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The Serbian Lake Pannon Formations – Their Significance and Interregional Correlation

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Abstract. The problem of correlating Lake Pannon sediments across its basin has been the occupation of many geologists. At first, it was hampered by the prevalence of biostratigraphic, rather than lithostratigraphic correlation. The task became accomplishable when, thanks to seismic survey data, the strongly progradational character of Lake Pannon sedimentation had been understood. Thus, this paper aims to describe the formations from all parts of Lake Pannon and compare them to the ones described in Serbia. Material used includes published and unpublished data from all countries with Pannonian Basin System upper Miocene and lower Pliocene deposits, in the form of seismic, borehole and outcrop data.

Even though the system is strongly asymmetric, both spatially and temporally, the formation synthesis framework should help better understanding among geologists operating within the basin. For the first time the informal formations are proposed for all Lake Pannon sediments in Serbia. The formations are linked to a progradational deltaic system within the following succession: basinal plain–turbidite–slope–delta front–delta plain–lacustrine and alluvial environments.

The lithostratigraphic correlation has a huge potential in the context of industry. The main potential surely lies in petroleum geology, but it could be also very useful for exploration of geothermal energy, hydrogeology and construction materials.

Key words:
lithostratigraphy, deltaic progradation, Pannonian Basin System, Lake Pannon, upper Miocene-Pliocene, petroleum geology.

Апстракт. Проблемом корелације седимената свих области језера Панон бавили су се многи геолози. У почетку препреку је стварала доминација биостратиграфске наспрам литостратиграфске корелације. Задатак је постао решив када је, захваљујући подацима сеизмичких истраживања, схваћен изразито проградациони модел седиментације језера Панон. Стога, овај рад има за циљ да опише формације из свих делова језера Панон и упореди их са онима описаним на простору Србије. Коришћени материјал је представљен публикованим и непубликованим сеизмичким, бушотинским и површинским подацима из свих земаља које су припадале Систему Панонског басена током горњег миоцена и доњег плиоцена.

Иако је систем изразито асиметричан, како просторно тако и временски, алгоритам формационе анализе допринеће бољем разумевању геолога који раде на поменутом простору. По први пут предложене су нефор-

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Кључне речи:
литостратиграфија, делтна проградација, систем Панонског басена, језеро Панон, горњи миоцен-плиоцен, геологија угљоводоника.

малне формације за све седименте језера Панон који се налазе на простору Србије. Формације су везане за проградациони делтни систем са следећом сукцесијом: басенска равница–турбидити–падина–чело делте–делтна равница-језерска и флувијална депозициона средина. Литостратиграфска корелација има велики потенцијал у индустрији. Главни потенцијал је свакако у нафтној геологији, али такође може бити корисна и при истраживању геотермалне енергије, подземних вода, као и грађевинског материјала.

Introduction

The problems related to late Miocene chronostratigraphy of Central Paratethys have been subject of numerous studies in the last couple of decades (e.g. Sacchi et al., 1997; Magyar et al. 1999; Sacchi & Horváth, 2002; Sacchi & Müller, 2004; Magyar et al. 2007). The first attempts of establishing a Lake Pannon stratigraphic framework were made at the end of 19th century. The study of standard outcrops does not provide enough chronological data (only 10^4 to 10^5 years) for the determining of the biostratigraphic turnover. Some early biostratigraphic studies focused on the chronological meaning of different fossil species. This practice was, however, proved to be wrong. In a geological setting of a Lake Pannon-style basin, various fossil species are indicative of a depositional environment, rather than age. In a certain point in time, several species could coexist in different depositional systems (e.g. delta plain, delta front, shelf, deep basin). The underlying principle of strata correlation in the early works on Pannonian upper Miocene was that biozones were interpreted horizontally, without understanding of the progradational system that existed in the basin. Nowadays, it is known that the biozones have both vertical and horizontal extent, leading to the different age of the same biozones in different parts of the basin (Magyar & Geary, 2010). When methods of exploration switched from solely logging outcrops to examining subsurface data (borehole material, well logging, regional seismic surveys), a full picture of a progradational system now became clear.

The previous regional stratigraphic nomenclature subdived upper Miocene sediments into two stages - Pannonian and Pontian (Rögl & Steininger, 1983) but the recent studies (Magyar & Geary, 2010; Kovačić & Pavelić, 2018; Mandic et al., 2019 among others) suggest avoiding use of Pontian stage in Central Paratethys since the first occurrence of early Pontian marker fossil Paradacna abichi precedes the Black Sea Basin Pontian stage (Krijgsman et al., 2010). The Pontian stage is excluded from Pannonian Basin System (later referred to as ‘PBS’) and abichi and rhomboidea beds are assigned to late Pannonian stage except the uppermost rhomboidea beds which are assigned to lower Pliocene Cernikian stage (Mandic et al., 2015).

Already complex stratigraphy is additionally aggravated with use of different names for Miocene-Pliocene formations with same characteristics in distinct PBS parts. The formation names are given by local places and only recently geologists tried to correlate them in the region (Malvić & Cvetković, 2013; Sztanó et al., 2016; Kovačić 2018; Sebe et al. 2020) while also some attempts were made for small part of PBS in Serbia - Northern Banat area (Radivojević, 2014; Radivojević & Rundić, 2016; Ivanišević & Radivojević, 2018; Anđelković & Radivojević, 2019).

The importance of formation correlation is both scientific and industrial. While the scientific correlation will improve regional knowledge about the postrift basin fill, the industrial importance lies in better understanding of petroleum system, geothermal potential and raw materials. The Lake Pannon sediments represent the most important element of PBS petroleum system (source, reservoir, and cap rocks) containing the greatest amount of generated and produced oil and gas reserves and resources.

The sediments representing the Lake Pannon are almost entirely found in the subsurface environment, and besides some outcrops (Mecsek Mt., Medvednica Mt., Slavonian Mts., Fruška Gora etc.), rock samples and data are governed by oil companies operating in the region (MOL, INA, NIS Gazpromneft, OMV Petrom, etc.) and because of that frequently treated as confidential. Additional problem is that the companies in some parts of PBS didn't find interest dividing these sediments into formations while in some parts they are still using Pontian stage just as is suggested to avoid.

This paper attempts to give a comprehensive review of upper Miocene and lower Pliocene PBS formations, their history and potential subbasin correlation pointing to importance of having a more precise stratigraphic framework. The study uses extensive published material and covers all countries occupying the PBS regardless the level of exploration and applied dating, and other methods.

There are several different direction prograding systems in PBS (Kovačić et al., 2004; Magyar et al., 2013; Sztanó et al., 2013; Radivojević et al., 2014; Budai et al., 2019 among others) from which the most important are paleo-Danube and paleo-Tisza rivers. For the logic of its division related to position in delta-lake depositional environment is suggested. One should be vigilant not to force interpretation and formation correlation without thorough study of sediments age, origin, lithology and depositional environment. In a strongly asymmetric basin filled with sediments at different age, such as the PBS, this kind of formational workflow could help easier understanding among geologists working in the PBS.

Geological setting

The Pannonian Basin System encompasses the basin and the pre-rift basement. Pannonian Basin is a classical back-arc basin formed during Oligocene-Miocene times (Horváth et al., 2006; Balázs et al., 2016) and occupies nine countries (Austria, Bosnia and Herzegovina, Croatia, Hungary, Romania, Serbia, Slovakia, Slovenia and Ukraine, Fig. 1).

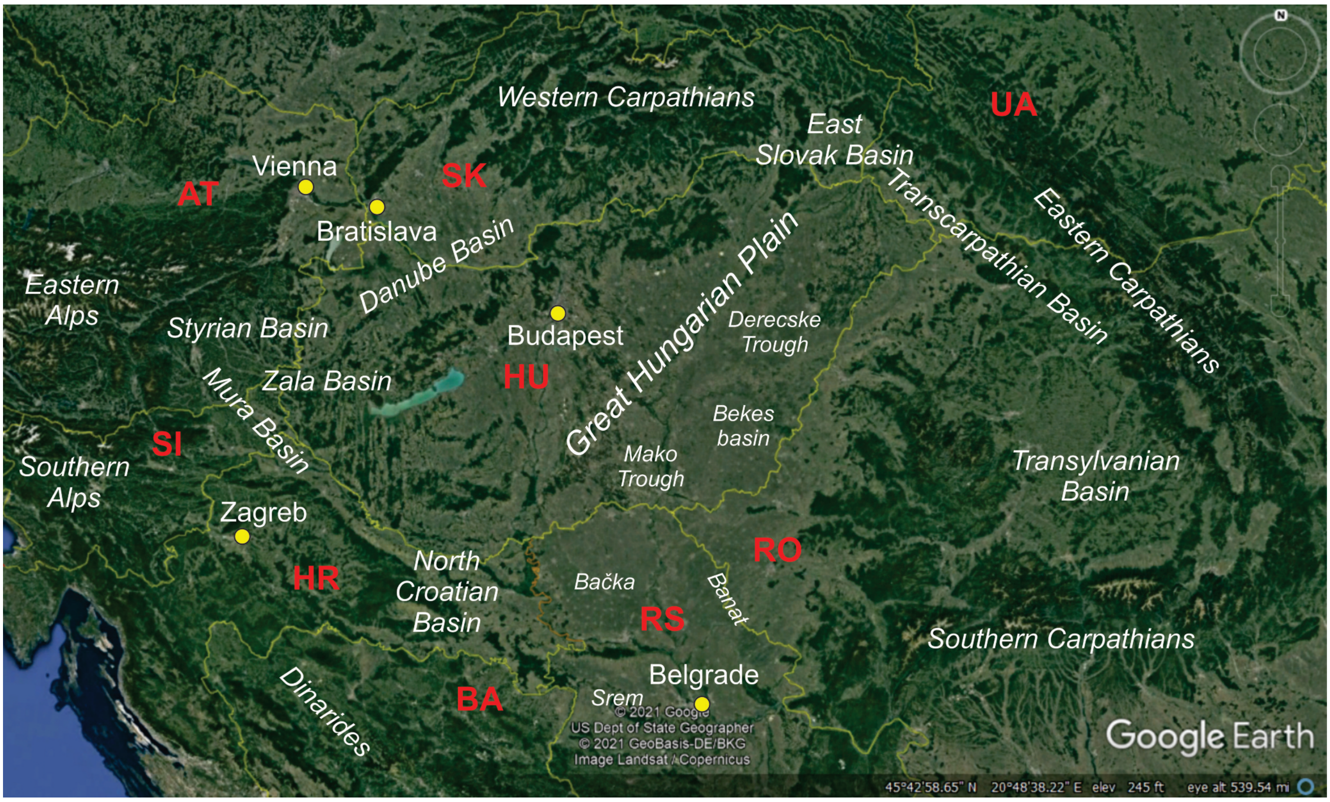

Fig. 1. *Pannonian Basin system and its surrounding. The red letters represent country codes of countries evaluated in paper.*

the first time, the informal formations are proposed for all parts of PBS in Serbia. Surely, the additional effort is needed to make them formal and accepted but

