Devínska Kobyla – a window into the Middle Miocene shallow-water marine environments of the Central Paratethys (Vienna Basin, Slovakia)

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Devínska Kobyla – okno do plytkomorských prostredí stredného miocénu Centrálnej Paratetýdy (Viedenská panva, Slovensko)

Abstract: Middle Miocene strata exposed at Devínska Kobyla Hill (Malé Karpaty Mts) document the temporal and spatial changes in shallow-water environments of the northern Vienna Basin during the Late Badenian and Early Sarmatian. Middle Miocene deposits of the Studienka and Holíč formations border this hill essentially along its full perimeter. The present overview of 16 localities based on published observations and new sampling shows that the Middle Miocene deposits contain species-rich micro- and macrofaunal assemblages as well as nannoflora. This contribution includes lists of all marine faunal (except tetrapods) and microfloral taxa known to date. The localities can be divided into three groups on the basis of their lithology and the abundance of molluscs and foraminifers in fossil assemblages: Devín area, Dúbravka area and Devínska Nová Ves area. On the basis of foraminifers the localities in the Dúbravka area (Dúbravská hlavica, Pektenová lavica, Starý lom, partly Fuchsov lom) can be assigned to the Early Sarmatian (based on benthic taxa), whereas the localities in the Devín (Šibeničný vrch, Štítová, Terasy, Lomnická, Lingulová lavica, Glosusová lavica) and Devínska Nová Ves (Sandberg 1–2, Malý Sandberg, Waitov lom, Glavica, Štokeravská vápenka-Bonanza) areas are predominantly of the Late Badenian age (based on benthic and planktonic taxa). However, molluscs imply that the deposits from the Dúbravka area are of Late Badenian age. The differences in the estimates of stratigraphic age between on molluscs and foraminifers can be explained with the persistence of typically Badenian mollusc taxa in the marginal parts of the Central Paratethys Sea during the Middle Miocene. For every studied locality palaeoenvironmental conditions based mostly on molluscs and foraminifers are inferred.

Key words: Vienna Basin, Central Paratethys, Badenian, Sarmatian, Studienka Formation, Holíč Formation, biostratigraphy, palaeoenvironmental reconstruction.

1. INTRODUCTION

The Paratethys was a large network of inland seas that once extended from the Alps to the Caspian Sea and it was intermittently connected to the Mediterranean and the Indo-Pacific (Rögl, 1998, 1999; Kováč, 2000; Harzhauser & Piller, 2007; Harzhauser et al., 2007). The Central Paratethys was located in the area that presently extends from Austria to Poland, Ukraine and Romania. During the Miocene the Vienna Basin was an intramountain basin that represented a part of the Central Paratethys. The development of the Vienna Basin was affected by global eustatic changes and relative changes in coastal onlap during the Badenian and Sarmatian (Hudáčková & Kováč, 1993). The Late Badenian (13.6–12.7 Ma, Early Serravallian) probably represents the last period of long-term marine connection between the Paratethys and the Mediterranean (Andrejeva-Gigorovich et al., 2001; Kováč et al., 2007). Transgression and regression during that time, however, were controlled mainly by sea-level changes inside the Central Paratethys (Kováč et al., 2007). The Sarmatian (12.7–11.6 Ma, Late Serravallian) corresponds to the last stage with the deposition in hypersaline-marine to brackish environments in the Vienna Basin (Harzhauser & Piller, 2007; Borgh et al., 2010). Analyses of depositional environments of the Upper Badenian and Sarmatian infill of the Vienna Basin show distinct facies zonation from the sedimentological (Kováč et al., 2004) and palaeontological aspect (e.g. Kováč et al., 2005).

Devínska Kobyla (northern Vienna Basin) is a 514 meters high hill and an area where numerous accessible outcrops with different lithofacies and faunal assemblages occur. The climate

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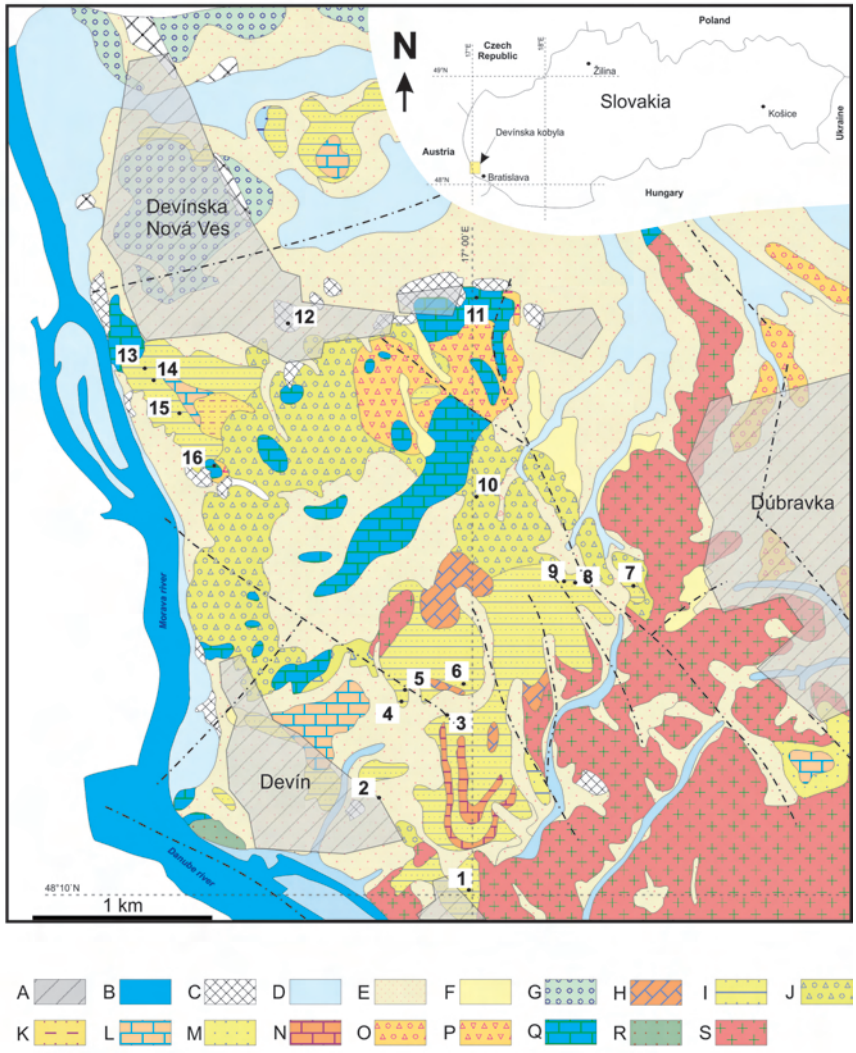

