica* R. HÖRNES, *Limnocardium syrmiense* R. HÖRNES, *Paradacna lenzi* (R. Hörnes), *Plagiodacna* cf. *auingeri* (FUCHS), *Congeria* cf. *zagrabiensis* BRUSINA, which could have marked the boundary between the Upper Pannonian and the Lower Pontian. Above, there is a layer of ferruginous sand bearing Upper Pontian faunal fossils including the frequent *Melanopsis decollata* STOLICZKA, *Congeria zagrabiensis* BRUSINA, *Congeria* cf. *rhomboidea* M. HÖRNES and *Caladacna steindachneri* (BRUSINA). The fossil fauna and some lithological and structural characteristics were used to date the Early Pannonian (Slavonian, sensu STEVANOVIĆ) deposits in the Southern Field and the more widespread Late Pannonian (Serbian, sensu STEVANOVIĆ) in the Middle and Northern Fields. Generally, different characteristics of the investigated mollusk and ostracode species indicate stable conditions in a relatively deep-water environment. The common findings of *Congeria banatica* as well as *C. subdigitifera* point to deeper (basinal) development whilst the association with *Limnocardium*, *Valenciennessius* and *Paradacna* indicate a more shallow-water, sublittoral influence (MAGYAR *et al*., 1999). In addition, ostracode associations with smooth, thin and elongated forms of carapace suggest a calm deeper environment. Based on the results of stable isotope data from mollusk's shells, the climate in the Lake Pannon was changeable. The Early Pannonian was a period with an arid, subtropical climate that was followed by a more humid climate during the Middle ("Upper") Pannonian (HARZHAUSER *et al*. 2007). All the analyzed fossil assemblages indicate a mesohaline sublittoral environment of the Lake Pannon. The salinity of the lake water was estimated as 8–16 ‰. This is quite comparable to the recent sublittoral zones of the Black Sea and Caspian Sea (CZICZER *et al*. 2009).

Generally, the Pannonian deposits in the Filijala property have a dip direction to the NNW, only forming a gentle flexure (Fig. 2) at the Middle/Northern Field border. From the initial 20°, the deposits have a smaller dip angle in the central Interfield, again an increase in the inclination to the southern border of the Northern Field, and a lowering of the dip to the northern property border. Gentle flexures in the Pannonian marl may be explained by tectonic events that caused differential block faulting of the older geologic units under the marls. The molding of the marl probably evolved through the Lower Pontian, after the deposition of the Pannonian marl, when sedimentation ceased in the Beočin area due to an uplift of a part of Fruška Gora. Pannonian marl, still fresh and ductile sediments, possessed plasticity to form gentle flexures adjusting to the new underlying morphostructure without themselves being block faulted or displaced.