The PBS was a subject of intensive tectonic and geodynamic processes. The rifting took place along asymmetric simple shear extensional mechanism

(MATENCO & RADIVOJEVIĆ, 2012; BALÁZS et al., 2017). The extensional regime is strongly time-transgressive, with syn-rift and post-rift sequences of different age found in various parts of the basin system. The analysis of syn-kinematic reflectors demonstrates that normal faulting migrated in time and space and that in the Serbian part of the PBS, extension took place on a wide Miocene time interval (roughly 20–5.5 Ma) (MATENCO & RADIVOJEVIĆ, 2012). ŠUJAN et al. (2021) described several extension terminations and restarts in the Slovakian Danube Basin. That means that there are several syn-rift and post-rift sequences before the final definite post-rift phase (in accordance with the "punctuated subsidence model" described by HOLZ et al., 2017). The same could be expected in the Serbian part of PBS where the final post-rift phase is represented by upper Miocene and Pliocene sediments. The uplift and thermal subsidence begins somewhere in the Sarmatian (variously defined, for example RADIVOJEVIĆ & RUNDIĆ, 2016 or RUNDIĆ et al., 2019), but reaches its climax in the upper Miocene. Younger parts of Pliocene and Quaternary belong to the basin inversion phase (MATENCO & RADIVOJEVIĆ, 2012).

The PBS basement is of highly varying lithology, namely Paleozoic igneous and metamorphic rocks; Triassic sediments and metasediments; Jurassic ophiolitic mélange; Lower Cretaceous carbonates and clastics and Upper Cretaceous-Paleogene heterolithic turbidites (ČANOVIĆ & KEMENCI, 1988; RADIVOJEVIĆ, 2014).

The Neogene depositional history starts with the continental to lacustrine deposition during early Miocene times. The true marine conditions appear within early Badenian which is far more abundant then middle and upper part of stage (MATENCO & RADIVOJEVIĆ, 2012). The brackish Sarmatian sediments have much less areal extent and thickness, except in SE part of Serbian PBS (MATENCO & RADIVOJEVIĆ, 2012) with thick fine-grained deep-water facies. In the other parts they are represented with thin shallow-water reef sediments or eroded.

The late Miocene of Central Paratethys generally had a two-fold internal division: usually the whole of it is described as having a single stage, the Pannonian *sensu lato* (further subdivided in different ways); however, in Serbia the distinction between Pannonian and Pontian *sensu stricto* is still widely used in industry (similar to the chronostratigraphy of the Eastern Paratethys: VASILIEV et al., 2011; POPOV et al., 2013; VAN BAAK et al., 2016).

Late Miocene geological setting is characterized by progradation of paleo-deltas in a relatively deep-water lake environment. The lake, named „Lake Pannon" (MAGYAR et al., 1999), was actually a saline one, somewhat similar to the present Caspian Lake (MAGYAR & GEARY, 2010), hence the often-used term „caspibrackish" (e.g. to describe the Lake Pannon's waters). Thus, the main difference is made between marginal (onshore) and basinal (offshore) facies. They are further subdivided into several distinct depositional environments, which are the basis for establishing the formations later discussed in the paper.

The Lake Pannon sedimentary infill is generally characterised by the presence of several linked depositional environments, in a framework of a deltaic progradational system. Hemipelagic open basin environment is present on the basinal plain. It is represented by mudstones (usually clays and marls, sometimes micrite), which are sandy on the lake boundaries and become cleaner basin-ward. Basinal turbiditic sediments, deposited from underwater channels usually overly the hemipelagic muds. They are of siliciclastic composition, being represented by sands and muddy intercalations. The shelf slope environment is home to mostly mud, silt and intercalated sand. Overlying the shelf slope are the deltaic environments: delta front, delta plain and coastal plain. They are represented by silts, sands, and lignite seams. Lake Pannon sediments generally contain abundant fauna (bivalvia, gastropoda, ostracoda) and flora (terrestrial plants, calcareous nannoplankton, dinoflagellate cysts, palynomorphs).

Overlying the upper Miocene sediments are the sediments of the Pliocene. These sediments are generally divided into clays of the remnant Paludina Lake („Lake Slavonia" in HARZHAUSER & MANDIC, 2008), and siliciclastics of the alluvial plain (IVANIŠEVIĆ & RADIVOJEVIĆ, 2018).

The Quaternary is a period of intense climate change, and has left a big mark on the Pannonian realm. The thickness of Quaternary sediments is very small in the southern margins of the PBS, and gets bigger when moving north. The sediments show continental depositional environments, including loess and loessoids, alluvial and fluvial sediments (Čičulić-Trifunović & Rakić, 1976).

Overview of Lake Pannon formations by country

By definition, a formation is the principal lithostratigraphic unit. The formation should be regarded as a geological body with specific sedimentological characteristics, which are the result of a single depositional environment. It does not have to be of the same age in all its parts. In order to formally define a formation, a reference outcrop or a borehole must be selected (Dimitrijević & Dimitrijević, 1989). One must bear in mind that some of the formations described in this paper are only informal at the present moment. The classical way to describe an outcropping formation may not prove viable when dealing with seismic data, because of lateral variability of deltaic and fluvial formations.

Upper Miocene sediments have been thoroughly studied in most areas of PBS. Hungarians were the first to codify formations, producing a „stratigraphic lexicon" (Csaszar, 1997). Simultaneously and independently, geologists from neighbouring countries have defined various local formations. The difference in defining formation extent varies by country – for example, Ivanka Formation of Slovak nomenclature is equivalent to three different formations in Serbia.

Austria

The Styrian Basin is the part of Austria which can be considered as a subbasin of the Pannonian Basin, while the Vienna Basin is a separate entity, comprising the Central Paratethys together with Pannonian and Transylvanian Basins.

Styrian Basin

The Styrian Basin is a marginal subbasin of the Pannonian Basin System, 100 km long and 60 km wide (Reuter & Piller, 2014). Total thickness of Neogene sediments exceeds 4 km in the deepest part. It is separated from the rest of the PBS by the South Burgenland Swell (Sachsenhofer et al., 1996; Kosi et al., 2003) (Fig. 2).

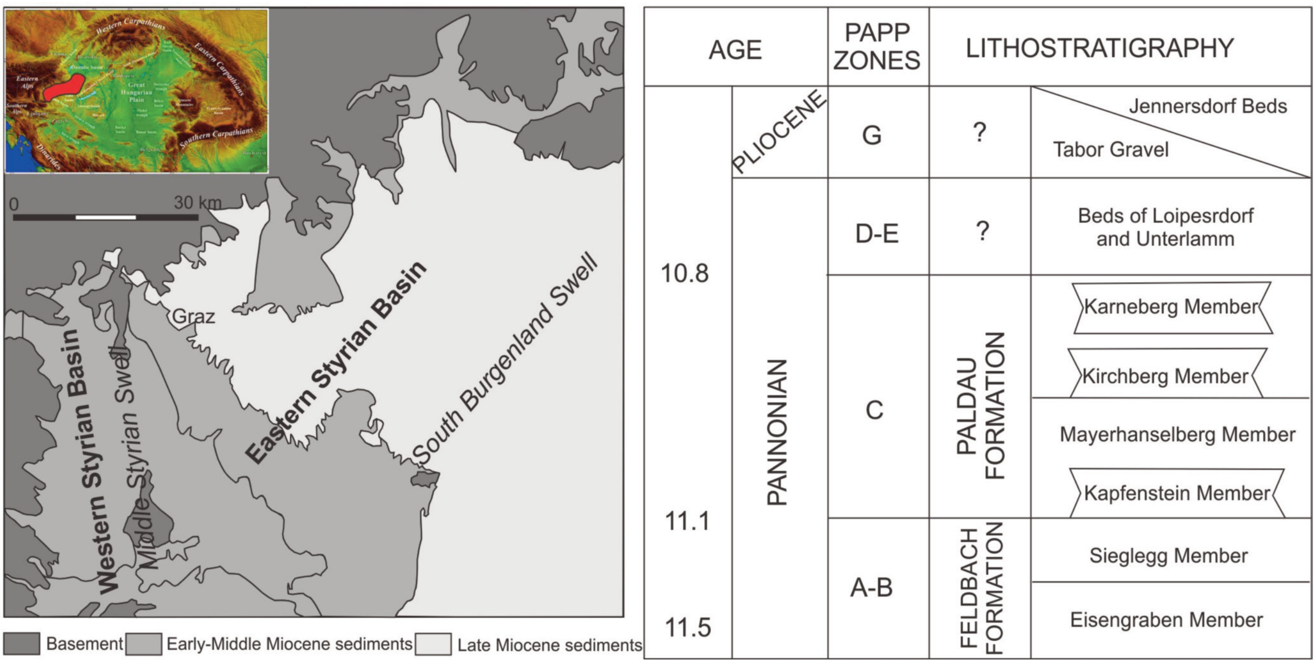

Fig. 2. *Styrian Basin geological map (left, after Gross et al., 2007) and its position within PBS (indicated with red polygon at the map in top left corner). The Lake Pannon formations and members (after Rögl & Daxner-Höck, 1996; Gross, 2000) defined within the basin (right).*

Lithostratigraphical subdivision of the Styrian Basin has been mentioned by Kollmann (1965) and studied in detail by Gross (2000, 2003). Papp biozones (Papp, 1951, 1953) are used in the chronostratigraphy of the Styrian Basin, although they are calibrated for the Vienna Basin, so their use could be inadequate.