Fig. 1. Geological map of Devínska Kobyla with the position of studied localities; 1 – Šibeničný vrch (SV); 2 – Lomnická (LO); 3 – Štítová (SI); 4 – Terasy (TE); 5 – Glosusová lavica (GL); 6 – Lingulová lavica (LL); 7 – Dúbravská hlavica (DH); 8 – Pektenová lavica (PL); 9 – Starý lom (SL); 10 – Fuchsov lom (FL); 11 – Štokeravská vápenka-Bonanza (ST); 12 – Glavica (GV); 13 – Sandberg 1 (SA1); 14 – Sandberg 2 (SA2); 15 – Malý Sandberg (SA3); 16 – Waitov lom (WL); A – urbanized area; B – rivers; C – anthropogeneous deposits and dumps (Holocene); D – fluvial sediments (Holocene); E – deluvial, fluvial and proluvial sediments (Pleistocene–Holocene); F – loess (Upper Pleistocene); G – fluvial sediments (Middle Pleistocene); H – bryozoan-serpulid limestones of the Holíč Fm (Lower Sarmatian); I – sands with sandstone beds of the Sandberg Mb (Upper Badenian); J – breccias and conglomerates of the Sandberg Mb; K – aleurites and clays of the Sandberg Mb; L – corallinacean limestones of the Sandberg Mb; M – conglomerates and gravel of the Sandberg Mb; N – corallinacean limestone of the Jakubov Fm (Middle Badenian); O – breccias and gravel of the Devínska Nová Ves Fm (Middle Badenian); P – breccias of the Špačince Fm (Middle Badenian); Q – carbonates and conglomerates (Mesozoic); R – conglomerates (Palaeozoic); S – granitoids and metamorphites (Palaeozoic). Modified after Földes (1960) and Polák et al. (2011).

during the time of deposition was fairly uniform, reflecting the stable subtropical conditions of the Miocene Climate Optimum (Kováč et al., 2007). The aims of the present study are 1) to summarize the published data on the Middle Miocene localities of Devínska Kobyla with marine fossil fauna; 2) to add new data on the known localities and to describe new outcrops; 3) to refine stratigraphic assignment of these localities, with biostratigraphic dating based on foraminifers and calcareous nannoplakton; 4) to provide updated lists of fauna and nannoflora; 5) and to infer preliminary palaeoenvironmental conditions based mostly on molluscs and foraminifers.

Moreover, our presented synopsis of the Middle Miocene localities of Devínska Kobyla can be used as a field guide.

2. GEOLOGICAL SETTINGS

The studied area is situated in the eastern marginal part of the Vienna Basin at the foothills of the Malé Karpaty Mts in the Bratislava urban area (Slovakia). At Devínska Kobyla Hill numerous outcrops with Miocene marine and non-marine sediments are situated (Fig. 1). Middle Miocene marine sediments belong mostly to the Studienka Formation (Špička, 1966; Vass, 2002), which is characterized by deep-water pelites, mostly grey calcareous clay and claystones and their marginal facies equivalents. These marginal facies formed basis for establishing the Sandberg Member, lithostratigraphic unit characterized as transgressive sediments originated in littoral zone (Baráth et al., 1994). It lies erosively on Mesozoic sequences and gradually laterally passes into deep-water pelites. The lowermost part of the member consists of breccias and conglomerates followed with sands, gravel, silts and bioclastic limestones. The maximum thickness of the Sandberg Member is approximately 100 m (Baráth et al., 1994; Vass, 2002; Kováč et al., 2008).

The age of the Studienka Formation has been uniformly treated as the Late Badenian (e.g. Vass, 2002; Kováč et al., 2008). Such age was determined on the basis of both foraminiferal assemblages belonging to the Bolivina/Bulimina Zone or CPN 9 Velapertina Biozone (Cicha et al., 1975) and nannofossils of NN6 Zone (Kováč & Hudáčková, 1997). Numeric age of 13.58 Ma was based on $^{86}Sr/^{87}Sr$ ratio derived from tests of *Pappina neudorfensis* from deep-water pelites of Devínska Nová Ves-Brickyard (Tehelňa) (Hudáčková et al., 2003; Kováčová & Hudáčková, 2009).

Table 1. Synopsis of studied localities at Devínska Kobyla; summary of prevailing lithology and age estimated on different groups of fossils. Discrepancies in the age estimation (DH, PL, Sandberg facies 4) are discussed in the text. Note: Inaccessible = the locality does not exist anymore; negative = without representatives of studied group; without sampling = no samples taken.

Locality	Sedimentology	Age according:		
		Foraminifera	Calcareous nannoplankton	Mollusca
Šibeničný vrch (SV)	coarse sand, breccias	negative	negative	Late Badenian (Švagrovský, 1981; Michalík & Zágoršek, 1986)
Lomnická (LO)	Sandberg Member facies–pelites	inaccessible	inaccessible	Badenian (herein)
Štítová (SI)	calcareous sand–sandy clay	Late Badenian (herein)	negative	Badenian (herein)
Terasy (TE)	yellow-gray sandstones–fine aleuritic sands	Late Badenian Bulimina/Bolivina Zone, CPN9 (herein)	NN6 (herein)	Late Badenian (Švagrovský, 1981)
Glosusová lavica (GL)	sandy marls and clays–greenish sandy clays	Late Badenian Bulimina/Bolivina Zone, CPN9 (herein)	NN6 (herein)	Badenian (herein)
Lingulová lavica (LL)	fine-grained sands and sandstones	Late Badenian (Bulimina/ Bolivina Zone, CPN9) – ?Early Sarmatian (herein)	negative	Badenian (herein)
Dúbravská hlavica (DH)	fine calcareous sands	Early Sarmatian (Hyžný & Hudáčková, 2012)	negative	Late Badenian (Ondrejičková, 1987)
Pektenová lavica (PL)	fine-grained yellow/rusty sands and soft sandstones	Early Sarmatian (herein)	negative	Badenian (herein)
Starý lom (SL)	fine-grained pale–rusty calcareous sandstones and limestone	negative	negative	Badenian (herein)
Fuchsov lom (FL)	coarse sandstones with clasts and lithotamnia, fine massive limestones, corralinacean clay	Late Badenian, CPN9 – Early Sarmatian, CPN11 (herein)	negative	Late Badenian (Švagrovský, 1981)
Štokeravská vápenka (ST)	unconsolidated sand	without sampling	without sampling	Late Badenian (Holec et al., 1987)
Glavica (GV)	unconsolidated sand	inaccessible	inaccessible	Late Badenian (Holec, 2001)
Sandberg facies 1 (SA 1)	fine-grained pale-brown–rusty sands, occasionally with thin lenses of gravel	Late Badenian Bulimina/Bolivina Zone, CPN9 (herein)	NN6 (herein)	Late Badenian (Švagrovský, 1981)
Sandberg facies 2 (SA 1)	fine-grained pale-brown–pale-gray sands with sandstone beds and concretions	Late Badenian Bulimina/Bolivina Zone, CPN9 (herein)	NN6 (herein)	Late Badenian (Švagrovský, 1981)
Sandberg facies 3 (SA 2–3)	pale-gray sands with sandstone beds	Late Badenian Bulimina/Bolivina Zone, CPN9 (herein)	NN6 (herein)	Late Badenian (Švagrovský, 1981)
Sandberg facies 4 (SA 2–3)	massive beds of organodetritic and corralinacean limestones with sandy and clayey admixture	Late Badenian (Bulimina/ Bolivina Zone, CPN9) – ?EarlySarmatian (herein)	Early Sarmatian (NN6; FO *Calcidiscus macintyrei*) (herein)	Late Badenian (Švagrovský, 1981)
Waitov lom (WL)	sands	without sampling	without sampling	Late Badenian (Zágoršek, 1985)

