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2. Neogene and Palaeogene Fill of the Slovak Part of the Dunajská Panva Basin within the Region 1: 50,000 Podunajská Nížina Lowland – Podunajská Rovina Flat

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Abstract: Palaeogene and Middle Miocene sediments are probably involved in the basal Cenozoic fill. We do not have any direct evidence, we conclude this from seismic profiles. The oldest documented rocks are volcanic products of various varieties of andesites of the Lower Badenian (Seravallian) age. The oldest documented rocks are volcanic products of various varieties of andesites of the Early Badenian (Langhian) age. Above them are sediments of marine facies in the form of pelitic and sandy sediments of the Badenian (Langhian-Serravallian) age, which are overlain by the brackish deposits of the Sarmatian (Serravallian) and Early Pannonian (Tortonian) ages of the same lithological composition. The end of the pre-Quaternary sedimentation period is represented by sand-clay deposits of the continental environment with interlayers of coal clays to lignites and in the upper parts with dominating gravel-sand deposits, Pliocene in age.

Key words: Neogene and Palaeogene fill, biostratigraphy, lithological composition

2.1 Introduction

From the structural-tectonic point of view, with an exemption of a narrow part of the foothills of the Malé Karpaty Mts. the area of the Danube Lowland-Danube Flat region is an intra-arc basin, which consists of a system of "smaller" sub-basins (Royden et al., 1983). The sub-basins underwent partially different evolution during the Miocene and Pliocene, as a result of which they differ not only in the overall thickness of their Neogene sedimentary fill, but also in the chronostratigraphic sequence of the formations within individual sedimentary sequences, in representation, or absence of some complexes and their lithological character and thickness (Kováč, 2000).

The current shape of the *Danube Basin* (Fig. 2.1) as a body is the result of complex tectonic and complex geological evolution in time and space (Adam & Dlabač, 1961, 1969; Pagáč et al., 1995). One manifestation of this facies within its territory is the occurrence of several other tectonically different depocentres (depressions), which recorded maximum subsidence activity in different time periods and in different intensity (Keith et al., 1989; 1994; Hók et al., 2016; 2019). One of these depressions, representing the largest part of the region, is the Gabčíkovo Basin. It represents its deepest part, where the thickness of the Neogene sediments reaches over 8,500 m (Kilényi & Šefara, 1989; Hrušecký et al., 1996).

According to the latest research and interpretations (Hók et al., 2016; 2019) during the Early Miocene, the paleostress regimen changed from transtension into transpression mode in the pre-rift stage. The Danube Basin Transversal Fault (DBTF) and parallel NW – SE oriented failures were activated as normal faults. The area southwest of the DBFT was then eroded up to crystalline basement. In the Middle Miocene in the syn-rift stage, the extension was oriented in the NW – SE direction and caused the opening of the finger-like depressions in the NW part of the Slovak part of the Danube basin.

The extension mode of the NW – SE direction persists also in the post-rift stage up to the Early Pleistocene.

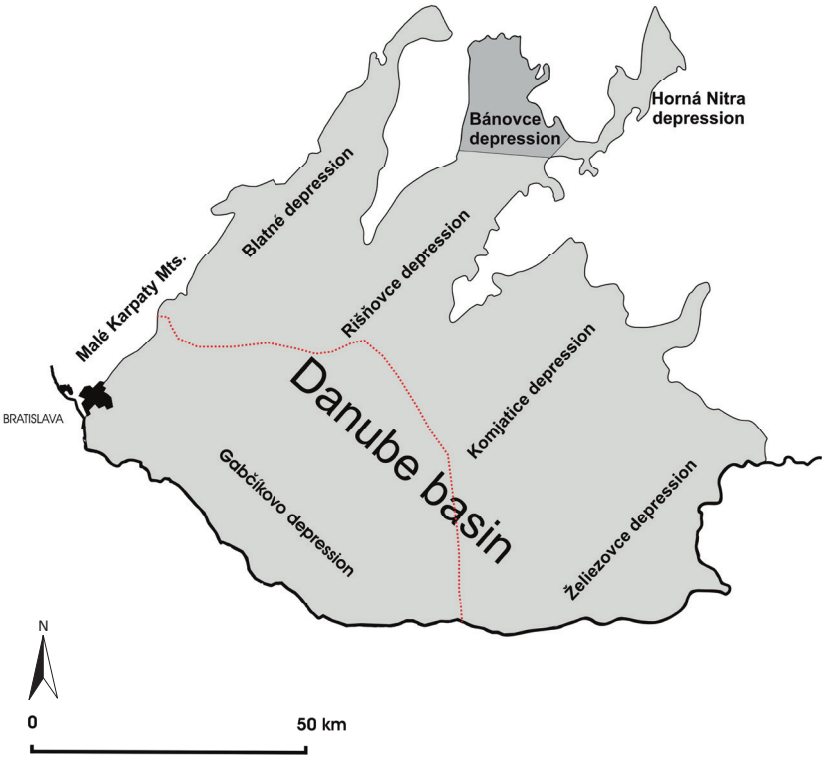


Fig. 2.1 Location of the Danube Basin sensu Vass (2002). The red-dotted contour delimits the studied region of the Danube Flat at a scale of 1: 50,000

2.2 Sedimentary fill of the Basin

According to data from seismic sections (Hrušecký et al., 1993, 1996, 1998; Hrušecký, 1999), the thickness of sedimentary rocks in the central Gabčíkovo Depression reaches about 8,000 – 9,000 m. However, the sum of the thicknesses of the Neogene sediments verified by boreholes and partly also by seismic measurements is only about 6,000 m.

Since the seismic image shows the presence of sedimentary rocks in the overburden of the pre-Cenozoic bedrock, the above-mentioned authors assigned the lower part of the fill to the presence of sediments of the ***Palaeogene to Early Miocene*** age. Although the data on their existence are indisputable, there is no direct evidence, so we do not discuss their closer characteristics.