Pannonian sediments of the Styrian Basin are separated from Sarmatian sediments by a regional unconformity. Feldbach Formation (Papp zones A-B) is composed out of two members: Eisengraben and Sieglegg (Fig. 2). Eisengraben Member is characterised by fine-grained sediments (clays, silts and marls) (Kosi et al. 2003), possibly deposited in a shallow, sublittoral environment, as indicated by small thickness of clinoforms, showing delta slope position. Sieglegg Member is a remnant of a limnic-deltaic system, comprising sands and clays. The overlying Paldau Formation (Papp zone C) contains several members: Kapfstein Member (sandy gravel basal unit), Mayerhanselberg Member (limnic-deltaic), and Kirchberg (middle Paldau) and Karnerberg (upper Paldau) Member (Fig. 2), composed of fluvial gravels and interfingering clays and sands (Kosi et al. 2003). The final parts of Pannonian s.l. are represented by Beds of Loipersdorf and Unterlamm (Papp zones D-E), and the Pliocene sediments are described as parts of Tabor Gravel and Jennersdorf Beds (Papp zone G) (Fig. 2) (Kosi et al. 2003).

Bosnia and Herzegovina

Only a small part of the PBS is present in Bosnia and Herzegovina (Fig. 3). Most of the data about Pannonian sediments are related to oil and gas exploration from deep depressions, even though the main discoveries and oil and gas shows are related to older Mesozoic and Paleogene-early Miocene rocks (Soklić, 1951–53; Hrvatović, 2006; Šajnović et al., 2020). Since the Pannonian age rocks do not have significance to petroleum system, not much attention was given to them and they were not subject of lithostratigraphic analysis. They could be found in the northernmost part of the country and represent the southern and eastern prolongation of well-known basins in Croatia and Serbia. The Posavina, Semberija and Prnjavor (Fig. 3) sub-basins could be connected to Slavonija–Srijem basin (Croatian "Srijem" has the same meaning as Serbian "Srem"), showing slope progradation from the NE direction (Ašanin, 2019), while Dubica and Prijedor basins

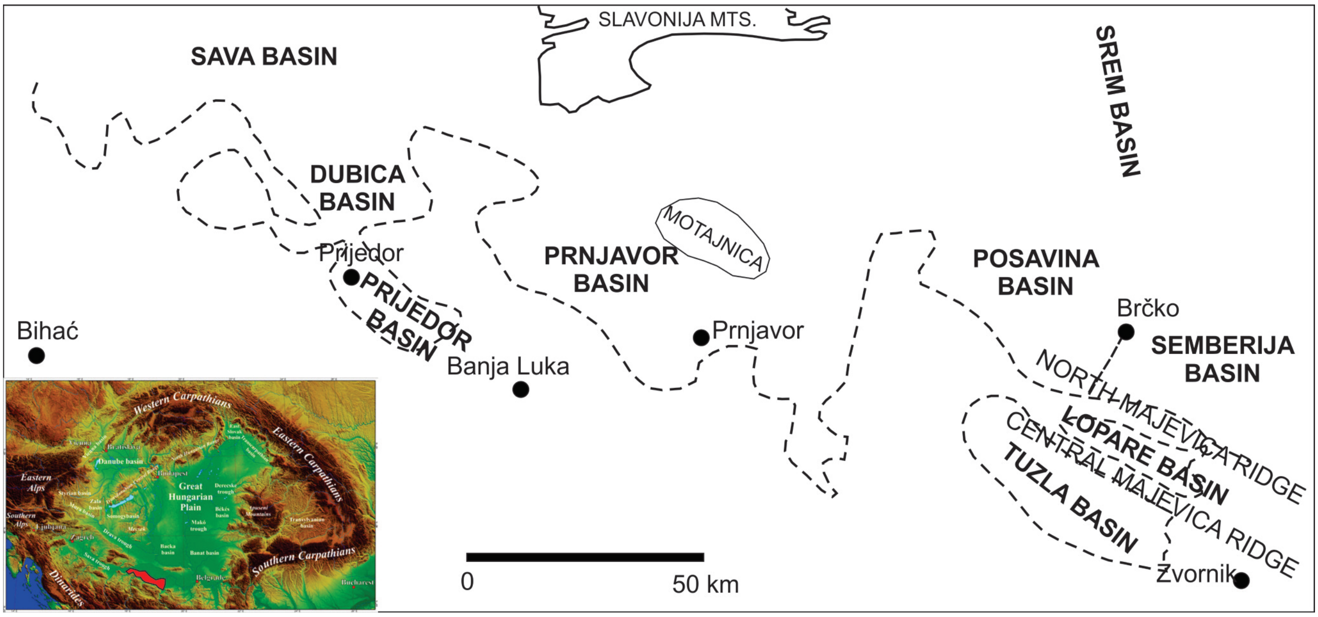

Fig. 3. The Bosnia and Herzegovina basins within PBS indicated with red polygon at the map in bottom left corner.

represent the southern part of bigger Sava Basin (Fig. 3). There are also two other basins which are separated from Slavonija–Srijem basin with North Majevica Ridge (Lopare basin) and Middle Majevica Ridge (Tuzla basin) (Fig. 3).

Croatia

According to the latest publications (Pavelić & Kovačić, 2018; Matošević et al., 2019; Sebe et al., 2020), the Croatian part of the PBS can be divided into two basins: North Croatian Basin (NCB further in the text) and Zagorje Basin (Fig. 4). The NCB encompasses Sava, Drava and Srijem-Slavonija subbasins (Fig. 4). The Zagorje Basin is connected to Slovenian Mura Basin and its formations are described in the part of the text concerning Slovenia.

Formations of the NCB were first analysed by Šimon (1966, 1980) and Velić et al. (2002). Malvić and Cvetković (2013) have given an extensive review age. West Drava depression has the following formations: the upper part of Moslavačka Gora shallow to open basin calcareous marl (with Koprivnica sandstones and Križevci member), Ivanić-Grad deep open lacustrine marls, Kloštar Ivanić basinal turbidites, Bilogora slope clays and delta sediments and Lonja lacustrine and alluvial sediments of Pliocene age (Sebe et al., 2020). Eastern Drava depression contains following formations: Valpovo basinal calcareous marl; Vinkovci basinal hemipelagic marls; basinal turbidites and shelf slope clayey marls; Vera delta slope and delta plain sand, silt, clay and lignite; as well as Pliocene Vuka lacustrine formation.

However, these authors did not unite the subdepressions in a single framework. This is misleading, because the North Croatian and Zagorje Basins were a single depositional area during the late Miocene. Thus, a set of formations described by Kovačić et al. (2017), Kovačić (2018) and Sebe et al. (2020) are most adequate in the description of Croatian part of PBS (Fig. 4).

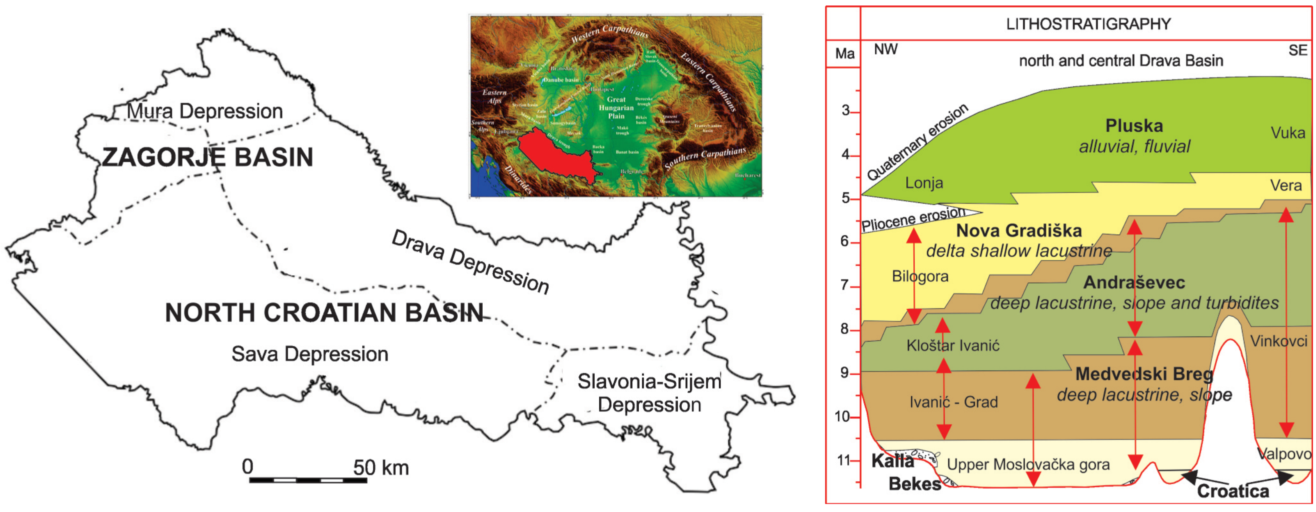

Fig. 4. North Croatian Basin with its depressions and Zagorje Basin (after Pavelić & Kovačić, 2018, left), and its position within PBS - indicated with red polygon. The Lake Pannon lithostratigraphic units defined within the NCB (right), Preferred formation names are bold, abandoned, or local names are in plain format according to Sebe et al., 2020.

of the formations where they have described different formations for Sava and Drava subbasins of the NCB. Sava depression encompasses following formations: Prkos and Ivanić-Grad formations of early Pannonian age, Kloštar Ivanić and Široko Polje formations of late Pannonian age and Lonja of Pliocene

Four formations, one member and two lenses were defined (Fig. 4). The succession begins with the Croatica Formation. It has a thickness of 20–50 m and is represented by lacustrine limestones. Medvedski Breg Formation is represented by the hemi-pelagic lacustrine depositional environment, built up of marls and silty marls, with a thickness of 20–80 m. The formation encompasses the Ozalj Member, Sveti Matej Lense and Baćun Lense (Kovačić, 2018). These three units are represented by sand and gravel and are of local significance, originating from the islands already present in the basin. Andraševec Formation is represented by a distal turbiditic system, made up of sands, silts and marls. It is defined as deep-basin distal turbidites in its lower part and the shelf slope environments in the upper part. It has a thickness of up to 600 m. Nova Gradiška Formation belongs to a delta system, especially the topset part. It is represented by silts, sands and coal and it has a thickness of 5–160 m. The succession ends with the Pluska Formation, which is of Pliocene age and deposited in delta plain and lacustrine environments.

Hungary

First mention of formations in Hungarian geology is by Jámbor in 1980. Hungarian geologists have since then produced an extensive stratigraphical lexicon, codifying formations from around the country, published in 1997 by the Geological Institute of Hungary and edited by Geza Csaszar. The latest achievements in this field are made by Sztanó et al. (2016). In this chapter the focus is given to Great Hungarian Plain and Little Hungarian Plain formations, while Zala Basin (synonymous with Mura Basin) formations are given in Slovenia section. Such description was described because earlier studies were limited to the country borders and regional correlation began only in recent times. Besides that there are dozens of other formations which have local significance and are out of scope of this paper.

