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VODA 2019

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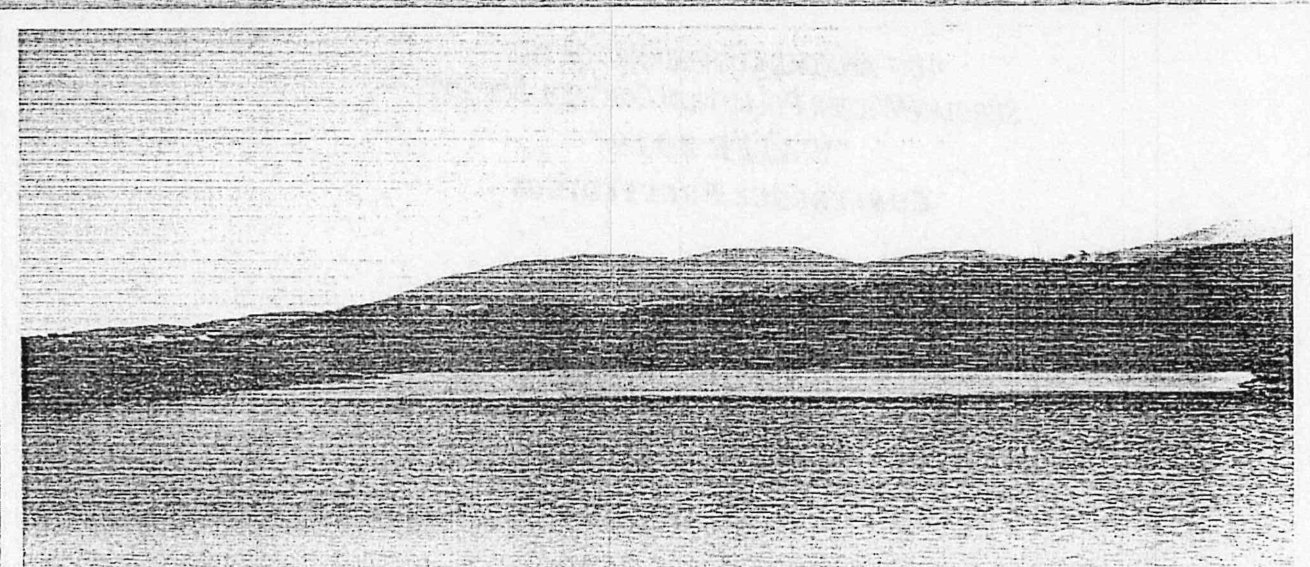

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POLYCICLIC STRATA FORMING ALONG THE CROSS SECTION FROM Rb-1M TO Rb-36 WELL AT THE BELGRADE WATER SOURCE, WITH RETROSPECT ON LOCAL TECTONICS

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ABSTRACT
Characteristics of alluvial water sources in the lower course of the Sava River, stratification ie. the cyclicity, granulometric and mineralogical-petrological composition of the layers are the result of the formation conditions during Pleistocene, primarily climate change, namely the shift of several glacial and interglacial periods. In addition to the climatic condition that caused the cyclicity in terms of the diversity of the granulometric composition and the lithofacial characteristics of the layers, sedimentation conditions were predisposed by tectonic activity, which locally predisposed the possibility of sedimentation and the thickness of layers. The Belgrade water source is specific for several reasons. This is the largest source in the Sava River Basin in Serbia, the most downstream source, located at the very confluence of the Sava River and the Danube River, and the alluvial waters are exploited using 99 wells with horizontal drains and some vertical wells. Since the alluvial aquifer of Belgrade's groundwater source is characterized by great differences in terms of thickness and lithofacial characteristics of layers and filtration characteristics, as a consequence of complex genesis, the sustainable development and exploitation of the wells depend on the identification and analysis of the relevant ones for each of the wells individually. This paper presents an overview of local sedimentation conditions, from the aspect of tectonic conditions, on the profile Makiško polje – Donje Polje, based on three boreholes near the Rb-1m, Rb-6 (right bank) and Rb-36 wells (left bank).

