Carpathian Journal of Earth and Environmental Sciences, May 2012, Vol. 7, No. 2, p. 239 - 248

GEOMORPHOMETRICAL METHOD FOR DELINEATION OF PLAINS - CASE STUDY OF THE SOUTH-EASTERN (SERBIAN) SEGMENT OF THE PANNONIAN PLAIN

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Abstract: Usage of the terms Pannonian Basin and Pannonian Plain in physical and regional geography is often characterised by vague spatial extent, especially in Serbian geographical literature. The aims of this paper are directed towards establishing a method which would define a plain in geomorphological and geomorphometrical sense. Although the case study is focused on definition of the actual boundary of the Pannonian Plain in Serbia, the method of delineation can be used on other locations as well, especially in the wider area of the Pannonian (Carpathian) Basin. The method relies on the numerical analysis of a digital terrain model, which produced the value of the surface roughness coefficient. By combining the geomorphometrical analysis with spatial extent of characteristic lithologies (Quaternary) and morphological processes (dominant fluvial aggradation and eolian process), the exact delineation of the Pannonian Plain in Serbia was carried out. As opposed to some earlier opinions, the Pannonian Plain extends further to the south from the Sava and the Danube Rivers, encompassing also the lower parts of the Drina, Kolubara, Velika Morava and Mlava basins. Within Serbia, the Pannonian Plain occupies 24,450 km^2, which is 27.6% of the territory of the country. The elevation ranges from minimal 68.5 m a.s.l. to the maximum of 155 m a.s.l. The mean elevation of the Pannonian Plain in Serbia is 83.5 m a.s.l.

Key words: Pannonian Basin, Pannonian Plain, geomorphology, geomorphometry, relief roughness, Serbia

1. INTRODUCTION

The term Pannonian Basin is often used in geosciences, referring to the low land and hilly area in central and south-eastern Europe. While the usage of the term in palaeogeography, palaeontology, sedimentology/stratigraphy and structural geology is mostly clear and unambiguous, in physical and regional geography of the countries at its southern rim, there are many inconsistencies and imprecise definitions (e.g. Marković, 1970; Milanović et al., 2011). In regional-geographical literature, the term Pannonian Basin is often interchanged with the term Pannonian Plain, but without the clear semantic and spatial delineation.

Introduction of the term Pannonian Basin into geological literature took place when the Pannonian stage was defined in stratigraphical references by Róth von Telegd (Róth, 1879; Róth von Telegd, 1879). The term originated from the name of the ancient Roman province Pannonia, which existed in the Roman Empire from 1^{st} to 4^{th} century A.D, encompassing the areas from the Vienna Basin on the north to the Sava River on the south, while the eastern border approximately followed the course of the Danube River.

In the paper named "The surface of the Alföld" ("Az Alföld felszíne"), Cholnoky (1910) discussed the general features of the Great Hungarian Plain (Alföld), realizing that the plain continues further from the southern parts of Hungary of that time, to Serbia, Croatia and northernmost parts of Bosnia (Fig. 1). He stressed the need for more precise delineation of the southern boundary of the plain, stating that such studies will be "the task of the Serbian colleagues" (Cholnoky, 1910, p. 420).

The aims of this paper address both forementioned problems: (a) to determine the geomorphological definition of a plain, within a case study of the Pannonian Plain (through definition of topography, forms and active processes), to be used in physical geography; (b) to outline the Serbian part of the Pannonian Plain (i.e. its south-eastern boundary).