Five Miocene and one Pliocene formations have been described in the Great Hungarian Plain and Little Hungarian Plain (Fig. 5).

The Szak Formation was deposited in an open-water lacustrine environment (Fig. 5), below the storm wave base and is represented by silty clay marls and silts with thin sandstone intercalations. Its average thickness is less than 50m. It is similar to the Endrőd Formation, but contains more shallow-water fauna (Sztanó et al., 2016).

The Endrőd Formation was first to overlie the basement (Fig. 5) in the deeper parts of depressions. It is an open water formation with varying depths of 125 to 800 m. Its lowest part is described as Tótkomlós Member, represented by calcareous marl (Juhasz; in Csaszar, 1997). The depositional character then shifts to hemipelagic marl and clayey marl (Sztanó et al., 2016).

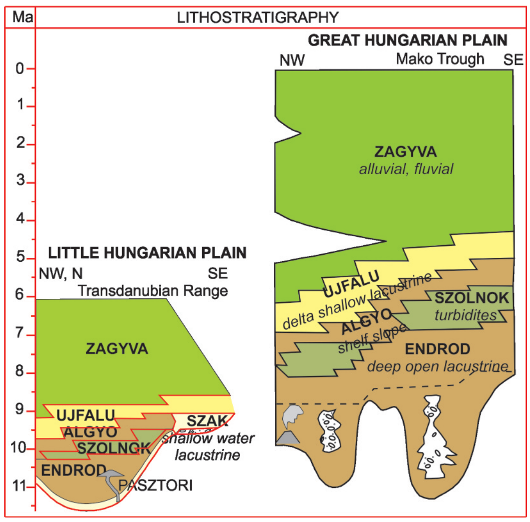

Fig. 5. Hungarian basins and its position within PBS - indicated with red polygon (left). The Little Hungarian plain lithostratigraphic units according to Sztanó et al., 2016, Great Hungarian plain lithostratigraphic units according to Sztanó et al., 2013 (right).

The Szolnok Formation represents the remnants of an extensive turbiditic system (Fig. 5) (Sztanó et al., 2016). It is characterised by an alternation of deepwater turbidic fine-grained sandstone, siltstone and clay (Juhasz et al.; in Csaszar, 1997). The sands were transported far from the slope by the means of large lobes (Sztanó et al., 2016). Coalified plant remnants are abundant. The formation's thickness exceeds 1000 m in deep basins (Juhasz et al.; in Csaszar, 1997).

The Algyő Formation is represented by sediments deposited in a shelf slope environment (Fig. 5). It is built up of dark-grey clayey marl. Turbiditic channel and gravitational sediments can be encountered and their thickness is 100 to 900 m (Gajdos et al.; in Csaszar, 1997).

The Újfalu Formation left sediments forming part of the delta front and delta plain environments (Fig. 5), represented by an alternation of sandstone, siltstone and clayey marl. The sandstone bodies may be very thick. There are numerous finds of coalified plant remnants, sometimes forming beds. The thickness is 20 m to 1000 m (Nemeth et al.; in Csaszar, 1997.).

The Zágyva Formation mostly belongs to the late Miocene and Pliocene epoch. These sediments were deposited in lacustrine and alluvial plain environment (Fig. 5) and are represented by an alternation of loose medium-grained sands, silt, clay and marl beds. Lignite seams are found throughout the formation. The total thickness of the formation exceeds 1000 m (Juhasz et al.; in Csaszar, 1997).

Romania

The Pannonian deposits are found in the Romanian Banat region (Fig. 6), west of Apuseni Mts. The studied sediments show a progradational shelf slope, so the lithostratigraphic units can be correlated with the formations in other countries of the PBS. First ideas about the deltaic origin of these se-

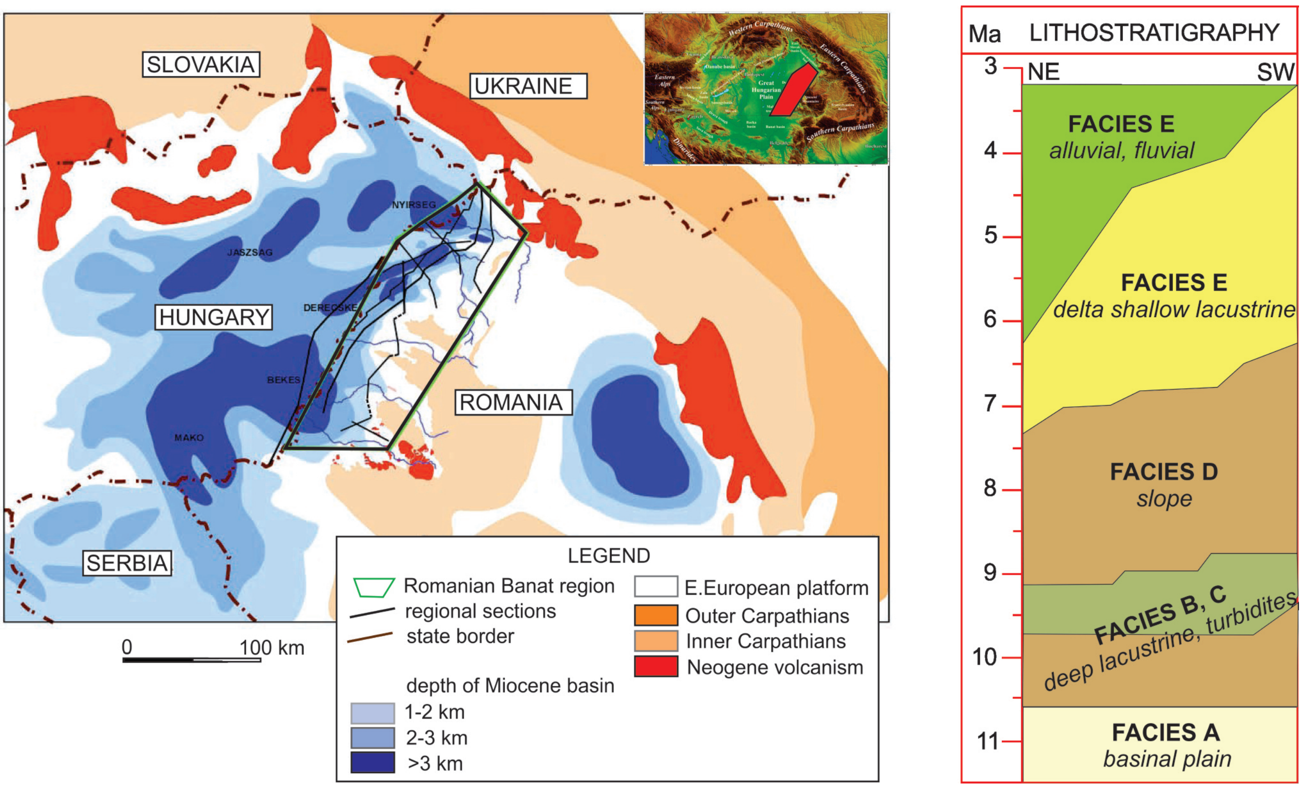

Fig. 6. Romanian Banat region (after Răbăgia, 2009) and its position within PBS - indicated with red polygon (left). The Lake Pannon facies (after Răbăgia, 2009) defined within the basin (right).

diments were introduced in 1975 by Mucsi & Révész. Berczi and Phillips (1985) improved this concept and defined various parts of delta, linked to different facies.

Răbăgia (2009) describes facies of the Romanian part of PBS, which are not described as formations. However, they mostly correspond to the formations defined in other countries, so these facies will be described as primary lithostratigraphic units. The facies have been named A–F in chart (Fig. 6).

The facies A is represented by pelagic fine-grained sediments. They have a widely varying thickness, from 20 to 800 m. The facies B is described as distal turbidites, and achieve a maximum thickness of 3500 m in depocentres (Răbăgia, 2009). The facies C are the shelf slope sediments and are divided into two subfacies: inclined proximal turbidites and non-deformed pelitic sediments. The facies D represent the upper part of the shelf slope. The sediments are mostly pelitic, with varying content of sand and coalified plant remains and have thickness of 200–1000 m. The facies E are delta plain and littoral, composed of alternating sand, silt and clay. Brown coal and lignite strata are encountered. The final facies F are represented by sediments deposited in a fluvial-palustrine environment of the alluvial plain, built up of an alternation of pelites, silts and sands.

Slovakia

The Slovakian part of the PBS is represented by the Danube Basin, which is present in Hungary as well (known as the Little Hungarian Plain or Kisalföld Basin) (Sztanó et al., 2016), as well as the Eastern Slovakian Basin in the east (Kováč, 2000; Lexa et al., 2000) (Fig. 7). Its formation is tied to the general pattern of PBS basin evolution. In the Pannonian age, it has been subject to the progradation of the paleo-Danube deltaic system.

The pioneers of the Pannonian formational subdivision in Slovakia were Priechodská & Harčár (1988) and Vass (1990, 2002). Formations were analysed by Kováč et al. (2006, 2011), Rybár et al. (2015), Csibri et al. (2018) and Vojtko et al. (2019) among others and recently described in detail in Sztanó et al. (2016), Šujan (2019) and Šujan et al. (2021).

Danube Basin

The newest data available are from Sztanó et al. (2016) and Vlček et al. (2020), so mostly these data will be cited in this chapter. Four formations were defined: Nemčiňany, Ivanka, Beladice and Volkovce (Fig. 7).

The Nemčiňany formation is represented by fan delta sands and gravel. The formation's thickness is usually 10–20 m, up to a maximum of 40m.

Sztanó et al. (2016) subdivides the Ivanka Formation into three units of lower rank. The lower part of the Ivanka Formation is deposited in a profundal lake environment. It is represented by calcareous marl in the base of the succession, with upward decrease of the carbonate content and the sediments becoming more clayey. Thin intercalations of siltstone are present. The unit has average thickness of 200 m (Sztanó et al., 2016). The middle part of Ivanka Formation was deposited by turbidite flows. It is represented by alternation of sandstone and siltstone/marl, with the dominance of sandstones. Graded beds, lamination and convolution are present. The thickness of the unit can reach almost 1000 m (Sztanó et al., 2016). The upper part of Ivanka Formation overlies the middle Ivanka turbidites and is deposited in a shelf slope environment. It is represented by clays, marls, silts and sporadic sandy intercalations. They can be laminated or massive. Convolution and soft-sediment deformations may point to turbidity currents or slumps (Sztanó et al., 2016). Cyclicity in sediment input and lake level change influence the progradational properties of this unit (Uhrin & Sztanó, 2012; Sztanó et al., 2013).