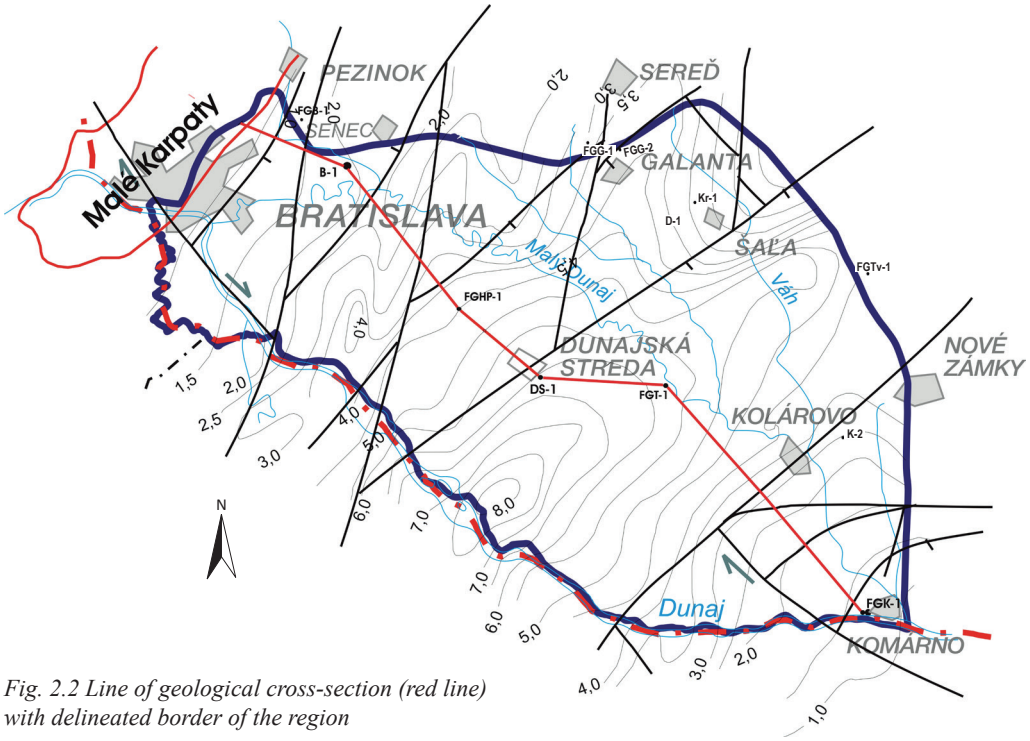


Fig. 2.2 Line of geological cross-section (red line) with delineated border of the region

Based on the works of Šefara & Kováč (in Šujan et al., 1996) and Pereszlényi, Vass, Elečko & Vozár (in Tkáčová et al., 1996) we compile the geological cross-section of the sedimentary fill (Fig. 2.2).

The sediments and volcanic rocks of Middle Miocene age do not crop out to the surface of the studied region. They are covered by thick fluvial deposits of Quaternary age.

In the isolated occurrences, only sediments of the ***Late Miocene*** to ***Pliocene*** age are exposed, particularly in NE parts of the geological map of the region.

Despite the fact that sedimentation in the *Gabčíkovo Basin* generally began only in the Early Badenian, since it continued more or less smoothly up to the Pliocene and Quaternary, the oldest Neogene sediments so far found in this part of the basin are considered volcanic breccias of Early Badenian age, formed by fragments of andesites (Pálfalvi, 1975). In the overburden of these sediments on W outskirts of the Basin near Rusovce the HGB-1 borehole (Kantor et al., 1987) proved the presence of Early Badenian (Langhian) volcanites, referred to as *Šurany volcanites* (Vass, 2002. They are represented by amphibolic andesites, passing into hornblende-pyroxenic andesites.

The oldest Neogene rocks (Figs. 2.3, 2.4) are represented in the Slovak part of the Danube Basin (range of the described region) by Šurany volcanites, caught by exploration wells. Based on radiometric dating the Early Badenian (Langhian) age was assigned to them. The oldest Neogene sediments are of the Early Badenian age (in terms of Kováč et al., 2007, Rybár et al.,

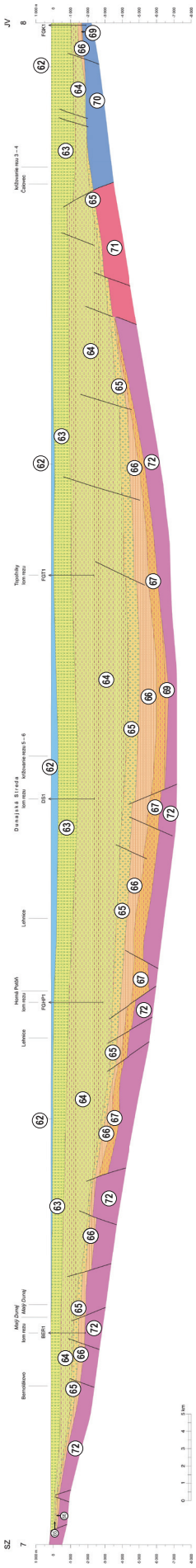


Fig. 2.3 Geological section of the Tertiary fill of the Slovak Part of the Dunajská panva Basin (Danube Basin within the Region 1: 50,000 Podunajská nížina Lowland – Podunajská Rovina Flat (Danubian Flat).
62 – Quaternary undivided; 63 – Late Miocene-Pliocene; 64 – Pannonian (Tortonian); 65 – Sarmatian (Serravallian); 66 – Late Badenian (Serravallian); 67 – Early Badenian (Langhian); 69 – Palaeogene-Neogene; 70 – Mesozoic (Silicicum s.l.); 71 – Palaeozoic-Mesozoic (Veporicum undivided); 72 – Palaeozoic-Mesozoic (Tatricum undivided)

2015) and belong to the Špačince Formation. In their overburden there are sediments of the Late Badenian (Serravallian, Báhoň Fm.), Sarmatian (Serravallian, Vráble Fm.), Late Miocene (Pannonian – Tortonian; Ivanka, Beladice, Volkovce Fms.) and Pliocene age (Kolárovo Fm.).

2.2.1 Badenian (Langhian-Serravallian)

The chronostratigraphic regional stage of the Central Paratethys – Badenian, approved at the 1st Symposium of the Subcommittee for Paratethys in 1968 in Bratislava, was divided into three sub-stages – the Early (morav), the Middle (vielič) and the Late (kosov). Since that time, there have been implemented several refinements of its duration and division (Kováč et al., 2007; Hohenegger et al., 2014; Rybár et al., 2015). In this work we use a two-part division of Badenian in terms of Kováč et al., (2007); Rybár et al., (2015) and a lithostratigraphic division of the Neogene deposits of the Danube Basin sensu Vass (2002).

