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Quaternary tectonic and depositional evolution of eastern Srem (northwest Serbia)

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Abstract: The area of eastern Srem is situated in the southern periphery of the Pannonian basin. Its depositional evolution during the Neogene and the Quaternary has been controlled by tectonic processes. Miocene extensional subsidence was followed by the Pliocene-Quaternary inversion of the basin. The latter was accomplished as the result of replacement of the tensile by the compressive stress field. Since the Late Neogene, the regional tectonic activity has been controlled by compressive stress produced by the north-northeastern propagation of the Adria microplate. In the compressive NE–SW-oriented stress field, the recent structural plan of the Pannonian basin and its wider environment, including its southern periphery, was reactivated. The youngest tectonic deformations are characterized by positive and negative vertical motions of large intrabasinal segments and basinal periphery, resulting in the final inversion of the basin. The effects of the basinal inversion can be recognized in genetic features of Quaternary sediments and geomorphological characteristics of the relief. Sources of data used for the interpretation of the Quaternary tectonic activity in the area of eastern Srem are of geological, geomorphological, thermochronological, and geophysical character. The positions of prominent fault structures have been ascertained by remote sensing, interpretations of available geophysical cross-sections, and using the field data.

Key words: tectonic activity, Pannonian basin, northwest Serbia, subsidence, basin inversion, eastern Srem, Quaternary.

Апстракт: Подручје источног Срема налази се у јужном ободном делу Панонског басена. Његова депозициона еволуција током неогена и квартара била је контролисана тектонским процесима. Миоценску екстензиону субсиденцију, прати плиоценско-квартарна инверзија басена. Инверзија басена је изведена као последица смене тензионог напонског поља са компресионим. Касно-неогена и рецентна тектонска мобилност контролисана је компресионим стресом, генерисаним север-североисточном пропагацијом адријске микроплоче. Рецентни структурни план читавог Панонског басена и његовог ширег окружења, укључујући и јужни обод, реактивиран је у домену компресионог напонског поља, оријентисаном по правцу североисток–југозапад. Најмлађе тектонске деформације карактерише позитивна и негативна вертикална мобилност значајних унутарбасенских сегмената као и периферије басена, што је резултирало финалном инверзијом басена. Ефекти басенске инверзије препознају се у генетским карактеристикама квартарних седимената, као и у геоморфолошким карактеристикама рељефа. Извори података који су коришћени за интерпретацију квартарне тектонске активности у подручју источног Срема су геолошког, геоморфолошког, термохронолошког и геофизичког карактера. Позиције значајнијих раседних структура утврђене су даљинском детекцијом, интерпретацијом расположивих геофизичких профила и на основу теренских података.

Кључне речи: тектонска мобилност, Панонски басен, северозападна Србија, субсиденција, басенска инверзија, источни Срем, квартар.

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Introduction

In the area of eastern Srem during Quaternary period tectonic activity has been manifested as a significant control factor of deposition and final shaping of modern relief (MAROVIĆ *et al.* 2007). However, tectonic evolution of the Pannonian basin has started much earlier, hence all tectonic structures that have been active in Quaternary, are actually a part of previously existing structural pattern and they belong to the category of inherited structures. Furthermore, sedimentation as a dominant process of final phases of filling of an inverted depositional basin, took place in previously tectonically defined domains (MAROVIĆ *et al.* 2002, and other references therein).

During the younger stages of Pliocene and earlier part of Quaternary, after the retreat of Paratethys, the area of the southern rim of the Pannonian basin in whole passed through the terrestrial phase of development (NENADIĆ *et al*. 2010, 2011). In that interval tectonic shaping of low intensity has been carried out, by which regional morphostructural forms were finally shaped. Also, tectonically controlled mobility within basinal segments caused the absence of some stratigraphical substages of Pliocene, and change of facies and thickness of the youngest lithostratigraphical units (MAROVIĆ *et al.* 1996, 1998; RAKIĆ *et al*. 2005).

In the southern parts of the Pannonian basin, Pliocene-Quaternary tectonic activity was manifested in gradual, continuous descending of extensional areas in Posavina toward the interior parts of the Pannonian basin and in uplift of the area of the Fruška Gora massif, Belgrade promontory and some parts of Šumadija (MAROVIĆ *et al.* 2007). This vertical mobility brought significant changes in relief and initiated the development of exogenic denudation-accumulation processes.

The postbasinal structural complex, formed in a post-Neogene phase, is represented by a relatively thick sequence of sediments within which two parts, differing in superposition and origin, can be distinguished (NENADIĆ *et al*. 2003, 2009).

– *older*, fluvial and fluvio-lacustrine, with relics of basinal frame, generated by movements on the boundary between Pliocene and Quaternary, which were manifested in a poly-phase lowering of the former basin bed and formation of complex alluvial plains of the pre-Danube and pre-Sava.

– *younger*, which corresponds to the fluvio-denudation system s.s., and which comprises morphological structures made in the Late Pleistocene and Holocene.

Geological settings

The Pannonian basin is an intracontinental entity situated between the Dinarides, the Alps, and the Carpathians. It is filled with Neogene and Quaternary deposits. The basement of the basin is formed by the tectonic units of both Adriatic and European continental affinity: the Dinarides (as a part of Adria), Tisza and Dacia (as parts of Europe), and also tectono-stratigraphic contents that belong to the Sava zone (as a suture between Adria and Europe, SCHMID *et al*. 2008). The territory of Serbia includes the southernmost parts of the Pannonian subsidence area represented by basinal and peribasinal structures, and deeply penetrated towards the south between Dinaric and Carpatho-Balkan morphostructures (MAROVIĆ *et al.* 2007). Neotectonic movements formed some interesting structural, depositional, and morphological features that are different from those in the other parts of the Pannonian basin.

In the recent literature, there are interpretations that the southern boundary of the Pannonian basin in Serbia is formed by the rivers Danube and Sava, while the areas south of them, made of Neogene deposits of similar or same composition as those in the Pannonian basin, belong to the peri-Pannonian area. Although this boundary has a certain geographical and geomorphological sense, from the geological point of view it is difficult to place it here, since the basin boundary is situated further south of the Sava and Danube. Locally, the investigated area belongs to eastern Srem, limited by the Danube and Sava from the north, east and south, and by the line Sremska Mitrovica–Neštin from the west (Fig. 1A).

Identification of structures in the investigated part of the area, as well as monitoring of their activity during the youngest tectonic phase, was carried out on the basis of palaeogeographical, structural, thermochronological, and geophysical, characteristics of this area. When reconstructing the tectonic evolution, beside the remote sensing analysis, the data from the exploration wells and field data have been used as well as reinterpretation of available seismic sections.

Material and methods

The positions of prominent fault structures in the investigated area have been ascertained by remote sensing, interpretations of available geophysical cross-sections, and using the field data. The field data were obtained by the analysis of numerous borehole cores situated in the investigated area. The mineralogical and petrological composition of these samples has been preliminary analyzed. Remains of molluscs and ostracodes have been picked out under a binocular microscope and determined to the level of species when it was possible, using the qualitative methods. When no fossils were available, the age of deposits has been estimated by the so-called superposition principle.