The Beladice Formation overlies the Ivanka Formation and is made up of sediments formed by the progradation of delta on the shallow shelf. It is represented by cyclically-deposited sands, silts, clays and lignitic clays and could reach the thickness of 500m (Sztanó et al., 2016; Šujan, 2019).

The Volkovce Formation forms the upper part of the progradational system and is represented by clays, silts and sandy channel fills deposited in a lacustrine environment (Šujan, 2019).

An additional Kolarovo Formation of alluvial origin are sometimes included in the scheme representing Pliocene sediments (Šujan, 2019).

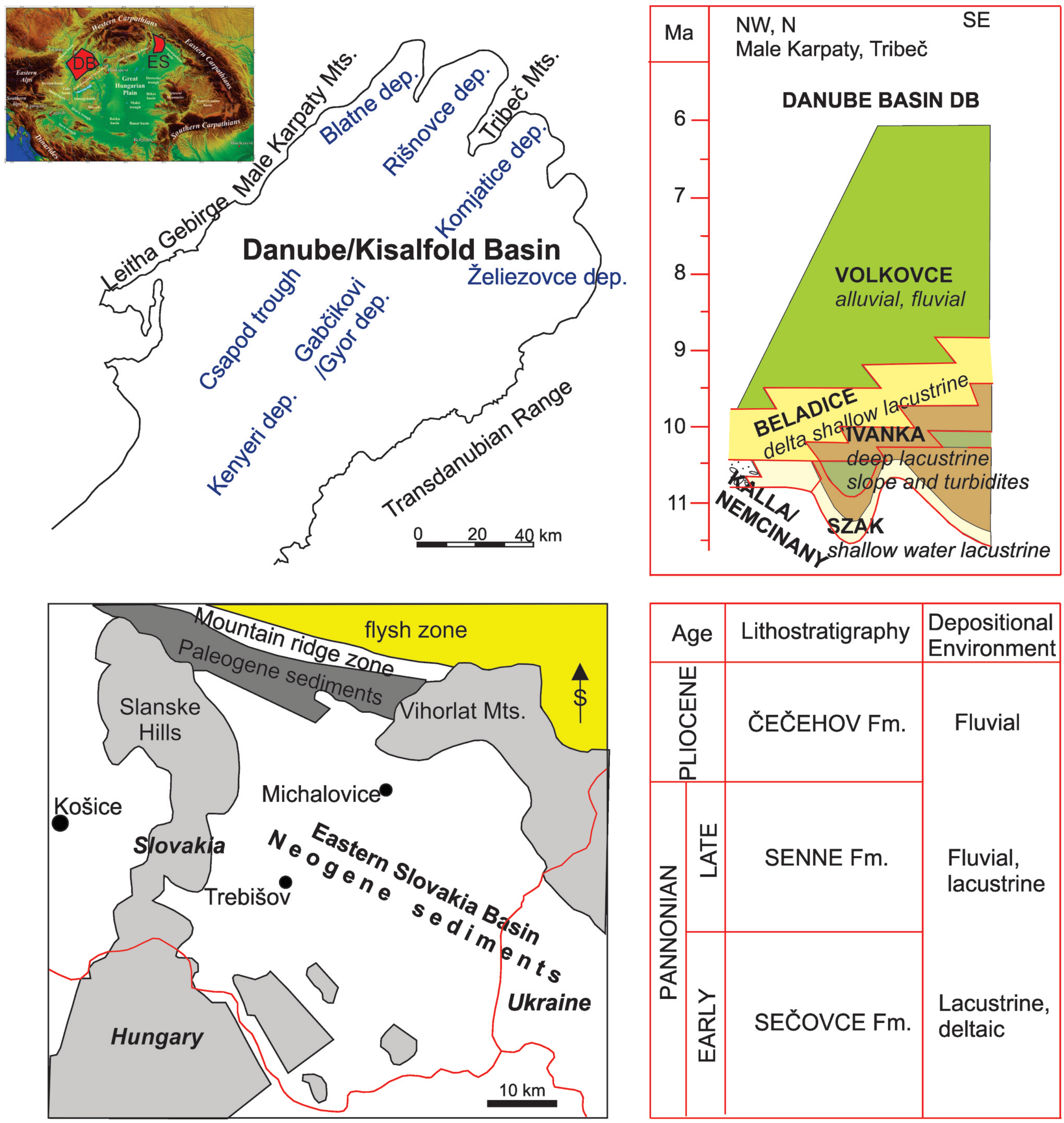

Fig. 7. *Slovakian Basins and its position within* ***PBS*** *– indicated with red polygons (top left),* ***DB*** *– Danube basin;* ***ES*** *– Eastern Slovakia basin. The Danube basin Lake Pannon formations (after* Sztanó *et al., 2016 and references within) defined within the basin (top right). The Eastern Slovakia (Transcarpatian) basin Lake Pannon formations (after* Kováč*, 2000;* Lexa *et al., 2000) defined within the basin (bottom).*

Eastern Slovakian Basin

Three formations were defined in this basin by Kováč (2000) and Lexa et al. (2000) (Fig. 7).

Sečovce Formation is the product of early Pannonian lacustrine and deltaic sedimentation. It is represented by calcareous shales with lignite and tuff (Kováč, 2000; Lexa et al., 2000).

Senné Formation is the late Pannonian fluvial-lacustrine unit. It consists of grey and variegated shales, with lignites (Kováč, 2000; Lexa et al., 2000).

Čečehov Formation is represented by Pliocene lacustrine and fluvial sediments: grey and variegated shales, gravel and sand (Kováč, 2000; Lexa et al., 2000).

Slovenia

Slovenia occupies a small portion of the PBS, but formations have nevertheless been defined, probably as a consequence of petroleum exploration. Within Slovenia, the productive series all lie in the Mura basin (Mioč & Žnidarčič, 1996; Kerčmar, 2018). Mura basin (Fig. 8) is adjacent to and shares the geological setting with the Croatian-Hungarian Drava basin, as well as the Hungarian Zala basin. Thus, the formations are very similar in character when compared to the Croatian part of the Drava basin (Sebe et al., 2020). First attempts to codify the formations were done by Mioč and Žnidarčič (1996), and were followed by Šram et al. (2015), Kerčmar (2018) and Sebe et al. (2020). Three formations and two members were defined in this area (Fig. 8).

The upper part of the Murska Sobota Formation belongs to the early Pannonian. It is represented by hemipelagic marls formed on a basinal plain. The formation additionally contains two members: Petišovci Sandstone and Benica Member (Mioč & Žnidarčič, 1996; Sebe et al., 2020), which were probably part of distal turbidites.

Lendava Formation is represented by turbiditic deepwater sands and silts, clays and marls of the shelf slope (Šram et al., 2015; Kerčmar, 2018; Sebe et al., 2020).

Mura Formation is deposited in delta front and delta plain environments and is represented by sands, silts, clays, marls and coal (Šram et al., 2015; Kerčmar, 2018; Sebe et al., 2020).

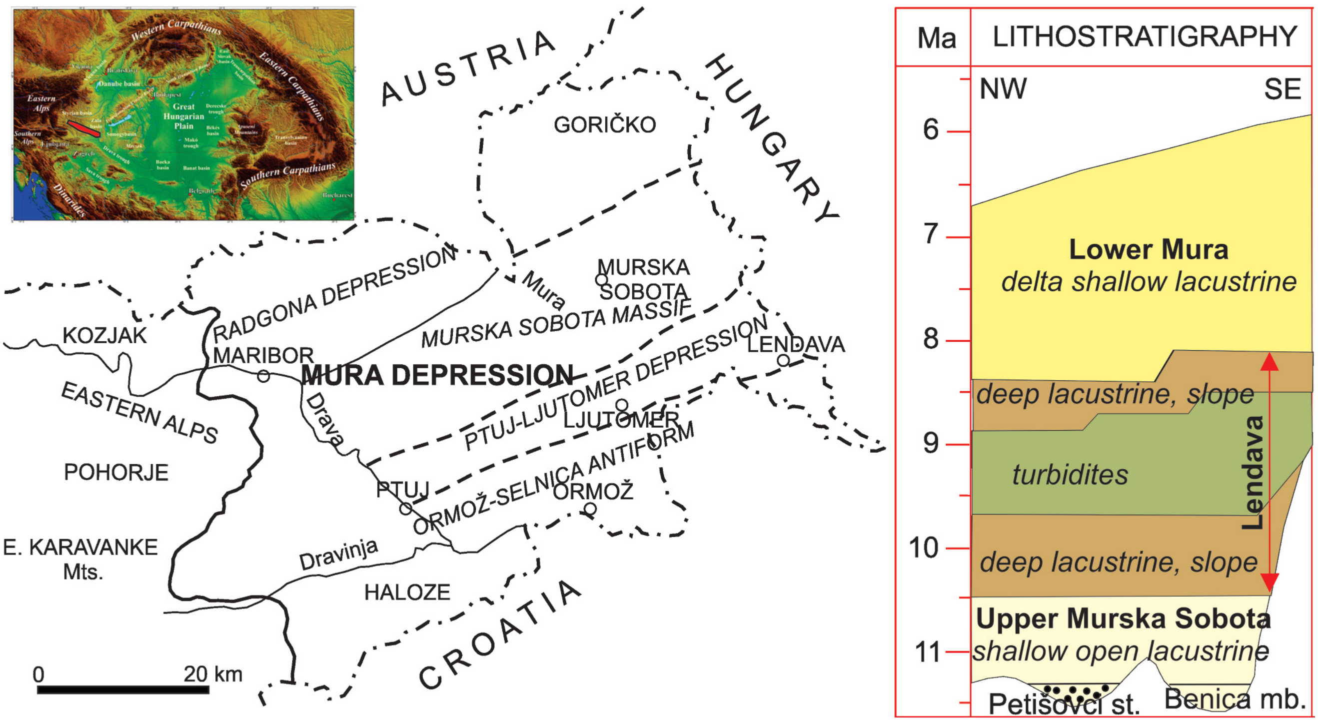

Fig. 8. Mura basin (after Mioč & Žnidarčič, 1996) and its position within PBS -indicated with red polygon (top left). The Lake Pannon formations and members (after Šimon, 1980; Sebe et al., 2020) defined within the basin (right).

Ukraine

A small part of the PBS belongs to Ukraine (Fig. 9). It is a part of the Transcarpathian Basin, where three formations pertaining to the Lake Pannon have been described by Kováč (2000) and Lexa et al. (2000).