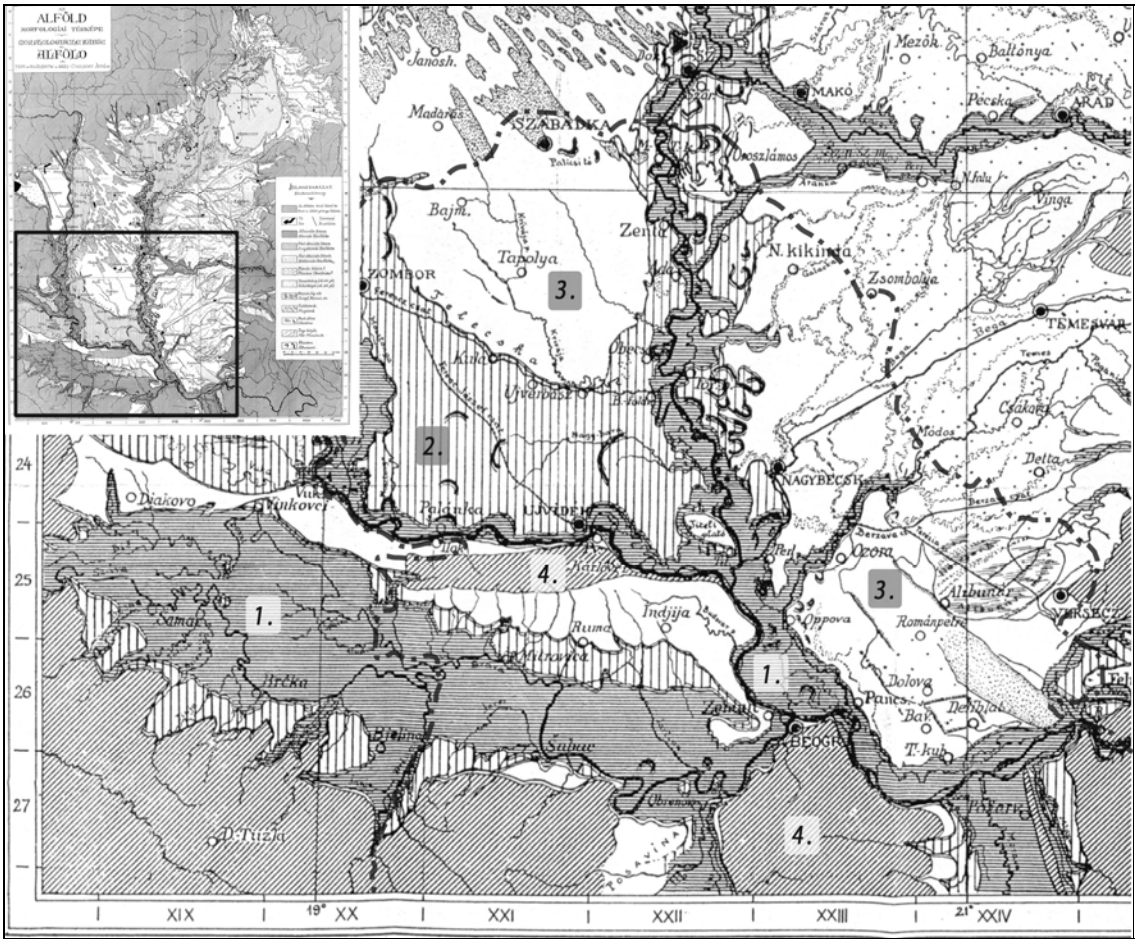

Figure 1. One of the first maps of the Alföld (Great Hungarian Plain), by Cholnoky (1910), indicating that the plain stretches further to the south from the Danube River (1 – alluvial plains in Alföld, 2 – upper Dilluvial areas in Alföld, 3 – lower Dilluvial areas in Alföld, 4 – area not belonging to Alföld). Present state borders added for easier orientation.

2. STRUCTURAL-TECTONIC DEFINITION OF THE PANNONIAN BASIN SYSTEM

The basement of the Pannonian Basin is a complex of several tectonic units (terranes). complex of several tectonic units (terranes). The greatest part of the area is divided between the units ALCAPA, to the north-west of the Mid-Hungarian Shear Zone (MHSZ), and the unit Tisza (e.g. Fodor et al., 2005) or Tisza-Dacia (e.g. Dombardi et al., 2010), to the south-east of the MHSZ. This zone is even nowadays characterised by intense tectonic activity (Marótiné Kiszely, 2010). Apart from these two units, the south-eastern part of the basin consists of two more units – the Vardar Zone and Serbian-Macedonian Massif (Fig. 2).

The basin formation within the Alpine orogenic belt began in the early Miocene, through the extension and subsidence in the back-arc basin due to the collision between the Adria microplate and the European continent (Bada et al., 1999). Changes in the regional stress field in Pliocene and Quaternary caused the so-called "basin inversion" which marks the neotectonic phase characterized by compression and differential vertical movements. The compression resulted from the continuous counter-clockwise rotation and northward indentation of the Adria microplate (e.g. Bada et al, 1999; Dombardi et al., 2010). Complex tectonic pattern and evolution led to the introduction of the term Pannonian Basin System, which was used for the first time by Royden et al. (1983a,b).

Although some parts of the basin were subject to uplifting during the neotectonic phase, several flat-lying, low altitude areas were subject to continuous subsiding since the early Miocene and filled with thick sequences of sediments (Bada et al., 2006). The most conspicuous of such areas are the Great Hungarian Plain, Little Hungarian Plain, Sava and Drava throughs. Flat-lying plain in the south-eastern (Serbian) part of the Pannonian Basin System has not been thoroughly geomorphologically studied. In Serbian literature references, it is usually called the Pannonian Plain (e.g. Marković, 1970), but its precise definition and extent have not been defined yet.