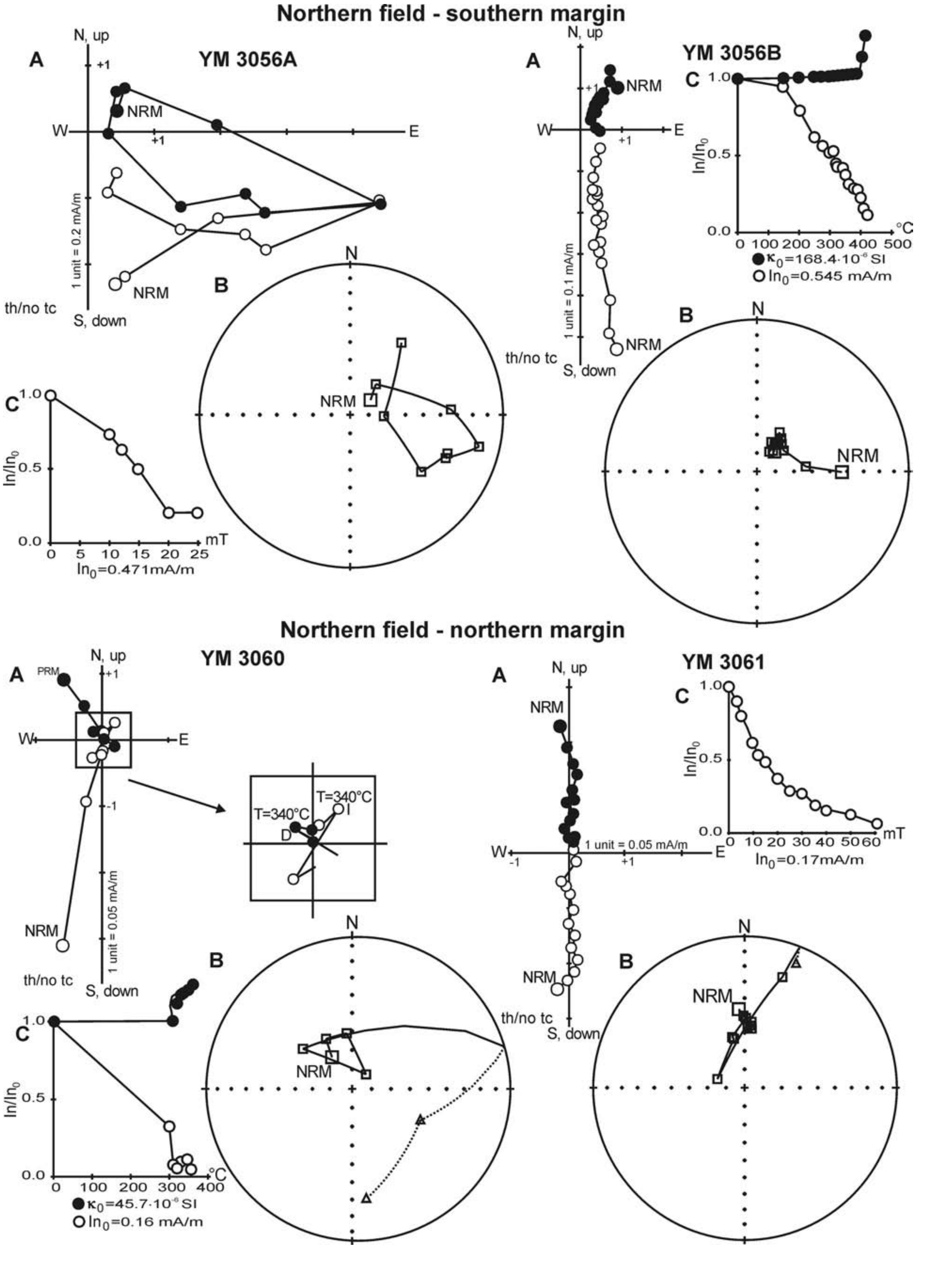

Fig. 9. Typical demagnetization curve: **A**, Zijderveld diagram (full/open circle: projection of the NRM in the horizontal/vertical plane); **B**, Schmidt diagram (square/triangle: projection on the lower/upper hemisphere, initial NRM position); and **C**, NRM intensity and susceptibility variations during demagnetization (In_o, initial intensity, k_o, initial susceptibility).

Another type of deformation features prevailing in the structural pattern of the Neogene deposits are different fractures and faults, the products of radial faulting (Fig. 5G). Fractures are visible everywhere in the exposed marl beds in the open pit. Interlacing fractures usually form two perpendicular systems: (a) one in the dip direction, SSE–WNW or slightly deviating from it and (b) the other transversal to the primary system of fractures. Diagonal fissures are present locally in more heavily crushed areas, which traverse the bedding planes at an angle.

There also are interstratal fissures along natural discontinuities between bedding planes, in the open pit easily filled with groundwater, the so-called fissure aquifers. A number of "springs" occur in the cross-points of interstratal and longitudinal fractures, for example below the slide face in the southern part of the Northern Field, in the observation point determined by the coordinates 45º11'56" N and 19º44'19" E.

The areas of visible fractures and much crushed deposits are always potential landslides. Such an area is where fractures and small faults form networks (block faulting 1 m high) in the north of the Middle Field and the south of the Northern Field (Fig. 5G).

Potential gravity slides in the Filijala property are related to the structural pattern and dip to the NNW of the Neogene deposits, the nature of rocks and long uncontrolled exploitation in the northern part of the marl deposit. Two potential landslide areas are identified: (1) fault zone at the contact of the Pannonian marl and the Pontian sand at the base of the Oštra Glavica Hill (Fig. 5H, I) and (2) the steeper-sloping part of the flexure in the border area of the Middle and Northern fields (Fig. 5C). Slides develop in places of pressure relief of removed artificial deposits, which leads to relaxation of the rocks and to fracturing along naturally predisposed discontinuity surfaces. Slides of this type usually develop under the effect of abundant rain or melting snow, when water infiltrates along the fault. A newly developed slide in the north of the Middle Field has exposed how colluvial gravity materials broke and divided marl beds along the fracture surfaces into square or polygonal flat-faced sharp-edged blocks.

The most complex structural geology in the Filijala property is found above the northern slope of Oštra Glavica. Several faults near the unconformable Pannonian/Pontian contact and within the Pannonian marl controlled the formation of a particular structural pattern. It could be suggested as the phase of post-Sarmatian basin inversion and later, the post-rift subsidence combined with uplifting (HORVÁT *et al*. 2006).