KEY WORDS: Belgrade water source; alluvial polycyclic sediments; pleistocene climate; tectonics

FORMIRANJE POLICIKLIČNIH SLOJEVA DUŽ PROFILA IZMEĐU BUNARA RB-1M I RB-36 NA BEOGRADSKOM IZVORIŠTU, SA OSVRTOM NA LOKALNU TEKTONIKU

REZIME
Karakteristike aluvijalnih izvorišta u donjem toku reke Save, slojevitost tj. cikličnost, granulometrijski i mineraloško-petrološki sastav slojeva, posledica su uslova formiranja

tokom pleistocena i to prevashodno klimatskih promena, tačnije smene više glacijalnih i interglacijalnih perioda. Pored klime koja je uslovila cikličnost u pogledu različitosti granulometrijskog sastava i litofacijalnih karakteristika slojeva, uslovi sedimentacije predisponirani su i tektonskom aktivnošću, koja se lokalno odrazila na mogućnost istaložavanja i debljinu pojedinih slojeva. Beogradsko izvorište specifično je iz više razloga. Ovo je najveće izvorište u slivu Save kroz Srbiju, najnizvodnije izvorište, koje se nalazi na samom ušću reke Save u Dunav, a podzemne vode aluvijalne izdani eksploatišu se pomoću 99 bunara sa horizontalnim drenovima i cevastim bunarima. Budući da se aluvijalna izdan beogradskog izvorišta podzemnih voda odlikuje velikim razlikama u pogledu debljine i litofacijalnik karakteristika slojeva i filtracionih karakteristika, kao posledica kompleksne geneze, održivi razvoj i eksploatacija bunara zavise od identifikacije i analize relevantnih, za svaki od bunara pojedinačno. U ovom radu dat je prikaz lokalnih uslova sedimentacije, sa aspekta tektonskih uslova, na profilu makiško polje – donje polje, na osnovu tri bušotine na lokacijama bunara Rb-1M, Rb-6 (desna obala) i Rb-36 (leva obala) na beogradskom izvorištu.

KLJUČNE REČI: beogradsko izvorište; aluvijalni policiklični sedimenti; klima pleistocena; tektonika

INTRODUCTION

Today, the prevailing opinion (Nenadić, 2003) is that the polycyclic riverine sediments were deposited in a spacious alluvial plain, as wide as a lake but with river-like dynamics. Since they are genetically associated with tectonic processes involving multiple sinking of the accumulation plain, these sediments are characterized by cyclical recurrence of typical riverbed sediments (gravels, sandy gravels, sand), and floodplain sediments (silts and sandy clays). In addition to active tectonics, varying climate conditions in the Pleistocene were one of the key drivers of the sedimentation cycles at BGS (Zarić, 2019).

The need to explore and identify Pleistocene alluvial sediments and their characteristics arose due to intensive groundwater extraction at Belgrade Groundwater Source (BGS, Fig. 1). BGS is currently comprised of 99 radial collector wells and 47 tube wells. Stratigraphic and hydrogeological data from borehole core investigations in 2016 and 2017, as well as the outcomes of previous research, served as the starting point of the research. The objective was to define the lithological and stratigraphic characteristics of the BGS polycyclic alluvial sediments as accurately as possible. The results of this research were published in several papers dealing with the problem of polycyclic Quaternary formations at the BGS, their genesis, and their link to different climate cycles throughout the Pleistocene era in correlation to other quaternary formations (Dimkić 2017, Knežević 2018, Zarić 2018).