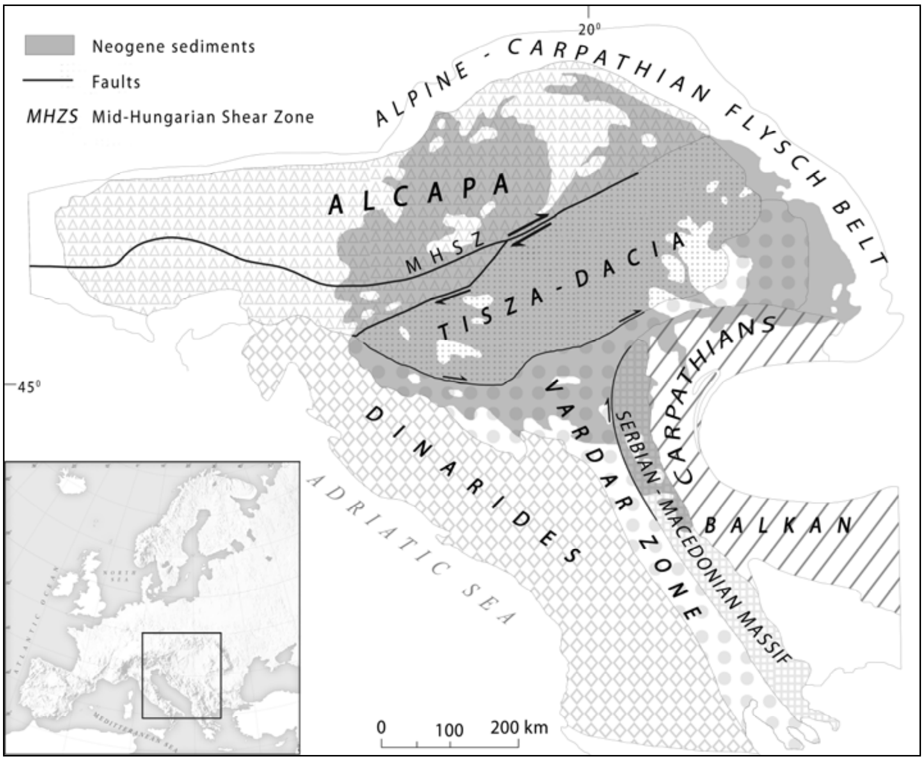

Figure 2. Main structural elements of the Pannonian Basin and the distribution of Neogene sediments, (compiled after the data of Haas et al., 2001; Royden & Horváth, 1988; Fodor et al., 1999; Dombárdi et al., 2010; Dimitrijević, 1992)

In the basement, this part of the plain is formed of three main tectonic units: Tisza-Dacia, the Vardar Zone and the Serbian-Macedonian Massif. The Vardar Zone is characterized by ophiolithic geology (Karamata et al., 1998) and one of its uplifted outcrops is Mt.Fruška Gora, situated between the river courses of the Danube on the north and the Sava on the south. The Northern Unit of the Serbian-Macedonian Massif was affected by a Miocene extension in the Pannonian Basin (Psilovikos, 1984). Tisza-Dacia unit is separated from the Vardar Zone by a deep system of ruptures known as the Drava Fault (Prelogović et al., 1997). In the Serbian part of the Pannonian Plain, this fault does not have the surface morphological expressions (Vukašinović, 1973). Detailed elaboration of neotectonics in the southern part of the Pannonian Basin System can be found in Marović (2002, 2007).

3. PALAEOGEOGRAPHICAL AND STRATIGRAPHICAL DEFINITION OF THE PANNONIAN BASIN

Pannonian Basin is a palaeogeographical term related to the area of the Lake Pannon or Pannonian Lake (in German: Pannonische See). Some authors use the term Pannonian Sea (e.g. Eremija, 1975, p. 195; Gábris, 1994). Pannonian Basin is a palaeogeographical term connected to the spatial extent of the Lake Pannon and its sediments.

Under the name Great Pannonian Basin (in German: *grossen pannonischen Becken*; in Hungarian: *nagy pannoniai medencze*), Róth von Telegd (Róth, 1879; Róth von Telegd, 1879) presented the sedimentation basin in which the following facies were deposited: Pontian (Congeria beds), Levantine (Paludina beds) and Trachian (Belvedere beds; restricted to the Vienna Basin). The reason for the birth of this term was to unite the above mentioned beds, which could not be clearly separated one from another. At that time, this term perfectly fitted because it encompassed the areas to the east of the Danube course in the Carpathian Basin (Middle-Danube Basin) and the Vienna Basin – locations where the Pannonian sediments are distributed.

In the later research, Lőrenthey (1900) excluded the freshwater Pliocene Levantine beds from the Pannonian stage. Consequently, the final phase of the Pannonian was represented by caspibrackish Pliocene sediments. The Lake Pannon evolved from the Central Paratethys (or Paratethyan Sarmatian Sea, after Harzhauser & Mandic, 2008), with salinity change from mesohaline to (caspi)brackish environment.

Neither the Pannonian Basin System (structurally) nor the Lake Pannon (hydrologically) were uniform, “dish-like” features during their evolution. On the contrary, they functioned as dynamic systems, divided on many locations by islands and peninsulas (Magyar et al., 1999).

The time frame of the Lake Pannon genesis and evolution varies across different sedimentation realms. It is considered that the lower time limit of the Lake Pannon on the present Hungarian territory was approximately 12 Ma ago, when it evolved from the Sarmatian Paratethyan Sea (e.g. Kázmér, 1990; Magyar et al., 1999), while on the present Austrian territory this temporal milestone took place about 11.6 Ma ago (Harzhauser & Piller, 2007; Harzhauser and Mandic, 2008).

In Serbian references, geologists and palaeontologists have for a long time used the term Pannonian Sea, while the term Pannonian Basin was used for a segment of Paratethys (e.g. Eremija, 1975, p. 195) starting from the early Sarmatian (13.5 Ma ago). Generally, the authors avoided the term Lake Pannon (e.g. Stevanović, 1977). Instead, they used the salinity values to mark the phases of the Pannonian Sea development, where the (caspi)brackish phase is analogous with the Lake Pannon. Disappearance of the Transcarpathian strait separated the Pannonian realm from the rest of the Paratethys and was a milestone for the formation of the Pannonian "sea-lake" (Laskarev, 1950; Stevanović, 1960, 1977). Precise distribution of Neogene sediments in South-Eastern Europe is still a subject of scientific research in geosciences and the forthcoming results will help in better understanding of the complexity of Neogene phenomena.