Iza Formation represents the lower Pannonian basinal and deltaic depositional environments and is made up of calcareous shales, with lignite and tuff occurrences (Kováč, 2000; Lexa et al., 2000).

Radivojević (2014). The Serbian part of PBS encompasses different progradational paleo-river systems but so far only northern Banat area was discussed.

The Lake Pannon sediments filled the basin with large amount of material prograding from different directions and sources which points to necessity of having distinct formations. The northern Banat for-

AGE		LITHOSTRATIGRAPHY	DEPOSITIONAL ENVIRONMENT
PLIOCENE		ILICA FORMATION	Fluvial
PANNONIAN	LATE	KOLEŠEVO FORMATION	Fluvial, lacustrine
	EARLY	IZA FORMATION	Lacustrine, deltaic

Fig. 9. *Ukranian Carpathians tectonic map (simplified from Glushko & Kruglov, 1986) with Transcarpathian Basin and its position within PBS - indicated with red polygon (top left). The Lake Pannon formations and members (after Kováč, 2000; Lexa et al., 2000) defined within the basin (right).*

Koleševo Formation belongs to the upper Pannonian succession, being deposited in lacustrine and fluvial environments and represented by grey and variegated clays with lignites (Kováč, 2000; Lexa et al., 2000).

The sediments of Ilica Formation have been deposited during the Pliocene in a lacustrine and fluvial environment and represented by gray and variegated shales, gravel and sand (Kováč, 2000; Lexa et al., 2000).

Comparison to the state-of-art Pannonian lithostratigraphy in Serbia

Formational analysis of Pannonian sediments is an emerging field in Serbian geology with pioneering works made by Pigott & Radivojević (2010) and

mations with progradation system from N and NW have been extensively evaluated in the last couple of years (Radivojević & Rundić, 2016; Ivanišević & Radivojević, 2018; Anđelković & Radivojević, 2019) (Fig. 10a). The prograding system which has migrated from south and southeast with sediment source in the Dinarides, Carpathians and local sources remains undiscussed so far. The only exception to the general depositional architecture in the Serbian Lake Pannon is northern Bačka area, where lake's sediments are thin and represented almost exclusively with topsets (Fig. 10d).

Northern Banat area

Northern Banat is the most prolific hydrocarbon area in Serbian part of PBS (Radivojević, 2014;

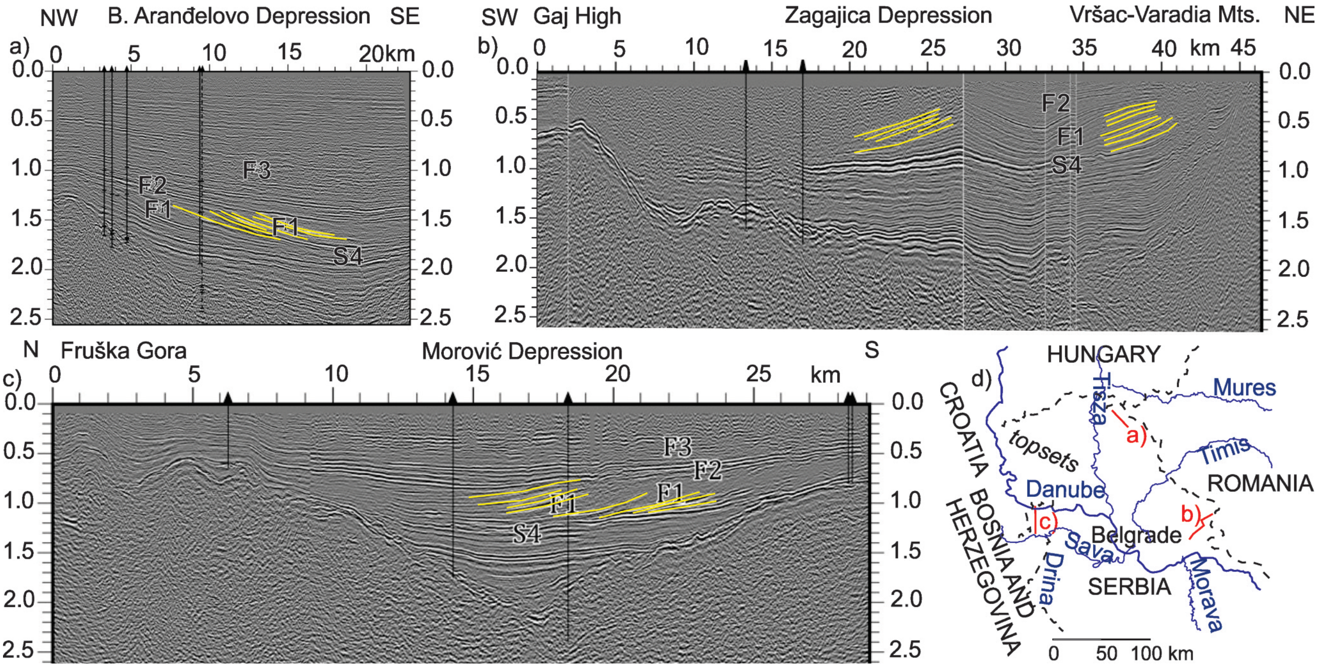

Fig. 10. The different progradation direction of Lake Pannon sediments in Serbia. ***a)*** *Banatsko Aranđelovo Depression – clinoforms showing progradation toward southeast,* ***b)*** *Zagajica Depression – clinoforms showing progradation toward west-southwest,* ***c)*** *Morović depression – clinoforms showing progradation toward north.* ***S4*** *– bottomset,* ***F1*** *– shelf margin,* ***F2*** *– marine lacustrine,* ***F3*** *– alluvial sedimentation (seismic lines modified from TER BORGH et al., 2015), The Upper Pannonian sediments are present at surface in Zagajica depression because of recent Vršac Mountains uplift. Hence, the F3 is missing.* ***d)*** *Map of Northern Serbia with locations of seismic profiles shown. Also, only topsets are present in the Bačka area, as indicated on the map.*

RADIVOJEVIĆ & RUNDIĆ, 2016; IVANIŠEVIĆ & RADIVOJEVIĆ, 2018) and is bordered by Southern Banat, Romanian Banat, Great Hungarian Plain (Alföld) and Bačka basins. Five formations have been described by IVANIŠEVIĆ & RADIVOJEVIĆ (2018) (Fig. 11). They are defined on the basis of seismic surveys and borehole data. For example, MAGYAR et al. (2013) define the Endrőd (correspondning to Hetin) Fm. as having low-amplitude continuous reflections, whether Szolnok (corresponding to Majdan) turbidites have high-amplitude continuous reflections. The lower boundary of Mokrin Formation is diagnosed on seismic profiles as a downlap surface, whereas the upper boundary marks the shelf break (IVANIŠEVIĆ & RADIVOJEVIĆ, 2018),

Hetin Formation is represented by hemipelagic marls. Unlike other parts of PBS, there is no vertical change in carbonate content and clay marls directly overlie synrift sediments. The calcareous marl unit is not confirmed, but its existence could be assumed (PIGOTT & RADIVOJEVIĆ, 2010; RADIVOJEVIĆ, 2014; IVANIŠEVIĆ & RADIVOJEVIĆ, 2018). The formation is covered by either Majdan turbidites or the Mokrin Formation (IVANIŠEVIĆ & RADIVOJEVIĆ, 2018).

Majdan Formation is represented by turbidites deposited in a deep-basin fan environment, generated by an overspill from upstream basins (SZTANÓ et al., 2013; IVANIŠEVIĆ & RADIVOJEVIĆ, 2018). The turbidites are represented by sandstones, clays and marls. They were deposited on top of Hetin marls. They are always overlain by Mokrin Formation (IVANIŠEVIĆ & RADIVOJEVIĆ, 2018).

Mokrin Formation has traits characteristic of a prograding shelf slope built up of clayey marls, siltstones and intercalated sands, with well-developed clinoforms (IVANIŠEVIĆ & RADIVOJEVIĆ, 2018).

Kikinda Formation is represented by sediments deposited in a shallow environment of delta front, delta plain and coastal plain. These sediments are sandstones with silt and clay intercalations, as well

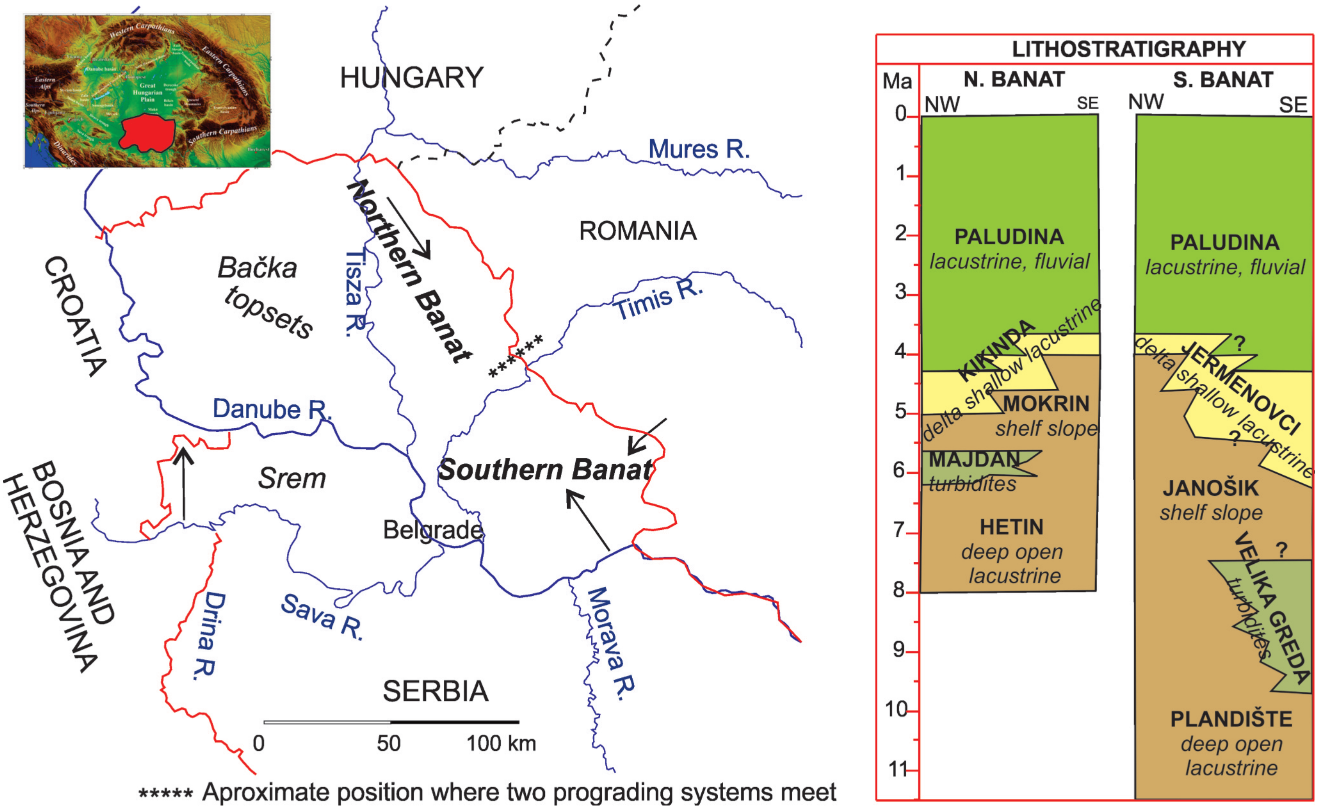

Fig. 11. *Serbian Basins and its position within PBS - indicated with red polygons (top left), asterisks represent the position where two prograding systems meet. Arrows indicate shelf progradation direction (from* ter Borgh *et al., 2015). The Northern Banat lithostratigraphy is taken from* Ivanišević & Radivojević, *2018) while the Southern Banat is new proposed one.*

