

## The subsurface geology along the route of the new bridge at Ada Ciganlija Island (Belgrade, Serbia)

SLOBODAN KNEŽEVIĆ<sup>1</sup>, LJUPKO RUNDIĆ<sup>1</sup> & MERI GANIĆ<sup>1</sup>

**Abstract.** The largest single-pylon, cable-stayed bridge in the world was opened in Belgrade on January 1, 2012 and it passes over the tip of the Ada Ciganlija Island. Its monumentality, architectural design and construction innovations became a new symbol of Belgrade. Core samples from the boreholes drilled for the construction of the bridge revealed a relatively complex subsurface geological structure. An Upper Cretaceous–Paleogene flysch formation and Middle Miocene Sarmatian sediments were found near the surface on the right bank of the Sava River. However, at the tip of Ada Ciganlija, the Upper Cretaceous–Palaeogene flysch strata were found below several different Miocene and Quaternary units. In the deepest borehole DB-6, the flysch deposits were found at a depth of 80 meters. On the left bank of the Sava River in New Belgrade, only Upper Miocene Pannonian marls and Pleistocene and Holocene alluvial deposits were drilled. Based on a comparative analysis of the borehole sections and structural characteristics of the rocks, it could be concluded that the Pre-Quaternary units cascade subsided along sub-parallel faults towards N–NW.

**Key words:** Subsurface geology, blocks subsidence, Upper Cretaceous, Miocene, Quaternary, Belgrade.

**Апстракт.** Највећи мост на свету са једним носећим пилоном отворен је у Београду 1. јануара 2012., а пролази преко шпица острва Аде Циганлије. Његова монументалност, архитектонско решење и грађевинске иновације постали су нови симбол Београда. Анализирани узорци језгра бушотина изведених за потребе изградње моста, указали су на једну релативно комплексну подповршинску структуру. На десној обали реке Саве, горњокредно-палеогени флиш и средњомиоценски сарматски седименти су откривени близу површине терена. Међутим, на шпицу Аде Циганлије, утврђено је да флишне наслаге леже испод неколико различитих миоценских и квартарних јединица. У најдубљој бушотини DB-6, флишни седименти су откривени на дубини од 80 метара. На левој обали реке Саве, у Новом Београду, набушени су само горњомиоценски панонски лапорци и плеистоценске и холоценске алувијалне наслаге. На основу упоредне анализе профила бушотина и структурних карактеристика стена, може се закључити да су пре-квартарне јединице по систему субпаралелних раседа каскадно спуштене у правцу С–СЗ.

**Кључне речи:** Подповршинска геологија, тектонско спуштање, горња креда, миоцен, квартар, Београд.

### Introduction

A new concrete-steel bridge over the Ada Ciganlija Island directly connects roads in Čukarica, on the right bank of the Sava River, and roads in New Belgrade, on the left bank of the river. It represents a part of the future Inner City Semi-Ring Road. Its total length is 996 meters and the width is exactly 45.06 m. The bridge is based on a large 200 m-high pylon that is located at the tip of the Ada Ciganlija Island. The dis-

tance between pylon and the left bank of the Sava River (main span) is 376 m, while the distance between the pylon and the supporting pillar on the right bank of Sava River is 250 m (see Plate 1). Exploration boreholes were drilled for the construction of a pylon at the tip of Ada Ciganlija and the pillars on the right and left bank of the Sava River (Fig. 1). On the right bank, in Čukarica near the famous restaurant “Stenjka”, the boreholes DB-9 and DB-10—were drilled. Next to the pylon at the Ada Ciganlija tip, near

<sup>1</sup> Department of Historical and Dynamic Geology, Faculty of Mining and Geology, University of Belgrade, Kamenička 6, 11000 Belgrade, Serbia. E-mails: slobodan.knezevic@rgf.bg.ac.rs; rundic@rgf.bg.ac.rs; merig@rgf.bg.ac.rs

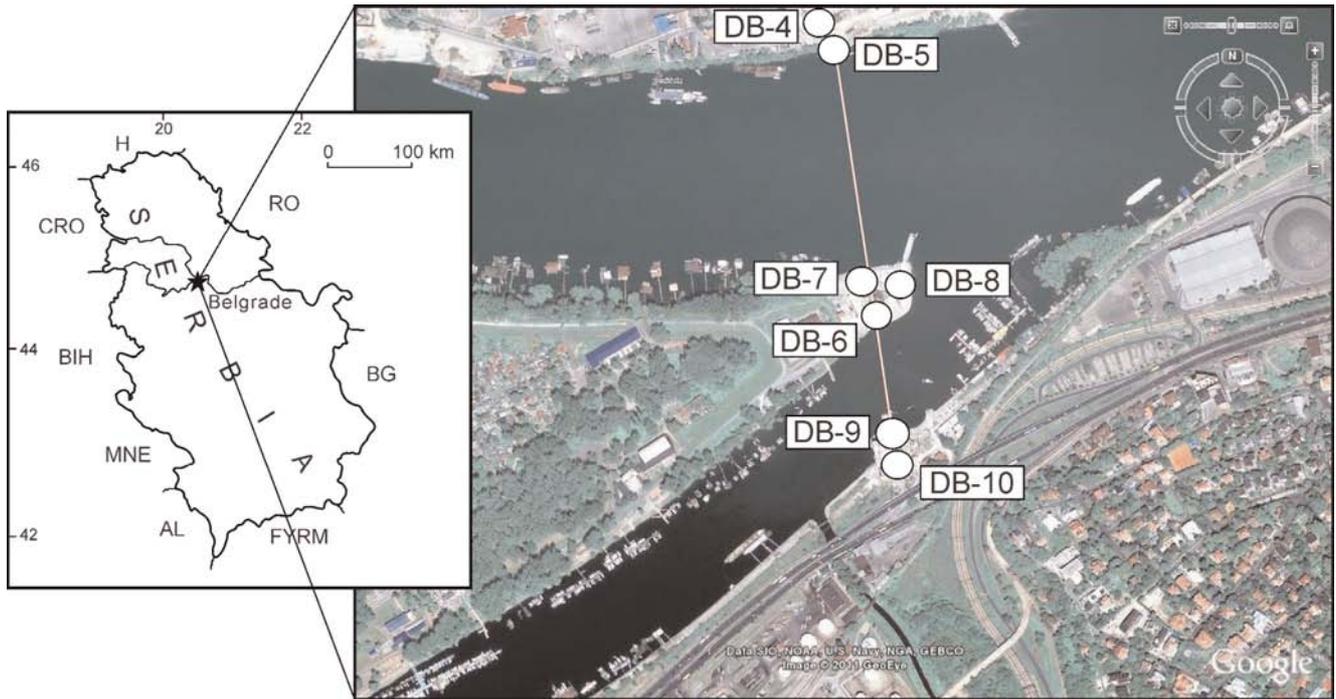


Fig. 1. The projected position of the new bridge over the Ada Ciganlija Island (Belgrade) and the locations of the investigated boreholes (Google Earth, 2011).