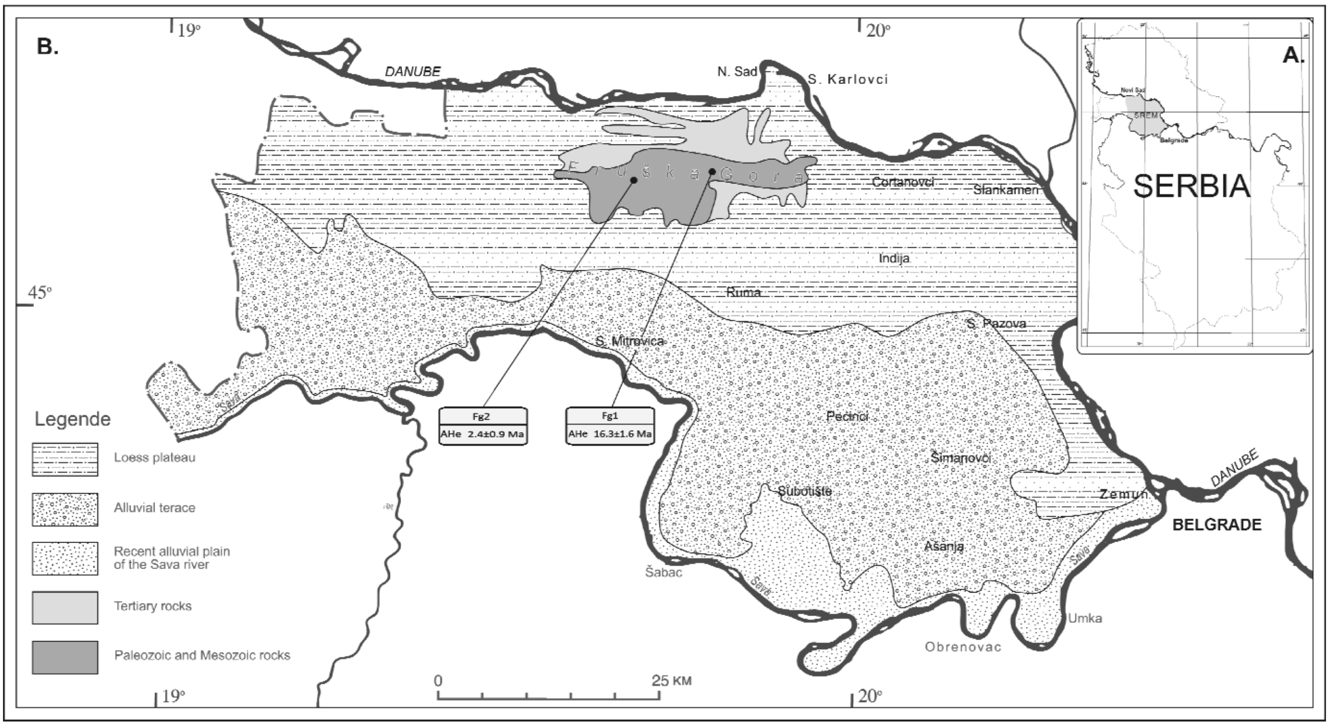

Fig. 1. **A,** Geographic position; **B,** Simplified geological map of the study area with localities where samples for new (U-Th)/He apatite thermochronology ages (AHe) werecollected.

Results and discussion

Quaternary tectonic mobility

Quaternary tectonic activity of the southern parts of the Pannonian basin has been perceived in context of the regional Miocene extensional evolution of the entire basinal area and its Pliocene-Quaternary inversion (e.g. HORVATH *et al.* 2006; MAROVIĆ *et al.* 2002; MAROVIĆ *et al.* 2007; MATENCO & RADIVOJEVIĆ 2012 and other references therein). Miocene extension, produced by rollback of European lithosphere in the Carpathians, was accompanied by rifting, thinning of the lithosphere and subsidence in the domain of the Pannonian basin. A long-term Middle and Late Miocene post-rift subsidence, controlled by thermal sag cooling (HORWATH & CLOETINGH 1996; CLOETINGH *et al.* 2006), was followed by the Pliocene–Quaternary basin inversion, performed in compressive stress field. The extensive stress field was replaced by compression, which was activated as a result of the final break off of the subducted European lithosphere in the domain of the Carpathians, on one side, and the north-northeastern progression of the Adria plate, on the other side (BADA *et al.* 2007). During Pliocene and Quaternary, both the Dinaric-Carpathian orogen and intracontinental Pannonian basin were exposed to constant compression, generally oriented towards NE–SW in this region (BADA *et al.* 2007). Under these conditions the lithologically heterogeneous lithosphere in the basement of the Pannonian basin, wrinkled in kilometer-scale folds, was thinned (CLOETINGH *et al.* 2006). The regional folding of lithosphere was accompanied by vertical mobility of segments of the lithosphere, of different direction and intensity, which finally resulted in a relatively rapid uplift and denudation of the peripheral parts of the basin and further subsidence and deposition of the central domains of the basin. At the same time the existing tectonic pattern was reactivated by local redistribution of compressive stress. This pattern was responsible for the control of tectonic mobility within basinal entities, such is the area south of Fruška Gora (TOLJIĆ *et al.* 2013). Regionally, in the Pannonian area, to the north of the Danube and Sava slow subsidence has been continuing throughout Quaternary, but with smaller velocity than in Neogene and with a constant tendency of weakening until recent time. In contrast to this sinking, peripheral part of the Pannonian basin and intrabasinally situated morphostructure of Fruška Gora have been raised.

Quaternary tectonic activity can be identified by studying the origin and thickness of sediments. Of particular significance here are pre-loess fluvial polycyclic deposits in the southern and deluvial-proluvial sediments in the northern part of the area. Geomorphological data, such as hypsometric relationship, position of fluvial terraces, process of erosion, etc., also point to tectonic changes. Also, information on geodetic measurement and seismic activity are of special interest. Furthermore, thermochronology can yield information on the exact timing of the tectonic activity.

Basic geophysical characteristics of the investigated area

Seismicity represents one of the most relevant factors in detecting recent fault activity in the Pannonian and peri-Pannonian region (MAROVIĆ *et al.* 2002). On the basis of existing data it can be concluded that the Serbian part of the Pannonian basin shows very low seismicity, with exception of the Fruška Gora massif and the area of eastern Banat. Particularly, these areas are characterized by quakes of magnitudes which do not exceed M=4.5, except the area of Fruška Gora (M=4.5–5) and a part of eastern Banat. In the Serbian part of the Pannonian basin the most seismically active faults are of direction NW–SE, representing structures across which there have been transcurrent left movements, with a pronounced reverse component (MAROVIĆ *et al.* 2002). Southern periphery of the Pannonian basin belongs to a seismic active region in Serbia, with maximum magnitude M=5,5–6. Southern periphery of the Pannonian basin and its immediate hinterland are characterized by seismically active, transcurrent right faults of direction NE–SW (ENE–WSW). These two systems of conjugated faults are further active in the compressive stress field which has an axis of maximum compression oriented in general direction NE–SW.

Recent mobility of the Earth's crust in the area of the Pannonian basin has been confirmed by geodetic measurements (JOVANOVIĆ 1971, FGS 1972). The general model of vertical mobility of the Earth crust in the domain of the southern parts of the Pannonian basin suggests that the northern periphery of the investigated area (the area of Fruška Gora) has been raised by the rate up to +2 mm/year (MAROVIĆ *et al.* 2002; MAROVIĆ *et al.* 2007). The peripheral northeastern parts of the Dinarides show a similar trend. Recent subsidence (by the rate of approximately 1 mm/year) has been ascertained in the area of Srem (Map of recent vertical movements of the Earth's crust in the area of SFRJ, FGS 1972, MAROVIĆ *et al.* 2002, MAROVIĆ *et al.* 2007). The most recent geodetic study of the Earth's crust mobility in the southern parts of the Pannonian basin shows a low level of mobility in the area of Srem (SUŠIĆ 2013). Isolines map is (Fig. 2) showing rates of vertical tectonic movement in the area of Srem.