Negative results of the paleomagnetic study of marls in the Filijala Northern Field was surprising considering the promising preconditions: known stratigraphic age, comparatively gentle slope of the beds, detailed petrological and mineralogical studies additionally based on the new exposure of the lower section and, finally, the suitable of marl for paleomagnetism. For this reason, Pannonian marls were "measured" once more west of the Filijala property under the magnetostratigraphic survey on the Belo Brdo Hill. The obtained results were practically the same. Low and isotropic magnetic susceptibility (10^{-5} SI), the intensity of the RM, which varied along the entire core (of 10^{-6} to 10^{-3} A/m), unstable directions of the characteristic RM and variable angle of inclination. These are all parameters that indicate an environment with variable physical-chemical conditions (oxidated water), during which constant transformation of magnetic mineral bearing the remanent magnetization occurs. An inference based on the correlation with the paleomagnetic data for the Pannonian–Pontian locations in Croatia (VASILIEV *et al*. 2007; BABINSZKI *et al*. 2007), Hungary (BABINSZKI *et al*. 2007) and Fruška Gora is that sediments with magnetite that bears remanent magnetization are not capable of "bearing" a coherent magnetic signal, because the RM was induced during the formation of secondary magnetite. If the bearer of the remanent magnetization is primary magnetite, it is low and, consequently, the "remanent signal" very weak, often additionally burdened by "magnetic disturbance" due to the presence of pyrite. Overall, the general paleomagnetic direction of Pannonian–Pontian deposits in the Pannonian domain coincides with the actual direction of the geomagnetic field, which indicates that the remanent magnetism is of a recent date. In contrast, fine-grained Pannonian–Pontian deposits with greigite, formed through the early diagenetic process, mostly possess a harmonized paleomagnetic signal, often of reversed polarity, with a declination deviating from the recent Earth's magnetic field due to the rock mass rotation around the vertical axis (MÁRTON *et al*. 2002a, b; MÁRTON & FODOR 2003).

The latest magnetostratigraphic prospecting of Pannonian marl in the Filijala property has been started (BORGH *et al*. 2010) and is expected to produce additional information on the marl chronostratigraphic position and the time of the isolation of the Lake Pannon.

Conclusions

The open pit Filijala is located on the NE ridges of Fruška Gora, near the Danube, over a surface area of 792563 m^2. It consists of three unequal in size worked fields (the Northern Field, the Middle Field or Interfield and the Southern Field). The entire marl deposit belongs to a belt of the late Neogene and Quaternary on the margin of the large horst morphostructure of the Fruška Gora Mountain.

Most widespread in the Filijala property are the Pannonian deposits of the Upper Miocene, which are apparently conformable over Sarmatian sediments (recently, more precise data concerning the nature of the Sarmatian/Pannonian boundary are missing). These deposits are present in the facies of marls, which are mined and used in the cement works. The distribution of the Pannonian marls is about 1.5 km long, and their assumed thickness is more than 200 meters. The marls dip in the Southern Field by about 20°, then 18° in the central Middle Field, slopes at 25° or 26° in the border area of the Middle and Northern Fields, and the dip continuously decreases across the Northern Field to some 12°. In the geological section, marl strata in the Filijala have the shape of a gentle flexure (monocline).

Elements of radial tectonics, dominantly systems of fractures and small faults (of very small throws), are recognized in the property. Major deformations by appreciable differential block faulting were formed on the Oštra Glavica Hill in the north of the property area. Surface landforms are related to these faults. There is a small but deep trough in the form of an elongated unequilateral triangle. The down-thrown block in the trough is formed of Pannonian marl and Pontian sand. The depth of the subsidence is not uniform, being the greatest in the B-1/07 area west in the depression. A correlation of Pannonian–Pontian strata from a borehole in the trough and from rises above the trough indicates differential faulting (heave and throw) of 35 to 50 meters. The folding structures, monoclines and flexures presumably formed at the time when the marl was still unsolidified (probably during the Early Pontian when sedimentation ceased as a result of uplifting). The widespread system of fractures and faults, and the trough in the Oštra Glavica Hill developed later in relation to the radial faulting during the Pliocene and early Quaternary (Pleistocene).

All analyzed fossil assemblages indicate a mesohaline, basinal development of the Lake Pannon. The salinity of the lake water was estimated as 8–16 ‰, which is quite comparable to the recent zones of the Black Sea and Caspian Sea.

By a paleomagnetic investigation, it was established that magnetite-bearing sediments deposited during the Pannonian mainly do not carry a coherent.