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

No.	Boreholes	Coordinates (WGS84)	
1.	DB-4	N 44° 47' 54.37"	E 20° 25' 30.44"
2.	DB-5	N 44° 47' 53.84"	E 20° 25' 32.53"
3.	DB-6	N 44° 47' 42.08"	E 20° 26' 02.23"
4.	DB-7	N 44° 47' 41.74"	E 20° 25' 34.10"
5.	DB-8	N 44° 47' 41.84"	E 20° 25' 35.87"
6.	DB-9	N 44° 47' 34.32"	E 20° 25' 36.39"
7.	DB-10	N 44° 47' 34.73"	E 20° 25' 36.65"

the rowing club “Partizan”, the boreholes DB-6, DB-7 and DB-8 were drilled. The borehole DB-5 was drilled on the left bank of the Sava River, in the courtyard of Gemax Co., above the riverbank. The borehole DB-4 was drilled further away from the riverbank along the bridge route (Fig. 1, Table 1). The alignment of the bridge has a direction of NNW–SSE, and like other bridges on the Sava River in Belgrade, connects two geographic regions: the Balkan Peninsula and the Pannonian Plain.

Geological structure of this area has been interpreted based on the cores from the exploration boreholes. Results obtained in this study are valuable for understanding the geological evolution of Belgrade city area and geodynamic processes that occurred during the

Neogene and Quaternary on the border between two realms: the Pannonian Plain and the Balkan Peninsula.

## Material and methods

Samples were obtained from seven boreholes in the study area (Fig. 1, Table 1). Preliminary core analyses were realised in the field. Detailed stratigraphic and paleontological analyses of seventeen core samples were performed at the Faculty of Mining and Geology, University of Belgrade using classical methods of rock preparation (cleaning, washing and thin-sections).

## Stratigraphy

The results obtained from the core samples revealed very interesting geological information concerning the subsurface terrain along the route of the new bridge. Upper Cretaceous–Paleogene flysch deposits represent the oldest unit, which make the basement rock for the overlying Miocene and Quaternary sediments.

## Upper Cretaceous – Paleogene

The basement rocks of the terrain along the Sava River near the new bridge consist of beds with the so-called Ostružnica flysch. These beds comprise grey

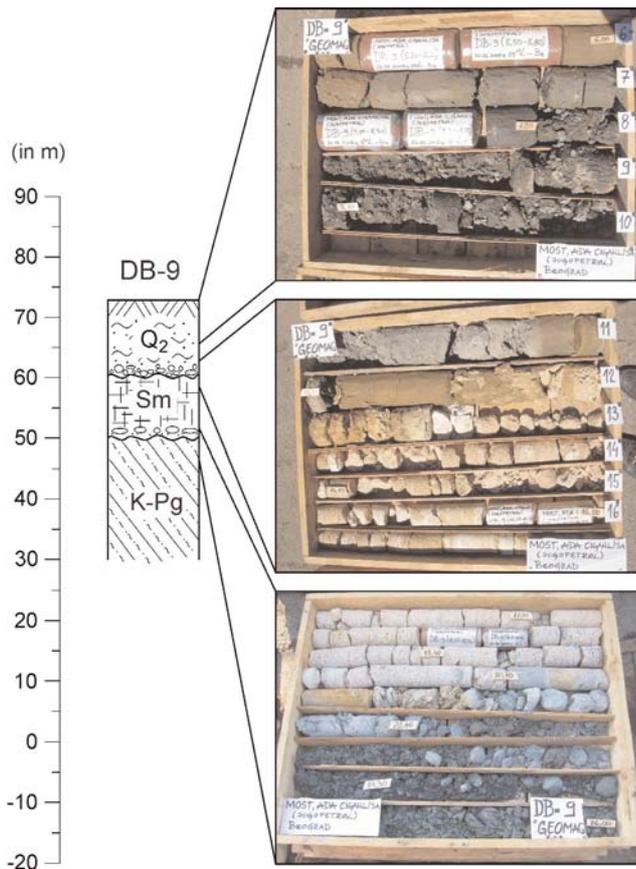


Fig. 2. The stratigraphic column and the core samples from the borehole DB-9. Key: **K-Pg**, Upper Cretaceous–Paleogene; **Sm**, Middle Miocene Sarmatian; **Pn**, Upper Miocene Pannonian; **Q<sub>1</sub>**, Pleistocene, **Q<sub>2</sub>**, Holocene.

and greyish-brown sandstones (micro-conglomerates occasionally) and clay interbeds. The youngest flysch formation in the vicinity of Belgrade is already known from the numerous wells in New Belgrade (near the Heating Station) and the Sava–Danube confluence (next to the Museum of Applied Arts and the famous shopping mall “Ušće”). The same formation was found at a small depth on the right bank of the Sava River (below 20 m, at Prince Marko Street No. 2 – KNEŽEVIĆ & GANIĆ 2005). Therein, based on the presence of nannoplankton species, the Upper Cretaceous age was confirmed. According to ANĐELKOVIĆ (1987), the flysch was formed at the end of the Upper Cretaceous and Early Paleogene.