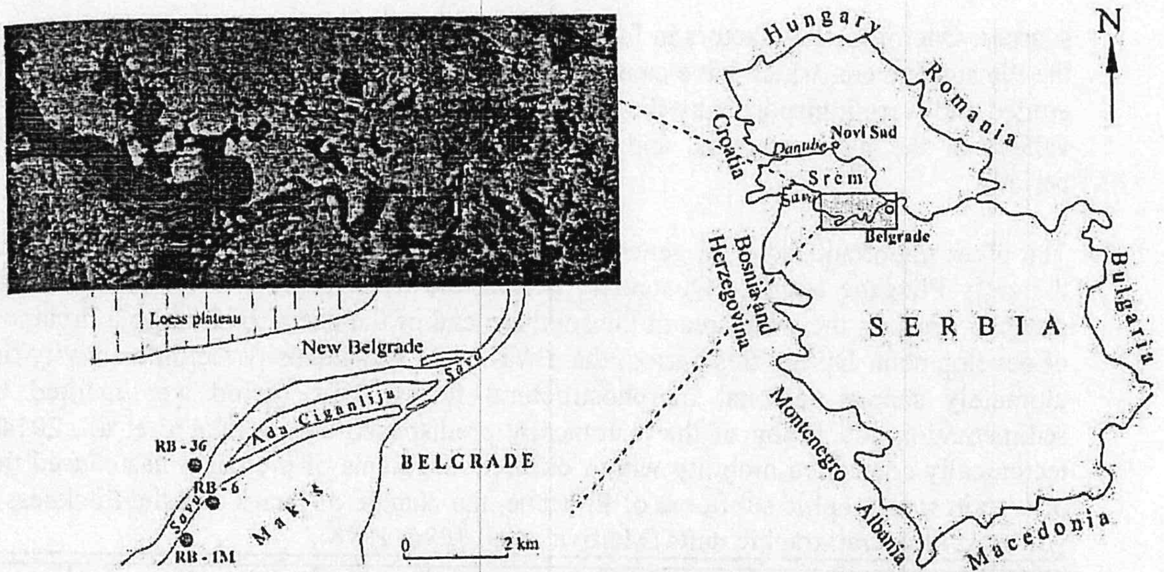

Figure 1. Study area of BGS with location of wells where exploratory drilling was conducted

This paper will focus on sedimentation and characteristics of Quaternary strata as seen through the prism of sedimentation factors with regards to tectonic conditions on both local and regional level. Regional level shows BGS area as the contact of the Pannonian Basin and Belgrade hillside, while at the local level there is the influence of different fault structures on sedimentation in terms of position and thickness of strata and certain lithostratigraphic units on Sava's left and right bank.

GEOLOGICAL SETTING

The Tethys Sea, separating two continents - Gondwana and Laurasia during much of the Mesozoic Era, was split in two parts – Paratethys and Mediterranean due to intensive tectonic activity. Within the Central Paratethys, due to the sedimentation and tectonic movements, Pannonian Lake was formed, in the beginning of the Upper Miocene (Pannonian), around 11,6 million years ago (Rundić et al. 2011). The Lake consisted of a basin complex of lakes. Due to filling with different sediments from northwest, northeast and west, the bank of Pannonian Lake was forced to regress at the beginning of Pliocene era (Stevanović, 1959, 1978). At the beginning of Pliocene era (around 4,5 million years ago, according to Magyar et al., 1999; Popov et al., 2006), in the deepest parts of the Pannonian sedimentary region a freshwater Paludin Lake was formed, which, at its peak, spread across most of today's Slavonia and Vojvodina, and it's assumed to have dried out during the Lower Pleistocene. After its disappearance, initial relief of the Pannonian plane has started to form and conditions were met for a more dynamic development of paleo-courses of today's rivers.

The river system of the paleo-courses brought the cyclical accumulation of the alluvial sediments which formed the, so called polycyclic strata that contain today's groundwater sources. One of the key factors in formation of these strata were the climate changes during the Pleistocene era, which have caused accumulation of gravelly and sandy strata, that later eroded and were transported by the fast streams of the melted glaciers and deposited in the valleys of the paleo streams, and clay and dust strata, accumulated during the colder periods.

The other important factor in genesis of the polycyclic sediments is the tectonics. During the early Pliocene and late Quaternary period, the water level in the freshwater lake has dropped, causing the wide area in the southern end of the basin to undergo a dryland phase of development. During this period, there was some low intensity tectonic activity that has ultimately shaped regional morphostructural forms. This period was marked by the sedimentation and filling of the tectonically predisposed basins (Toljić et al., 2014). The tectonically controlled mobility within different segments of the basin has caused the lack of certain stratigraphic subfloors of Pliocene, the change of facies and the thickness of the youngest lithostratigraphic units (Marović et all 1996, 1998).