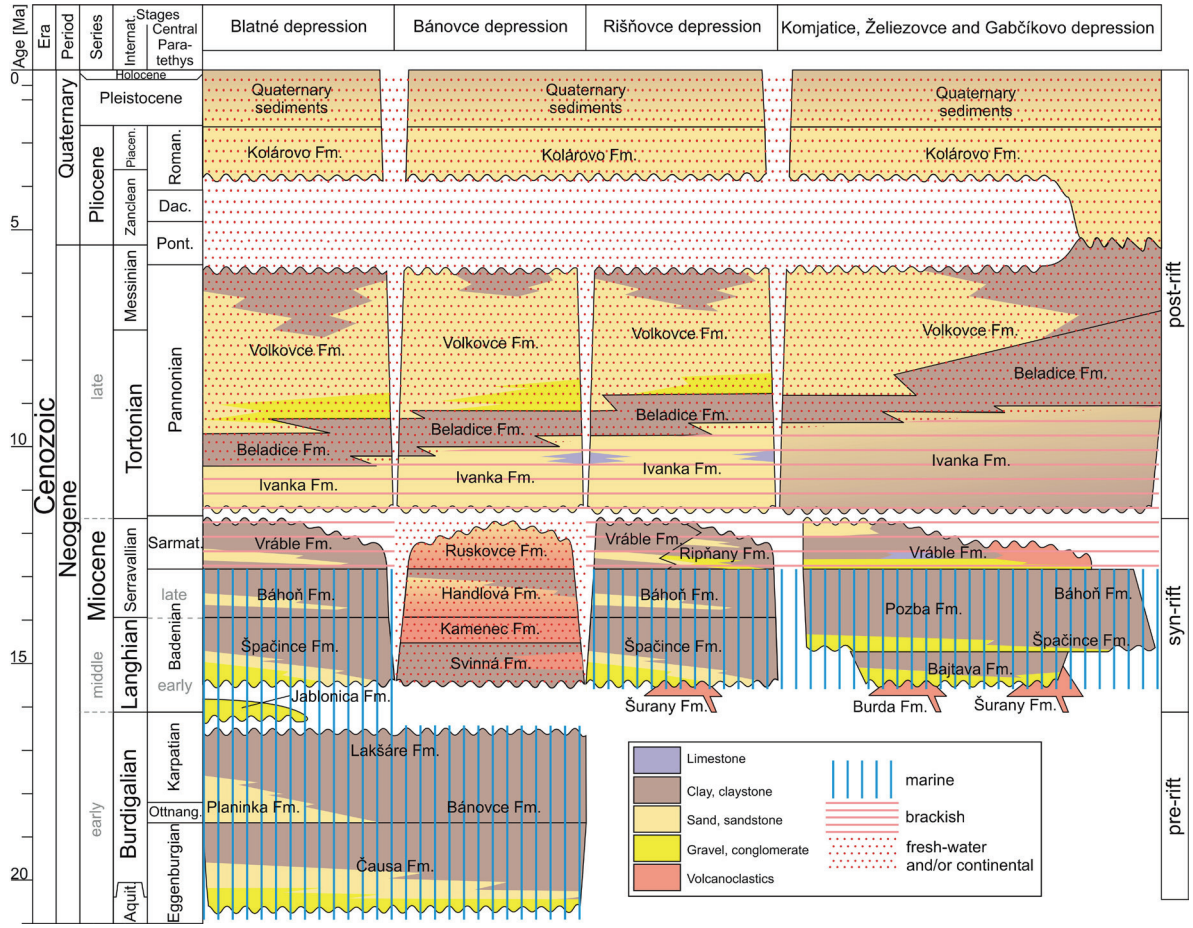
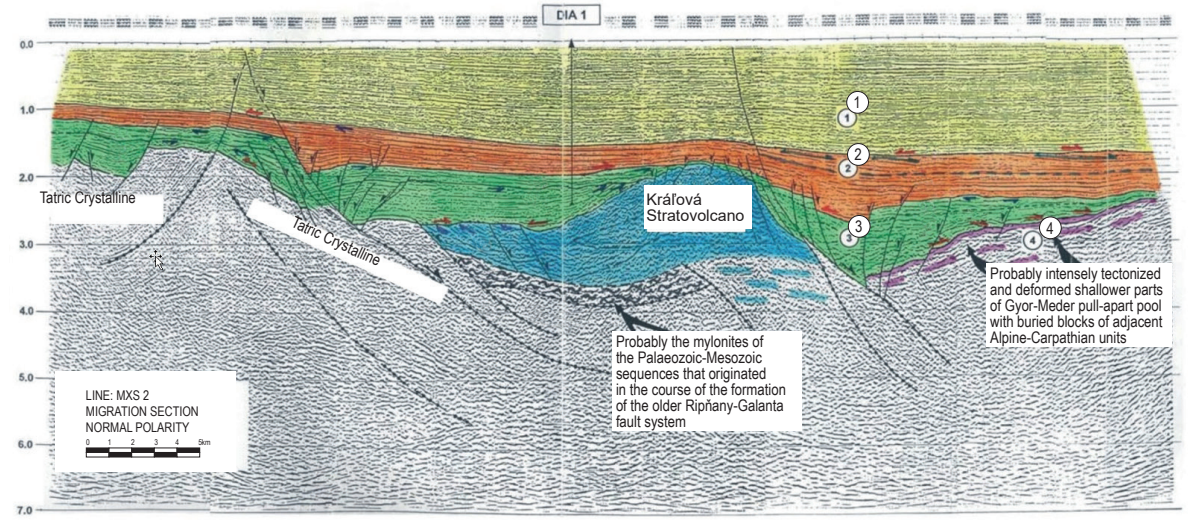


Fig. 2.4. Lithostratigraphic column of the sedimentary fill of the Slovak part of the Danube Basin (Hók et al., 2019, edited by Nagy & Fordinál)



1 – Middle Pannonian (Tortonian) – Quaternary; 2 – Early Pannonian (Tortonian); 3 – Early Badenian (Langhian) – Sarmatian (Serravallian); 4 – Pre-Cenozoic basement

Fig. 2.5 Geological section of a part of the Danube Basin (wider surroundings of the Kráľová borehole, Hrušecký, 1997)

2.2.1.1 Early Badenian (Langhian)

Šurany volcanites

In the Danube Basin there are buried andesite volcanites below the sediments of the Late Badenian age. They are widespread in the central part of the basin and also at its western edge and represent *Šurany volcanites* (Vass, 2002). In the basement of younger Neogene sediments of the Danube Basin they build a buried ridge in the space between Šurany and Šaľa. This is shown by the results of magnetic measurements (Filo in Šefara et al., 1987; Gnojek & Kubeš, 1988; Šutora et al., 1988). They are widespread in the central part of the Danube Basin and near Rusovce, at its western edge.

The volcanites were drilled by the borehole Šurany-1 near the town of Šurany north of Nové Zámky, at a depth of about 1,820 – 2,700 m as well as by the borehole Kráľová-1 near the village Kráľová nad Váhom, NW of Šaľa, but it did not drill through the volcanics (Fig. 2.5). Similar rocks were drilled by the borehole HGB-1 near Rusovce, S of Bratislava.

Stratotype profile provided incoherent core recovery borehole Šurany-1. As the Šurany-1 well showed, the volcanites overlie the pre-Cenozoic bedrock and are covered by the Špačince Fm. In the Kráľová-1 borehole, the volcanic rocks are covered by the Báhoň Fm. The drilled thickness of the volcanites in the Šurany-1 borehole is about 890 m (1,810 – 2,700 m).

The Šurany volcanites are represented by black greenish amphibolic andesites passing into the overburden made of the amphibolic-pyroxenic andesites penetrated by tiny calcite veins. The above mentioned andesites were drilled by HGB-1 borehole (1,027 – 1,124 m) in Rusovce. In their subsoil, at a depth interval of 1,124 – 1,259 m, there were found volcanic breccia formed by sharp-edged fragments of white-grey and green-black andesite cemented with a grey solid matrix (Pálfalvi, 1975). Based on argon radiometric dating, the age of andesite from the HGB-1 borehole was determined to be 16.2 ± 0.5 million years, which corresponds to Early Badenian (Kantor et al., 1984; 1987).

The Šurany volcanites are part of the Badenian volcanic arc, which continues eastwards through Burda, Börzsöny, Dunazug, Krupinská planina Plateau, Cserhát, and Mátra into NE Hungary, where the arc is buried in the Transtissia area, similarly to the Danube Basin (Vass, 2002).

Špačince Formation

The sediments of the Špačince Fm. are formed in the marginal part of the basin by sandstones, which in the direction of the basin pass into clay or claystones.

In the Blatné Depression, which extends to the region from the north, the sediments consist of sandstone, limestone, rarely organogenic sandy limestone (Jiříček in Papp et al., 1978; Vass, 1989 and Vass in Keith et al., 1989).