The Ostružnica flysch strata were found on the right bank of the Sava River at Čukarica, as well as on the tip of Ada Ciganlija. On the right bank, the flysch strata were found in the boreholes DB-9 (from a depth of 22.3 m to its bottom at approximately 42 m – Fig. 2) and DB-10 (from 19 to 65 m). Thus, these layers were found in two out of three boreholes situated next to the pylon. In the deepest borehole DB-6, the flysch deposits were found from a depth of 80 m to its bot-

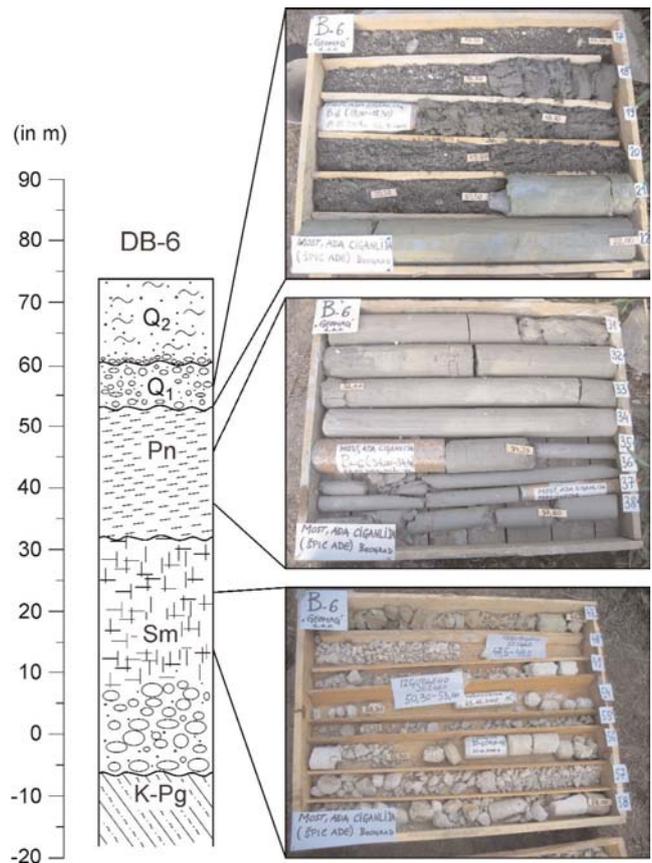


Fig. 3. The stratigraphic column and the core samples from the borehole DB-6. For the key, see Fig. 2.

tom at approximately 90 m (Fig. 3). In the second pylon borehole, which is only 20 m away from the above-mentioned boreholes, the Ostružnica flysch layers were found at a much smaller depth (less than 60 m).

## Miocene

Miocene sediments were found in all wells along the route of the new bridge (Figs. 4–6). Stratigraphically, they correspond to the Middle Miocene Sarmatian and Upper Miocene Pannonian Stage (see LASKAREV *et al.* 1932; STEVANOVIĆ 1977; KNEŽEVIĆ & ŠUMAR 1993).

The Middle Miocene Sarmatian brackish-marine sediments lie unconformably and transgressively over the mentioned flysch strata. They were discovered in the boreholes on the right bank of the Sava River at Čukarica and at the tip of Ada Ciganlija close to the position of the pylon. The older parts of the Sarmatian sediments consist of coarse-grained rocks, such as basal conglomerates and breccias. At the tip of the island, in the borehole DB-6, such deposits were discovered in the interval between 65 and 80 m depth,

or between  $-7$  m and  $+8$  m altitude, with a total thickness of about 15 m (Figs. 3, 6). Moving toward the right bank of the Sava River, the horizon of clastites becomes thinner, until it reaches a total thickness of 0.5 m (between 22.3 and 21.7 m depth) in the borehole DB-9 (Fig. 6). Organogenic limestones are widely distributed and form the younger and thicker part of the Sarmatian sediments. Sometimes (*i.e.*, borehole DB-6 at a depth of 54.30–59.60 m), they are porous with molds and imprints of fossil gastropods (*Pirenella picta*, *P. disjuncta*, *Gibbula* sp., *Hydrobia* sp.) and bivalves (*Maetra vitaliana*, *Cerastoderma vindobonense*, *C. latisulcum*, *Irus gregarius* etc.). These fossils indicate the presence of the Lower/Middle Sarmatian boundary – the *Maetra* beds. Sarmatian limestones were found in all boreholes in Čukarica and at the tip of the island (Figs. 2, 3, 6). Their greatest thickness of about 24 m was found in the borehole DB-6, at the location of the pylon (Fig. 6). Hydrogeologically, the Sarmatian limestone unit is permeable rock and can represent an extremely good aquifer of groundwater, particularly in the tectonically folded terrain of the island and on the left bank of the Sava River (RUNDIĆ *et al.* 2005). On the right bank, similar carbonates were identified in the borehole DB-9 at a depth between 21.7 and 11.7 m (about 52–62 m above s.l.). On the other hand, within the boreholes located in the island, the Sarmatian limestones were found at much lower elevations, between 7 and 32 m altitude.

Upper Miocene Pannonian brackish (“caspi-brackish”) sediments have been found in the boreholes at the tip of the island of Ada Ciganlija and on the left bank of the Sava River in New Belgrade (Figs. 3–6). They were deposited over the Sarmatian limestones and make the basis for the Quaternary alluvial deposits. Lithologically, these sediments consist of grey marls and marly clays. On the island, near the location of the pylon, these sediments are located at an altitude between 30 and 53 m. Stratigraphically, they correspond to the lower part of the Pannonian (Slavonian Substage). Its lower and upper boundaries may vary slightly (the Pleistocene at the top and Sarmatian in the base). One or two interbeds with marly limestone up to 15 cm thick lay within these marls close to the Sarmatian limestones (*i.e.*, in the borehole DB-7 at a depth of 44 m). A rare molluscs fauna, mainly bivalves (*Paradacna cekusi*, *Limnocardium praeponticum*), and small gastropods (*Gyraulus* cf. *praeponticus*, *Radix* cf. *croatica*) was found. On the left bank of the Sava River in New Belgrade, similar sediments were found in the borehole DB-5, which is located above the riverbank, and in the borehole DB-4. In the borehole DB-5, Pannonian sediments were found from a depth of 29.5 m to its bottom at approximately 65 m (Fig. 4). In the borehole DB-4, the Pannonian deposits were found at a depth of 27.8 m. In contrast to the mentioned boreholes at the pylon, the layers with Upper Pannonian greyish marly clay