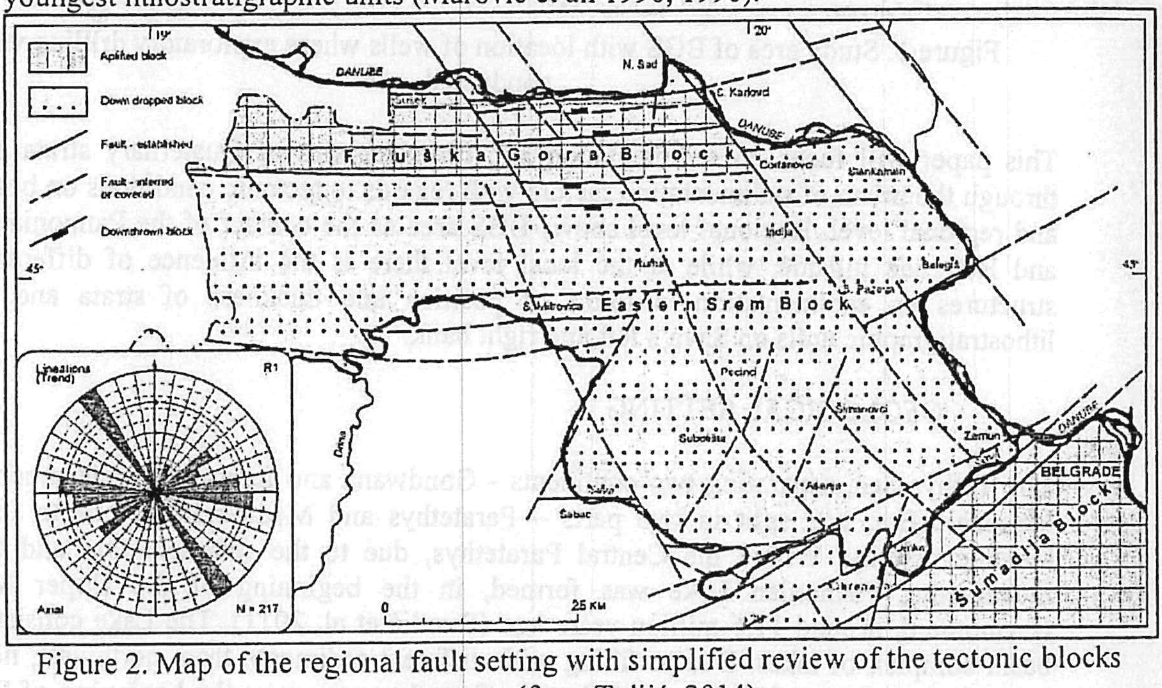

Figure 2. Map of the regional fault setting with simplified review of the tectonic blocks structure (from Toljić, 2014)

Towards the end of Pliocene and during Upper and Central Pleistocene period, there was a continual uplift of Fruska Gora's horst and the far north part of Šumadija (Belgrade's hillside) (Ćalić et al., 2012), while at the same time the tectonic trench of River Sava was being dug between the two structures. The most important neo-tectonic form in the BGS zone is Kalemegdan fault. It is a complex fault comprised of echelon faults associated in an spreading in northeast-southwest direction, almost parallel to today's Sava river bed (picture 2), from Kalemegdan to Obrenovac, moving on to southwest (Toljić et al., 2014), Pre-Quaternary formations split across Kalemegdan fault in several blocks, that descend towards north and southwest. This caused the cascade descent of older geological formations on the left bank of Sava as compared to the right bank. At the expense of subsidence of older rocks, along those lines the thickness of Quaternary post-basin formations is increasing.

The influence of local tectonics on the position and thickness of the so-called "motley clays" is visible when extracting stratigraphic units at BGS, as it is presented in the previously published paper (Figure 3). In that paper the cyclical nature is shown with regards to the climate changes in Quaternary period, with no detailed analysis of tectonics as a factor of genesis of polycyclic sediments (Zarić 2018).