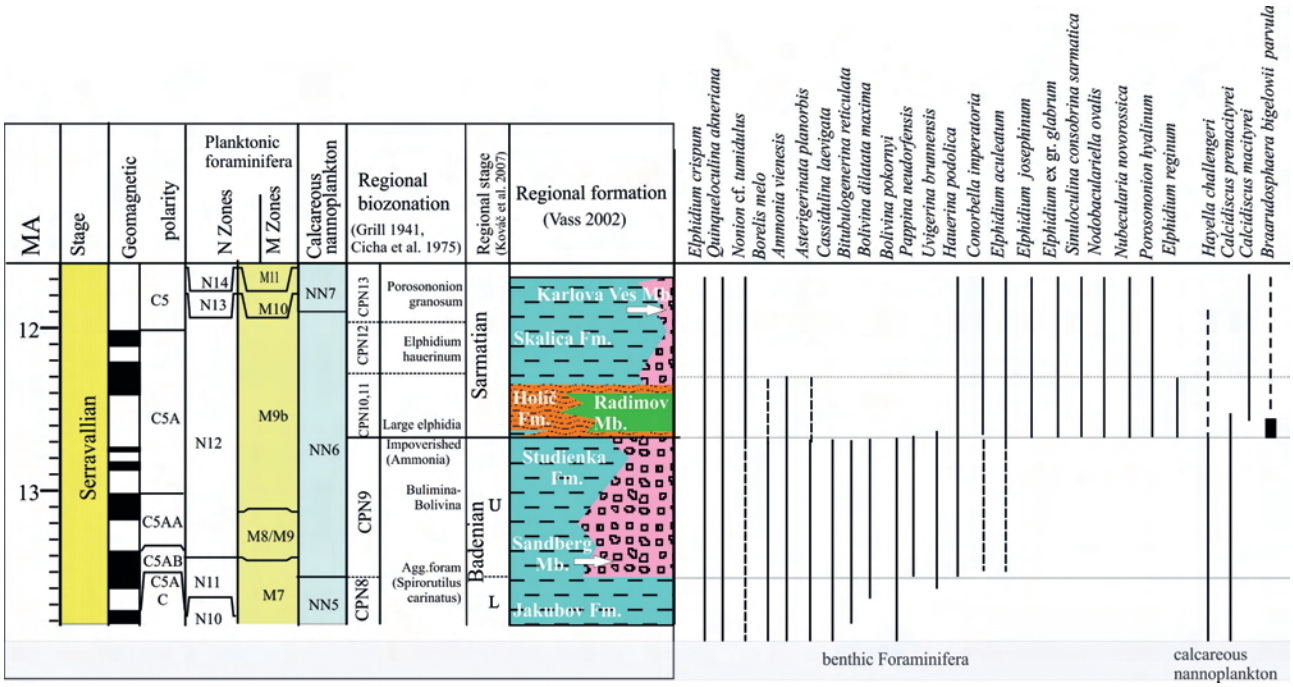

Fig. 2. Stratigraphic significance of selected taxa of benthic foraminifers and calcareous nannoplankton.

The Lower Sarmatian is represented by the Holíč Formation (Elečko & Vass in Baňacký et al., 1996; Elečko & Vass, 2001). The predominant lithofacies of the formation are represented by calcareous clay to silt with layers of clay, sand and/or sandstones. These deposits contain foraminiferal assemblages of the Elphidium reginum Biozone (Large elphidia Biozone) and Elphidium hauerinum Biozone (*sensu* Grill, 1941).

3. MATERIAL AND METHODS

Studied localities can be divided into three groups: 1) localities that were described in literature, including Sandberg (SA) or Dúbravská hlavica (DH); 2) localities known to collectors, but never properly treated in literature, such as Fuchsov lom (FL), Pektenová lavica (PL) or Lingulová lavica (LL); 3) and outcrops made by authors, and reported here for the first time, such as Glosusová lavica (GL) or Štítová (SI). Some localities do not exist anymore (Glavica, GV; Lomnická, LO). Geographic position of the localities was referenced using global positioning systems (GPS).

The localities were studied in different extent depending on accessibility of outcrops and abundance of fossiliferous horizons. With few exceptions (see below) each lithofacies at individual localities was sampled for micro- and macrofauna and nannoflora. Probability of detection of rare faunal elements was maximized by repeated collection activities over a range of years. If more than one prevailing lithofacies is present at locality, we divided the sequence into lithological members and numbered them consecutively from the base upward. The faunal assemblages have been evaluated separately from each lithological member to ensure that ecologically disparate assemblages will not be mixed.

Presented compiled lists of the fossil marine fauna (excluding tetrapods) (Appendices 1 and 2) and nannoflora (Appendix 3) are based on three types of sources: 1) published data; 2) data presented in unpublished manuscripts and theses; and 3) data based on extensive collecting by the authors. All data given in not peer-reviewed theses or manuscripts were carefully scrutinized including re-examination of figures. These literary sources are kept at the Department of Geology and Palaeontology (Comenius University, Bratislava) and can be accessed if needed.