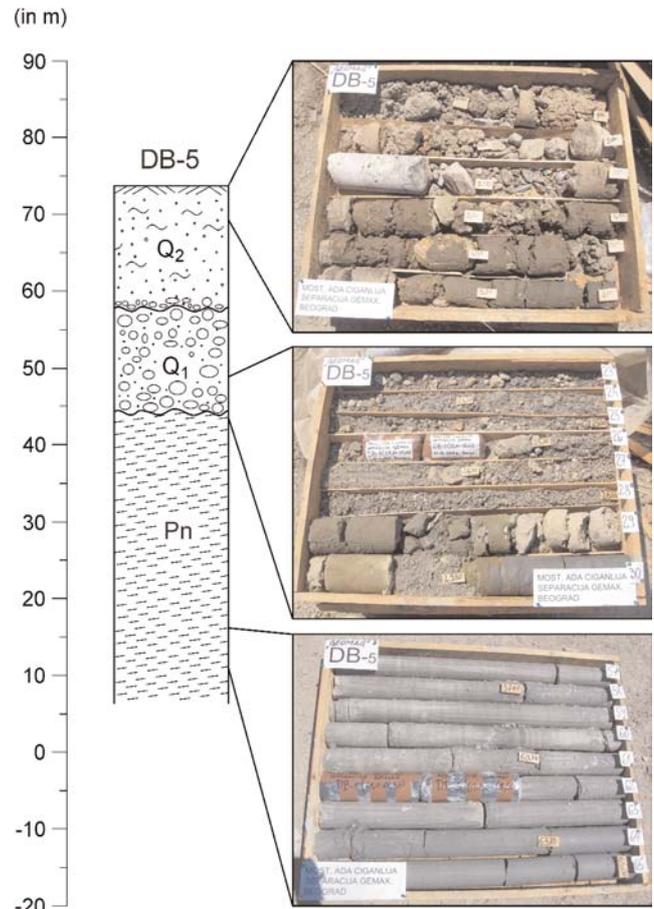


Fig. 4. The stratigraphic column and the core samples from the borehole DB-5. For the key, see Fig. 2.

with rare fossil remains, such as *Congerina banatica*, *Paradacna* cf. *syrmienne*, *Gyraulus praeponticus*, etc., were found (depth between 35.30–35.80 m)

## Quaternary

Quaternary deposits are widely spread throughout the study area (Figs. 2–7). The dominant alluvial sediments can be divided into two distinct geological units based on superposition: 1) Pleistocene, polycyclic fluvial sediments and 2) Holocene, modern alluvial deposits of the Sava River and its tributaries.

### *Pleistocene - Polycyclic fluvial sediments*

The older formation of alluvial deposits includes old, polycyclic river sediments, known from previous literature as “Makiš strata” or beds with “*Corbicula fluminalis*” (LASKAREV 1938). This formation consists mainly of sandy-gravel sediments deposited in the Early Pleistocene. It was formed during the stage of active tectonic movements, in the alternating phases of subsidence of the Sava River valley and rapid dep-

osition of alluvial sediments. Within the lithological succession, there are alternations of riverbed sediments (gravel, gravelly sands and sands), floodplain sediments and oxbow-lake sediments (alevrites, and clays). Along with recent mollusc species, these sediments also contain fossil forms (*Corbicula cor*, *C. fluminalis*, *Viviparus boeckhi*). These beds occur in the Ada Ciganlija Island and on the left bank of the Sava River in New Belgrade. They contain large groundwater aquifers, which are exploited through wells for the water supply of Belgrade.

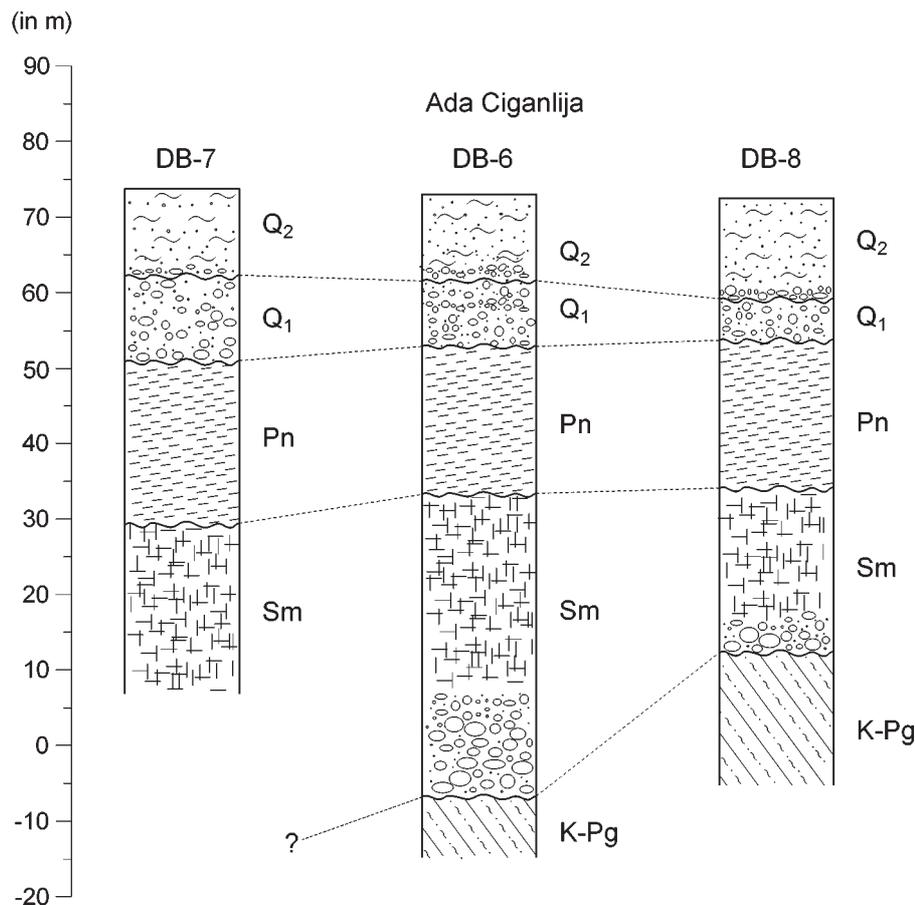


Fig. 5. Comparative stratigraphic sections of the boreholes at the tip of Ada Ciganlija. For the key, see Fig. 2.

Based on studies of the three boreholes at the tip of the Ada Ciganlija Island, it was determined that the thickness of the Pleistocene polycyclic fluvial sediments varies. In the borehole DB-7, the sediments reach a thickness of about 10 m, while in the other two boreholes, their thickness decreases to about 7 m (Fig. 5). On the left bank of the Sava River in New Belgrade, these sediments are thicker and their lower boundary is at a significantly lower depth comparing to those at the tip of the island. In the borehole DB-5 drilled above the left bank of the Sava River (Figs. 4, 6), they mark a lithological boundary to the Pannoni-

an marls at a depth of 29.5 m (the whole thickness of the Pleistocene is about 13 m). In the borehole DB-4, situated about 150 meters away from the bank, this boundary is shallower and was identified at a depth of 27.8 m.