Acknowledgements

The authors wish to thank STJEPAN ĆORIĆ (GEOLOGICAL SURVEY, VIENNA) and the anonymous reviewer for the useful comments that significantly improved the paper. Also, many thanks go to the "HIDRO-GEO RAD" for unlimited access to the borehole cores. The study was supported by Ministry of Science and Technological Development of the Republic of Serbia, Project No. 146009 and 146023.

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Резиме

Горњомиоценски лапорци Панонског језера на површинском копу Филијала (Беочин, северна Србија): нови геолошки и палеомагнетни подаци

Површински коп Филијала у Беочину, налази се на североисточном ободу гребена Фрушке горе, у близини Дунава, на површини од око 792.563 m^2. Састоји се од три радна поља тј. ревира неједнаке величине: Северно поље, Средње поље или Међупоље и Јужно поље.

Панонски лапорци горњег миоцена представљају главни стратиграфски и продуктивни ниво на копу (основна цементна сировина) и леже преко старијих, сарматских слојева са којима граде јединствену структурну етажу. На основу идентификованих макро и микрофосила односно проучених структурно-стратиграфских карактеристика, цементни лапорци припадају доњем панону (славонијен) на Јужном пољу односно горњем панону (сербијен) на Средњем и Северном пољу. Протежу се у дужини од око 1,5 километара, док им укупна дебљина премашује 200 метара. На основу хемијских карактеристика седимента као и анализе фосилних остатака (доминантна врста *Congeria banatica* R. HÖRNES) сматра се да су поменути лапорци продукт седиментације у мирним, дубљим („басенским“) деловима јужног обода некадашњег Панонског језера.

На основу структурних особина, добро документованог падног угла (од 18°–20° у подручју Јужног и Средњег поља, 25°–26° у пограничном подручју Средњег и Северног поља, до само 12° на Северном пољу) утврђено је да панонски лапорци имају облик благе моноклинале (флексуре). Системи пукотина и малих разлома са слабим вертикалним кретањима су доминантне радијалне структуре на копу. У северном делу лежишта, на вису Оштра главица и у његовом подножју, присутни су и већи раседи са јачим диференцијалним кретањима раздвојених блокова. Ови раседи су утицали и на морфолошке карактеристике рељефа. Овде је утврђено постојање малог али дубоког тектонског рова облика издуженог разностраничног троугла у коме је спуштен блок изграђен од панонских лапораца и понтских пескова. Дубина спуштања је неједнака, а највећа је у локацији бушотине Б-1 на западној страни увале. Корелацијом панонско-понтских слојева из бушотине у рову, са истим седиментима на височима изнад рова, утврђено је да су вертикална кретања 35–50 m.

У погледу датирања структурно-тектонских деформација, може се рећи да је моноклинала настала у млађој фази развоја Панонског језера, када су лапорци били још неконсолидоване стене (вероватно у доњем понту када је постојао прекид у седиментацији услед издизања дела Фрушке Горе). Поменути и распрострањени системи пукотина и раседа, као и тектонски ров на брду Оштра главица, настали су углавном касније, под утицајем радијалне тектонике током плиоцена и старијег квартара (плеистоцена).

За палеомагнетска испитивања узорковани су лапорци са северног и јужног обода Северног поља. Магнетска сусцептибилност лапораца је ниска и магнетски изотропна. Реманентна магнетизација је формирана током седиментације. Ниског је интензитета због мале концетрације магнетичних минерала. Доминатни носилац РМ је магнетит, праћен пиритом. Правци РМ издвојени након демагнетизације су хетерогени, са веома лошим статистичким параметрима сигурности (κ, α_{95}) на нивоу локалитета. Дисперзија праваца РМ независних узорака последица је трансформације примарних минерала носилаца магнетизације у секундарне. Панонски лапорци били су предмет и магнетостратиграфских испитивања на локалитету Бело Брдо (ББ-115),` западно од копа Филијала. Магнетска сусцептибилности, кохерентна по интензитету и магнетским својствима, поклапа се са вредностима измереним на лапорцима Филијале. Супротно магнетској сусцептибилност, интензитет и правац РМ варира са дубином испитивања, што указује на средину са нестабилним физичко-хемијским условима у којој је долазило до стицања реманентне магнетизације током вишеструко поновљених трансформација магнетичних минерала.

Уочено је да панонски седименти код којих је доминантан магнетични минерал, магнетит, не поседују примаран магнетски запис због: (а) мале концентрације примарног магнетита који носи слаб реманентни сигнал и (б) честе трансформације примарног магнетита у секундаран.