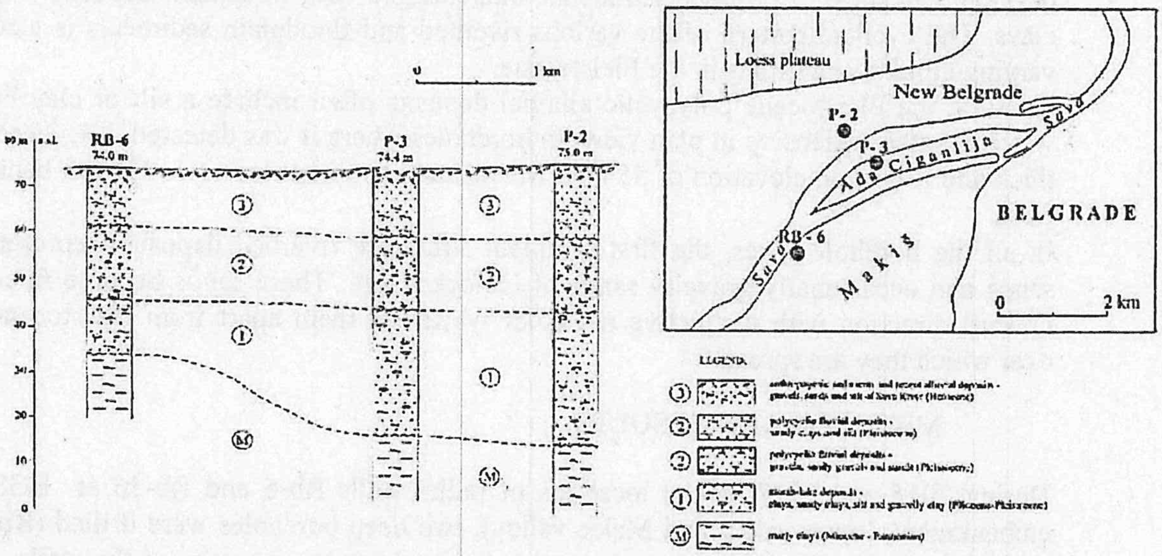

Figure 3. Correlation of stratigraphic sections: Makiš (RB-6) – Ada Ciganlija (P-3) – Novi Beograd (P-2), (from Zarić 2019).

STRATIGRAPHIC UNITS

Since stratigraphic units of BGS have already been described in much detail in previous publications (Knežević 2012, Nenadić 2016, Polomčić), this paper will just give a short description of each of them with some basic characteristics.

Quaternary sediments on Sava's riverside are around 20 cm up to 30 cm thick. They contain the typical fluvial formations, whilst differentiating among the following stratigraphic units:

- bog-lacustrine-terrestrial sediments of the Pliocene-Pleistocene era (so-called "motley clays")
- polycyclic alluvial deposits of the Pleistocene era (so-called "Makiš strata"), and
- Holocene alluvial sediments of the river Sava and its confluents.

The oldest Quaternary sediments are scattered discordantly over the Pannonian sediments on almost entire grounds of the groundwater source, comprising the upper layer of the Pannonian and the ground level of Pleistocene alluvial formations. Lithologic composition, as well as scarcity of paleontological markings suggest that the formations of the earliest

Quaternary period were created in the shallow, aquatic depositional areas (such as lakes or ponds) that would periodically dry out. Lithologically, they are present in clays and sandy clays, or gravel-sand-clay mixtures. There can often be found oolites of manganese and iron oxides, with concretion of calcium carbonate (Nenadić et al., 2015), which is why they are called "motley clays".
The older formation of polycyclic sediments, detected in all boreholes, with the lower boundary at a absolute height of 43-45 m. The lithologic composition are clastic sediments – sandy gravels alternating with fine and coarse gravelly sands, originating from the development stage of riverbed sediments, interchanged with floodplain deposits – silts and clays. The cyclical pattern of the various riverbed and floodplain sediments is a result of varying climate conditions in the Pleistocene.
At BGS, the Pleistocene polycyclic alluvial deposits often include a silt or clay interbed, which is rather extensive in plan view. In boreholes where it was detected, it is 20 to 50 cm thick and it is at an elevation of 55 m at Makiš and somewhat lower on the left bank of the Sava.
In all the borehole cores, the first sediment strata are riverbed deposits, represented by sands and occasionally gravelly sands of Holocene age. These sands become finer in the upward direction with distinctive red color which set them apart from Pleistocene sands over which they are spread.