#### *Holocene - modern alluvial sediments*

The entire surface of the study area has been formed by recent alluvial sediments from the Sava River and its tributaries. The sediments are deposited discordantly over the Pleistocene alluvial deposits because the younger layers from the Pleistocene were previously eroded. On the right bank of the Sava River, at Čukarica, the recent alluvial sediments were deposited over the Sarmatian limestones. According to the superposition, as well as the genesis of these deposits, the recent alluvial sediments can be divided into riverbed sediments (sands, gravelly sand) and floodplain sediments (grey-yellow and brown alevrites, alevritic sands and sandy clays). Occasionally, there are oxbow-lake sediments and wetland deposits (greyish-dark clay and clayey alevrites rich in organic matter), especially in areas distant from the riverbank in New Belgrade. On the right bank of the Sava River at Čukarica, in both of the mentioned borehole, only floodplain sediments are presented that lie unconformably over Sarmatian limestones.

An interesting observation was noticed at the borehole DB-4 in New Belgrade: the appearance of alternating replacements of riverbed sediments of the Sava River and its left tributary, called the Galovica Stream, both in the vertical and horizontal direction. Here, the former Sava riverbed sediments and small migrated riverbed sediments of its tributary are crossed. The Sava riverbed sediments comprise coarse-grained material, mostly quartz-micaceous sand, fine-grained gravel made of chert fragments, quartz and other rocks. The riverbed sediments of the Galovica Stream, which come from areas of the Srem Loess Plateau, contain many fine-grained alevrites with the cross-stratification tracks. Today, the Galovica Stream is displaced into the Galovica channel, and its

mouth is located far upstream of the Sava River. However, the core of the mentioned borehole showed that the former riverbed sediments of the Galovica Stream in its natural confluence with the Sava River are preserved below the surface, under the route of the new bridge in New Belgrade. In addition, recent alluvial sediments from the Sava River are deposited, on the island Ada Ciganlija, forming an elongated river bar (lenticular sands, fine-grained sands and alevrites with distinct cross-stratification).

#### *Holocene - anthropogenic or technogenic sediments*

Anthropogenic deposits are present over a large surface area along the route of the bridge. These sediments consist of excavated sands, various dams, construction waste and other materials. Excavated sands are the most widespread, reaching a thickness of 5 meters on the left bank of the Sava River, in New Belgrade.

### Discussion and interpretation

The basement rock consists of Upper Cretaceous–Paleogene deposits (the Ostružnica flysch). The overlying rocks comprise Miocene sediments of the

Sarmatian and Pannonian Stage. Different Quaternary alluvial sediments represent the youngest deposits. This structural pattern is previously known from some other parts of the Belgrade City area (KNEŽEVIĆ *et al.* 1998; NENADIĆ *et al.* 2009; RUNDIĆ *et al.* 2011). Based on the samples from the boreholes along the route of the bridge (Figs. 6, 7), it was confirmed that the basement rocks and Miocene sediments subsided stepwise from the right bank of the Sava River to the left bank in the N–NW direction. This is consistent with previous studies in the area of the Sava–Danube confluence where a similar tectonic setting was observed (KNEŽEVIĆ & GANIĆ 2008, RUNDIĆ *et al.* 2011). On the right bank of Sava River in Čukarica, the Upper Cretaceous–Paleogene flysch deposits and Sarmatian sediments are located much shallower. No other rocks, except recent thin deposits occur on the surface. At the location of the bridge pylon, the same rocks are found at a much greater depth, which means that the boundary between the Ostružnica flysch and Sarmatian clastites is about 57 m lower than at Čukarica (Figs. 2, 3, 5). At the tip of the Ada Ciganlija Island and along the bank of the Sava River in New Belgrade, Pannonian strata and Pleistocene polycyclic fluvial sediments are present. On the left bank of the Sava River, the bore-holes reached Pannonian sediments and Pleistocene fluvial sediments of greater thickness. This

indicates that the older stratigraphic units lie deep under the surface. This is consistent with other data from the area near the Sava–Danube confluence, where the Middle Miocene Badenian rocks have a higher vertical displacement and lie more than 70 m below the surface (RUNDIĆ *et al.* 2011). However, a more detailed analysis of the structural elements is necessary for a precise determination of the major faults and the structural features of the area.

Finally, it can be concluded that there are fault structures that run sub-parallel to the Sava River, which split all pre-Quaternary rock units into blocks. During the Mio-Pliocene, these blocks were differentially displaced along the faults and subsided from the right bank of the Sava River to the flat terrain of the Pannonian Plain on the left.

In terms of geomorphology, a part of the terrain along the route of the new bridge is

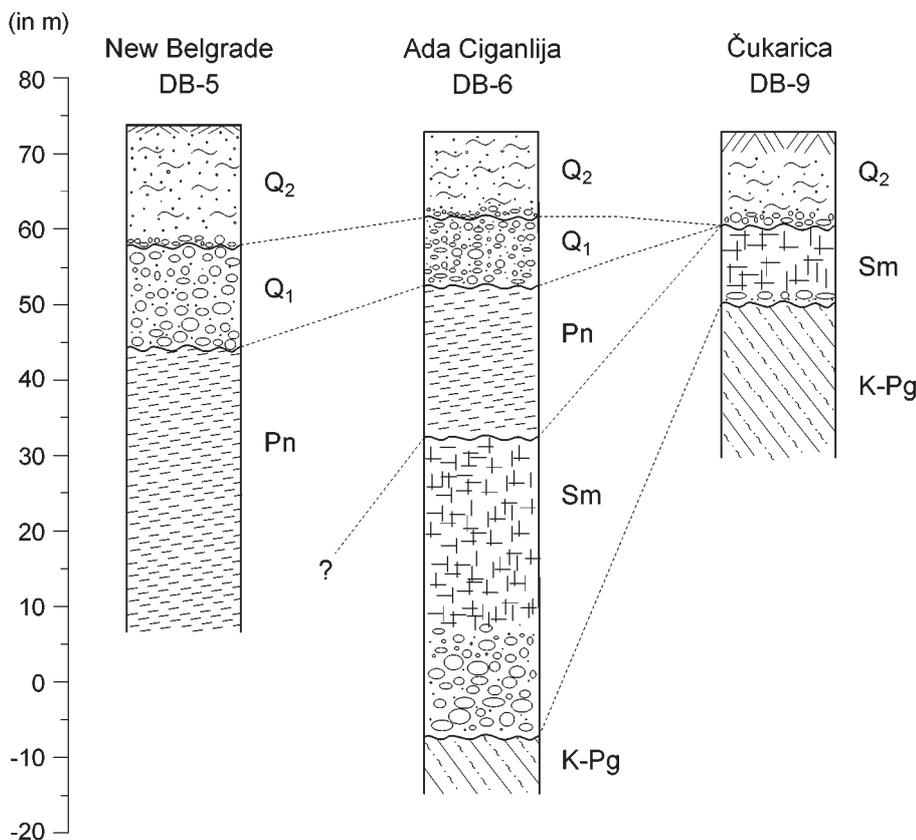


Fig. 6. Comparative stratigraphic sections of the boreholes along the route of the new bridge. For the key, see Fig. 2.