as local appearance of lignites. They are marked by clay-sand alternations. The base of Kikinda Formation is characterised by more sandy intervals. Kikinda Formation is overlain by Pliocene Paludina Formation, formed in a lacustrine and fluvial environment, whose sediments were not subject to core sampling or well-logging (Ivanišević & Radivojević, 2018).

Southern Banat area

The southeasternmost depressions in Vojvodina (Zagajica and Plandište, mentioned by Matenco & Radivojević, 2012) shows progradation of Pannonian sediments toward north and west sourced from Carpathians and probably local sources (Vršac Mountains) (Fig. 10b). The published seismic lines (Matenco & Radivojević, 2012; ter Borgh et al., 2015) and well data allow division to five formations (Fig. 11). All these formations, or at least most of them, could be transferred toward south to Podunavlje area.

Plandište basinal plain formation is represented with homogenous, horizontally laminated dark gray marlstones. Also, gray clay-sandy marls are present with intercalation with fine-grained marly sandstones and dark-green to black coloured silty and clayey marlstones.

Velika Greda basinal turbidite formation is presented with rhythmic interlayering of deepwater sandstones, marls and silts and clays with internal cross-lamination, convolution, load and flame structures.

The Janošik shelf slope formation is represented by clayey marls, siltstones and intercalated sands.

The Jermenovci formation delta plain and delta front facies of clay-marly-sandy sediments which frequently have laminas and thin layers of clayey coals and coals.

The Paludina lacustrine formation with fine to medium- grained sands represent the last stage in the evolution of PBS. The freshwater lake, named "Lake Slavonia" by Harzhauser & Mandic (2008) or "Lake Paludina" by Krstić et al. (2012), covered a relatively small area.

Srem

The only area where these northward prograding Lake Pannon sediments could be recognized is Morović depression (Fig. 10c) whose eastern part is settled in Serbia while western lies in Croatia. Due to a lack of seismic and borehole data, no formations have been defined.

Regional correlation and economic importance of formational analysis

Taking all the aforementioned into account, it can be concluded that defining basin-scale formations is not a simple task. Correlating sediments deposited in several paleodelta progradation directions (Magyar et al., 2013; Radivojević, 2014; ter Borgh et al., 2015, among others) or correlating littoral and basinal strata can sometimes prove to be problematic. Even though Lake Pannon sediments covered nine countries, it is possible to compare and unify its formations. Styrian Basin has been omitted from strict correlation because it was semi-isolated during the Pannonian age, and lacks the deep-water basinal depositional environment, which is present in all other basins.

The use of formations as principal stratigraphic units enables correlation of time-rock units across the various parts of the basin. Basically, all of the Lake Pannon formations belong to basin floor-turbidites-slope-delta-lacustrine-alluvial system. The main difference lies in progradation direction and material source which point to necessity of having different formations which still belong to the same depositional system (Fig. 12). Thanks to oil industry, subsurface data allow good insight in the architecture of these sediments and establish a quite functional framework for formation definition with depositional systems defined.

Several basins within the PBS can be linked due to spatial and temporal proximity, as well as belonging to the same progradational system. The basis for temporal correlation would be dated slope positions cited from Magyar et al. (2013). The PBS is divided into three different correlatable areas, based on progradation direction and position within the System.

The first correlatable area is Slovakian Danube Basin-Little Hungarian Plain-Slovenian Mura Basin-Croatia (NCB and Zagorje). All of these basins are related to paleo-Danube delta progradation, with the dominant direction being NW-SE. Slovakian Danube Basin has a slope progradation age of 10 Ma. It is important to notice that fluvial and alluvial deposition started already during late Pannonian, at about 9.5Ma, and ended at about 6Ma. These dates are quite early when compared with most other basins (fig. 12). The Little Hungarian Plain has all the characteristics of the Danube Basin, except slightly different timings. It has a slope age of about 9.5 Ma. Slovenian Mura basin is of simple archicture, with the slope age defined as about 8.6 Ma. There was no freshwater deposits in the Mura Basin because it was rapidly inverted and eroded. The Croatian NCB and Zagorje Basin contain the full deltaic sequence, whose formations could be expanded to Bosnia and Herzegovina and Srem/Srijem areas. The slope age recorded in this part of PBS (near Zagreb) is 8 Ma. The end of freshwater lacustrine sedimentation in connection with Lake Slavonia is dated at about 3Ma. It can be concluded that the following correlations could be made: basinal plain (lower Ivanka/Endrőd/upper Murska Sobota and lower Lendava/Medvedski Breg); deep-water distal turbidites (middle Ivanka/Szolnok/middle Lendava/lower Andraševec); slope (upper Ivanka/Algyő/upper Lendava/upper Andraševec); delta front–delta plain (Beladice/Ujfalu/Lower Mura/Nova Gradiška); lacustrine-fluvial (Volkovce/Zagyva/Pluska) (Fig. 12).

The second area is Great Hungarian Plain–Northern Banat/Southern Banat (Serbia)–Romanian Banat. The basins forming this area are of more

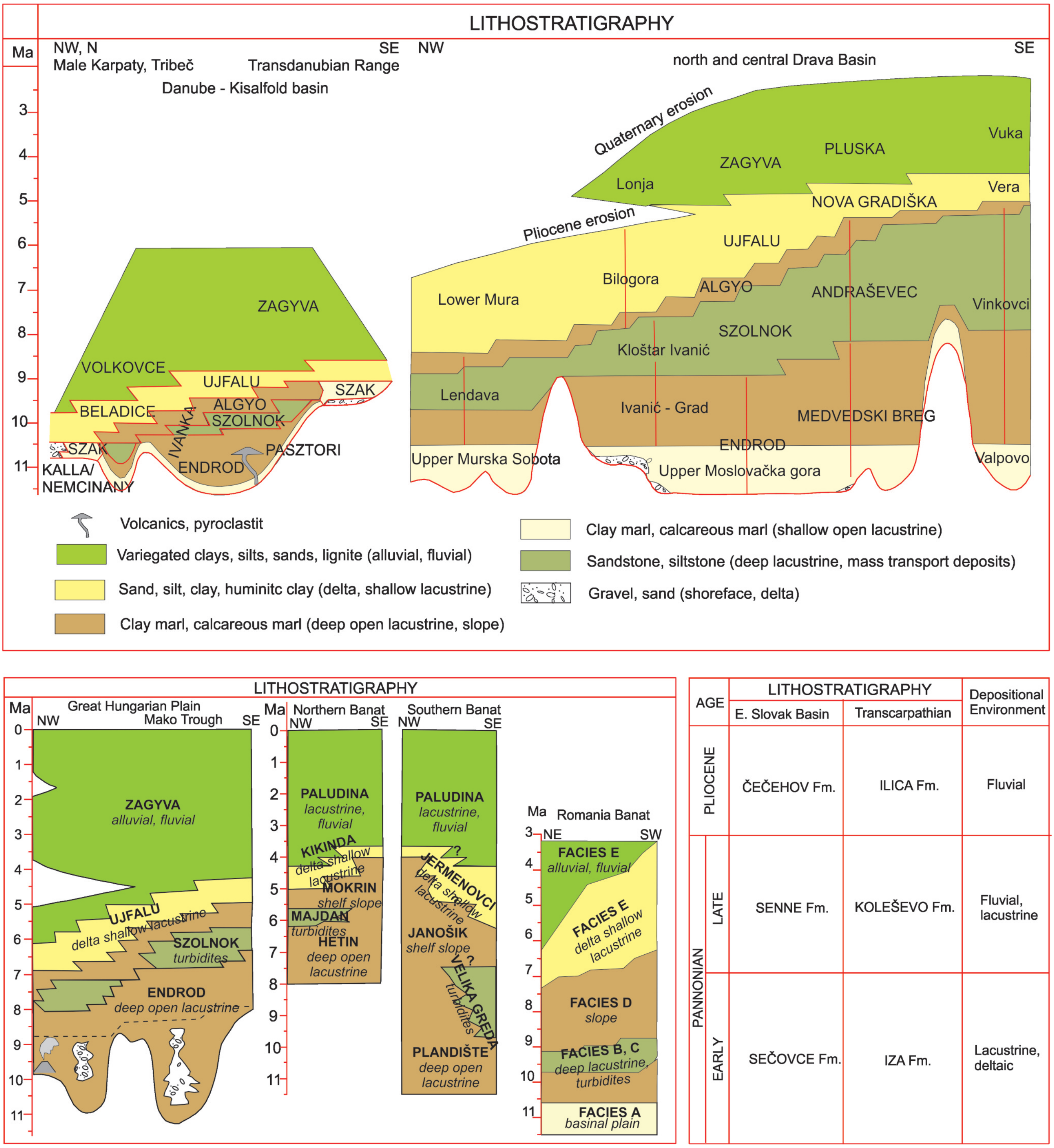

Fig. 12. *Correlation of upper Miocene – Pliocene lithostratigraphic units of Danube – Kisalfold (Little Hungarian Plain) basin, northern and central Drava basins (modified from* S*ZTANÓ et al., 2016 and* S*EBE et al., 2020) (top figure). Correlation of upper Miocene-Pliocene lithostratigraphic units between Great Hungarian Plain (from* S*ZTANÓ et al., 2013), Northern Banat (*I*VANIŠEVIĆ &* R*ADIVOJEVIĆ, 2018), Southern Banat (newly proposed here for the first time) and Romanian Banat area (*RĂBĂGIA, 2009) (bottom left). *Correlation of upper Miocene and Pliocene lithostratigraphic units between Eastern Slovakian basin and Transcarpathian basin (modified from* K*OVÁČ, 2000,* L*EXA et al., 2000 (bottom right).*