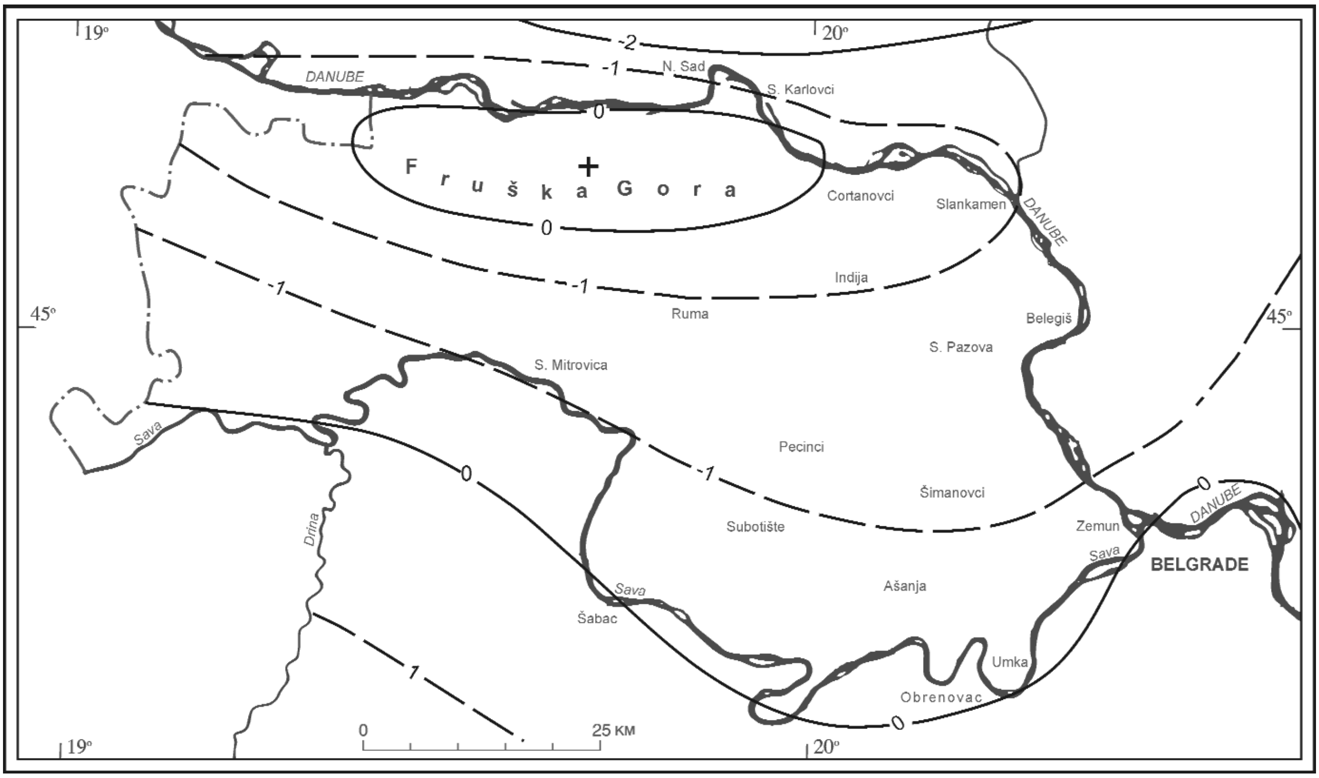

Fig. 2. Map of velocities of the recent tectonic movements in the area of Srem (modified after MAROVIĆ *et al,* 2002).

In the sections of seismic profiles in the area of Fruška Gora (MATENKO & RADIVOJEVIĆ 2012) in the south of the mountain an association of faults that form the Vrdnik fault could be recognized (TOLJIĆ *et al.* 2013). The southern block was primarily gravitationally downthrown across this structure, so the thickness of Pliocene-Quaternary sediments to the south of the fault exceeds 500 m. The synthesis of the data obtained by seismic profiling and deep exploration drilling in this area, also indicates the significant thickness of Pliocene-Quaternary sediments (MARTINOVIĆ *et al*. 2010). The greatest thickness is observed between Stara Pazova and Šabac, in the depression whose axis lies in the E–W (ENE–WSW) direction. While the Vrdnik fault is situated in the northern periphery of the depression, central parts of the area are controlled by an association of horsts and grabens defined by the faults across which the central part of the Sefkerin depression was downthrown (MATENCO & RADIVOJEVIĆ 2012). The southern periphery of the investigated area in seismic section shows a complicated tectonic nature of a transitional region between the Pannonian basin and its uplifted southern hinterland. The Kalemegdan fault (as association of faults) stands out as a dominant structure. It is a syndepositionally active fault(s), across which subsidence of the NW domain has continued to take place in Quaternary, as suggested by the significant thickness of the youngest sediments. This scenario is also indicated by a relatively small thickness of Pliocene-Quaternary sediments to the east of this fault. In a planar view, the association of faults which constitute the Kalemegdan fault consists of echeloned faults with the NE–SW direction that may be followed from Kalemegdan across Obrenovac and further to SW (Fig. 4).

Geomorphological analysis

Effects of Quaternary tectonic movements can be considered by studying morphogenetic characteristics of the area and sedimentological features of deposits. The former include forms of relief, dynamics and origin of river valleys, sharp de?ection of river valleys etc., while the later can be obtained by analysis of thickness of facies and types of sedimentation.

In the investigated area, three units can be clearly distinguished by the shape of relief: 1) hilly northern part, which belongs to the positive morphostructure of Fruška Gora showing constant uplift trend, 2) transitional part, which corresponds to the higher fluvial terraces of Pleistocene age, and 3) the lowland part of the Sava valley with lower terraces, which are undoubtedly situated in the area of significant, tectonically controlled, subsidence.

Fruška Gora represents a horst whose tectogenesis began as early as Early Miocene, but it was generally formed in Early Quaternary, and has been permanently modified until recent time (TOLJIĆ *et al.* 2013). Significant part of primary shaping of morphostructures in this massif took place in the Miocene, and it can be recognized in gravitational shear across the faults of the E–W direction. During Pliocene and the earlier parts of Quaternary some of these faults were reversely reactivated, by which an antiform and positive structural build of Fruška Gora was additionally highlighted. This was accompanied by a rapid erosion of the uplifted parts and an equally rapid accumulation in the neighbouring lowered domains. Consequently, recent morphostructural and morphosculptural appearance of this massive is a reflection of causality and interaction of numerous processes, of both endogenic and exogenic origin, so the recent geomorphological features represent the result of complex morphogenesis of this mountain.

In the Early Miocene, the metamorphic core of the mountain was primary exhumed from the ductile domain across the zone of decolman shear, situated at the boundary of metamorphic and underlying Mesozoic non-metamorphosed tectono-stratigraphical contents. Further extensional deformations in the brittle domain were performed in Middle and Late Miocene across the gravitational faults, which are now situated in the northern and southern slopes of the mountain (TOLJIĆ *et al.,* 2013). Finally, in the Pliocene and the Quaternary, the Dinaric-Carpathian system entered into compression while the Pannonian basin was progressively inverted and filled by Plio-Quaternary terrestrial sediments. Differential vertical motions of block structures led to intensification of erosional processes and final modelling of an asymmetrical horst structure surrounded by Quaternary deposits of Srem and Bačka plains.

The uplift that began at the end of Pontian reached its maximum at the Pliocene/Pleistocene boundary, when across the existing E–W directed faults remobilization occurred, characterized by asymmetrical rotation of the Fruška Gora block. This is recognized in stronger uplift of the southern edge of the massif, resulting in high hypsometrical position of the mountain range.

Throughout the Quaternary time, the activities along these faults continued in the peripheral parts of the recently formed Fruška Gora horst, particularly mobile being the zones of the Vrdnik fault, Karlovac dislocation and Čortanovci transverse fault. The Danube fault, whose trace coincides with the riverbed of the Danube, along with the above mentioned faults, played a key role in the formation of the Fruška Gora horst, around which very specific genetic categories of Quaternary sediments were deposited.

After the intensified uplift of Fruška Gora, accompanied by subsequent subsidence of the southern foothills, a relatively shallow basin was formed, with axial parts oriented in accordance with the orientation of tectonically active structures (i.e. E–W). Also, it can be considered that these movements were causally related to climatic changes at the Pliocene-Pleistocene boundary, so that the proluvial sediments formed in that time have a regional distribution and represent landmark for the drawing of the lower boundary of Quaternary in this part of the area.

The neotectonic uplift of the Fruška Gora horst caused the intensive, but uneven cutting of the Fruška

Gora watercourses, which on both slopes belong to a parallel drainage system, developed at the right angle to the direction of the peripheral structures and parallel to the generally N–S oriented structures. Thus formed river valleys are composite, mainly transverse and consequent. The watercourses that belong to the Sava drainage system have deeply cut and narrow valleys only in their source parts. In lower parts, because of gentler slopes and a gradual transition into the plain, river valleys are wider, watercourses are often ephemeral, and form an alluvial fan, often with waterlogging phenomena. At the northern slopes of the mountain, rivers are deeply cut, of small width, with steep valley sides in their upper and middle parts, while in the lower parts they expand and form narrow floodplains.

Unlike the areas with a steady trend of rising, in the lowered regions relatively thick deposits of different origin were formed. Among them are products of fluvial, swamp, deluvial, and in Late Pleistocene also aeolian type of sedimentation. In the areas more lowered by tectonic agents, the watercourses of the Danube and Sava have been developed. Vast meanders, sharp de?ection of river valleys and apparent asymmetry of their valleys represent distinctive characteristics of watercourses under the influence of neotectonic and recent tectonic processes.