located in the border area between the Pannonian Plain and the foothills of the Balkan Peninsula. Additionally, from a morphostructural point of view, it represents the boundary between the Pannonian Basin and the Peri-Pannonian realm (MAROVIĆ *et al.* 2007). According to the neotectonic subdivision of the Belgrade City area, along the central part of the northern Šumadija there is a large structure called the Avala-Orešac Composite Structure in the NNW-SSE direction (MAROVIĆ *et al.* 2007). This structure separates the Velika Morava Graben to the east from the Kolubara–Tamnava Graben to the west (MAROVIĆ & KNEŽEVIĆ 1985, 1987). Consequently, several minor sub-blocks were generated, such as the complex Avala–Koviona Horst (MAROVIĆ *et al.* 2007). The core of the horst consists of the Palaeozoic–Mesozoic rocks of the Vardar Zone that make the so-called Šumadija Beam (STEVANOVIĆ 1980). During the Early Middle Miocene, the horst was uplifted and positioned as an isolated island in the Paratethys Sea, known as “the Avala land” (EREMIJA 1989). Later, during the Middle–Late Miocene, under the influence of tectonic movements, it was broken into tectonic blocks with local grabens within it and the sediments of the Paratethys Sea as well as of the Lake Pannon were deposited.

Along the route of the new bridge, the oldest formation consists of Upper Cretaceous–Paleogene deposits (the Ostružnica flysch). It is a part of the northern margin of the Mesozoic core of the Avala–Koviona Horst. Herein, the deposits of the Sarmatian and Pannonian stage (Late Middle and Early Late Miocene) are the products of sedimentation in local trenches and former bays. Comparing the Miocene sediments along the banks of the Sava River, it could be concluded that near the new bridge, there are no widespread Badenian deposits downstream close to the Sava–Danube confluence (KNEŽEVIĆ & ŠUMAR 1994, KNEŽEVIĆ & GANIĆ 2005, 2008; GANIĆ *et al.*

2011; RUNDIĆ *et al.* 2011). This means that here the process of the formation of coves and bays around the former Avala Land commenced later than at the mentioned confluence. In addition, some differences in the facial characteristics and distribution of Sarmatian sediments were also noticed. Near the Sava–Danube confluence and the Kalemegdan Fortress, these sediments are often absent. The thickness and lithology of these layers vary at different places. It is likely that Sarmatian sediments are spread everywhere along the route of the new bridge. Among them, younger strata represented by organogenic limestones are dominant. It seems that similar depositional conditions upstream and downstream of the Sava River were established during the Pannonian when the marly sediments were deposited almost everywhere.

The presence of faults and differential movement of the blocks separated by the faults along the bank at the Sava–Danube confluence was observed previously (KNEŽEVIĆ & GANIĆ 2005, 2008; GANIĆ *et al.* 2011; RUNDIĆ *et al.* 2011). Then, it was noticed that the terrains on the right bank of the Sava River are relatively elevated in comparison to the plain terrain on the left bank. By studying the subsurface geological setting in the new bridge area, it was found that here at least two faults occur along which subsidence of blocks was determined (Fig. 7). One fault is present in the small estuary of the Sava River between Ada Ciganlija Island and Čukarica. The entire rock units at the tip of Ada Ciganlija (at the position of a bridge pylon) have subsided with respect to the right bank of the Sava River. On the Čukarica block, the younger Pannonian sediments are eroded, while they are present at the tip of Ada Ciganlija. Sarmatian sediments and the flysch strata are deeply subsided with respect to the Čukarica block. On the left bank of the Sava River, at a relatively greater depth (below the absolute elevation of 0 meters), all the boreholes were realised

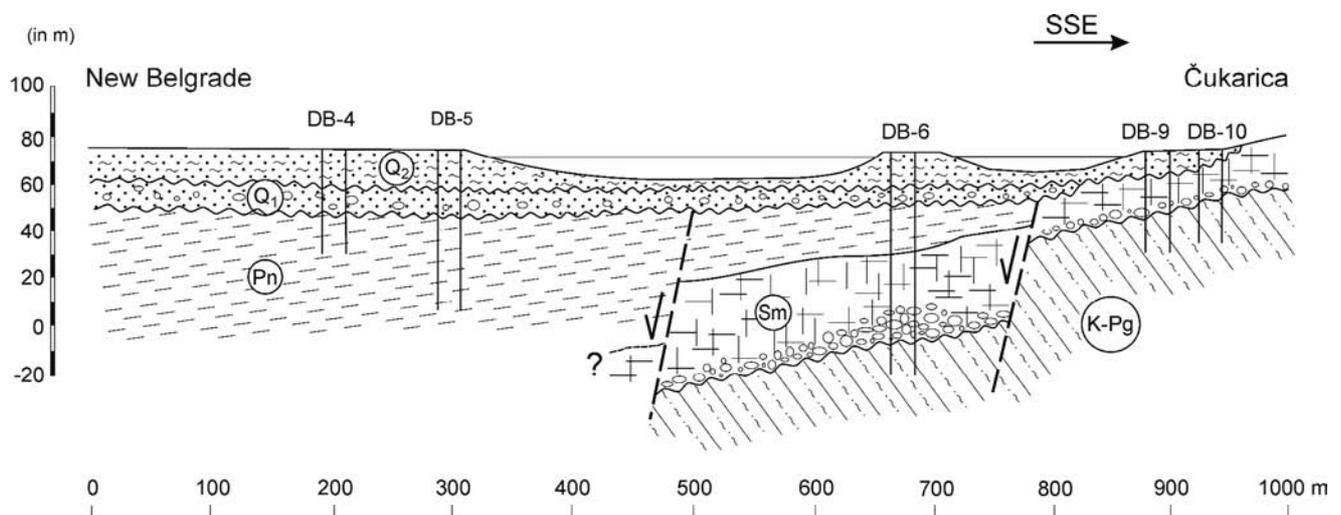


Fig. 7. A simplified geological cross-section along the route of the new bridge. Key: **K-Pg**, Upper Cretaceous-Paleogene; **Sm**, Middle Miocene Sarmatian; **Pn**, Upper Miocene Pannonian; **Q<sub>1</sub>**, Pleistocene, **Q<sub>2</sub>**, Holocene. *v* – Assumed fault.

in the Pannonian marls. This means that the older rocks are even deeper compared to Ada Ciganlija (Figs. 6, 7). Based on this, the presence of a second fault under the large estuary of the Sava River between the left bank and Ada Ciganlija Island can be assumed. These structural configurations were created under the influence of the neotectonic movements during the Pliocene and Early Quaternary. Exogenous processes later transformed the initial relief and the whole terrain along the route of the new bridge was levelled by a long-living deposition of alluvial sediment.