The stratigraphic age of the studied sediments was inferred either from the foraminifers, nannoplankton or molluscs (Table 1). In most localities results from at least two independent sources were compared. Localities Štokeravská vápenka-Bonanza (ST), Glavica (GV) and Waitov lom (WL) were not studied in detail, thus, their stratigraphic age was not verified by us; presented synopsis gives only an overview of already published data for these localities.

Altogether 48 samples were taken for the study of foraminiferal assemblages; number of samples for each locality is given in brackets: Šibeničný vrch (1), Štítová (1), Terasy (1), Glosusová lavica (16), Lingulová lavica (7), Fuchsov lom (6), Pektenová lavica (7), Dúbravská hlavica (4), and Sandberg (5). The samples were wet sieved with 0.2 mm, 0.125, and 0.071 mm mesh sizes. Foraminifers (benthic and planktonic) were picked and identified for the biostratigraphic analysis. From each positive sample, about 200 specimens of benthic foraminifers were picked (if possible), identified and counted. The raw data were transformed into percentages over the total abundance and percentage abundance curves were plotted. For the samples containing at least 100 individuals, palaeoecological parameters were evaluated on the presence and dominance of taxa exhibiting special environmental significance. Species with similar environmental significance were grouped to better interpret their distributional patterns (Table 2).

Assemblage structures and environmental stress of foraminifers were investigated through the diversity indices (Simpson, Shannon-Wiener – H' and Evenness – J').

Calcareous nannofossils were analysed semiquantitatively in smear slides prepared from all lithologies by standard techniques described by Bown & Young (1989). Slides were studied under Olympus BX 50 polarising microscope (magnification 1250×).

For the biostratigraphic interpretations of the foraminiferal associations the standard zonation by Grill (1941) and Cicha et al. (1975), and stratigraphical ranges of benthic foraminifers by Cicha et al. (1998) were used. For the calcareous nannoplankton biostratigraphic interpretations, Perch-Nielsen (1985) stratigraphic ranges were used and applied into the NN zones *sensu* Martini (1971). The range of selected stratigraphically important taxa is shown in Fig. 2. Biostratigraphic significance of molluscs was consulted mostly with Steininger et al. (1978), Švagrovský (1981), Studencka (1986), and Studencka et al. (1998). The current status of the Miocene Central Paratethys stratigraphy was summarized by Piller et al. (2007); thus, we make a reference to this paper in the matter of correlation between the Central Paratethys regional stages and the Mediterranean scale.

In order to better identify and characterize changes in assemblage structures and to relate these to changing environmental conditions for the general palaeoecological interpretation and among-locality similarity, the data were treated statistically using software PAST (Hammer et al., 2001) and R (R Development Core Team, 2012). From the data (presence/absence of studied taxa) classes representing palaeocommunities by hierarchical clustering using the Bray-Curtis Similarity were obtained; this has been done both for molluscs and foraminifers separately as well as for the entire faunal assemblages. Based on the same similarity matrix, samples have successively been ordered by non-metric Multidimensional Scaling (nMDS) to represent the assemblages along the ecological gradients subtending them.

4. SYNOPSIS OF STUDIED LOCALITIES AT DEVÍNSKA KOBYLA

The studied localities can be divided into three groups according to their exposure on the slopes of the Devínska Kobyla Hill (cf. Švagrovský, 1981): 1) localities on the southern slopes of the hill close to Devín, indicated by numbers 1–6 in Fig. 1 (corresponding to the localities Šibeničný vrch, Lomnická, Štítová, Terasy, Glosusová lavica, and Lingulová lavica); 2) localities on the eastern slopes of the hill close to Dúbravka, indicated by numbers 7–10 in Fig. 1 (corresponding to the localities Dúbravská hlavica, Pektenová lavica, Starý lom, and Fuchsov lom); and 3) localities on the northern and western slopes close to Devínska Nová Ves, indicated by numbers 11–16 in Fig. 1 (corresponding to the localities Štokeravská vápenka-Bonanza, Glavica, Sandberg 1, Sandberg 2, Malý Sandberg, and Waitov lom). From the localities on the southern slopes most complete sequence can be studied at Šibeničný vrch; similarly Fuchsov lom on the eastern slope and Sandberg on the western slope represent the most complete sequences of respective areas. At these three localities, several independent lithostratigraphic units with different faunal composition occur, whereas most other localities are outcrops in one or two lithofacies.

In the synopsis below, every locality was labelled with two-letter code. These codes are used in Appendices as well as in the subsequent text. We widely use Slovak names of the localities; if applicable English translations are given too. At the end of the title of each locality a number in brackets is given – it represents the number under which the locality is marked in Fig. 1.

4.1 Devín-Šibeničný vrch (SV) – Šibeničník Hill (1)

Other names – Devín-Pieskovňa (Švagrovský, 1981); Devín-Záhradky, Šibeničník-Hill (Galgenberg) (Michalík & Zágoršek, 1986).

Geographical position – The locality is situated SE of Devín on the southern slope of the Šibeničník Hill. The area of

Elphidiids	Attached	Epifauna-	Infauna	Miliolids
non-keeled elphidiids, nonioniids 0-70‰ sal., partly infauna	**permanently**	**high organic influx**		**32-65‰ sal.**
Elphidium cf. *hauerinum* *Nonion tumidulus* *Nonion commune*	*Lobatula lobatula* *Planorbulina*	*Cancris auriculus* *Cassidulina laevigata/carinata* *Melonis barleanum* *Hoeglundina elegans* *Discorbis*	*Bolivina* aff. *plicatella* *Bolivina* aff. *pseudoplicata* *Bolivina antiqua* *Bolivina* cf. *hebes* *Bolivina pokornyi* *Bolivina dilatata maxima* *Bolivina spathulata* *Bolivina viennensis* *Bulimina aculeata* *Bulimina elongata* *Bulimina intonsa* *Buliminella elegantissima* *Pappina* *Uvigerina*	*Articulina* *Quinqueloculina* *Miliolinella* *Triloculina*
keeled elphidiids 30-70‰ sal., phytal	**temporary**	**phytal reef, hard substrate seagrasses**		
Elphidium fichtellianum *Elphidium aculeatum* *Elphidium josephinum* *Elphidium crispum* *Elphidium macellum*	*Rosalina* *Schackoinella*	*Amphistegina* *Borelis* *Asterigerinata* *Heterolepa* *Miniacina miniacea*		

Table 2. Ecological significance of selected taxa of foraminifers. After Poag (1981), Corliss & Chen (1988), Kaiho (1994) and Murray (2006).