The intermontane valley of the river Sava has been sinking during Quaternary, while the horst of Fruška Gora and the northernmost parts of Šumadija have been rising. As a result of this trend of movement, within the young trough a wide river valley was formed, whose origin was connected to the tectonically controlled, slow but continuous subsidence. Throughout the Early and Middle Pleistocene the tectonic trough of the Sava river was constantly descending, which was reflected in the increased thickness of the deposits and their polycyclic character. Of particular importance were gravitational movements across the Kalemegdan fault, which controlled the development of the asymmetrical Sava trough. The depression axis migrated over time, from NW to SE, which was followed by migration of the Sava riverbed. From morphological point of view, the valley of this river belongs to the asymmetrical type of river valleys – its right side is in constant motion toward SE, while the left one is quite poorly distinguished and covered by deluvial deposits. The longer axis of the river valley is generally parallel to the extension of the recent depression, with the width amounting to up to 25 km.

Looking at the broader area, a distinctive double sharp de?ection valleys of this river can be observed on the line Sremska Mitrovica–Šabac. Namely, under the influence of a great floodplain of the Drina, this river has been shifted towards Sremska Mitrovica, so outside the zone of its influence it turns abruptly towards Šabac, from where it spreads (occasionally meandering) to Belgrade, following mainly the Kalemegdan fault along the Pannonian part of the section. Its valley in this part also has an asymmetrical character, because the loess and alluvial terrace are much more developed on the left, than on the right side of this watercourse.

The dynamic stage of the longitudinal profile of the Sava river, especially in its lower part to its confluence with the Danube, is characterized by permanent sinking, which is manifested in the morphology of the river valley, as well as in polycyclic character of sedimentation. Beside the extreme meandering of the course of this river, numerous deserted meanders are present, from completely dry, over occasionally to permanently active. Permanent lowering within the Sava trough is also indicated by a significant increase of the thickness of fluvial deposits with thick alluvial deposits of Late Pleistocene and Holocene overlying them. The younger part of these deposits was formed in conditions of relative rest in this area.

Also, from the regional point of view the Danube near Vukovar turns from the meridional direction at the angle of almost 90° towards the east, following the faults along the northern foothill of Fruška Gora, all the way to Stari Slankamen where the watercourse changes its direction and flows to the south. The river valley in this area is pronouncedly asymmetrical with the morphologically low left valley side and the right side marked by a steep section. This can be explained by the recent lowering of the area to the north of the fault, followed by migration of the riverbed to Fruška Gora.

From Stari Slankamen to Belgrade the Danube turns twice. The first turning (Stari Slankamen) is controlled by the mobility of the faults present on the eastern slopes of Fruška Gora, the activity of which led to the separation of the Titel loess plateau from the Srem loess plateau. Both of them were parts of the same entity before the deposition of the penultimate loess level (GORJANOVIĆ–KRAMBERGER 1921), when they were separated by a fault near Stari Slankamen, which controlled the turning of the Danube and formation of the recent valley. Another turning is in the area of Stara Pazova. It has a distinctive elbow character, so it may be related to the fault structures that control the area of uplift to the south of Stari Banovci (MARTINOVIĆ *et al*. 2010). At the same time, this is an area of the contact of the Fruška Gora and Zemun parts of the Srem loess plateau. The valley in this part also has a pronouncedly asymmetrical character, wherein its left side makes a vast loess and alluvial terrace (Pančevački rit), while the right side forms a very steep loess section, permanently eroded by the river.

Lithofacial analysis

Throughout Quaternary in the Serbian part of the Pannonian basin, and to a much lesser extent in its periphery, a relatively thick succession of genetically different types of sediments was deposited. Of special interest are pre-loess deposits, whose thickness and great distribution indicate that in the wider area of southern part of the Pannonian basin intensive sinking of the terrain was taking place throughout Pleistocene. This is particularly indicated by the presence of fluvial-lacustrine sediments, whose thickness in some places exceeds 200 m. However, despite the great thickness of deposits it can be concluded that subsidences were of low intensity compared to those in the central parts of this basinal system, such as the Great Hungarian depression, where the thickness of Quaternary deposits exceeds 700 m (RONAI 1974). As opposed to the deposits formed in the subsided regions, deluvial-proluvial sediments („Srem series“, „Kličevac Series“, etc.) that have been formed on the slopes occasionally aquatic (swampy) areas, which were eroded from the adjacent uplifted structures (Belgrade Promontory). These parts of the area were subsided across the cascade systems of faults, indicated by an increased thickness of older Pleistocene deposits.

Deposits of Plio-Pleistocene age (marsh-lacustrine deposits) were found by deep drilling in the area of Zemun and Novi Beograd, where their upper boundary is situated at an altitude of about 30,0 m, and lower at –60,0 m; while in some boreholes which are even deeper, their lower boundary is not reached, so presumably it could descent to a much greater depth. Taking into consideration that in the area of the Kvantaš pijaca (meaning Green market) in Zemun the Neogene basement was not reached even at the depth of 260 m, it can be concluded that these deposits have a great thickness (Fig. 3).

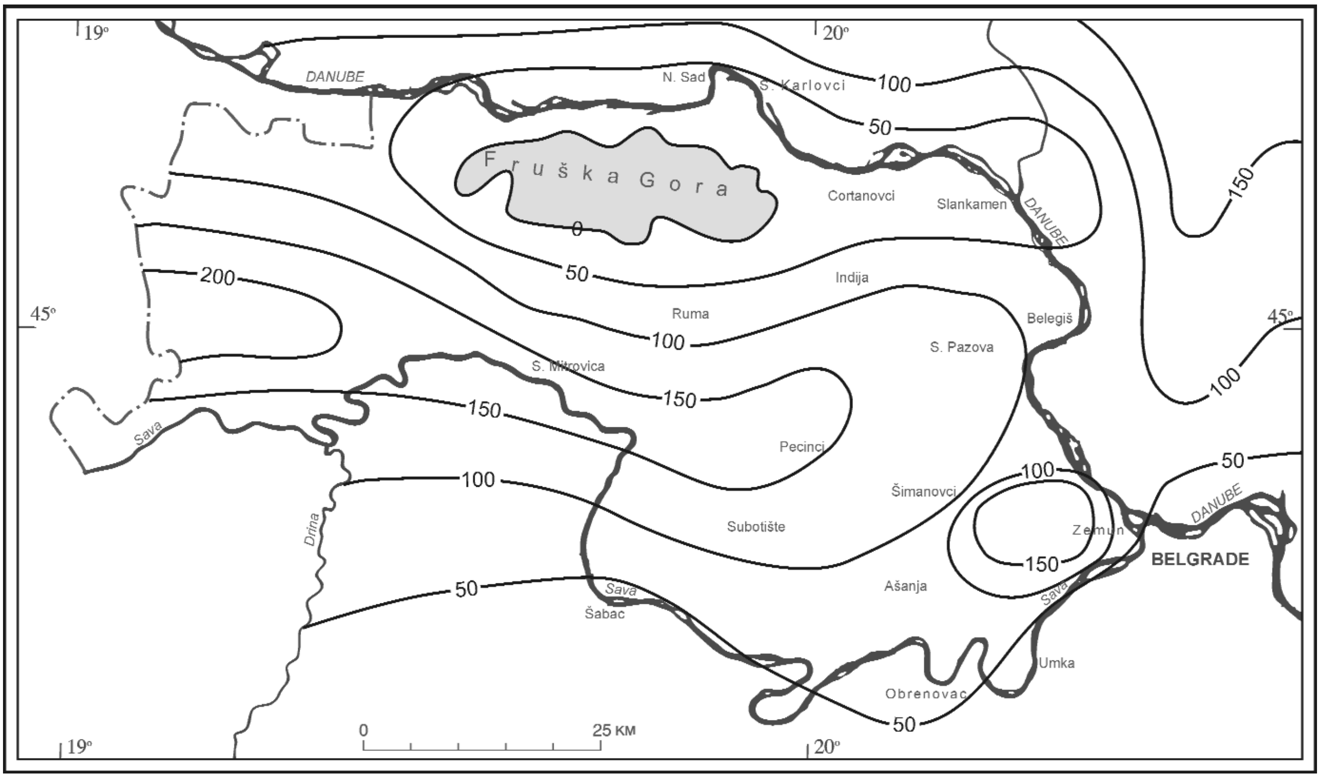

Fig. 3. Map of thicknesses of the pre-loess Pleistocene deposits in the area of Srem (amended after MAROVIĆ *et al.* 2002).

of Fruška Gora and in the peripheral belt of the Pannonian basin, especially in its eastern part towards the Carpathians (RAKIĆ, 1977), indicate the environment of inflicted areas between elevated regions.