The basinal development is represented by grey calcareous clay with a slate disintegration, siltstone and claystone. The thickness of the lithological complex within the area of the geological map reaches about 600 m. The age of the Formation is documented by foraminifer communities from the *Spiroplectammina carinata* zone (sensu Grill, 1941).

The sediments of the Špačince Fm. originated in the marine environment, whose depth and salinity had gradually decreased.

2.2.1.2 Late Badenian (Serravallian)

Báhoň Formation

The sediments of the Late Badenian age represented by the Báhoň Fm. are preserved almost throughout the Danube Basin. On the base of the complex, in the marginal part of the basin, there are light green and green-grey breccias, formed by sharp-edged granitoid fragments and gravel with abundant intercalations of grey calcareous clays. Light grey fine- to coarse-grained sandstones are found in their overburden. In the above clays (FGB-1, Chorvátsky Grob), foraminifer communities of the Bulimina-Bolivina zone of the Late Badenian were found. The following species have been identified: *Bulimina elongata* (Orb.), *Bolivina dilatata* Reuss, *Ammonia beccarii* (L.), etc. In addition to the foraminifers, presence of molluscs *Nucula nucleus* L., *Turritella spirata* (Br.), *Megaxinus incrassatus* (Dub.) (Franko et al., 1976) was identified.

The white sand and grey-white limestones, drilled by the HGB-1 borehole near Rusovce, belong likely to the Báhoň Fm. There are small andesite fragments in the basal limestone. The presence of bryozoans and fragments of both macro and microfauna were found in limestones (Pálfalvi, 1975).

The sediments of the Báhoň Fm. in the region were found in the FGB-1 (Chorvátsky Grob) borehole at a depth range of 734.5 – 1,197.5 m (Franko et al., 1976), G-1 (Grob) at a depth range of 708 – 1,283 m (Gaža, 1970), HGB-1 (Rusovce) at a depth interval of 1,027 – 1,011 m (Pálfalvi, 1975; Brestenská in Vaškovský et al., 1984) and probably in a well drilled in Pezinok (Svoboda in Dlugi & Svoboda, 1958).

2.2.2 Sarmatian (Serravallian)

Vráble Formation

At the beginning of the Sarmatian, a sea level retreat (Grill, 1941) was documented throughout the Alpine – Carpathian region, associated with the erosion of Badenian marginal sediments (Hudáčková & Kováč, 1993; Baráth, 1993).

The sediments of the Sarmatian age are represented in the Danube Basin by the Vráble Fm. (Priechodská & Harčár, 1988; Vass, 1989 and Vass in Keith et al., 1989). On its basis, in the periphery of the basin (Bratislava region) there are coarse-grained quartz sands and sandstones, in which there occur at places horizons of gravel with pebbles composed of granitoids and crystalline schists. The thickness of the basal sediments reaches about 5 m. The above deposits overlie directly the crystalline bedrock (Cílek, 1960; Toula, 1915). Towards the overburden, the basal sediments of the Vráble Fm. pass into grey clays with unique tiny sandstone layers and into green-grey, sporadically light green sandy clays, which are strongly spotted at the bottom. This led to the earmarking of the so-called variegated and grey development of Sarmatian sediments. Varicoloured sediments and the lower part of the grey sediments belong from the stratigraphic point of view to the Early Sarmatian (Cílek, 1960).

A rich fauna of various fossil groups of organisms was found in marginal Early Sarmatian sediments.

The following foraminifers were detected: *Elphidium crispum* (L.), *E. reginum* (Orb.), *E. aculeatum* (Orb.), *Quinqueloculina karreri* (Reuss), etc., ostracods *Cytheridea mülleri* (Münst.), *Cyamocytheridea leptostigma* (Reuss), *Loxoconcha* sp., *Leptocythere* sp., gastropods *Mohrensternia pseudoangulata* (Hlb.), *M. inflata* (Andrz.), *Rissoa inflata inflata* (Andrz.) and bivalves *Cardium vindobonense vindobonense* (Partsch) and *Musculus sarmaticus* (Gat.) (Cílek, 1960; Pokorný, 1946). In the Middle Sarmatian sediments – zone *Elphidium hauerinum* there were identified foraminifers *Elphidium hauerinum* (Orb.), *E*. cf. *josephinum* (Orb.), *E*. cf. *aculeatum* (Orb.), *Nonion granosum* (Orb.) and in the Late Sarmatian deposits the foraminifers *Nonion granosum* (Orb.), *Ammonia beccarii* (L.), *Triloculina* sp. and gastropods *Acteocina lajonkaireana* (Bast.) and *Hydrobia* sp. (Cílek, 1960).

In the basin part of the Danube Basin, the terminal sediments of the Vráble Fm. consist of calcareous sandstones alternating with calcareous claystones. Thickness of the sandstone layers reaches from 3 to 13 m and claystone from 11 to 20 m. Calcareous claystones predominate, as a rule. The $CaCO_3$ content varied from 18.8% to 39% in these sediments (Priechodská in Franko et al., 1985). Foraminifers were found in microfauna from Sarmatian sediments, mainly taxa *Protelphidium* ex gr. *granosum* and *Elphidium* ex. gr. *macellum* (Brestenská in Franko et al., 1985). In the above-mentioned sediments, the highest amount of heavy minerals was represented by garnet (19.31%), tourmaline, staurolite, apatite, biotite, chlorite, ilmenite and magnetite in the amount from 1 to 5%. Minerals such as hypersthene, epidote, zoisite, zirconium, rutile and leucoxene had less than 1% share (Franko et al., 1985). Based on the above-mentioned minerals occurring in the deposits of the Vráble Fm., it can be concluded that the clastic material originates mainly from metamorphic and sedimentary rocks.

The Vráble Fm. sediments were found in the studied area in boreholes HGB-1 (902 – 1,027 m) in Rusovce (Pálfalvi, 1975), FGG-2 (2,032 – 2,101 m) in Galanta (Franko et al., 1985), in the well FGČ-1 (2,300 – 2,500 m) in Čilistov (Franko et al., 1981).

2.2.3 Late Miocene

In the past, the sediments of the Late Miocene and Pliocene age in the Danube Basin were divided into several lithostratigraphic units. Early and Middle Pannonian sediments were incorporated into the Ivanka Fm., the Late Pannonian sediments into the Beladice and Volkovce Formations and the Pliocene sediments into the Kolárovo Fm. (Kováč et al., 2011; Priechodská in Harčár et al., 1988; Vass, 2002).

New studies (dating $^{10}Be/^{9}Be$) have pointed to the heterochronous age of the aforementioned lithostratigraphic units. Sediments of the Ivanka Fm. deposited in the time interval 11.6 – 9.0 Ma, sediments of the Beladice Fm. in the interval 11.0 – 8.7 Ma and sediments of the Volkovce Fm. in the interval 10.5 to 5.0 Ma (Šujan et al., 2016).