Devín-Záhradky as presented by Michalík & Zágoršek (1986) covered five different outcrops (not accessible today) (Michalík & Zágoršek, 1986: fig. 1). The present study is based on additional existing outcrop.

GPS coordinates: N 48°10'06'', E 17°00'04'' (225 m).

Locality description – A discontinuous outcrop is approximately 30 m long and at some places about 3.5 m high (Fig. 3A). The exposed succession is several meters thick and corresponds to β and γ members of Michalík & Zágoršek (1986). The lower member (β) consists of unsorted clastics (conglomerates). Macrofossils are represented mostly by molluscs (e.g. families Pectinidae, Cypraeidae, Conidae), bivalve shells are usually disarticulated. The presence of at least six coral taxa (*Actinastraea*, *Discotrochus*, *Flabellum*, *Porites*, *Siderastraea*, and *Tarbellastraea*) in this member is notable because at studied localities corals are usually absent (see Appendix 1). The upper member (γ) consists of pale friable coarse arcose sandstone (or sand) with angular grains. The malacofauna is dominated by bivalves; sessile epifauna is

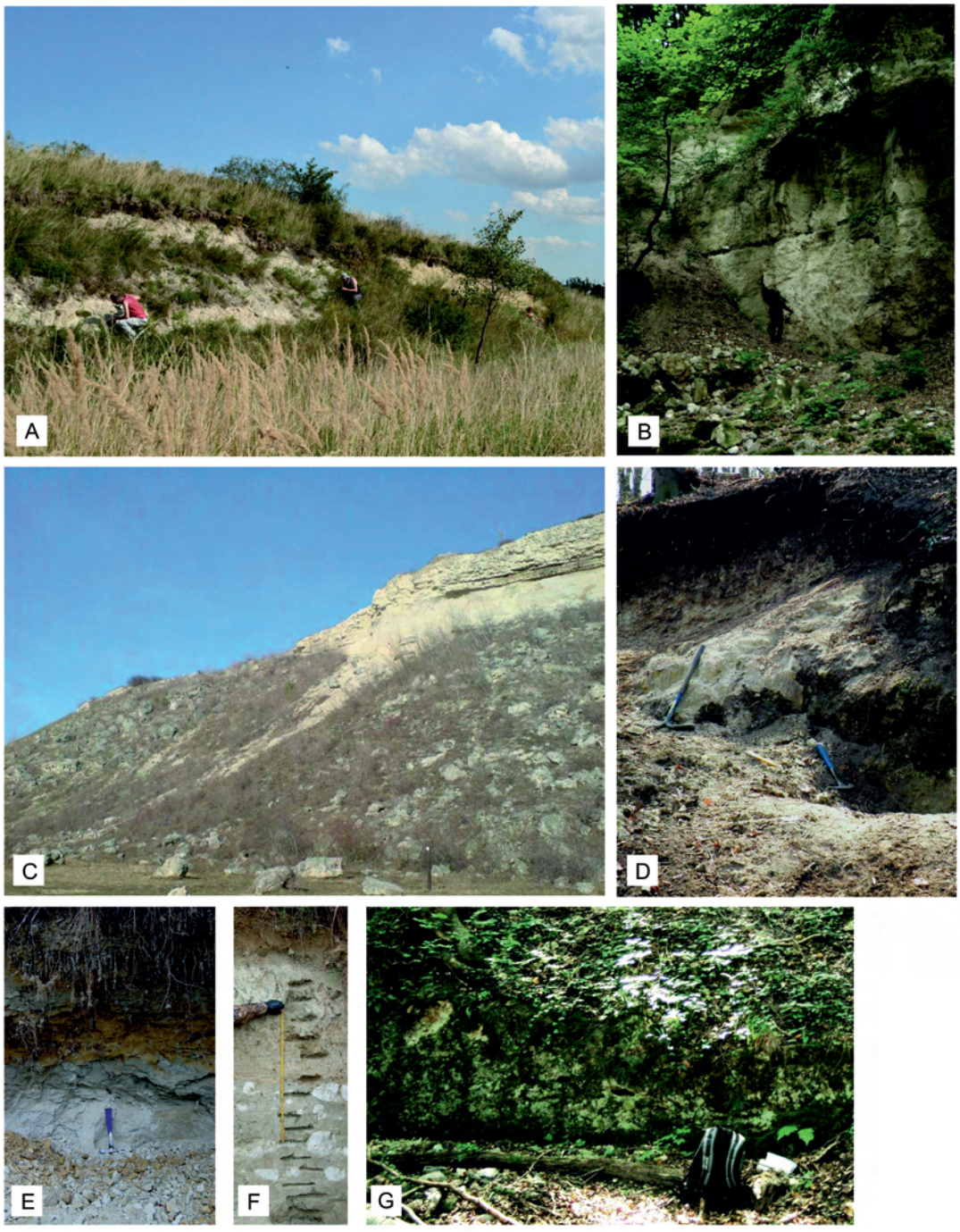

Fig. 3. Photographic documentation of selected studied localities; A – Šibeničný vrch (SV); B – Fuchsov lom (FL); C – Sandberg 2 (SA 2); D – Pektenová lavica (PL); E – Lingulová lavica (LL); F – Glosusová lavica (GL); G – Starý lom (SL). Photos by the authors: A (RB); B (MH); C, G (SR); D (TF); E–F (NH).

represented by genera *Cubitostrea*, *Anomia*, and *Spondylus*, mobile epifauna by *Crassadoma*, *Aequipecten*, *Flabellipecten*, and *Oppenheimopecten*. Fauna of other lithological members *sensu* Michalík & Zágoršek (1986) is summarized in Appendix 1.

Stratigraphic age – According to Steininger et al. (1978) and Švagrovský (1981), *Flabellipecten besseri*, *F. leythajanus*, *Oppenheimopecten aduncus*, *Codakia leonina*, and *Acanthocardia* (*A.*) *turonica* are in the Central Paratethys confined to the Badenian. Švagrovský (1981) and Michalík & Zágoršek (1986) estimated the age of sediments as Late Badenian. No foraminifers were obtained from the studied sample.

Previous studies – Group of small outcrops in the area was mentioned by Koutek & Zoubek (1936). The malacofauna of Šibeničný vrch was investigated by Švagrovský (1981). Detailed lithofacies description together with the list of fossil fauna was published by Michalík & Zágoršek (1986). They investigated the lower 40 metres of the approximately 70 m thick sequence (today it is partly covered with debris) and recognized six lithologically and faunistically different members (α – ζ) (Fig. 4).