Regarding the upper time limit of the Lake Pannon, the exact values differ depending on the sedimentation realm. The prevailing opinion of the Austrian scientists, whose datasets are focused on the westernmost parts of the Pannonian Basin (particularly the Vienna Basin), is that the Lake Pannon existed till the end of the Pannonian stage 5.8 Ma ago (Harzhauser & Mandic, 2008; Piller et al., 2007). The research teams from Budapest allow the possibility that the Lake Pannon existed also during the Pontian stage until approximately 4.6 Ma ago (Magyar et al., 1999; Popov et al., 2006).

In the south-eastern parts of the former Pannonian sedimentation realm, in Slavonia and some parts of Vojvodina, the freshwater Slavonian or Paludina Lake existed from 4.5 Ma ago (Magyar et al., 1999; Popov et al., 2006) and its upper time limit has not been clearly determined yet.

4. GEOMORPHOLOGICAL DEFINITIONS OF A PLAIN

Although extensively used in toponymy and regional geosciences, the term "plain" is insufficiently defined in textbooks, dictionaries and encyclopedias. Among all geosciences, it is geomorphology which should give a clear definition of the term. The existing precise definitions mostly refer to particular sub-types within the term, such as: floodplain, coastal plain, alluvial plain, alluvial fan, etc. In his "Dictionary of Geography" Moore (1972) defines a plain as "an extensive area of level or gently undulating land, usually of low altitude", and lists the above mentioned sub-types defined according to the ways of formation. Encyclopedic references usually give short consice definitions of general and qualitative character ("large area of level or nearly level land" in Columbia Electronic Encyclopedia; "relatively level area of the Earth's surface that exhibits gentle slopes and small local relief" in Britannica Concise Encyclopedia; etc.). In many references (e.g. Guzzetti et al., 1997; Panin et al., 1999) particular forms within plains are discussed, but the overall notion of the plain is taken for granted, without an exact definition. Bognar (1987) offered quite a broad definition of a plain (in the case study of the Pannonian Plain), suggesting that apart from the flat lowland and plateau morphographic types, the plain includes also the hilly and mountainous forms occurring within its borders.

One of the very rare quantitative approaches to the definition of major relief units, including plains, was given by Hammond (1954). Instead of usual geomorphological focussing on particular forms, he pointed that the small-scale representation should be based on "*areas*, not simply of individual features." (Hammond, 1954; p.35). His aim was to distinguish regional patterns of crustal relief explicitely and objectively, using the following factors: relief (dissection; vertical difference; "flatness"), slope, pattern and surface material. The areas having >80% of flat land with less than 33 m dissection are classified as plains (Hammond, 1954).

Taking into account both genesis and morphometry, we could define a plain as a levelled area of topographic surface, the development of which is conditioned by geotectonic processes and paleogeographical evolution, and whose morphology is characterised by meter-scale topographic denivelations of exogeneous origin. Fluvial accumulation (aggradation) is the dominant geomorphological process in low-lying plains. Apart from fluvial forms (floodplains, oxbow lakes), aeolian processes and forms are often present as well, shaping the detailed morphology of a plain.

5. GEOMORPHOMETRICAL METHOD FOR DELINEATION OF A PLAIN

Geomorphometrical methods are a tool with a widespread usage in geomorphology (e.g. Etzelmüller, 2000; Ruszkiczay-Rüdiger, 2009).

The aims of the present study refer to the geomorphometrical definition of a plain, within a case study of the Pannonian Plain on the territory of Serbia. Apart from the above-mentioned analysis of Hammond (1954), the issue of "relief flatness" or, as the opposite notion, "surface roughness" was studied by a number of authors (e.g. Hobson, 1972; Perko, 2001; Hrvatin & Perko, 2009), each taking into account the elevation differences within a given area unit. The method of Hammond (1954) also relies on this parameter ("Local relief may be figured in various ways, the least subjective being the familiar method of ascertaining the maximum difference in elevation within a given small area"; p. 35).

For the present study, elevation data were taken from the SRTM database (cf. Rabus et al., 2003), with 90 m resolution. The accuracy of SRTM data for the territory of Serbia was experimentally tested by Samardžić & Milenković (2010), who stated that it is a good alternative for digital terrain models created from the maps of the scale 1:50,000 and smaller. The subsequent calculations and analyses were done using the raster-based GIS software *Idrisi Andes*®. In the further process, SRTM was resampled from 90 x 90 m grid cells to 200 x 200 m grid cells. 5 x 5 cells were gathered into a moving window for calculation of average elevation within a window (Fig. 3).