2.2.3.1 Pannonian (Tortonian)

Ivanka Formation

At the end of the Sarmatian (Seravallian) and the beginning of the Pannonian (Tortonian), the Carpathian Mountains were uplifted, which caused the separation of the Pannonian region from the Paratethys. The Pannonian Lake was formed, which was gradually desalinised as a result of the inflow of fresh waters (Kázmér, 1990). The Pannonian (Tortonian) age sediments represented by the Ivanka Fm. deposited in a lake of caspi-brackish character, which was filled with sediments transported by rivers from the uplifted Alpine-Carpathian orogeny (Priechodská & Harčár, 1988; Vass, 1989 and Vass in Keith et al., 1989). Shallow-water and deep-water lake sediments, sediments of shelf slope and turbidites can be distinguished within the Ivanka Fm. (Šujan et al., 2016).

In the northern part of the Gabčíkovo Depression, the Ivanka Fm. is represented by layers of sand alternating with calcareous clay and silt (Pagáč et al., 1991; Hrušecký et al., 1996; Nagy et al., 1998 in Császár (ed.) et al., 2001). Coal clays and seams of lignite are rarely found in the terminal part of the formation (Vass & Gašparik et al., 1978). The layer thickness is up to 2,500 m.

Marginal sediments of the Ivanka Fm. (Bratislava area) consist of sand of various colours (yellow, grey, brown) and sandstone with granitoid fragments, which alternate with large blocks and fragments of granitoids and pegmatites (Koutek & Zoubek, 1936). In this area, biozones C and D of Pannonian with rich fauna of molluscs, ostracods, fish and calcareous nanoplankton have been identified in the sediments of the Ivanka Fm.

Sediments of the Pannonian C biozone, predominantly formed by sands, are found directly on the granitoid bedrock (Nagy et al., 1995). They contain rich communities of molluscs (gastropods, bivalves), rarely fish otoliths and calcareous nanoplankton. Taxa of *Congeria martonfii pseudoauricularis* (Lörenthey), *Parvidacna tinnyana* (Lörenthey) and *Lymnocardium spinosum* (Lörenthey) were identified among biostratigraphically significant bivalve species (Fordinál, 1995; Fordinál in Nagy et al., 1995). Among the fish, otoliths of the species "*Raniceps" pannonicus* Pana were found (Brzobohatý in Nagy et al., 1995). Calcareous nanoplankton was represented by the species *Coccolithus pelagicus* (Wallich) Schiller, *Noelaerhabdus bozinovicae* Jerkovic and *N. jerkovici* Bóna et Gál (Raková in Nagy et al., 1995).

Sediments of biozone D formed by sand with thin layers of clay and silt contained, similarly as deposits of biozone C, rich mollusc communities (gastropods, bivalves), to a lesser extent fish otoliths and calcareous nanoplankton. Among the gastropods the species *Melanopsis varicosa nodifera* Handman, *M. pumila* Brusina, *M. lebedai* Lueger, *M. austriaca* Handmann and bivalves *Lymnocardium conjungens* (Hoernes), *Caladacna ornata bisepta* (Papp) and *Parvidacna loerenthey* (Pavlović) (Fordinál, 1993 1995; Fordinál in Nagy et al., 1995) have been identified. The fish otoliths of the species *"Raniceps" pannonicus* Pana, *Atherina* sp., "Genus aff. *Umbrina* "(Schubert), *Scianidae indet*., *Perciformes indet*. and button-shape teeth of fish, probably of the *Sparidae* family (Brzobohatý in Nagy et al., 1995) were found. In the calcium nanoplankton community there were found species *Coccolithus pelagicus* (Wallich) Schiller, *Thoracosphaera deflandrei* Kamptner, *Reticulofenestra pseudoumbilica* (Gartner), *Noelaerhabdus bozinovicae* Jerković and *N. jerkovici* Bóna et Gál (Raková in Nagy et al., 1995).

In the sediments of both biozones heavy minerals were found coming from moderate to high-metamorphic rocks of paragneiss and mica schist nature. The following minerals have been identified: garnet, staurolite, muscovite chlorite and biotite (Uher in Nagy et al., 1995).

The sediments of the Pannonian E biozone of the peripheral part of the Danube Basin are predominantly composed of green-lime calcareous clays with interlayers of sand, lignite and occasionally gravel.

In the basinal part, the basal sediments of the Ivanka Fm. (Biozone A) consisted of fine-grained calcareous sandstones and grey and brownish clays/claystones. The above-mentioned lithological types alternate irregularly, with clays slightly prevailing over sandstones. The thickness of clay layers reaches 2 to 68 m, the thickness of sandstone ranges from 3 to 23 m. The $CaCO_3$ content ranged from 13.7 – 15.5%. In these sediments, ostracods communities represented by species were found: *Amplocypris* cf. *abscissa* (Reuss), *Cyprideis tuberculata* (Méhes), *Candona reticulata* (Méhes), *Hemicytheria hungarica* (Méhes), *Hungarocypris* sp. (Franko et al., 1985; Pálfalvi, 1975). In addition to ostracods, the foraminifers of *Miliammina subvelatina* Venglinski (Brestenská in Franko et al., 1985) were also found in these sediments. In the association of heavy minerals garnet prevailed (18.2 – 20,1%), in larger quantities minerals biotite (2.7 – 7.6%), chlorite (7.7%) and pyrite (1.7 – 14.1%) were also represented. Rarely, tourmaline, zoisite, ilmenite and magnetite have been reported (1 – 5%; Priechodská in Franko et al., 1985).

The Pannonian B biozone deposits in the basin are predominantly made up of light green to green-green, slightly sandy calcareous clays with charred plant residues. Sandy sediments are found only to a small extent at the eastern edge of the Slovak part of the basin. The fossil residues found in the pelitic sediments of the Pannonian B biozone were represented by sporadically occurring molluscs (bivalves) and in greater numbers represented by ostracods. From bivalves, the tests of the genera *Congeria* and *Lymnocardium* were identified (Dlugi & Svoboda, 1958).

The Pannonian C biozone sediments in the basin consist mainly of light green, light grey calcareous clays with intercalations of light grey, sometimes greenish fine- to medium-grained calcareous sandstones and sandstones. The deposits of the Pannonian D-E biozones consist mostly of greenish and light grey calcareous clays with interlayers of light grey, fine- to medium-grained calcareous sandstones and sandstones.

Beladice Formation

In the sediments of the Beladice Fm. (Priechodská & Harčár, 1988; Vass, 1989 and Vass in Keith et al., 1989), the predominant lithotype is greenish calcareous clay with silt and sand admixture, or with layers of sand. The type profile is in borehole D-1, W of the village Diakovce, depth interval 282 – 1,447 m (Homola, 1960 fide Biela, 1978).

The Beladice Fm. is characterized by dark coal clay and seams of lignite found in the area around Svätý Jur and Vajnory (Cílek, 1960). At the edges of the basin gravel/conglomerate is also present, especially at the base (Buday in Buday et al. 1962, 1967; Priechodská & Harčár, 1988; Hrušecký et al.,1991, 1996; Fordinál & Nagy, 1997). In the Sereď area, the sediments of this zone are largely developed in variegated facies and are formed by lightgreen as well as grey-green calcareous clays, often containing charred plant residues or lignite fragments (Čermák, 1969; Gaža, 1962).

The sediments of the Beladice Fm. include the Pannonian biozone F (formerly a Coal Series) and correspond to the IInd Pannonian zone, which was earmarked in the vicinity of Ivanka near Bratislava by Pokorný (1946).