4.2 Devín-Lomnická (LO) (2)

Geographical position – Due to the construction progress in Devín the locality does not exist anymore. It consisted of several outcrops in the abandoned vineyard area.

GPS coordinates: N 48°10'43", E 16°59'46" (235 m).

Locality description – In several discontinuous outcrops, three different transitional facies between the Sandberg Member facies (cf. Baráth et al., 1994) and the pelitic sediments of the Studienka Formation have been exposed. The lower part of the sequence consisted of grey clays and pale brown-grey to brown-yellow sandy clays. This facies was dominated by gastropods *Nassarius illovensis* and *Euspira helicina*, and bivalve *Corbula gibba*. In the upper part of the sequence, they passed into grey pelites with abundant molluscs (bivalves *Corbula*, *Glossus*, *Flexopecten*, *Scalaricardita*, *Neopycnodonte*, *Lucinoma*; gastropods *Turritella*, *Zaria*; scaphopod *Fissidentalium*). At some places also beds of massive fossiliferous corallinacean limestones and breccias rich in bryozoans, serpulid polychaetes and bivalves (*Neopycnodonte*, *Cubitostrea*, Pectinidae) were exposed.

Stratigraphic age – According to Steininger et al. (1978), Švagrovský (1981), Studencka (1986), Studencka et al. (1998), and Mandic (2004) bivalves *Flexopecten lilli, F. scissus, Flabellipecten besseri, F. leythajanus, Oppenheimopecten aduncus, Hinnites crispus*, and *Acanthocardia (A.) turonica,* and gastropod *Conus (Ch.) fuscocingulatus* are known in the Central Paratethys only from the sediments of Badenian age.

Previous studies – The locality was neither previously studied nor mentioned in literature. Similar molluscan assemblages were reported from the western side of Devín by Švagrovský (1981) and Ondrejičková (1987); these, however, originated from different outcrops situated more to the south.

4.3 Devín-Štítová (SI) (3)

Geographical position – The locality is situated in the former vineyard on the southern slope of Devínska Kobyla, NE of Devín

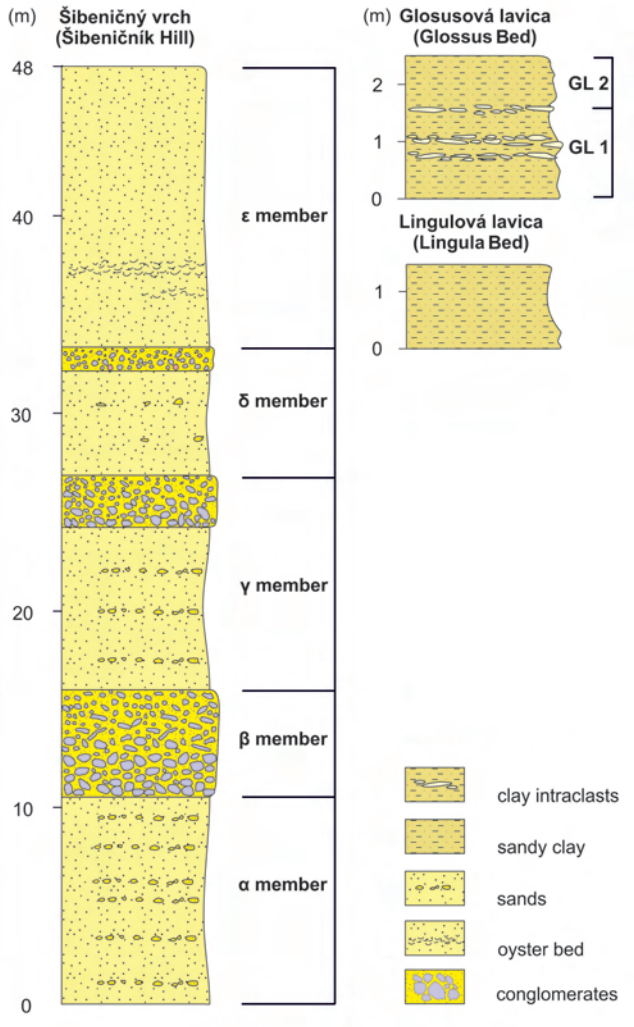

Fig. 4. Simplified lithological schemes of studied sections in the Devín area. The scheme of Šibeničný vrch was modified after Michalík & Zágoršek (1986); the uppermost member ζ is not included.

near Štítová (garden area), approximately 360 m W from the Lingulová lavica locality.

GPS coordinates: N 48°10'42", E 16°59'58" (259 m).

Locality description – The locality is represented by a small outcrop with sands and sandstones. Lower part of the outcrop consists of bioclastic sandstones with lithoclasts and plant fragments. Gastropods are very common (*Turritella*, *Conus*); bivalves are less abundant (*Acanthocardia*). Upper part of the outcrop consists of fine-grained sands with abundant bivalve shells (Pectinidae, Ostreidae). Foraminiferal assemblage from the very coarse residuum rich in mica and quartzite is dominated by large-shelled ammonias (*Ammonia inflata*) and *Elphidium crispum*. Shells of ostracods and moulds of gastropods and bivalves were also present in residuum.

Stratigraphic age – Late Badenian on the basis of co-occurrence of benthic foraminifers *Elphidium aculeatum, E. crispum*, and *Neoconorbina terquemi*. According to Steininger et al. (1978), Švagrovský (1981), Studencka (1986), and Studencka et al. (1998), *Flabellipecten besseri*, *Cardites partschi*, and *Acanthocardia (A.) turonica* are in the Central Paratethys known only from the Badenian.

4.4 Devín-Terasy (TE) – Terraces (4)

Other names – Devín–Terassen (Švagrovský, 1981).

Geographical position – The locality is situated on the southern slope of Devínska Kobyla, NE of Devín, approximately 360 m W of the locality Lingulová lavica. The locality is composed of scattered small outcrops in old vineyards.

GPS coordinates: N 48°10'38'', E 16°59'48'' (235 m).

Locality description – Yellow-grey sandstones with impoverished macrofauna are exposed together with fine aleuritic sands and sandy marls with massive concretions with high abundance of mostly infaunal bivalves (*Glossus, Thracia, Corbula*). Foraminiferal assemblage is dominated by rather deep-water taxa (*Melonis, Pullenia*). Diverse calcareous nannoplankton assemblage was obtained from the sample (*Coccolithus pelagicus, Holodiscolithus macroporus, Helicosphaera carteri, H. mediterranea, H. wallichii, Pontosphaera japonica, P. kamptneri, Umbilicosphaera rotula, Reticulofenestra haqii, Syracosphaera pulchra*).