In the Sava River valley, there are two previously known geological formations of alluvial sediments (LASKAREV 1938; KNEŽEVIĆ *et al.* 1998; NENADIĆ 2001; NENADIĆ *et al.* 2009). The older formation of the Lower Pleistocene polycyclic fluvial sediments is distributed in the Ada Ciganlija Island and the bank of New Belgrade, but not on the right bank of the Sava River. This formation was deposited in the initial phase of the formation of the Sava River valley, which was characterized by cyclic processes of tectonic subsidence of the terrain and alluvial sedimentation. At the tip of Ada Ciganlija, the old polycyclic fluvial sediments have a lower depth than on the terrain upstream on the same island and on the left bank of the Sava River (Fig. 7). The lower boundary to the Pannonian strata is at 18–19 m, *versus* the usual 25–26 m. The older horizons are missing, which could suggest that at a later stage of a fluvial process, part of the terrain entered the river bed.

Recent fluvial processes have led to major erosion of younger horizons of the old polycyclic fluvial sediments and creation of new alluvial sediments of the Sava River and its tributaries. Clastites from the Pleistocene polycyclic fluvial sediments were eroded and redeposited in the current riverbeds. On the left bank of the Sava River, along the route of the new bridge, the presence of the previous flow of the Galovica Stream was found. It is a left tributary of the Sava River that migrated during time. Its water flow comes from the Srem Loess Plateau and inflowed the river to the right of the studied area.

## Conclusions

Belgrade's Ada Bridge that passes over the tip of the island of Ada Ciganlija has become one of the new symbols of Belgrade. It is the longest single-pylon, cable-stayed bridge in the world.

Data obtained from seven boreholes are presented for the first time herein.

The geological setting of the subsurface of the terrain was reconstructed based on lithological successions, stratigraphic sections and the basic structural elements. The following geologic units were found: Upper Cretaceous–Paleogene flysch formation (the Ostružnica flysch), Middle Miocene Sarmatian and

Upper Miocene Pannonian sediments, different alluvial sediments of Quaternary age as well as modern anthropogenic sediments.

On the right bank of the Sava River, the older geological units were observed in the upper part of the sections. On the other hand, they had much greater depth at the location of the bridge pylon.

Pannonian marls have a different depth on the island Ada Ciganlija and on the left bank of the Sava River, where they reach up to 60 m in depth.

Among the Quaternary alluvial deposits, there are two different geological formations. The older one, presented by Pleistocene polycyclic sediments includes mostly gravels and sands. This one was never detected at the surface. However, it represents the major groundwater aquifer for the water supply of Belgrade. The younger one consists of Holocene modern alluvial sediments that have a wide distribution over the whole area.

The appearance of alternating replacements of riverbed sediments of the Sava River and its left tributary, named the Galovica Stream, was noticed.

There are faults that run sub-parallel to the Sava River and divide all the pre-Quaternary rock units into blocks. These blocks separated by faults are differentially displaced. They subsided stepwise from the right bank of the Sava River to the flat terrain of the Pannonian Plain.

## Acknowledgments

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Project No. 176015 (grant to LJ. RUNDIĆ). Special thanks go to Mrs. SANJA KNEŽEVIĆ ANTONIJEVIĆ (UNC Chapel Hill, USA) for her English revision of the manuscript. Also, the authors are very thankful to the reviewers, Dr. STJEPAN ĆORIĆ (Geological Survey, Vienna) and Dr. RADOSLAV NAKOV (BAS, Sofia), for their constructive remarks and useful suggestions.

## References

- ANDJELKOVIĆ, M. 1987. The Upper Cretaceous. In: ANDJELKOVIĆ M. (ed.), *Geology of the general Belgrade area - Geology and Geodynamics*, 116–135. Faculty of Mining and Geology, Belgrade (in Serbian).
- EREMIJA, M. 1989. The Pannonian Stage. In: ANDJELKOVIĆ M. (ed.), *Geology of the general Belgrade area - Paleogeography*, 244–259. Faculty of Mining and Geology, Belgrade (in Serbian).
- GANIĆ, M., KNEŽEVIĆ S., RUNDIĆ LJ., MILUTINOVIĆ A. & GANIĆ A. 2011. Neogene geodynamics in the light of 3-D visualization – an example along the Sava River (Belgrade). Proceedings of the 17<sup>th</sup> Meeting of the Association of European Geological Societies, MAEGS-17: *Geology and Digital Age*, Abstract, 157–158, Belgrade.