METHODS AND RESULTS

During 2016 and 2017, at the locations of radial wells Rb-6 and Rb-36 at BGS (Sava embankment, lower valley and Makis valley), two deep boreholes were drilled (Rb-6/p-5d and Rb-36/p-4d). Piezometers were constructed in the near proximity of the wells, zone of the active radial well laterals. Aquifer is formed in the Quaternary gravels and sands of the so-called polycyclic alluvial deposits of the BGS. Alluvial gravels and sands are cyclically interchanged with semi-permeable and impermeable strata of alevrite and clays. In order to define a local lithological profile and the additional research of the ground floor of alluvial horizons, 2 deep boreholes were drilled with the aim to penetrate through the entire depth of layers of so-called „motley clays" of Pliocene-Pleistocene, all the way through to underlying marly clays of Pannonian age.

Drilling was carried out with a continuous usage of coring tube for the coating column along the entire depth of the the rotary method drill which employs a Ø 128 mm and Ø 98 mm tubes up to the depth of 51 m (at the location Rb-6/p-5d) and 60 m (at the location Rb-36/p-4d), the drill Rb-1m was not ended in the Miocene base, but in „motley clays" strata of Pliocene-Pleistocene.

The core was removed and stored in plastic cases. Based on the mapping of the core sediments, all lithological units and transitory units were distinguished. Sediment samples were taken for each significant lithological change.

Grain-size distribution analyses included both dry and wet methods. They were carried out on the samples of the unconsolidated aquifer material as well as semi-permeable and semi-consolidated material from strata interbeds.

Based on in situ core mapping and the results of the grain-size distribution analyses, geological profiles of two boreholes were created and sedimentation cycles were distinguished. A comparative display of the grain-size distribution analyses of two deep boreholes and the one at the location of Rb-1m well (Rb-1m/p-3d) can be seen on Figure 4, along with the illustration of separate lithological units.

Based on the distribution of the diameter of the grain size at different depths of the boreholes, it can be noticed that the number of cycles corresponds at all research sites. The clay stratum can be found in both deep borehole sites, on the left bank at the elevation of 53 m a.s.l., about 20 cm thick, while on the right bank at the elevation of 55 m a.s.l. and the thickness is about 30 cm. The identified stratum corresponds to the general stratigraphic scheme which foresees its deposition slightly below 55 m a.s.l. on the left bank, in accordance with local tectonic conditions.

The Miocene base was reached only in the Rb-6/p-5d borehole, while the borehole Rb-36/p-4d ended in "motley clays". The borehole at the left bank (Rb-36/p-4d) enters the "motley clays" at 32.0 m of depth and ends in the same strata at the dept of 61.2 m. The borehole at the right bank reaches the "motley clays" at 27.0 m of depth, with underlying Pannonian horizons, discovered at 40.5 m of depth. This also corresponds to the sinking of the basins from the Belgrade hillside (right bank), along the north-northwest line towards the center of the basin in the direction of Fruška Gora. A major fault from Neoalpine tectonics map is situated right between the Rb-1m/p-3d and Rb-6/p-5d on one side, and Rb-36/p-4d on the other side (Figure 4).