According to the thickness of Quaternary deposits, in particular Pleistocene pre-loess deposits, it can be assumed that in the extreme SE part of Srem (today's territory of Novi Beograd and Zemun) the differentiation of relief under the influence of vertical tectonic movements occurred in Early Pleistocene (KNEŽEVIĆ *et al.* 1998; NENADIĆ 1997, 2003; NENADIĆ *et al.* 2009, 2010, 2011). The lowered parts were then quickly buried by rapid accumulation of slope deposits in

A very distinct and relatively extended subsidence in the area of Zemun and Bežanija is indicated also by a great thickness of fluvial polycyclic deposits of Early Pleistocene, which largely overlie the Plio-Pleistocene deposits. The faults that caused cascade subsidence in this part of the area, are covered with these sediments and other overlying Quaternary deposits. NE–SW directed structures can be followed from Kalemegdan to Obrenovac, from where further on, in a planar view, they form a system of echeloned faults of similar orientation.

The deposits of the Early Pleistocene age are situated in the hilly areas to the south of the Danube and

Sava rivers (area of the Belgrade Promontory and around it) on the significant height which is variable and ranges from an altitude of 170–179 m on Zvezdara, 135–156 m on Mirijevo, 113–130 m on Čubura, 69–78 m on Kalemegdan etc.

The hypsometric position of the fluvial polycyclic deposits to the north of the Danube and Sava is significantly lower. In the area of Novi Beograd their lower boundary begins on an altitude of 35–48 m, and the upper on approximately 55 m, sometimes over 66 m, so that some recent mollusk shells are found in these deposits together with the washed shells of the genus *Corbicula.* The most extensive subsidence was noticed in the area of Zemun, where the lower boundary of these deposits descends in some places to an altitude of 25 m.

A significantly decreased thickness of pre-loess Quaternary sediments in the riparian parts of the Sava river indicates that subsidence in this region took place a little later, in relation to northern parts of the territory. Locally, on the right bank of the river, a morphologically prominent fault system has been developed. Across these structures the NW block has been subsided, which brought to development of the Makiš depression. It can be concluded from the mentioned data that during Quaternary the overall subsidence in the area of the hanging-wall of the Kalemegdan fault was approximately 160 m.

Opposite to the areas of subsidence, the uplifted area of the Belgrade promontory and the Fruška Gora massif were in the stage of intensive erosion and accumulation of eroded material, which was transported by colluvial-deluvial processes and then deposited in the environments that were gradually sinking.

In the northern part of the territory (on the slopes of the Fruška Gora massif) the earlier Pleistocene proluvial-deluvial deposits were formed by a stronger hypsometric denivelation of the area on the boundary between Neogene and Quaternary, i.e. by a prominent tectonic activity manifested in the uplift of the core of this massif and subsidence of the outlying foothill areas. In the process of accommodation of the newly formed inflicted areas between the uplifted and subsided morphostructures, there was active erosion, denudation and filling of these areas with proluvial-deluvial deposits.

According to the stratigraphic-lithological characteristics of Quaternary deposits in the area of eastern Srem, it can be concluded that palustrine-lacustrine and fluvial polycyclic sediments mark the areas of subsidence, and proluvial-deluvial – inflicted areas beside the uplifted structures (RAKIĆ 1977; NENADIĆ 2003; NENADIĆ *et al*. 2011; NENADIĆ & GAUDENYI 2013).

During Late Pleistocene great areas of the Pannonian basin were covered by loess and loess-like deposits. Loess deposits cannot be an indicator of tectonic activities, because they could be primarily deposited at any height, but their thickness can immediately point to the existent palaeorelief, as well as to the intensity of erosional processes which occurred in the areas where these deposits were sedimented. Considering the number of palaeosols and loess horizons and their disturbances, ZEREMSKI (1960, 1961) established three phases of tectonic movements of epeirogenic character on the section of the loess plateau above the Danube. The oldest movements were finished before the accumulation of loess; the movements of the second phase took place during deposition of these sediments, while the third phase took place after the accumulation of the last loess horizon, in younger Neolithic. Movements of two older phases were manifested only in some parts across the profile line Stari Slankamen–Zemun, i.e. they have local character, while the younger ones were manifested on the whole profile of the loess plateau.

An example of tectonic activity can be seen near Slankamen (locality Surduk), where beneath two upper horizons of loes, which are horizontal, a package of deluvial-proluvial deposits is situated, tilted at the angle of 8° together with paleosols. On the contact of these two units there are slope debris and pebbles of hard Neogene and Mesozoic rocks. These were probably formed by the action of proluvial process on the slopes of the Fruška Gora mountain, in the course of which the base across which the water mass was moving was leveled. In this way, on the horizontal surface formed in such way the upper loess complex was deposited in the undisturbed position. This unconformity between lower and upper horizons, with colluvial gravels, was probably formed at the boundary between Middle and Late Pleistocene. In the other parts of the loess plateau similar elements that would point to the presence of tectonic activity have not been observed, since all loess horizons (as well as paleosols) are horizontal, which was also noted across the visible profiles from Surčin to Stari Slankamen.

According to the lithostratigraphic characteristics of deposits it can be concluded that tectonic activity in Holocene has a similar character as in Pleistocene, i.e. areas of subsidence were marked by fluvial, palustrine and swamp deposits, while deluvial and more rarely deluvial-proluvial deposits were linked to the inflicted areas toward the uplifted structures.

Thermochronological data

(U-Th)/He dating of apatite minerals (AHe) represents a low-temperature thermochronological technique, which is used for documenting the latest stages of cooling of rocks as they pass the uppermost levels of the crust, corresponding to the temperatures of ~75 °C (closure temperature Tc of AHe system, WOLF *et al*. 1996). Therefore, this method is frequently used to quantify the time of vertical movements in the uppermost ~1–2 km and correlate these movements with the associated tectonic phases. Two (U-Th)/He single grain ages were determined on the two rock samples collected in greenschist facies metamorphic core, located in the southern part of the Fruška Gora (Fig. 1B.). The ages were obtained following standard analytical procedures available at the VU University Amsterdam (see STOJADINOVIĆ *et al*. 2013).

The AHe single grain age of the sericite schist sample Fg1 is 16.3±1.6 Ma, while the AHe age of chlorite-sericite schist sample Fg2 is 2.4±0.9 Ma (Table 1). The older age of 16.3±1.6 Ma recorded in sample Fg1 reflects a Middle Miocene phase of cooling in the Fruška Gora metamorphic core. It represents the result of contemporaneous uplift caused by extensional deformations in the brittle domain that occurred along the gravitational faults along the southern slope of the mountain (TOLJIĆ *et al.* 2013). Hence, temporally it can be well correlated with the main phase of Pannonian extension (HORVATH *et al*. 2006). The younger, lowermost Quaternary, cooling age of sample Fg2 is 2.4±0.9 Ma, and it is associated with the most recent phase of regional tectonic activity. The obtained age corresponds well with strong uplift at Pliocene/Pleistocene boundary that was recorded in the southern parts of the mountain and was associated reverse reactivation of previously existing E–W oriented gravitational faults. It represents direct evidence of continuous uplift in the Pliocene and Quaternary, followed by intensive, tectonically induced erosion of the source area in the Fruška Gora and the fast deposition of proluvial-deluvial sediments in surrounding domains. This uplift is, again, associated with the contemporaneous phase of compression that affected the entire region (MAROVIĆ *et al*. 2002, 2007).

deposits (especially deposits of Plio-Pleistocene age) so they are usually not morphologically prominent but they represent significant control elements of subsurface geological structure. In the peripheral parts of the investigated area there are faults which directly affect the morphology of the terrain (for example, the faults by the rim of Makiš, along the Fruška Gora massif, etc.). Across the traces of these faults colluvial movements of rock masses are common.