complex character: paleo-Danube progradation (NW–SE, N–S), paleo-Tisa progradation (NW–SE), as well as S–N progradation in the case of Southern Banat. The first two basins are fully correlatable, having the same progradation direction (NW–SE), very similar vertical and areal distribution and similar depositional environment change timings. Both basins have continuous deposition up to Quaternary. The difference is the earlier dates of slope progradation, which are defined as 8.6 to 5.3 Ma in GHP and 5.3 to 4 Ma for Serbian Banat. Southern Banat is characterised by opposite progradation direction (SE–NW). The Serbian Banat systems (N and S) met in the area of Zrenjanin city at 4 Ma. Despite direction differences, correlation is fully feasible due to almost identical depositional environments present throught the basin. Romanian Banat has a very similar architecture, but different progradational direction (NE–SW) and different timing, with Pliocene deposition stopping before 3 Ma and then the basin being subject to erosion. Following formations, based on linked depositional systems, can be correlated: basinal plain (Endrőd/Hetin/Plandište/facies A & B); deep-water distal turbidites (Szolnok/Majdan/Velika Greda/facies C); slope (Algyő/Mokrin/Janošik/facies D); delta front and delta plain (Ujfalu/Kikinda/Jermenovci/facies E); lacustrine-fluvial (Zagyva/Paludina/facies E).

The third area is Eastern Slovakian Basin and Ukrainian Transcarpathian Basin. These two basins are actually two parts of the same basin, only separated by the administrative border between Slovakia and Ukraine. These basins are remote border areas of Lake Pannon and are not correlatable with other systems. Both have three formations described, with lacustrine and deltaic lower Pannonian (Sečovce/Iza), fluvial and lacustrine upper Pannonian (Senne/ Koleševo) and fluvial Pliocene (Čečehov/Ilica).

The significance of formation analysis also has its practical use, since Lake Pannon sediments present the great resource base for hydrocarbons, coal, geothermal, hydrothermal, etc. For example, the Pannonian basinal-type marls are both a very prolific source rock (Kostić, 2012), as well as a good raw material for cement industry (Ganić et al., 2012). The use of lithostratigraphic correlation implies having insight as to where the economically important strata can be expected, both in space and time.

Formation analysis greatly improves the understanding of the petroleum geological system of a basin or its part. Regionally important source, reservoir and seal rocks can be correlated within the basin. For petroleum companies it is very important to have resource base figures as accurate as they can be and imprecise definition of source and reservoir rocks could led to hydrocarbon potential over/underestimation. In Serbian part of the basin the Pannonian Age (*sensu* Stevanović, 1977) sediments are recognized as the main source rock (Kostić, 2000; Jelenković et al., 2008; Mrkić et al., 2011; Kostić, 2012). Still this time interval covers formations of basinal plain as well as turbidite sandy sediments and generating thickness map of „Pannonian“ age sediments could lead to hydrocarbon potential overestimation, while also some of the reservoir rocks would be overlooked. Turbidite sandstones and delta plain sandstones are most prolific reservoir rocks while alluvial and lacustrine clays represent the cap rock (Horváth & Tari, 1999; Radivojević, 2014).

Most of the Serbian part of PBS belong to mature exploration area where big structural traps were drilled. Still, the sole license owner NIS Gazpromneft invested a lot of money in 3D seismic surveys in last decade. Using interval attribute maps and 3D volume attributes (amplitudes as good indicator of facies types, and frequencies as good indicator of subsurface discontinuities) should help better understanding of paleoenvironments and unlock the potential in subtle stratigraphic traps.

Conclusions

The delta and shelf progradational system is time-transgressive throughout the basin and sediments comes from different sources (Alps, Dinarides, Carpathians, local uplifted areas). Still, it is possible to correlate Lake Pannon sediments using basin floor-turbidites-shelf slope-delta-alluvial plain/lacustrine system.

All formations are grouped into three areas based on progradation direction, material source and position within the basin. The main systems are related to paleo-Danube and paleo-Tisza while also lower magnitude local systems are present within Serbian part of the Pannonian basin.

In Serbian part of Lake Pannon sediments three different direction (toward SE, N and NW) progradational systems are detected at seismic sections and split into formations. The northern Banat area is connected to adjustment Great Hungarian plain formations. Small magnitude Serbian Srem northward progradational system is linked with Northern Croatian basins, while formations are introduced to southern Banat northwestern progradation. The southern Banat formations could be also transferred toward south to Podunavlje area.

At 4 Ma Serbian Banat progradation systems meet each other in last stage of Lake Pannon existence near Zrenjanin. Despite opposite progradation direction and different material source their formations could be correlated based on their position within the basin.

Future work on this subject would comprise formation formalization by writing a detailed description of its vertical and lateral extent, position and characteristics of a type section/borehole, precise data on contacts with other formations etc.

Unlocking the full potential of recently acquired 3D seismic surveys should help in better understanding of depositional environments using the modern techniques like seismic attributes, spectral decomposition etc., and help in formation correlation.

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Резиме

Формације језера Панон у Србији - њихов значај и међурегионална корелација

Корелација горњомиоценско-плиоценских седимената језера Панон последњих година

представља предмет великог интересовања хрватских, мађарских и словачких геолога. Иако су се неки новији радови бавили српским северним Банатом и неформалним предлогом увођења формација на овом простору до сада није постојала студија која би обухватила цео српски део простора Панонског басена као и његову корелацију са суседним областима.

Екстензија Панонског басена генерално има асиметричну геометрију са деформацијама које дуж њега мигрирају у простору и времену. Седиментациона еволуција касног неогена овог простора дуго је била слабо разумљива услед тога што су литостратиграфске јединице корелисане и интерпретиране у хроностратиграфском смислу. Проблем представља то што традиционалне биозоне заправо одговарају депозиционој средини и месту у проградирајућој делти, а не само времену седиментације. У систему где је проградација доминантан процес то неминовно доводи до погрешне корелације и лоше одређених стратиграфских граница.

Сви сетови формација (усвојених и предложених) у овом раду прате низ везаних депозиционих средина, које представљају део проградирајућег делтног система. Чланови низа су: басенска равница-дубоководни дистални турбидити–падина–чело делте и делтна равница-језерска и флувијална средина. Припадност одређеној формацији одређена је на основу сеизмичких података, података добијених истражним бушењем угљоводоника (језгро, узорци са вибросита, геофизички каротаж) и података са изданака и отворених профила. Доминантну улогу у одређивању формација имали су сеизмички подаци пошто је једино на њима било могуће пратити регионалне клиноформе везане за шелфну падину, која представљају кључни доказ проградационог карактера ових седимената.

У раду је дат кратак историјат формација и њихово последње виђење за свих девет земаља које се налазе на простору језера Панон. Поред већ добро познатих проградационих система везаних за палео-Дунав и палео-Тису дат је и неформални предлог увођења формација у јужном Банату за проградациони систем који се одвијао у супротном правцу од ових главних правца.

За потребе корелације формација истраживани басени су на основу правца проградације и спајања појединих система подељени у три области. Из корелација је изузет једино Штајерски басен у Аустрији обзиром да он има знатно другачију геолошку грађу и депозициону еволуцију - одвојен од остатка басена и без депоновања дубоководних седимената.

Прву област са доминантним правцем проградације СЗ-ЈИ чине: словачки Дунавски басен-Мала мађарска равница-Мура басен у Словенији-басени у Хрватској. Поред тога овој области могу се прикључити и седименти босанско-херцеговачког дела језера Панон и српског дела сремске депресије. У овим областима нису одређене посебне формације већ је препоручена употреба локалних хрватских формација за Источнославонско-сријемску депресију која је у новијој литератури припојена северно хрватским басенима.

Друга област има доминанте правце проградације С–Ј и СИ–ЈЗ, али и проградацију из супротног правца (југ–север). Место спајања ових система се налази у околини Зрењанина (пре око 4 милиона година) и представља последњу фазу егзистенције језера Панон. Ову област чине Велика мађарска равница-Северни/Јужни Банат у Србији-део Румунског Баната. На простору јужног Баната предложено је неформално увођење формација које су, и поред тога што (вероватно) имају различито порекло материјала и припадају проградационом систему који има супротан правац проградације, високо корелативне са формацијама северног Баната.

Трећу област представљају крајње североисточни делови система Панонског басена који су подељени између Словачке и Украјине. Количина расположивих података омогућава корелацију између административном границом одвојених Источно словачког басена и Транскарпатске области у Украјини, али не и њихову квалитетну корелацију са мађарским, односно румунским формацијама на југу.

Значај регионалне литостратиграфске корелације је како научни, тако и економски. Повезивање формација и њихова регионална корелација стварају оквир за боље и прецизније разумевање депозиционог система који је довео до потпуног запуњавања седиментима некадашњег језера Панон. Економски значај познавања депозиционе историје и архитектуре басена је вишеструк у различитим областима привреде од производње нафтне и гаса, преко коришћења геотермалне енергије и хидрогеолошког потенцијала, грађевинског материјала итд. Познато је да су на простору Војводине значајне матичне стене представљене басенским лапорцима, да пешчари везани за турбидитне токове и делтне системе представљају најзначајније резервоар стене, док падински пелити и покровни ситнозрни седименти чине заштитне стене. Коришћење формација и њихове старости уместо оквира који се везује искључиво за одређени временски интервал (рецимо карте дебљине панонских седимената) омогућило би тачнију процену нафтногеолошке потенцијалности и утицало на економске процене појединих пројеката. Такође, познавање депозиционог система има изузетно велики значај у откривању нових као и експлоатацији већ постојећих лежишта угљоводника.

У последње време, добри резултати коришћења напредних техника истраживања угљоводоника су довеле до великих финансијских улагања у 3Д сеизмику и савременије технологије производње. Коришћење пуног потенцијала методе 3Д сеизмике која би обухватила анализе сеизмичких атрибута, спектралну декомпозицију и друго би допринела бољем разумевању депозиционог система и имала значајне економске ефекте.

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