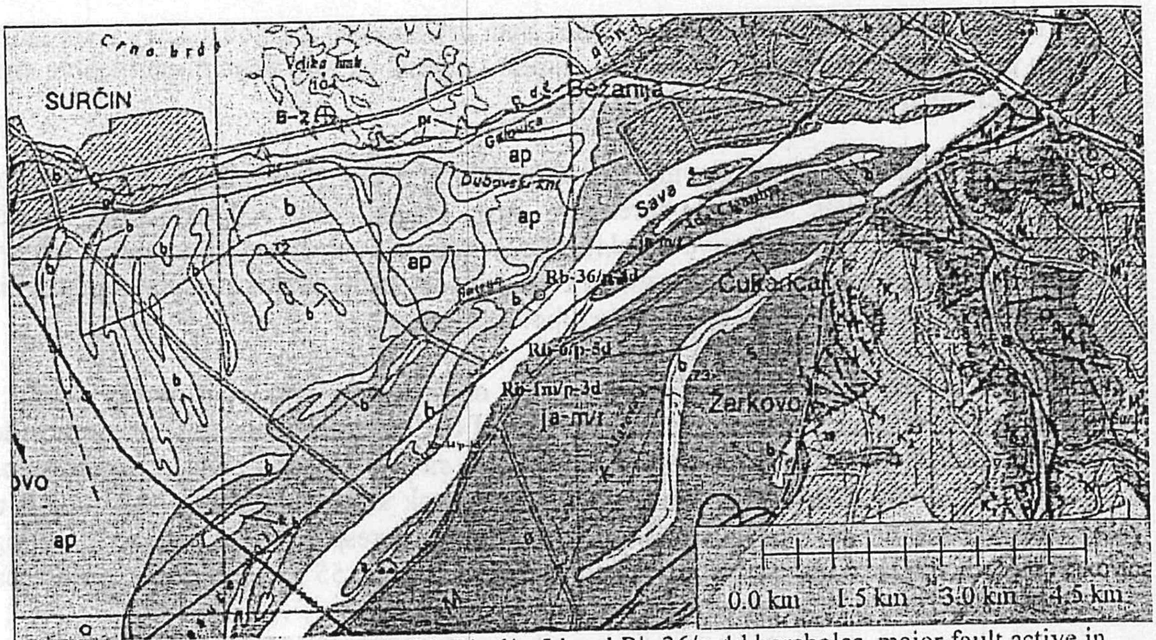

Figure 4. Position of Rb-1m/p-3d, Rb-6/p-5d and Rb-36/p-4d boreholes, major fault active in pleistocene (red line) on the basic geological map 1:100000 sheet Belgrade

The laterals of the wells are positioned at the elevation of 46.8 m a.s.l. at the left bank (Rb-36) and 51.3 m a.s.l. at the right bank (Rb-6) of Sava river at BGS.

The results are shown integrally in Figure 5 and Table 1.