Undoubtedly, the most striking structures are situated along the northern and southern periphery of the Fruška Gora massif, and they actually formed this asymmetrical horst surrounded by Quaternary deposits. The northern Danubian fault, whose trace generally coincides with the Danube riverbed, is covered by a thick package of Quaternary sediments but it is morphologically very distinct because of a pronounced asymmetry of the river valley. In the investigated area, on the southern slopes of the Fruška Gora, Vrdnik fault is situated (TOLJIĆ *et al*. 2013). Its trace is locally observed in the area of Vrdnik, while laterally it is mostly hidden by loess and pre-loess Quaternary sediments. In the eastern periphery this massif is laterally limited by the Karlovac and Čortanovci transverse structures. In the south of the investigated area especially striking is the Kalemegdan fault, developed along the Pannonian part of the section, extending from the SW part of the investigated area across Ostružnica, Železnik and Žarkovo to the confluence of the Sava. Across this complex fault its NW block was downthrown, which was accompanied by deposition of a thick package of sediments of Neogene–Quaternary age. The central parts of the area are covered by thick Quaternary deposits, hence fault structures are rarely visible on the surface. However, on the available seismic sections (MATENKO & RADIVOJEVIĆ 2012) syn-depositionally active faults are recognized, across which the axial parts of the Srem depression were deeply downthrown.

Table 1. Apatite (U-Th)/He (AHe) Analytical Data. Bold numbers represent corrected final AHe single grain ages obtained in this study. *Ft is fraction of alphas retained, “corrected ages” are corrected for this effect.

Sample name	Rock type	4He (atms)	4He error (atms)	238U/233U	238U (atms)	238U error (atms)	235U (atms)	235U error (atms)
Fg1	sericite schists	8.762E+09	1.820E+08	2.220	1.712E+11	9.293E+09	1.272E+09	6.740E+07
Fg2	chlorite-sericite schist	1.447E+08	4.513E+06	1.004	6.485E+10	3.521E+09	4.703E+08	2.554E+07

Sample name	Rock type	232Th (atms)	232Th error (atms)	Th/U	uncorrected He age (Ma)	Error	Ft factor*	corrected He age (Ma)
Fg1	sericite schists	1.368E+12	7.403E+10	7.99	14.0	1.3	0.86	16.3
Fg2	chlorite-sericite schist	–1.850E+09	–6.51E+14	–0.03	1.7	0.6	0.73	2.4

Quaternary active faults and structures

The faults across which movements were performed represent inherited structures, primarily formed in the Miocene, as previously interpreted by TOLJIĆ *et al.* (2013). They are mostly covered by Pleistocene

By the analysis of satellite image (1:250 000) information on spatial position of larger and morphologi-

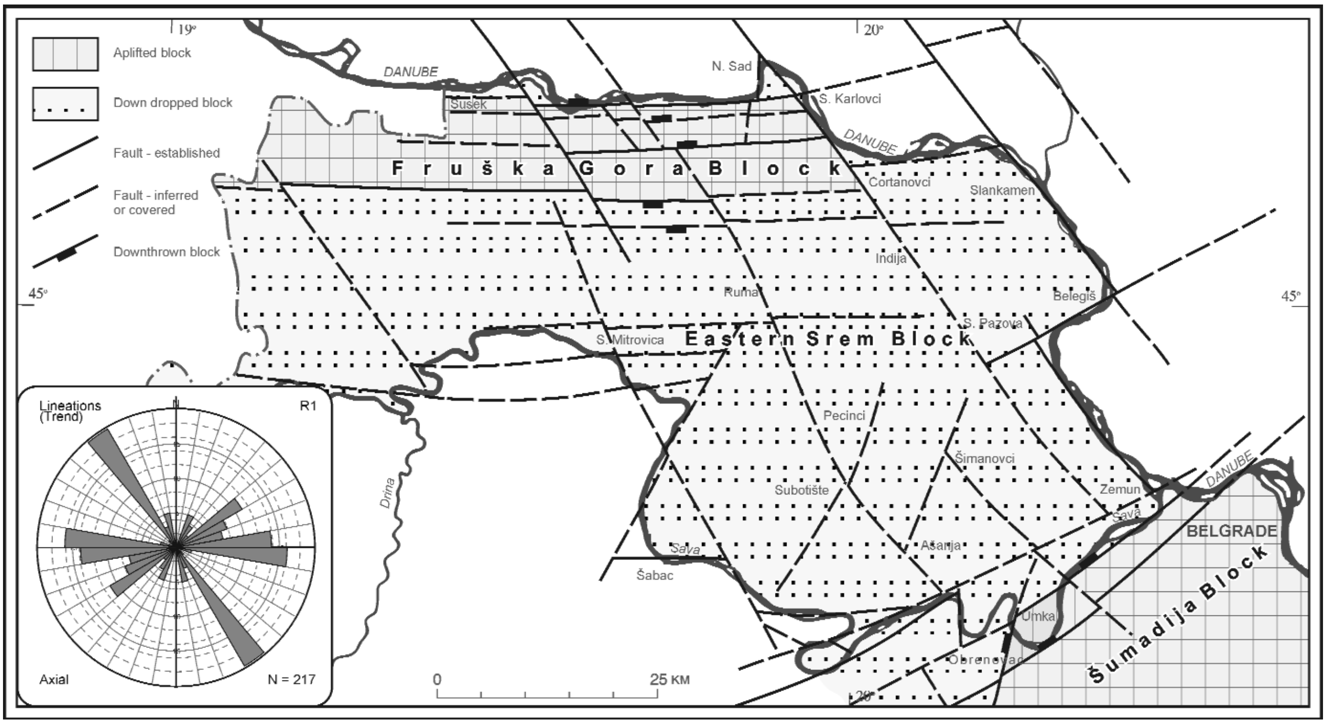

Fig. 4. Map of the regional fault setting of the eastern Srem with simplified review of the tectonic blocks structure.

cally prominent faults in the area of the eastern Srem has been obtained (Fig. 4). The basic feature of this structure is the existence of several fault systems. In the area of Fruška Gora the most significant faults are aligned with the strike of the plicative structures. These longitudinal structures are oriented in the E–W (ENE–WSW) direction and associated with the NW–SE directed faults. Longitudinal structures are large regional ruptures of deca-kilometre dimensions, among which the Vrdnik fault and Kalemegdan fault are particularly prominent. Across them the downthrow of central parts of the eastern Srem was performed (Eastern Srem Block), opposite to the uplift of the Fruška Gora Block in the north and Šumadija Block to the south of the investigated area (Fig. 4).

According to the determined positions of large faults, difference in spatial distribution of internal structures, as well as the lithofacial characteristics of the investigated deposits, 3 structural-depositional environments can be singled out in this area: Fruška Gora block, Eastern Srem Block and Šumadija block (Šumadija–Belgrade hills, Fig. 4).

Fruška Gora block

It represents an area limited by the Danube fault on the north and the Vrdnik fault on the south. By statistical data processing on spatial positions of the faults of this block, a maximum has been obtained with the direction 90–270 (diagram R1, Fig. 4). The majority of ruptures developed in this block generally belong to this system, which represent the faults that form the periphery of the positive Fruška Gora morphostructure. On the diagram in the form of a submaximum a system of faults with a statistical direction 150–330 is also observed. The NW–SE directed faults are often detected in the central and eastern parts of Fruška Gora.

Geodetic measurements confirm that the Fruška Gora block has been uplifted in recent times at the velocity of 0–1 mm/year (MAROVIĆ *et al.* 2002).

Eastern Srem block

On the north it is limited by the Vrdnik fault, and on the south by the Kalemegdan fault. This block is completely covered by Quaternary sediments, which hampered geometrical analysis of fault structures. Still, careful analysis of the satellite image made it possible to define spatial position of a part of dislocations developed in this area. The data on the fault structures were measured, statistically processed and shown on the diagram R1 (Fig. 4). On the rosetta a conspicuous maximum marks ruptures with a medium strike direction of 150–330. These structures are found on the eastern periphery and in center of the block. The submaximum with a medium direction 30–210 corresponds to the faults detected in the SW part of the block. Part of the fault setting developed in the domain of this block is also comprised of faults with the direction 90–270, which are situated in the area between Sremska Mitrovica and Pazova.

The available geodetic measurements indicate that the block of the central Srem subsided at the velocity up to –2 mm/year (MAROVIĆ *et al.* 2002).

Šumadija Block (Šumadija–Belgrade hills)

The northwestern boundary of this block makes the complex Kalemegdan fault, while the southern one is poorly defined and beyond the investigated area. The results of analysis of the faults are represented on the rosetta R1 (Fig. 4). Detected structures are uniformly oriented. On the diagram the faults that belong to the complex Kalemegdan fault have a statistical strike direction of 60–240. These faults are developed in the domain of the Sava river and they could be followed from Zemun on NE to Obrenovac and Debrec on SW.