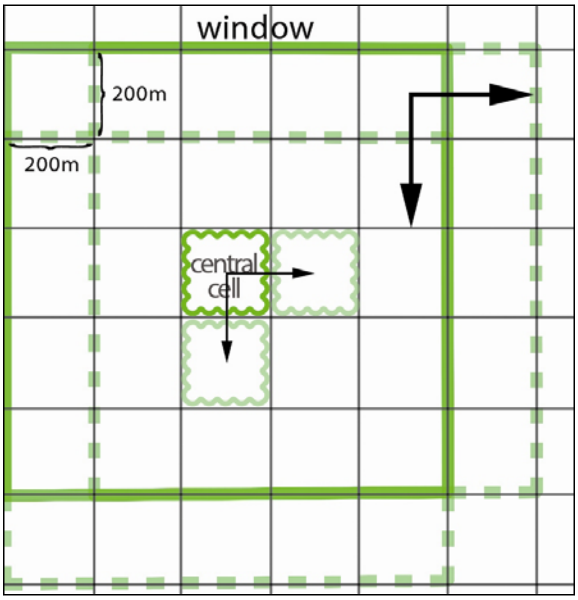

Figure 3. Moving window used for calculation of standard deviation of elevation differences.

Difference from the average elevation was calculated for each cell, and a standard deviation of differences within a moving window was assigned to the central cell, using the usual equation for standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{N}} \qquad (1)$$

which, expressed with the parameters of the present study, comes to:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{25}(\Delta h_i)^2}{25}} \qquad (2)$$

where Δh_i is the elevation difference between the particular cell elevation and average elevation of the window ($h_{cell} - h_{av}$), and 25 is the number of cells in a moving window (5 x 5).

In the further text, the obtained value of standard deviation will be treated as a surface roughness coefficient.

6. RESULTS

The map of surface roughness coefficients in the studied area, obtained by the aforementioned method, is given in the figure 4. The surface roughness coefficient lower than 5 indicates the flatness of the area characteristic for plains. By smoothing of the sharp-edged line which follows the particular grid cells (pixels), and taking into account the present small-scale anomalies within the plain, the southern border of the Pannonian Plain in Serbia has been delineated (Fig. 4).

Beside morphometrical principle of delineation (through flatness), the threshold value of roughness coefficient (5) was defined also morphogenetically and lithologically. In this way, the quantitative approach is supported by qualitative analysis, which is of essential importance in understanding of plain morphology.

Morphogenetical principle is based on the presence of typical aggradational forms (fluvial and aeolian). Within the delineated area, the most dominant forms are alluvial plains, loess plateaus, sandsheets and dunes. The segments showing the elements of a plain (roughness coefficient lower than 5), but with conspicuously linear character, within the surrounding dissected relief, are the alluvial plains of small adjoining rivers, and as such, are not included in the Pannonian Plain. Their formation is a result of solely fluvial aggradation process, while structural and dimensional characteristics do not meet the requirements for a plain. Mt.Fruška Gora, which is a structurally uplifted block of the Vardar Zone, is excluded from the Pannonian Plain. Lithological principle, which represents a qualitative segment in the delineation process, relies on the age and composition of the sediments. Stratigraphically, all sediments within the plain are of Quaternary age (Federal Geological Institute, 1970).