Stratigraphic age – Based on the mollusc fauna, Švagrovský (1981) proposed the Late Badenian age. The foraminiferal assemblage (*Bitubulogenerina reticulata, Bulimina gutsulica, Reussella spinulosa, Rosalina austriaca, Spirorutilus carinatus, Textularia laevigata, Uvigerina brunnensis*) corroborates with this age estimation. Calcareous nannoplankton NN6 Biozone was identified at the locality.

Previous studies – The locality was introduced by Švagrovský (1981) as Devín-Terassen. Ondrejíčková (1987) studied molluscs from the locality called „Devín-vinohrady", but the fauna does not completely fit with the locality as described by Švagrovský (1981). According to Meszároš (pers. comm. 2012) Devín-vinohrady represents a different outcrop, although situated not far away from the Devín-Terasy locality.

4.5 Devín-Glosusová lavica (GL) – Glossus Bed (5)

Other names – Lingulová lavica 1 (Fuksi, 2011).

Geographical position – The locality is situated on the southern slope of Devínska Kobyla, NE of Devín, approximately 40 m NE of Štítová (garden area).

GPS coordinates: N 48°10'44'', E 16°59'48'' (238 m).

Locality description – An approximatelly 2.5 m-thick sequence of sandy marls and clays is exposed in a small artificial outcrop (Fig. 3F). The sequence (Fig. 4) begins with yellow-brown sandy clays followed by grey to greenish sandy clays with calcareous concretions. Molluscan assemblage of this facies (GL 1) is dominated by *Glossus* and accompanied mostly by *Neopycnodonte* and *Thracia*. The upper part of the section consists of pale brown sandy marls and grey sandy clays (GL 2).

Foraminifers are characterized by typically deep-water Upper Badenian dysoxic association dominated by the genera *Cassidulina* and *Uvigerina*. Ostracods, organic walled dinocysts, remains of echinoderms and fish otoliths were also present in the residuum. Diverse association of calcareous nannoplankton was identified (*Braarudosphaera bigelowii, B. bigelowii parvula, Syracosphaera pulchra, Helicosphaera walbersdorfensis*).

Stratigraphic age – Bivalve *Flexopecten lilli* points to the Badenian age (Švagrovský, 1981; Studencka, 1986; Studencka et al., 1998). The Late Badenian age is documented by benthic foraminifers (*Uvigerina neudorfensis* and *Uvigerina bellicostata*). Calcareous nannoplankton of the NN6 zone was identified at the locality.

Previous studies – Mollusc assemblages were briefly studied by Fuksi (2011).

4.6 Devín-Lingulová lavica (LL) – Lingula Bed (6)

Other names – Lingulová lavica 2 (Fuksi, 2011), Devín-Merice (Hyžný, 2011b).

Geographical position – The locality is situated above the former vineyards NE from Devín on the southern slope of Devínska Kobyla, approximately 420 m NE of Štítová.

GPS coordinates: N 48°10'44'', E 16°59'48'' (241 m).

Locality description – A 1.5 m thick sequence of fine-grained sands and sandstones is exposed in a small outcrop (Fig. 3E, 4). The macrofauna is dominated by molluscs, polychaetes, bryozoans, echinoids and decapods. The presence of brachiopod *Lingula* cf. *dregeri* is typical of this locality (hence its name).

Stratigraphic age – According to Švagrovský (1981), Studencka (1986), and Studencka et al. (1998), in the Central Paratethys *Flexopecten scissus* is known only from the Badenian deposits. Foraminiferal assemblage (co-occurrence of *Cibicidoides ungerianus ornatus* with *Elphidium aculeatum, E. crispum, E. rugosum*, and *Uvigerina brunnensis*) conforms to this conclusion and refines the age estimation to Late Badenian.

4.7 Dúbravská hlavica (DH) – Dúbravka Point (7)

Other names – Dúbravka-pioniersky tábor (Ondrejičková, 1987), Dúbravka pole (Holec & Sabol, 1996; Holec & Sabol in Majzlan et al., 2005).

Geographical position – The locality is situated on the western edge of the borough Dúbravka, SW of the Dúbravská Hlavica elevation point.

GPS: N 48°11'08'', E 17°01'03'' (345 m).

Locality description – The locality is situated at the road cut and is approximately 20 m long. In the past, however, the sequence was exposed over broader spatial extent due to the construction site – more outcrops were accessible in the construction pits. Fine-grained calcareous sands are exposed in an approximately 2 m-thick section (Fig. 5). Macrofauna consists mostly of gastropod *Turritella* and callianassid ghost shrimps *Neocallichirus brocchii* and *Eucalliax pseudorakosensis*. Fills of presumed *Ophiomorpha* burrows are partially lithified. Some of them contain gastropod and bivalve shells or remains of shrimps, apparently preserved *in situ* (Hyžný, 2011a; Hyžný & Hudáčková, 2012). Exposed sands overlie the massive calcareous sandstones with abundant mollusc fauna (*Glycymeris, Callista, Pelecyora, Flabellipecten*).

Microfauna is recrystallized, foraminifers are represented by genera *Pseudotriloculina, Quinqueloculina, Nodobacullariella, Articulina*, and *Elphidium*. Ostracod shells and moulds of juvenile gastropods are also present. Calcareous nannoflora is very poorly preserved, smear slides contained spicules of sponges.

Stratigraphic age – According to Steininger et al. (1978), Švagrovský (1981), Studencka (1986), and Studencka et al. (1998), *Flabellipecten leythajanus, F. besseri, Oppenheimopecten aduncus,*

Cardites partschi, *Acanthocardia (A.) turonica*, and *Conus (Ch.) fuscocingulatus* are in the Central Paratethys known only from the Badenian. Ondrejičková (1987) estimated the age of the sediments at Dúbravská hlavica as the Upper Badenian. The foraminiferal assemblage, however, points to the Lower Sarmatian, Large elphidia Biozone *sensu* Grill (1941) or Biozone 10–11 (*Cibicides* aff. *badenensis–Elphidium reginum*) of Cicha et al. (1975). Hyžný & Hudáčková (2012) noted that despite the fact that the assemblage does not contain the main zonal species (*Elphidium reginum*), it contains *Affinetrina voloshinovae*, *Articulina sarmatica*, and *Nodobaculariella ovalis* which are in the Central Paratethys restricted to the Sarmatian (Cicha et al., 1998).