- KNEŽEVIĆ, S. & ŠUMAR, M. 1993. Contribution to the study of the Miocene in Belgrade area based on drilling data. *Geološki anali Balkanskoga poluostrava*, 57/2: 49–64 (in Serbian and English).
- KNEŽEVIĆ, S. & ŠUMAR, M. 1994. Contribution to the study of Belgrade local geology. *Geološki anali Balkanskoga poluostrava*, 58/2: 73–83 (in Serbian and English).
- KNEŽEVIĆ, S. & GANIĆ, M. 2005. Miocene sediments near the Sava–Danube confluence in New Belgrade. 14<sup>th</sup> Geological Congress of Serbia and Montenegro, 107–112, Novi Sad (in Serbian, English abstract).
- KNEŽEVIĆ, S. & GANIĆ, M. 2008. Geological survey of River Island “Veliko Ratno ostrvo” at the confluence of Rivers Sava and Danube. *Compte rendus of SGS (2007)*, 101–111 (in Serbian, English summary).
- KNEŽEVIĆ, S., NENADIĆ, D. & STELIĆ, P. 1998. Preloess Quaternary and Pliocene deposits of Zemun and Novi Beograd. *Geološki anali Balkanskoga poluostrava*, 62: 57–73 (in Serbian and English).
- LASKAREV, V., PETKOVIĆ, K. & LUKOVIĆ, M. 1932. Geologic map of the vicinity of Belgrade, 1: 25000. *Geological Institute of the Kingdom of Yugoslavia*, Belgrade (in Serbian).
- LASKAREV, V. 1938. Third note on the Quaternary deposits from the vicinity of Belgrade. *Geološki anali Balkanskoga poluostrava*, 15: 1–35 (in Serbian, French resume).
- MAROVIĆ, M., TOLJIĆ, M., RUNDIĆ, LJ. & MILIVOJEVIĆ, J. 2007. Nealpine tectonics of Serbia. *Serbian Geological Society*, series monographs, Belgrade, pp. 87.
- MAROVIĆ, M. & KNEŽEVIĆ, S. 1985. Neotectonics of a part of Šumadija and north-western Serbia. *Geološki anali Balkanskoga poluostrava*, 49: 221–252 (in Serbian, English abstract).
- MAROVIĆ, M. & KNEŽEVIĆ, S. 1987. Neotectonics. In: AN-DJELKOVIĆ M. (ed.), *Geology of the Belgrade surrounding – Geology and Geodynamics*, 386–408. Faculty of Mining and Geology, Belgrade (in Serbian).
- NENADIĆ, D. 2001. Palaeogeographical characteristics of preloess Quaternary deposits of Belgrade and the vicinity. *Vesnik*, 51: 1–12 (in Serbian).
- NENADIĆ, D., KNEŽEVIĆ, S. & BOGIĆEVIĆ, K. 2009. Stratigraphical and Paleogeographical characteristics of Pleistocene series in the Sava riparian area at Belgrade (Serbia). *Bulletin of the Natural History Museum*, 2: 63–83.
- RUNDIĆ LJ., KNEŽEVIĆ S. & GANIĆ M., 2005. Karst occurrences in the Miocene of Belgrade area. In: STEVANOVIĆ Z. (ed.), *Water resources and environmental problems in Karst*, 731–735. Proceedings of the First International Karst Conference, Belgrade.
- RUNDIĆ LJ., GANIĆ M., KNEŽEVIĆ S. & SOLIMAN, A. 2011. Upper Miocene Pannonian sediments from Belgrade (Serbia) – new evidence and paleoenvironmental considerations. *Geologica Carpathica*, 62/3: 267–278.
- STEVANOVIĆ, P. 1977. Miocene of Belgrade surroundings. In: STEVANOVIĆ P. (ed.), *Geology of Serbia - vol. II-3, Stratigraphy*, 107–145. Faculty of mining and Geology, Belgrade (in Serbian).
- STEVANOVIĆ, P. 1980. Review of the neotectonics and paleogeography of the Neogene terrain of Lower Šumadija.

*Proceedings of the Geographic Institute, SASA*, 32: 19–48, Belgrade (in Serbian).

## Резиме

### Подповршинска геологија терена дуж трасе новог моста на Ади Циганлији (Београд, Србија)

Највећи бетонско-челични мост на свету са једним носећим пилоном отворен је у Београду 1. јануара 2012, а пролази преко шпица острва Аде Циганлије. Његова монументалност и архитектонско решење постали су нови симбол Београда. Нови мост директно повезује транспортне путеве на Чукарици и Новом Београду и представља део будућег унутрашњег магистралног полупрстена који ће значајно растеретити саобраћајне гужве у Београду. Укупна дужина моста је 996 метара, а ширина 45.06 m. Мост је заснован на великом, 200 m високом пилону који се налази на шпицу острва Аде Циганлије (фотографије на табли 1).

Анализирани су узорци језгра из седам бушотина (DB-4, DB-5, DB-6, DB-7, DB-8, DB-9, DB-10) изведених током изградње моста. Ти резултати су указали на постојање једне релативно комплексне подповршинске структуре. Обављеним истраживањима, утврђено је да су у дубинској геолошкој грађи терена заступљене следеће геолошке јединице: формација остружничког флиша горњокредно-палеогене старости, миоценски седименти сармата и панона, алувијални седименти квартара и савремени антропогени наноси.

На десној обали реке Саве, утврђени су горњокредно-палеогени флишни седименти на малој дубини (22 m), одмах испод танких средњомиоценских сарматских седимената и савремених кварталних наслага. На средини моста, на шпицу Аде Циганлије, утврђена је другачија ситуација. Тамо је преко флиша у сукцесији неколико различитих миоценских и кварталних јединица, а наслага остружничког флиша су констатоване на различитим дубинама (у најдубљој бушотини DB-6, на око 80 m). На левој обали реке Саве, у Новом Београду, још више су потонуле старије формације и набушени су само горњомиоценски панонски лапорци и плеистоценске и холоценске алувијалне насlage. У односу на шпиц Аде Циганлије, панонски лапорци су спуштени на много већу дубину (до 60 метара).

Плеистоценски полициклични речни седименти (тзв. Макишки слојеви) који представљају најважнији водени аквифер на подручју Новог Београда, нигде нису констатовани на површини терена дуж трасе моста, мада на ширем простору имају велико распрострањење. Млађу формацију кварталних алувијалних наслага представља са-

времени алувијални нанос реке Саве и њених притока, чији су седименти распрострањени на целој траси проучаваног терена. Њих чине седименти корита, поводња, повремено старача и мртваја, а на острву Ади Циганлији и седименти речног пруда.

Значајно је распрострањење на површини терена различитих типова техногених наслага међу којима се истичу наноси рефулираног песка на новобеоградској обали.

Стратиграфском корелацијом профила проучених бушотина уочено је да старије геолошке је-

динице каскадно тону идући од десне ка левој обали Саве. Може се претпоставити присуство раседа који су преквартарне творевине разбили на блокове. Раседима раздвојени блокови су диференцијално кретани по типу гравитационих раседа. Главни раседни правци иду субпаралелно са коритом реке Саве. Тектонски покрети који су довели до спуштања делова терена на левој обали Саве, обављени су током плиоцена и старијег квартара (нпр. у време таложења доњоплеистоценских полицикличних речних седимената).

#### PLATE 1

Figs. 1–5. Different construction stages and the views of the bridge during its building.

Fig. 6. The largest single-pylon, cable-stayed bridge in the world was opened in Belgrade on January 1, 2012 (a view from New Belgrade).