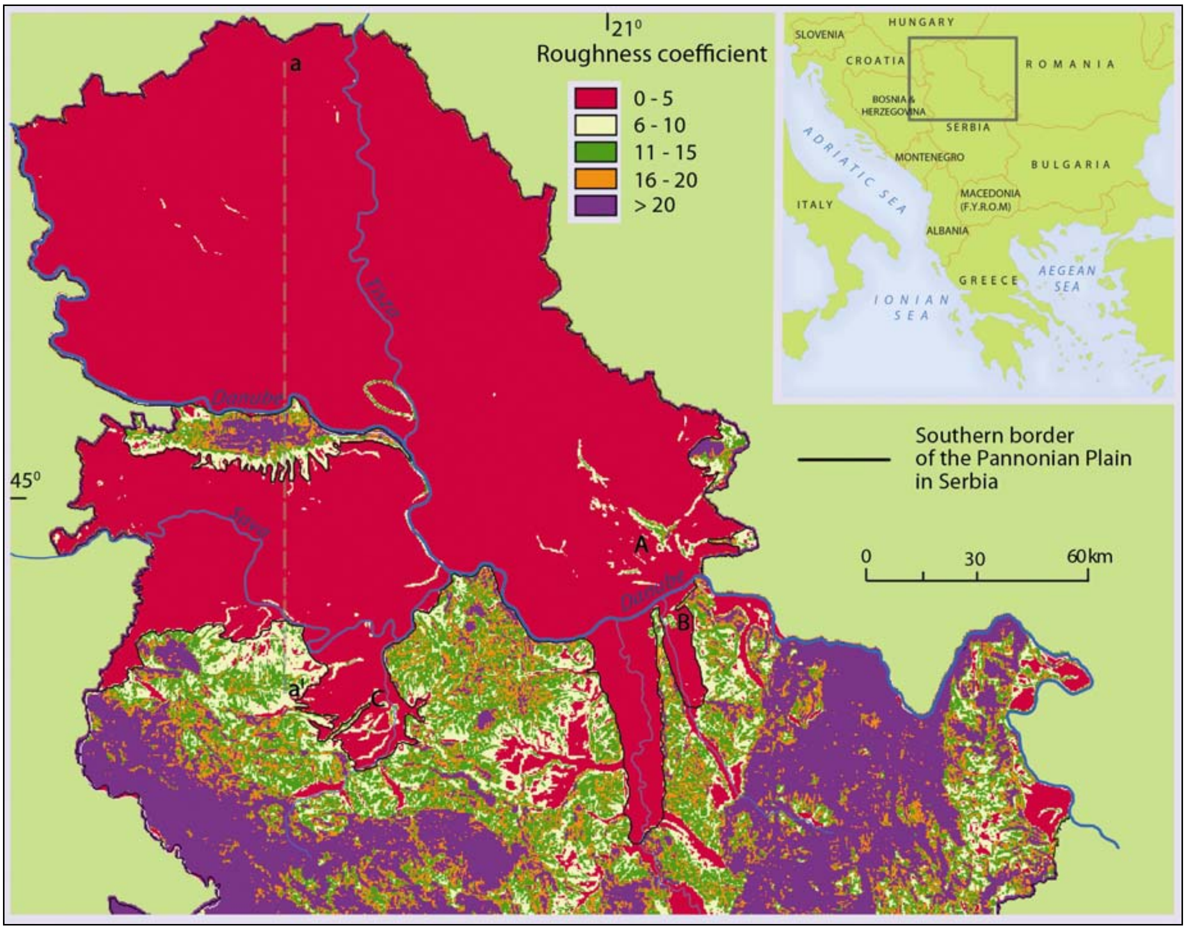

Figure 4. The map of surface roughness coefficients in the northern part of Serbia and the south-eastern border of the Pannonian Plain. Relief anomalies within the Plain are marked with capital letters (A – Deliblatska peščara; B – Drmno coal quarry; C – Kolubara-Tamnava coal quarry). Profile *a-a'* is shown in Figure 7.

Only the age of gravels and sandy clays of the Kolubara basin are identified as Plio-Quaternary (Filipović et al., 1976), but their position on the litho-stratigraphical column, as well as the recent official corrections of the Quaternary time-scale (Gibbard et al., 2010), indicate rather Quaternary (Lower Pleistocene) than Neogene (Pliocene) age.

Some Quaternary sediments are present also in the areas out of the Pannonian Plain, but it is important to stress that no lithologies older than the Quaternary are present within the Plain. This is strongly related to the presence of aggradational processes, mentioned within the morphogenetical principle of delineation.

The south-eastern (Serbian) part of the Pannonian Plain is composed of terrestrial and freshwater sediments. Terrestrial sediments are mostly of aeolian origin, deposited as loess plateaus, sand sheets and other aeolian sequences on alluvial plains and fluvial terraces. Lithologically, these sequences consist of loess and loess-like sediments.

Fluvial sediments of various granulation (gravel, sand and silt) are found in alluvial plains, fluvial terraces and oxbow lakes. Furthermore, there are lake-marsh sediments and smaller peat-bogs.

Within the procedure of plain delineation, two anomalies have occurred and must be explained:

(a) in the lower courses of the rivers Kolubara, Velika Morava and Mlava, there are significant coal quarries that have changed the topography of the area and thus must be disregarded in plain delineation. Their roughness coefficient is now higher than 5, but we must consider them in their natural condition, before the human interventions. The main examples are Tamnava – eastern and western coal field in the Kolubara River basin (marked with letter C in Fig. 4), as well as Ćirikovac and Drmno quarries with the adjoining tailing hills (marked with letter B in Fig. 4, and zoomed in Fig. 5b).

(b) in the sand sheet Deliblatska Peščara, the areas of increased denivellation (roughness) are present due to the typical dune relief. Regarding the fact that these anomalies result solely from exogeneous process of aeolian sedimentation, and that the structural and paleogeographical parameters are the same as in the adjoining flat areas, this anomaly is nevertheles included into the area of the plain (marked with letter A in Fig. 4, and zoomed in Fig. 5a).

Within Serbia, the Pannonian Plain occupies 24,450 km^2, which is 27.6% of the territory of the country. The elevation ranges from minimal 68.5 m a.s.l. to the maximum of 155 m a.s.l. (excluding the anomalies mentioned in the previous paragraph). The mean elevation of the Pannonian Plain in Serbia is 83.5 m a.s.l.

7. DISCUSSION AND CONCLUSION

When we sum up the interpretations of the spatial extent of the southern part of the Pannonian Plain in the available literature, two groups of references can roughly be distinguished: (a) those that claim that the southern border of the Pannonian Plain is defined by the Sava and/or the Danube River (Haas et al., 2001, Marović, 2002, Mrkajić et al., 2010, Sümegi et al., 2011); and (b) the authors who extend the border further to the south from the Sava and the Danube (Cholnoky, 1910, Marković, 1970, Rodić & Pavlović, 1994).