In the periphery of the Danube Basin (Bratislava area), brackish, freshwater and terrestrial molluscs were found in the sediments of the Beladice Fm. Among the brackish molluscs gastropods *Theodoxus soceni* Jekelius, *Melanopsis sturii* Fuchs, *M. affinis* Handmann, among bivalves *Congeria neumayri* Andrusov and *C. zahalkai* Špalek were identified. Among the freshwater molluscs the gastropods of the genera *Lymnaea, Planorbis, Anisus* were detected; among the terrestrial ones *Carychium pachychilus* (Sandberger), *Carychium* sp., *Vertigo oecsensis* (Halaváts). There were also found ostracods *Cyprideis pannonica* (Méhes), *C*. cf. *heterostigma* (Reuss), *Leptocythere* (*Amnicythere*) aff. *larga* Krstić, *Limnocythere sanctipatrici* Brady et Robertson (Fordinál & Tuba, 1992; Gaža, 1962; Grünnerová in Cílek, 1960).

During the deposition of the Beladice Fm., there was a fluctuation of the water level, which caused the rotation of the communities of freshwater and terrestrial gastropods with the transitional communities. Level fluctuations caused flooding of coastal marsh taxodium forests and consequently the formation of shallow lakes with a rich representation of aquatic plants (*Nymphaceae, Potamogetonaceae, Sparganiaceae-Typhaceae*; Papšíková, 1989).

Sediments containing lignite layers were formed in the delta plain environ (Vass in Keith et al., 1994). The layer thickness is several 100 m, in the D-1 (Dubník) borehole up to 1,165 m.

2.2.3.2 Late Miocene – Pliocene

Volkovce Formation

The sediments of the Volkovce Fm. (Priechodská & Harčár, 1988) of the Late Pannonian (Tortonian) to Pliocene age represent the final episodes of sedimentation in the Danube Basin under continental conditions in the river and partially lake environment (Kováč et al., 2010, 2011). In the marginal parts of the Danube Basin, the Volkovce Fm. consists of gravel and sand, and the central part of the Basin is formed with varicoloured clay, silt and sand.

Type profile of pelitic sediments is represented by borehole K-2, NE of Kolárovo, depth interval 250 – 1,500 m (Gaža 1966, fide Biela, 1978). We assume that in the region in the central part of the Danube Basin, the Volkovce Fm. reaches a thickness of up to 1,200 m.

Kolárovo Formation

The Kolárovo Fm. is represented on the territory of the region by medium- and coarse-grained sands, in which there are layers of fine-grained, sporadically medium-grained gravel and calcareous clays. The sands are the main component of the formation. The coloration of the

sands and gravels of the Kolárovo Fm. is grey to greenish, strikingly different from the overburdened rusty brown Danube gravels of the Pleistocene age (Janáček, 1969). The characteristic feature of the sandstone formation is the unique occurrence of pebbles up to 15 cm in diameter. The pebbles are made of quartz, chert, sandstone, rare quartzite and crystalline schist. Another typical feature is the local nodular lithification of sands with lime cement (Buday, 1959).

The clays of the Kolárovo Fm. are facially stable and attain a thickness of 10 to 40 m. They are light grey, grey and light green in colour, only locally brownish-spotted. Varicoloured clays are rare and their thickness is small.

Tests of *Unio* bivalves and representatives of the genera *Planorbis*, *Viviparus* and *Melanopsis* were found in the deposits of the Kolárovo Fm. (Buday, 1959).

The sediments of the Kolárovo Fm. overlie transgressively and with a slight discordance (Janáček, 1969) the clays of the Late Miocene Volkovce Fm. (Late Pannonian-Pontian) age (Kováč et al., 2011).

2.3 Conclusions

Although the sedimentary fill of the area was not the subject of research, we present a brief characteristic of the individual Tertiary age geological units involved in its setting.

Palaeogene and Early Miocene age units are also likely to occur upon the pre-Cenozoic bedrock. In the marginal parts there are locally products of andesite volcanism of Early Badenian age.

The main part of the sedimentary fill consists of marine Badenian (Langhian) sediments, the Sarmatian (Serravallian) brackish and of the Pannonian (Tortonian) to Pliocene freshwater deposits.

References

Adam, Z. & Dlabač, M., 1961: Nové poznatky o tektonice Čs. části Malé dunajské nížiny. Věstník ÚÚG, 36., 3, Praha, p. 188 – 198.

Adam, Z. & Dlabač, M., 1969: Vysvětlivky k mapám mocností a litofaciálního vývoje Podunajské nížiny. Zbor. geol. Vied, Západ. Karpaty, rad ZK, zv. 11 (Bratislava), p. 156 – 172.

Baráth, I., 1993: Podmienky sedimentácie a zdrojové oblasti spodno a strednomiocénnych hrubých klastík v zóne alpsko – karpatského styku. Thesis. Manuscript. Bratislava, Archive of Geological Institute of SAS.

Biela, A., 1978: Hlboké vrty v zakrytých oblastiach vnútorných Západných Karpát. Region. geol. Západ. Karpát (Bratislava), 10, 224 p.

Buday, T., 1959: Vysvětlivky pro generální mapu ČSR list L – 33 – 6 (Čalovo). Manuscript. Archive of SGIDŠ, Bratislava.

Buday, T., Cambel, B., Maheľ, M., Brestenská, E., Kamenický, J., Kullmann, E., Matějka, A., Salaj, J. & Zaťko, M., 1962: Vysvetlivky k prehľadnej geologickej mape ČSSR 1:200 000 M – 33 -XXXV M – 33 – XXXVI, Wien-Bratislava. Geofond – Vyd. Bratislava, p. 5 – 248.

Buday, T., Cicha, I., Hanzlíková, E., Chmelík, F., Koráb, T., Kuthan, M., Nemčok, J., Pícha, F., Roth, Z., Seneš, J., Scheibner, E., Stráník, Z., Vaškovský, I. & Žebera, K., 1967: Regionální geologie ČSSR II., Západní Karpaty, sv. 2., p. 7 – 624.

Cílek, V., 1960: Neogén v severovýchodním okolí Bratislavy. Geol. Sbor. (Bratislava), 11, 2, p. 213 – 237.

Császár, G. (ed.) Pistotnik, J., Scharek, P., Kaiser, M., Darida-Tichy, M., Nagy, E., Szurkos, G., Síkhegyi, F., Budai, T., Marsi, I., Gyalog, L., Ivancsics, I., Pristaš, J., Horniš, J., Halouzka, R., Elečko, M., Konečný, V., Lexa, J., Nagy, A., Vass, D. & Vozár, J., 1998: Surface geological map, 1: 100 000. Atlas of Danube Region Environmental Geology Program (DANREG), Mag. áll. földt. Intéz., Budapest.

Čermák, D., 1969: Plytký a stredne hlboký štruktúrny prieskum v Piešťanskom výbežku. Manuscript – SGIDŠ Archive, Bratislava.