Geodetic information confirms that this area has been slowly uplifted at the velocity of 1 mm/year (MAROVIĆ *et al.* 2002), whereas more to the south the velocity of uplift is increased up to 4 mm/year.

Generally speaking, by the analysis of obtained data it can be observed that in the blocks of Fruška Gora and Šumadija Block, as well as at their periphery, the E–W (ENE–WSW) directed faults dominate, while in the Eastern Srem Block the NW–SE faults prevail. The reasons for such discrepancies probably lie in the fact that the central block is covered by relatively thick Quaternary deposits, which masked older structures of this area, so their remote sensing is disabled in that way.

Conclusion

Quaternary tectonic activity in southern parts of the Pannonian basin genetically corresponds to the stress field, established earlier, at the end of Miocene (TOLJIĆ *et al.* 2013). As a consequence of the northward movement of the Adria microplate and final abruption of a segment of the subducted lithosphere in the Carpathian domain (MATENKO & RADIVOJEVIĆ 2012), the whole Pannonian basin was exposed to permanent compression. In the border area between the Dinarides and Pannonian basin, the axis of maximum compression is NE–SW oriented (BADA *et al.* 2007). In this stress field lithologically and structurally complex and thinned lithosphere of the basement of the Pannonian basin was folded in regional fold structures of low amplitudes. Folding has been accompanied by vertical mobility of blocks limited by the existing fault pattern.

By the analysis of spatial position of faults, their kinematic features and origin and mutual relationship of deposits formed in Quaternary, the data were obtained for the purpose of reconstruction of Quaternary tectonic mobility in the area of Srem. The peripheral southern parts of the Pannonian basin have similar evolution as the internal parts of the basinal area. In these parts there are also domains characterized by permanent late Neogene and Quaternary subsidence. Intensity of the subsidence is lower compared to the central parts of the Pannonian basin. Relatively highly hypsometrically uplifted blocks of Fruška Gora and northern parts of Šumadija have been developed on the periphery of the downthrown areas, in the area of Srem, during Late Neogene and Quaternary.

Simultaneous existence of neighboring domains, which are uplifted and subsided in a compression stress field, can be explained by flexion banding of the lithosphere (CLOETINGH *et al.* 2005; DOMBRÁDI *et al.* 2010), followed by reactivation of the large existing faults which are in the same time boundaries between the segments with a different character of vertical movement. Different character and intensity of vertical mobility of the lithosphere in the southern parts of the Pannonian basin have been, throughout Quaternary, the control factors of the origin and thickness of deposited sediments. A significant control factor of the Quaternary depositional environment were the faults on the southern slopes of Fruška Gora and to the southeast of the Sava river. The internal mobility and outline of the depressions are controlled on the east by the faults (from Sremski Karlovci, across Slankamen and Belegiš to Zemun), while the basin is open towards the west.

The central parts of the investigated area are generally characterized by a slow, permanent tectonically controlled subsidence, distinctive also in the recent time. The peripheral parts of the Šumadija-Belgrade hills and Fruška Gora horst have been in younger Neogene and Quaternary permanently and relatively slowly, uplifted. The (U-Th)/He cooling age obtained in the metamorphic core of the Fruška Gora horst, provides a direct evidence for the continuous uplift at the transition from Pliocene to Quaternary, which is the result of the ongoing compression. As a result of accommodation of uplift and following erosion of the uplifted blocks, in the domain of active faults relatively thick deposits of proluvial-deluvial character have been formed. In the subsided areas, thick deposits of different genetic origin have been formed. Among them the most prominent are lacustrine, alluvial, palustrine, and in younger Pleistocene aeolian deposits. In all tectonically subsided parts the flows of major rivers (Danube and Sava) have been developed. Their river valleys are situated in areas of faults in which during Quaternary gravitational movements of high intensity have been performed. These faults in the same time represent main tectonic boundaries of the morphostructural entities developed in this part of the Pannonian basin.

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Резиме

Квартарна тектонска и депозициона еволуција источног Срема (северозападна Србија)

Током квартара на подручју источног Срема, саставног дела Панонског басена, испољила се тектонска активност као битан контролни фактор депозиције и финалних уобличавања савременог рељефа. Тектонска еволуција Панонског басена је почела знатно раније, тако да су све током квартара тектонски активне структуре део раније постојећег предцртежа и спадају у категорију наслеђених и реактивираних структура. Седиментација, као доминантан процес финалних фаза запуњавања инвертованог депозиционог басена, вршила се у раније тектонски дефинисаним доменима.

Током млађих одељака плиоцена и старијег квартара, након повлачења Паратетиса, област јужног обода Панонског басена у целини пролази кроз копнену фазу развоја. У том интервалу обављена су тектонска обликовања ниског интензитета, којима су финално уобличени регионални морфоструктурни облици. Такође, тектонски контролисана мобилност унутар басенских сегмената проузроковала је недостатак неких стратиграфских подкатова плиоцена, промену фација и дебљина најмлађих литостратиграфских целина (MAROVIĆ *i dr*. 1996, 1998).

Постбасенски седименти, депоновани током квартара, представљени су релативно дебелим пакетом седимената у оквиру кога се суперпозиционо и генетски могу разликовати два дела:

- *старији*, речни и речно-језерски, са реликтима басенског склопа, генерисан покретима влашке или валахијске тектонске фазе, манифестујући се вишекратним спуштањем некадашњег басенског дна и стварањем сложених алувијалних равни пра-Дунава и пра-Саве, и
- *млађи*, који одговара флувиоденудационом систему у ужем смислу, а који обухвата морфолошке облике стваране током горњег плеистоцена и холоцена.

Квартарну тектонску активност јужних делова Панонског басена је сагледана у контексту регионалне миоценске екстензионе еволуције басенског простора и његове плиоценско-квартарне инверзије. Миоценска екстензија, продуцирана rollback-ом европске литосфере у Карпатима, била је праћена рифтингом, истањењем литосфере и субсиденцијом у домену Панонског басена (HORVATH *et al.* 2006). Дуготрајну средње и горњомиоценску пострифтну субсиденцију, контролисану са постепеним хлађењем литосфере у домену Панонског басена (thermal sag cooling, CLOETINGH *et al.* 2006), пратила је плиоценско-квартарна басенска инверзија, изведена у компресионом напонском пољу. Екстензионо напонско поље је смењено компресијом, активираном као последица финалног откидања (break off) субдуковане европске литосфере у домену Карпата, с једне стране, и север-североисточне прогресије Адријске плоче, с друге стране. Током плиоцена и квартара, Динарско-Карпатски ороген и интраконтинентални Панонски басен су изложени константној компресији, за ове просторе генерално оријентисаној по правцу СИ–ЈЗ (BADA *et al.* 2007). У овим условима је истањена и литолошки хетерогена литосфера у подини Панонског басена, убрана у наборе километарских размера (CLOETINGH *et al.* 2005, 2006). Регионална литосферна убирања су била праћена вертикалном мобилношћу сегмената литосфере, различитог смера и интензитета, што је као финалну последицу имало релативно брз аплифт и денудацију периферијских делова басена и даљу субсиденцију и депозицију централних басенских домена. При томе је локалном редистрибуцијом компресионог стреса реактивиран постојећи тектонски предцртеж, који је био у функцији контроле тектонске мобилности унутар басенских ентитета, какав је био простор јужно од Фрушке Горе.