In the group (a), the Pannonian Plain is erroneously limited by exogeneous relief forms such as riverbeds, although the flat areas extend far beyond these linear features. In fact, such a border is not of physio-geographical, but is rather of an archetype character. The Danube and the Sava have been an ethnic, cultural, political and socio-economical border for almost two millenia. Continuous divergent social and historical processes have lead to the incorporation of the Sava and the Danube into the cultural landscape, transforming it in people's minds to the "natural border" of all kinds. On the other hand, in the group (b), the authors do not stick to riverbeds in Pannonian Plain delimitation. However, their explanation that the Pannonian Plain extends in gulf-like segments upstream through the valleys of the rivers Drina, Kolubara, Morava, Mlava and Pek, is not followed by any criterion for such definition, and is often linked to purely hypsometric line of 200 m elevation. In this group, the best description is that of Cholnoky (1910), where he acknowledged that the precise border must be left unclear until the Serbian colleague-geographers find the way for its proper delimitation.

According to the results obtained within this paper, not only that the southern border of the Pannonian Plain in Serbia is defined in an objective way, but it is also obvious that this part of the Pannonian Plain is an indisputable morphological extension of the Great Hungarian Plain (Alföld). It was probably due to administrative reasons that these two sections of the same Plain have never been given a single toponyme.The criteria that define the southern border of the Pannonian Plain comprise morphometric, lithological and morphological aspects. Surface roughness coefficient span 0-5 has not been chosen randomly.

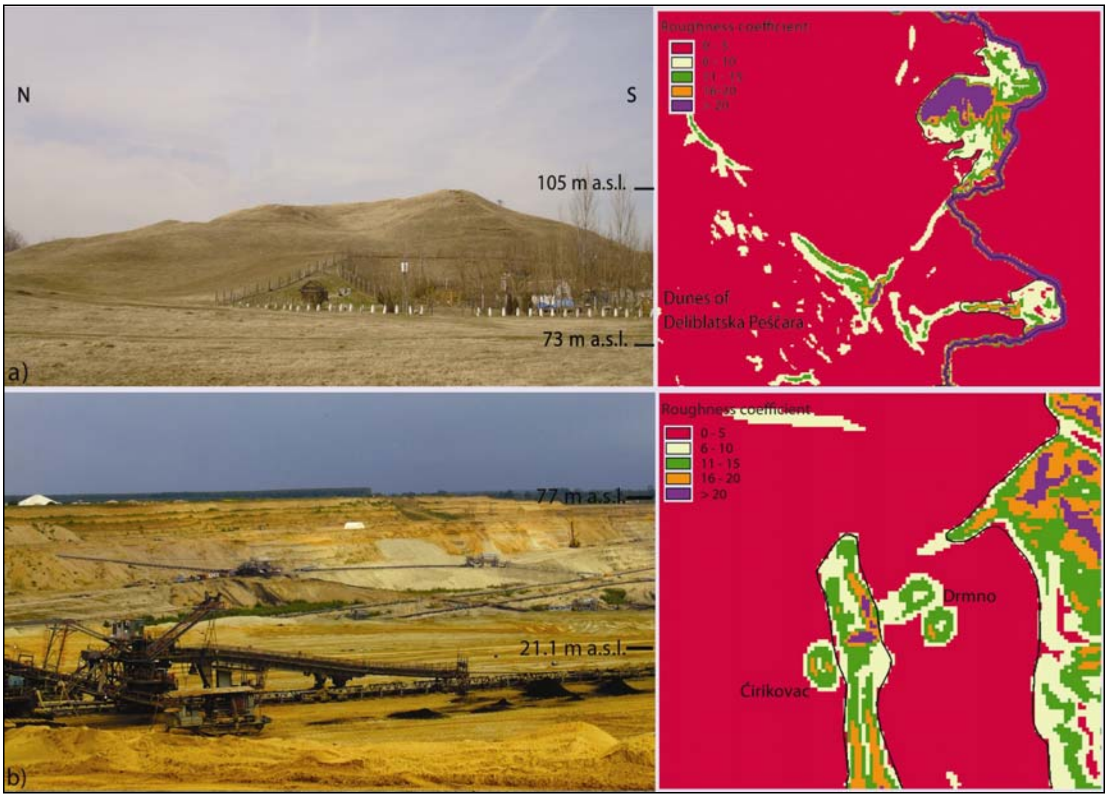

Figure 5. Examples of relief anomalies within the Pannonian plain, with zoomed sections from Fig.4 and the respective photographs: a) Deliblatska Peščara (photo: M.V. Milošević); b) Drmno coal quarry (photo: M. Jovanović).