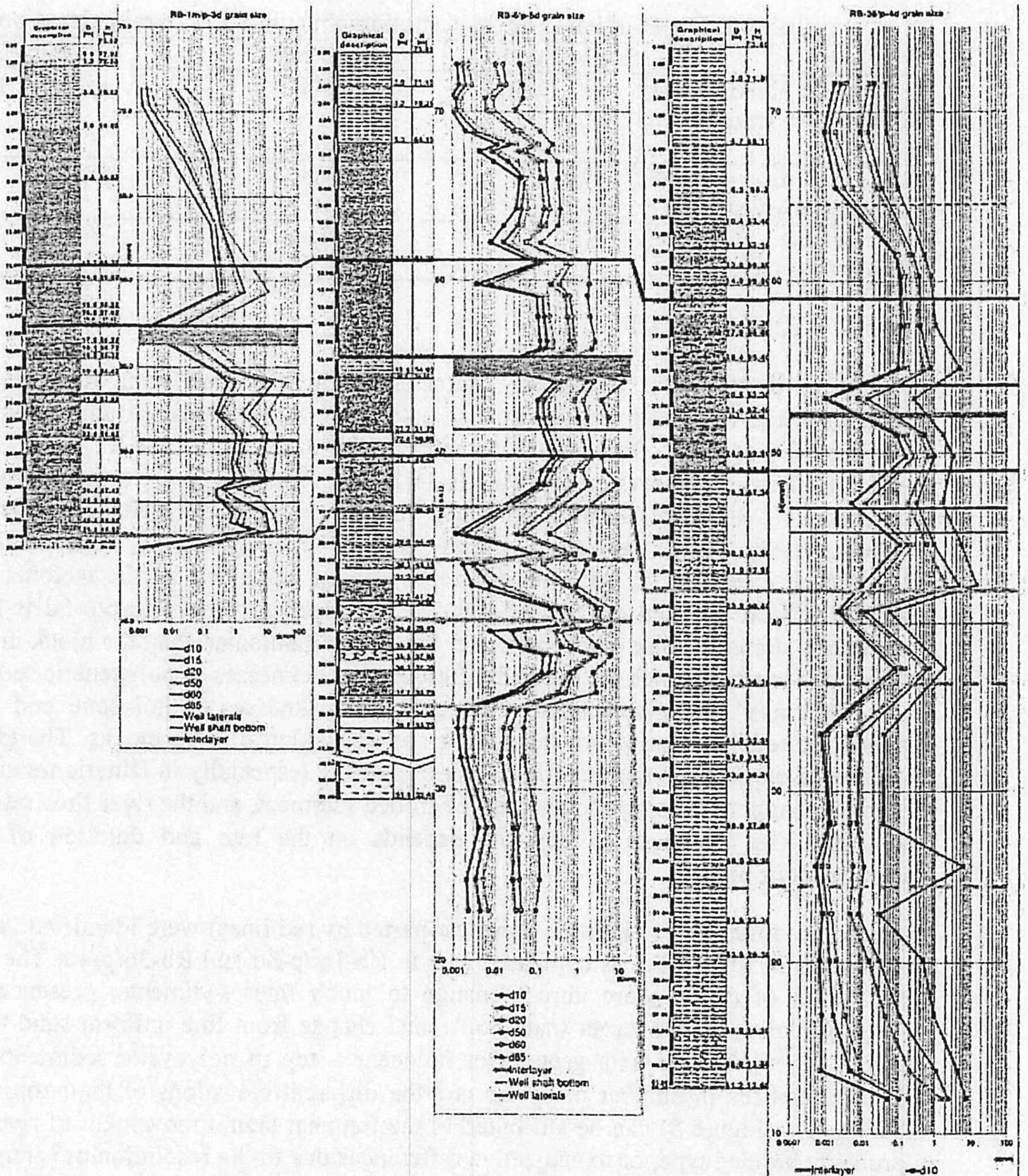

Figure 5. Comparison of disposition of stratigraphic units and cycles within them in boreholes Rb-1m/p-3d, Rb-6/p-5d and Rb-36/p-4d. Red lines represent top of polycyclic sediments and tops of cycles, orange lines represent top of „motley clays“ and tops of cycles, yellow line represents top of marine Pannonian sediments

Table 1. Depth of bases of basic stratigraphic units and terrain elevations

Borehole	Rb-1m/p-3d	Rb-6/p-5d	Rb-36/p-4d
Base of the holocene (base of high river stage silt and clay)	13.1 (5.0) m	12.2 (5.3) m	15.0 (10.4) m
Base of the polyciclic sediments – pleistocene	29.2	27.0 m	32.0 m
Base of the polygenetic sediments – pleistocene	?	40.5 m	>61.2 m

CONCLUSION

Thickness of holocene sediments, characterized by the high river stage silt and clay sediments and river course sediments in a form of well sorted fine and medium grained sand, is 12.5 m in the Rb-1m/p-3d and Rb-6/p-5d, and 15 m in the Rb-36/p-4d borehole. The thickness of polycyclic sediments is 16.1 m in Rb-1m/p-3d, 14.8 in Rb-6/p-5d and 17 m in Rb-36/p-4d. There is great difference in thicknesses of polygenetic sediments, the so called „motley clays“, as their thickness is 13.5 m in Rb-6/p-5d, while in Rb-36/p-4d borehole it exceeds 29.2 m. This difference can be explained by the tectonic movement along the fault outlined in red in Figure 2. The block in which Rb-6/p-5d is located has obviously started to sink much later after the end of Pannonian than the block in which Rb-36/p-4d is located, hence the marked difference in thicknesses of polygenetic sediments, i.e. „motley clays“. Relatively small difference in thicknesses of holocene and pleistocene polyciclic sediments points to the similar rate of sinking of both blocks. The grain size of sediments depends on the rate of melting of glaciers (especially in Dinaric mountains), and is proportional to the size and quantity of eroded sediment, and the river flow rate and water velocity. The thickness of deposits depends on the rate and duration of downward movement of block.

As can be observed in Figure 5, 4 cycles (parted by red lines) were identified in polycyclic sediments in Rb-6/p-5d, as compared to 3 in Rb-1m/p-3d and Rb-36/p-4d. The criteria for separation of cycles were abrupt change to much finer sediments, presence of clayey interlayer of thickness larger than 0.5 m, and change from fine uniform sand to coarse or medium grained sand with gravel (for holocene – top of polycyclic sediments partition). The differences in number of cycles and the different elevations of their top and bottom boundaries (Figure 5) can be attributed to the frequent lateral movement of river course of probably braided type, or to subjective differences due to the resolution of sampling for the grain size analysis, errors in depth estimation during the drilling and transferring of material to boxes etc. The research results not presented here suggest that each cycle corresponds to a melting of glaciers at the end of one interstadial during Würm (alpine chronology), or more exactly MIS 5 stage, and at the end of MIS 6 and MIS 8 stages.

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