На секцијама сеизмичких профила Фрушке Горе (MATENKO & RADIVOJEVIĆ 2012) може препознати асоцијација раседа који чине Врднички расед (TOLJIĆ *et al*. 2013). По овој структури је примарно гравитационо спуштен јужни блок, при чему је дебљина плиоценско-квартарних седимената јужно од раседа и преко 500 m. Такође синтеза података сеизмичког профилирања и дубоких истражних бушења изведених у овом подручју, упућује да је дебљина плиоценско-квартарних седимената значајна (MARTINOVIĆ *i dr.* 2010). Највећа дебљина седимената је између Старе Пазове и Шапца, у депресији чија оса се пружа правцем И–З (ИСИ–ЗЈЗ). На северној периферији депресије се налази Врднички расед, централне делове подручја контролише асоцијација хорстова и ровова дефинисаних раседима по којима је дубоко спуштен централни део Сефкеринске депресије (MATENCO & RADIVOJEVIĆ, 2012). Јужна периферија проучаваног простора на сеизмичким секцијама показује сложену тектонску природу прелазног подручја између Панонског басена и његовог издигнутог јужног залеђа. Као доминантна структура се препознаје Калемегдански расед, синдепозиционо активни расед, по коме је субсиденција северозадног домена била активна и током квартара, на што упућује значајна дебљина најмлађих седимената. На овакав сценарио указује и релативно мала дебљина плиоценско-квартарних седимената источно од овог раседа. Посматрано у плану, асоцијацију раседа који чине Калемегдански расед, чини низ ешалонираних раседа пружања СИ–ЈЗ који се могу пратити од Калемегдана до Обреновца и даље ка југозападу (Сл. 4).

Фрушка Гора представља хорст чија тектогенеза је отпочела још у доњем миоцену, генерално уобличен током раног квартара, перманентно модификован до у рецентно време. За примарно морфоструктурно обликовање овог масива значајна су миоценска обликовања која се могу препознати у гравитационим смицањима дуж раседа пружања И–З. Током плиоцена и старијег квартара део ових раседа је реверсно реактивиран, чиме је додатно истакнута антиформна, позитивна стурктурна грађа Фрушке Горе, што је било праћено рапидном ерозијом аплифтираних делова и исто тако рапидном акумулацијом у околним спуштеним доменима.

После интензивнијег издизања Фрушке Горе, праћеног субсеквентном субсиденцијом јужног предгорја, долази до формирања релативно плитког басена са аксијалним деловима оријентисани сагласно оријентацији тектонски активних структура пружања И–З. Такође, може се сматрати да су ови покрети каузално били повезани са климатским променама на граници плиоцена и плеистоцена, те да тада настали пролувијални седименти имају регионално распрострањење и представљају репер за извлачење доње границе квартара на овом делу терена.

Интрапланински ситуирана долина реке Саве током квартара тоне, док се хорст Фрушке Горе и најсевернији делови Шумадије издижу. Као последица оваквог тренда кретања, у оквиру младог рова формирана је широка долина реке, чија се еволуција може везати за тектонски контролисану спору, али континуирану субсиденцију. У току старијег и средњег плеистоцена тектонски ров Саве налазио се у константном спуштању, што се и одразило на повећану дебљину наслага и њихов полициклични карактер. При томе су посебно од значаја била гравитациона кретања по Калемегданском раседу, која су контролисала развој асиметричног Савског рова. Оса депресије је временом мигрирала, од северозапада ка југоистоку, што је било праћено и миграцијом речног корита реке Саве.

Током квартара у српском делу Панонског басена, а у знатно мањој мери на његовом ободу, наталожена је релативно дебела сукцесија генетски различитих типова наслага. Посебан значај при том су имале прелесне наслаге, чија дебљина и велико распрострањење упућује да су се на ширем подручју јужног дела Панонског басена током плеистоцена одвијала интензивна спуштања. На то нарочито указују седименти речно-језерског карактера чија дебљина местимично прелази и преко 200 m. Насупрот наслагама формираним у спуштеним областима, делувијално–пролувијални седименти („сремска серија“, „кличевачка серија“, итд.) који су формирани на падинама Фрушке Горе и на ободном појасу Панонског басена, посебно у источном делу према Карпатима (RAKIĆ 1977), указују на превојна подручја према издигнутим структурама.

На основу дебљине квартарних, посебно прелесних плеистоценских наслага, може се претпоставити да је на крајњем ЈИ делу Срема (данашњем простору Новог Београда и Земуна) долазило до диференцијације рељефа под утицајем вертикалних тектонских покрета током старијег плеистоцена (KNEŽEVIĆ *i dr.* 1998; NENADIĆ 1997, 2003; NENADIĆ *i dr.* 2009, 2010, 2011). При томе су спуштени делови затрпавани брзом акумулацијом падинских наслага у повремено акватичним (забареним) срединама, еродованих са околних издигнутих структура (београдског рта). Ови делови терена су дуж каскадних система раседа спуштани наниже, о чему нарочито сведочи повећана дебљина старијеплеистоценских наслага.

Творевине плио-плеистоцена (барско-језерске наслаге) су констатоване дубинским бушењем на подручју Земуна и Новог Београда, где им је одређена горња граница на око 30,0 mnv, а доња на –60,0 mnv, док поједине бушотине и преко те дубине нису стигле до његове подине, па је за претпоставити да се доња граница ових наслага местимично спушта доста ниже од горе наведене. Узимајући у обзир да се на простору Кванташке пијаце у Земуну није набушена неогена подлога ни на дубини од 260 m, за претпоставити је да ове наслаге местимично имају јако велику дебљину (Сл. 3).

Интересантни су и подаци добијени применом термохронолошке методе. Као што је познато, одређивање старости хлађења апатита коришћењем (U-Th)/He термохронолошке методе, представља технику која се често употребљава за дефинисање времена одвијања вертикалних тектонских покрета у најплићим нивоима земљине коре. Ово је омогућено тиме што је температура затварања (U-Th)/He система у апатитима ~75 °C (WOLF *et al.* 1996), што би одговарало хлађењу стена при њиховом вертикалном кретању кроз приповршинске нивое земљине коре (~1–2 km). Две старости хлађења добијене су анализом два узорка из метаморфног језгра Фрушке горе (Табела 1 и Сл. 1Б., Fg1 16.3±1.6 Ma и Fg2 2.4±0.9 Ma). Старост узорка Fg1 od 16.3±1.6 Ma, представља резултат хлађења изазваног издизањем метаморфног језгра Фрушке горе током миоценских екстензионих деформација дуж гравитационих раседа лоцираних на јужном ободу планине (TOLJIĆ *et al.* 2013). Старост узорка Fg2 od 2.4±0.9 Ma се, међутим, може корелисати са хлађењем ових стена током снажног издизања на граници плиоцена и плеистоцена, а која је асоцирана са реверсном реактивацијом већ постојећих гравитационих раседа оријентисаних по правцу исток–запад. Старост узорка Fg2 представља директан доказ континуираног издизања метаморфног језгра Фрушке горе током плиоцена и квартара, што представља последицу компресије која диктира рецентни тектонски режим читавог региона (MAROVIĆ *et al.* 2002, 2007).

На основу утврђених позиција крупних раседа, разлика у просторној дистрибуцији интерних структура, као и на основу литофацијалних карактеристика проучаваних депоната, на истраживаном подручју могуће је издвојити 3 структурно-депозиционе целине: *Блок Фрушке Горе*, *Блок источног Срема* и *Шумадијски блок (шумадијско–београдско побрђе)* (Сл. 4). Блок Фрушке Горе представља подручје ограничено Дунавским раседом на северу и Врдничким раседом на југу. Блок источног Срема је са севера ограничен Врдничким раседом, а са југа Калемегданским раседом. Шумадијски Блок као северозападну границу има сложени Калемегдански расед, док је јужна недефинисана и изван подручја истраживања.

Квартарна тектонска активност у јужним деловима Панонског басена генетски кореспондира са напонским пољем успостављеним раније, крајем миоцена. Као последица кретања Адријске микроплоче ка северу и финалног откидања сегмента субдуковане литосфере у карпатском домену, цео Панонски басен је изложен перманентној компресији. У граничном подручју између Динарида и Панонског басена, оса максималне компресије је оријентисана правцем СИ–ЈЗ. У овом напонском пољу је литолошки и структурно сложена и истањена литосфера подине Панонског басена, убрана у регионалне наборне структуре ниске амплитуде. Убирања су праћена вертикалном мобилношћу блокова лимитираних постојећим раседним предцртежом.

Истовремено егзистирање суседних домена који се издижу и тону у компресионом напонском пољу, могу се објаснити флексионим савијањем литосфере, праћено реактивирањем крупних, постојећих раседа који су уједно и границе сегмената са различитим карактером вертикалног кретања. Различит карактер и интензитет вертикалне мобилности литосфере у јужним деловима Панонског басена су током квартара били контролни фактори генезе и дебљине депонованих седимената. Као важан контролни фактор квартарног депозициног простора препознати су раседи на јужним падинама Фрушке Горе (Врднички расед) и југоисточно од реке Саве (сложени Калемегдански расед).