Dlugi, A. & Svoboda, S., 1958: Příspěvek k biostratigrafické charakteristice neogénu západní části Malé dunajské nížiny. In: Dlugi, A., Fischer, J., Homola, V., Janák, J., Mořkovský, M., Slavík, J., Svoboda, S., Šmeral, J. & Uhman, J.: Opěrná vrtba Báhoň – 1 v západní části Malé dunajské nížiny. Práce úst. pro naftový výskum (Brno), sv. 12, publ. 43, p. 41 – 58.

Fordinál, K., 1993a: Genus Melanopsis (Gastropoda) in Upper Miocene sediments in the Bratislava area. Západ. Karpaty, sér. Paleont. (Bratislava), 17, p. 57 – 69.

Fordinál, K., 1993b: Representatives of genus Parvidacna (Bivalvia) in Pannonian sediments of the Bratislava area. Západ. Karpaty, sér. Palaeont. (Bratislava), 17, p. 71 – 79.

Fordinál, K., 1995: Bivalvia (Dreissenidae, Cardiidae) from Upper Miocene Sediments in Bratislava. Geol. práce, Spr. (Bratislava), 100, p. 27 – 36.

Fordinál, K. & Tuba, Ľ., 1992: Biostratigrafické a palaeoekologické vyhodnotenie sedimentov územia centrálnej časti Bratislavy. Geol. Práce, Spr. (Bratislava), 96, p. 63 – 68.

Fordinál, K. & Nagy, A., 1997: Hlavinské vrstvy – okrajové vrchnopanónske sedimenty rišňovskej priehlbiny. Miner. Slovaca, 29, 6, p. 401 – 406.

Franko, O., Bodiš, D., Brestenská, E., Harča, V., Onrejičková, A., Priechodsjňká, Z., Remšík, A. & Vass, D., 1981: Správa o výskumnom geotermálnom vrte FGČ-1 v Čilistove. MS, Archive of Geofond, Bratislava.

Franko, O., Fendek, M., Bodiš, D., Brestenská, E., Priechodská, Z. & Vass, D., 1985: Správa o výskumnom geotermálnom vrte FGG-2 Galanta. Manuscript – SGIDŠ Archive, Bratislava.

Franko, O., Zbořil, O. & Mateovič, Ľ., 1976: Správa o výskumných geotermálnych vrtoch FGB-1 a FGB-1A v Chorvátskom Grobe. Manuscript – SGIDŠ Archive, Bratislava.

Gaža, B., 1962: Zpráva o štruktúrnom prieskume v oblasti Sereď v r. 1961. Manuscript – SGIDŠ Archive, Bratislava.

Gaža, B., 1970: Záverečná geologická správa o pionierskom vrte Grob -1, Manuscript, Archive of Nafta a.s., Plavecký Štvrtok.

Grill, R., 1941: Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen. Öl. u. Kohle (Berlin), 37, 595 – 602.

Vysvetlivky ku geologickej mape severovýchodnej časti Podunajskej nížiny 1: 50 000. GÚDŠ, Bratislava, p. 7 – 114.

Hohenegger, J., Ćorić, S. & Wagreich, M., 2014: Timing of the Middle Miocene Badenian Stage of the Central Paratethys. Geol. Carpath., 65, 1, p. 55 – 66.

Hók, J., Pelech, O., Teťák, F., Németh, Z., & Nagy, A., 2019: Outline of the geology of Slovakia (W. Carpathians). Miner. Slovaca, 51/1, Bratislava. p. 31 – 60.

Hrušecký, I., 1997: Centrálna časť dunajskej panvy na Slovensku – geofyzikálno-geologický model stavby a jeho vplyv na uhľovodíkové perspektívy oblasti. Thesis. Department of applied and environmental geophysics FNS CU Bratislava, 159 p.

Hrušecký, I., 1999: Central part of the Danube Basin in Slovakia: Geophysical and Geological Model in Regard to Hydrocarbon Prospection. Exploration Geophysics, Remote Sensing and Environment,VI, 1, p. 2 – 55.

Hrušecký, I., Pagáč, I. & Pereszlényi, M. et al., 1991: Vyhľadávanie a prieskum na ropu a zemný plyn v podunajskej panve. MS, Archive of Geofond, Bratislava

Hrušecký, I., Pereszlényi, M., Hók, J., Šefara, J. & Vass, D., 1993: The Danube Basin geological pattern in the light of

new and reinterpretation of old geophysical data. In: Rakús M. & Vozár J. (eds.): Geodynamický model a hlbinná stavba Západných Karpát, GIDŠ, (Bratislava), p. 291 – 296.

Hrušecký, I., Šefara, J., Masaryk, P. & Lintnerová, O., 1996: The structural and facies development and exploratioon potential of the Slovak part of the Danube Basin In: Wesely, G. & Liebl, W. (eds.): Oil and Gas in Alpidic Thrustbelts and Basin of Central and Eastern Europe. EAGE Spec. Publ. N. 5, p. 417 – 429.

Hrušecký, I., Bielik, M., Šefara, J. & Kúšik, D., 1998: Slovak part of the Danube Basin – From geological structure to lithospheric dynamics-defined from seismic profiles. Contribution to Geophysics and Geodesy, 28, 4, p. 205 – 226.

Hudáčková, N. & Kováč, M., 1993: Zmeny sedimentačného prostredia východnej časti Viedenskej panvy vo vrchnom bádene a sarmate. Miner. Slovaca, 25, 3, p. 202 – 210.

Janáček, J., 1969: Nové stratigrafické poznatky o pliocenní a pleistocenní výplni centrální části Podunajské nížiny. Geol. Práce, Spr. 50, p. 113 – 131.

Kantor, J., Harčová, E. & Rúčka, I., 1987: Izotopový výskum a rádiometrické datovanie z oblasti Veľkej Bratislavy. Manuscript – SGIDŠ Archive, Bratislava.

Kantor, J., Repčok, I., Ďurkovičová, J., Eliáš, K. & Wiegerová, V., 1984: Časový vývoj vybraných oblastí Západných Karpát podľa radiometrického datovania. Manuscript – SGIDŠ Archive, Bratislava.

Kázmér, M., 1990: Birth, Life and Death of the Pannonian Lake. Palaeogeography, Palaeoclimatology, Palaeoecology 79, p. 171 – 188.

Keith, J. F. JR., Vass, D., Kanes, W. H., Pereszlényi, M., Kováč, M. & Kráľ, J., 1989: Sedimentary basins of Slovakia, Part II., Final report on the Hydrocarbon pontenial of Danube Lowland Basin, vol. 1. Manuscript Univ. South Carolina, ESRI, Technical Report 89-0019, p. 1 – 143.

Keith, F. Jr., Vass, D. & Kováč, M., 1994: The Danube Lowland Basin. ESRI, Univ. S.C., Occasional Publ. 11 A, Columbia, p. 63 – 87.

Kilényi, E. & Šefara, J. (eds.), 1989: Pre-Tertiary basement contour map of the Carpathian Basin beneath Austria, Czechoslovakia and Hungary, 1: 500,000. Eötvös Lóránd Geophysical Institute, Budapest, Hungary.