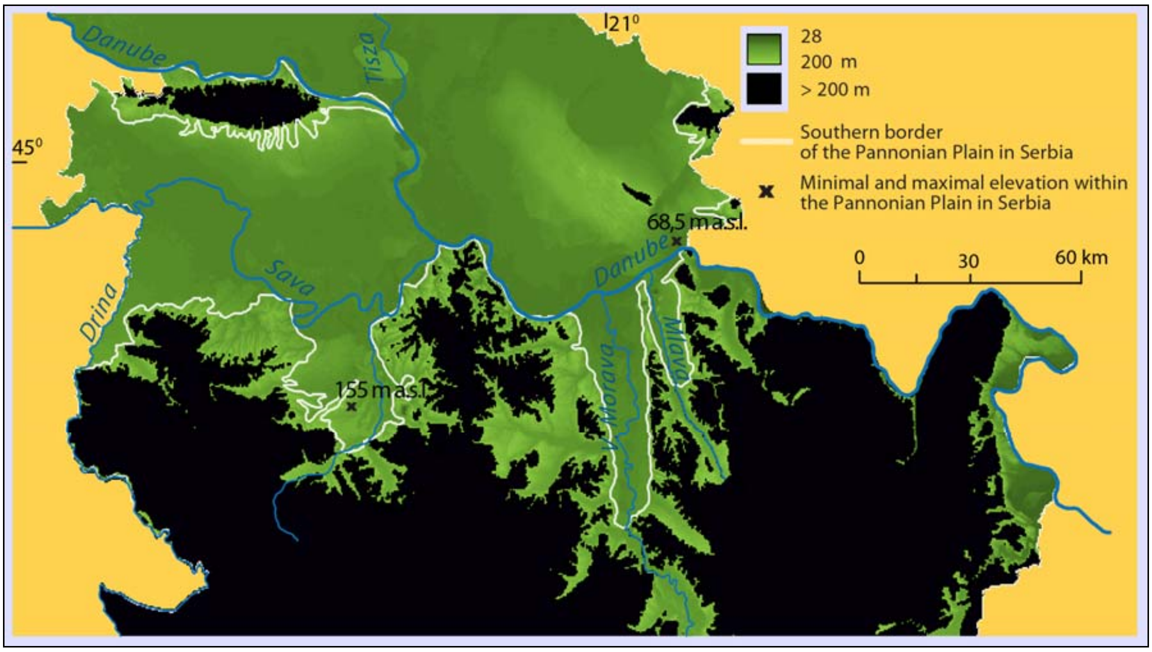

Figure 6. The map comprising various interpretations of the southern border of the Pannonian Plain in Serbia: the Sava and the Danube Rivers, the line of 200 m elevation, and the line defined in the present paper.

On the contrary, according to the morphological analysis, it was determined that for coefficients up to 5, the exogeneous relief forms are properly smoothed, thus encompassing the flat areas, while coefficients higher than 5 depict the areas subject to tectonic (endogeneous) uplift. The additional factor which proves such delineation is the fact that the line of coefficient span 0-5 coincides with the surface distribution of Quaternary sediments (indication of aggradational processes). Therefore, as stated also by Hammond (1954, p. 35), the use of quantitative methods has been only “a tool, and not an end in itself”. The exact line obtained by delineation procedure can be used only in small scale cartography. In the large scale context, the procedure would have to be adapted, by inclusion of the fuzzy logic principles (Zadeh, 1965; for usage in environmental studies, see Bajat et al., 2007).

Based on the argumentation conceptually shown in Fig. 7, it is highly recommended that the term Pannonian Basin should be used only in structural and paleogeographical context, while in regional geographical and geomorphological studies referring to present processes, the better option is to use the term Pannonian Plain.

ACKNOWLEDGEMENT

The paper shows the results obtained within the Project No. 47007, financed by the Ministry of Education and Science of the Republic of Serbia.

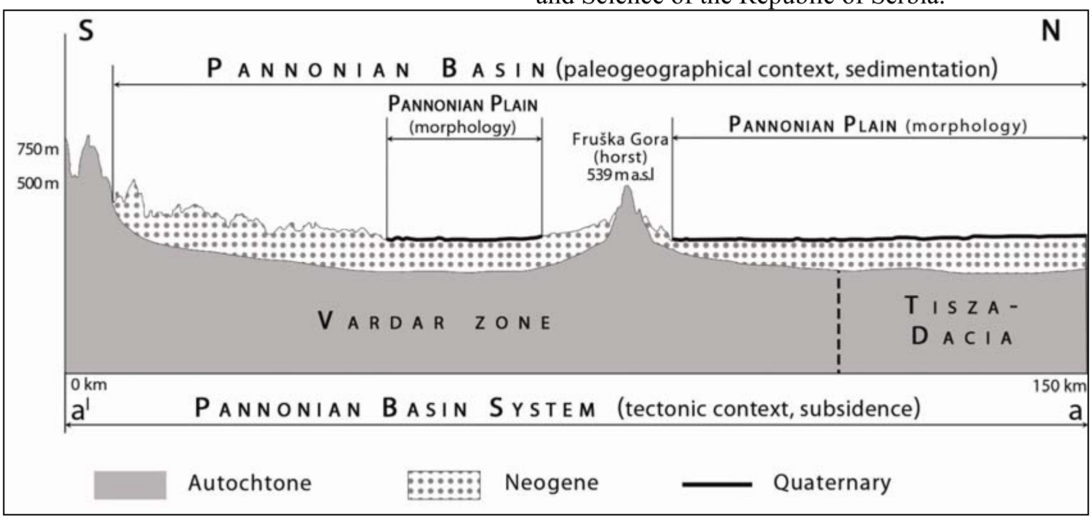

Figure 7. Schematic profile showing the horizontal and vertical extent of the Pannonian Basin System (tectonic context), Pannonian Basin (paleogeographical context), as well as the morphological unit of the Pannonian Plain. Vertical extent of sediments is not to scale.

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Received at: 07. 09. 2011
Revised at: 20. 02. 2012
Accepted for punlication at: 22. 02. 2012
Published online at: 24. 02. 2012