Kováč, M., Andreyeva-Grigorovich, A., Bajraktarević, Z., Brzobohatý, R., Filipescu, S., Fodor, L., Harzhauser, M., Nagymarosy, A., Oszcypko, N., Pavelić, D., Rögl, F., Saftić, B., Sliva, Ľ. & Studencka, B., 2007: Badenian evolution of the Central Paratethys Sea: palaeogeography, climate and eustatic sea-level changes. Geol. Carpath., 58, 6, p. 579 – 606.

Kováč, M., Synak, R., Fordinál, K. & Joniak, P., 2010: Významné eventy v palaeogeografii severnej časti Dunajskej panvy – nástroj na upresnenie stratigrafie jej vrchnomiocénnej a pliocénnej výplne. Acta Geologica Slovaca, 2, 1, p. 23 – 35.

Kováč, M., Synak, R., Fordinál, K., Joniak, P., Toth, Cs., Vojtko, R., Nagy, A., Baráth, I., Maglay, J. & Minár, J., 2011: Late Miocene and Pliocene history of the Danube Basin: inferred from development of depositional systems and timing of sedimentary facies changes. Geol. Carpath., 62, 6, p. 519 – 534.

Koutek, J. & Zoubek, V., 1936: Vysvětlivky ke geologické mapě v měřítku 1 : 75 000, list Bratislava 4758. Knih. St. geol. ústavu ČSR, sv. 18, p. 7 – 150.

Maglay, J., Fordinál, K., Nagy, A., Vlačiky, M. Šefčík, P., Fričovská, J., Moravcová, M., Kováčik, M., Baráth, I. & Zlocha, M., 2018: Geologická mapa Podunajskej nížiny – Podunajskej roviny; Geological map of the Danube Lowland – Danube Flat. Reg. geol. mapy Slovenska 1: 50 000. ME SR & SGIDŠ, Bratislava.

Nagy, A., Fordinál, K., Brzobohatý, R., Uher, P. & Raková, J., 1995: Vrchný miocén juhovýchodného okraja Malých Karpát (vrt Ma-1, Bratislava). Miner. Slovaca, 27, 2, p. 113 – 132.

Pagáč, I. et al., 1995: Zhodnotenie perspektív vyhľadávania uhľovodíkov vo vybraných oblastich Západných Karpát geofyzikálnymi metódami – časť geotermika. Archive of VVNP, Bratislava.

Pagáč, I., Hrušecký, I., Pereszlényi, M., Bartková, J., Trgiňa, P., Šatalová, M., Vitáloš, R., Kováčik, M., Balucha, M., Matisová, E., Rajec, M., Vaškor, I., Országh, M. & Slávik, M., 1991: Perspektívy vyhľadávacieho prieskumu na ropu a zemný plyn v Podunajskej panve. Manuscript – SGIDŠ Archive, Bratislava.

Papp, A., Cicha, I., Seneš, J. & Steininger, F. P., (eds.), 1978: Chronostratigraphie und Neostratotypen, Miozän M_4, Badenien, Veda Bratislava, p. 1 – 594.

Papšíková, M., 1989: Biostratigrafické vyhodnotenie vrtov z územia Bratislavy (centrálna mestská zóna) na základe palynomorf. Reg. geol. Západ. Karpát, (Bratislava) 25, p. 41 – 42.

Pálfalvi, F., 1975: Geotermálny vrt Bratislava. HGB-1. Manuscript – SGIDŠ Archive,Bratislava.

Pokorný, V., 1946: K mikrostratigrafii neogénu pannonské pánve v okolí Ivánky na Slovensku. Věstník St. geol. úst. Čs. Rep., (Praha), 21, p. 262 – 273.

Priechodská, Z., Harčár, J. (eds.), Karolus, K., Karolusová, E., Remšík, A. & Šucha, P., 1988: Vysvetlivky ku geologickej mape severovýchodnej časti Podunajskej nížiny 1: 50 000. GIDŠ, Bratislava, 114 p.

Royden, L. H., Horváth, F., & Rumpler, J., 1983: Evolution of the Pannonian basin system. I. Tectonics, 2, p. 61 – 90.

Rybár, S., Halásová, E., Hudáčková, N., Kováč, M., Kováčová, M., Šarinová, K. & Šujan, M., 2015: Biostratigraphy, sedimentology and palaeoenvironments of the northern Danube Basin: Ratkovce 1 well case study. Geol. Carpath., 66, 1, p. 51 – 67.

Šefara, J. & Kováč, M., 1996: Reliéf predterciérneho podložia s vyznačením hlavných zón krehkých deformácií in Šujan, M. et al., 1996: Geologické zhodnotenie oblasti atómovej elektrárne Bohunice. Manuscript – SGIDŠ Archive, Bratislava.

Šefara, J., Bielik, M., Bodnár, J., Čížek, P., Filo, M., Gnojek, I., Grecula, P., Halmešová, S., Husák, Ľ., Janoštík, M., Kráľ, M., Kubeš, P., Kucharič, Ľ., Kurkin, M., Leško, B., Mikuška, J., Muška, P., Obernauer, D., Pospíšil, L., Putiš, M., Šutora, A. & Velich, R., 1987: Štruktúrno-tektonická mapa vnútorných Západných Karpát pre účely prognózovania ložísk – geofyzikálne interpretácie. Final report. Manuscript, SGÚ Bratislava, 267 p.

Šujan, M., Braucher, R., Kováč, M., Bourles, D. L., Rybár, S., Guillou, V. & Hudáčková, N., 2016: Application of the authigenic $^{10}Be/^{9}Be$ dating method to Late Miocene-Pliocene sequences in the northern Danube Basin (Pannonian Basin System): Confirmation of heterochronous evolution of sedimentary environments. Global and Planetary Change

Tkáčová, H., Kováčik, M., Caudt, Ľ., Elečko, M., Halouzka, R., Hušták, J., Kubeš, P., Malík, P., Nagy, A., Petro, Ľ., Piovarči, M., Pristaš, J., Rapant, S., Remšík, A., Šefara, J. & Vozár, J., 1996: Podunajsko – Danreg. Čiast. záv. spr. GS SR, Geokomplex, ME SR, MS Geofond, Bratislava, 266 p.

Toula, F., 1915. Tiefbohrung bei Pressburg. Verh. K.-Kön. geol. Reichsanst. (Wien), 14, p. 265 – 271.

Vass, D., 1989: Alpine Molase basins as a mirror of genesis and development of block structure in the West Carpathians. Z. geol. Wiss. (Berlin), 17, 9, p. 879 – 885.

Vass, D., 2002: Litostratigrafia Západných Karpát: neogén a budínsky palaeogén. Št. geol. ústav D. Štúra, Bratislava, 202 p.

Vass, D. & Gašparik, J. et al., 1978: Štúdia o pevných palivách v Západných Karpatoch. Manuscript – SGIDŠ Archive, Bratislava.

Vass, D. & Pereszlényi, M., 1998: Assymetric lithospheric stretching in Danube Basin. Slovak Geol. Mag. 4, p. 61 – 74.

Vaškovský, I., Bárta, R., Hanzel, V., Halouzka, R., Harčár, J., Karolus, K., Pristaš, J., Remšík, A., Šucha, P., Vass, D. & Vaškovská, E., 1982: Vysvetlivky ku geologickej mape juhovýchodnej časti Podunajskej nížiny 1: 50 000. GIDŠ, Bratislava, 115 p.