Previous studies – The locality and its fossil fauna (focused on molluscs) was studied in several unpublished theses and manuscripts (Koubek, 1980; Zágoršek, 1980; Ondrejičková, 1987; Milovský, 1989). List of taxa was given by Michalík & Zágoršek (1986). Most recently, Hyžný (2012) and Hyžný & Hudáčková (2012) presented systematic redescription of several callianassid shrimp taxa occurring there in great numbers, and on the basis of foraminifers Hyžný & Hudáčková (2012) refined the age assignment of the sediments.

4.8 Dúbravka-Pektenová lavica (PL) – Pecten Bed (8)

Geographical position – The locality is situated on SE slope of Dúbravská hlavica, approximately 50–80 m SE of the Starý lom locality.

GPS coordinates: N 48°11'13", E 17°00'34" (365 m).

Locality description – An artificial outcrop on the slope (Fig. 3D) consists of fine-grained yellow-rusty sands and soft sandstones with abundant molluscs (*Turritella*, *Flabellipecten*, *Anadara*, *Cubitostrea*, *Cardites*, *Linga*). The upper part of the section is formed by pale massive bioclastic limestones with *Callista italica*. Bivalves *Flabellipecten besseri* and *F. leythajanus* are less abundant. Foraminiferal assemblage is species-poor, poorly preserved and recrystallized. It is dominated by shallow marine, epiphytic taxa as *Ephidium* (*Elphidium josephinum*) and small milliolides (*Pseudotriloculina rotunda*, *Nodophtalmidium* sp.).

Stratigraphic age – According to Steininger et al. (1978), Švagrovský (1981), Studencka (1986), Studencka et al. (1998) and Mandic (2004), *Flabellipecten leythajanus*, *F. besseri*, *Oppenheimopecten aduncus*, *Aequipecten malvinae*, *Codakia (C.) leonina*, *Cardites partschi*, and *Acanthocardia (A.) turonica* are known in the Central Paratethys only from the Badenian. Contrary to that, the foraminifers *Elphidium josephinum*, *E. reginum*, *E.* ex gr. *glabrum*, and *Sinuloculina consobrina* clearly indicate the Lower Sarmatian age. The stratigraphic position is similar to Dúbravská hlavica which is located close to Pektenová lavica (Fig. 1).

4.9 Dúbravka-Starý lom (SL) – Old Quarry (9)

Geographical position – The locality is situated on the eastern slope of Devínska Kobyla, approximately 50–80 m NW of the Pektenová lavica locality.

GPS coordinates: N 48°11'14", E 17°00'29" (383 m).

Locality description –Fine-grained pale to rusty calcareous sandstones with occasional intercalations of oolithic limestone crop out in a small abandoned quarry (Fig. 3G). The entire section is approximately 1.5 m-thick (Fig. 5). The macrofauna is dominated by bivalve *Callista italica* and accompanied by *Flabellipecten besseri*.

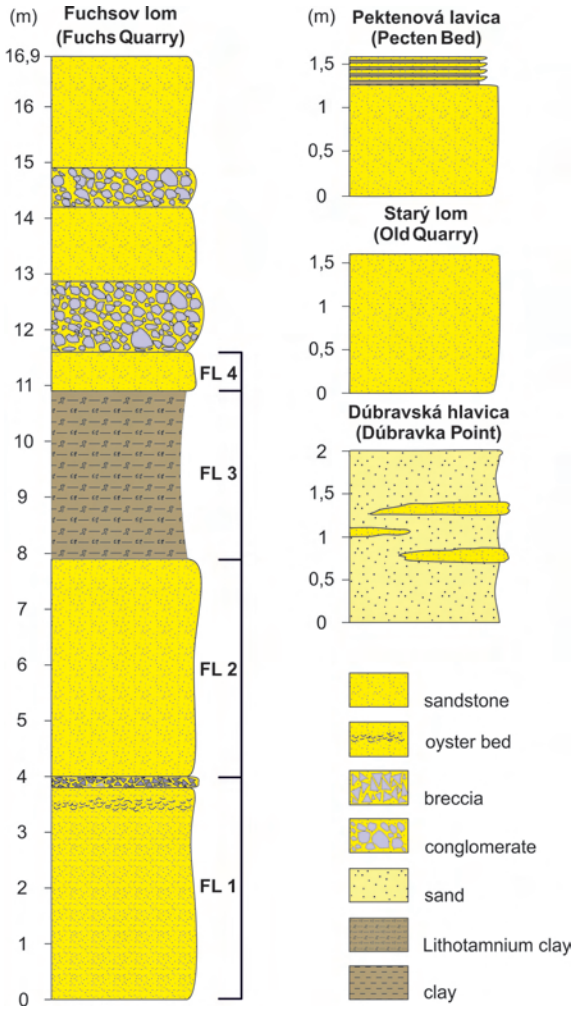

Fig. 5. Simplified lithological schemes of studied sections in the Dúbravka area. The uppermost part of the sequence at Fuchsov lom (12 m and higher) does not contain any macrofossil assemblages. The section scheme of Dúbravská hlavica was modified from Ondrejičková (1987).

Stratigraphic age – According to Steininger et al. (1978), Švagrovský (1981), Studencka (1986), and Studencka et al. (1998), the mollusc assemblage *Flabellipecten leythajanus*, *F. besseri*, and *Oppenheimopecten aduncus* is in the Central Paratethys typical only for the Badenian. However, it should be noted that the locality is situated very close to Pektenová lavica (Fig. 1) where the Lower Sarmatian age has been identified based on foraminifers (see above). These two localities are lithologically very similar.

4.10 Dúbravka-Fuchsov lom (FL) – Fuchs' Quarry (10)

Other names – Švagrovský (1981) described the locality as an abandoned quarry in corallinacean limestones NW of Dúbravka ("aufgelassener Steinbruch in Lithotamnienkalken nw. von Dúbravka"). Names Tri totemy or Biele skaly are sometimes used.

Geographical position – The locality is situated on the eastern slope of Devínska Kobyla between boroughs Dúbravka and Devínska Nová Ves.

GPS coordinates: N 48°11'43", E 17°00'12" (359 m).

Locality description –A sequence of sandstones, conglomerates and corallinacean clays is exposed in a 16.9 m-thick section (Fig. 5) in an abandoned quarry (Fig. 3B). The sequence starts with coarse-grained sandstones with clasts and red algae with indistinct bedding. The sediments become gradually finer (FL 1) higher in the sequence. In this lithofacies, up to a 20 cm-thick shell bed with *Cubitostrea* shells occurs. The sequence continues with a 20–30 cm-thick layer of breccia with large clasts followed by a thin layer of densely packed oyster shells. Higher in the section fine massive limestones, occasionally with rhodolits, are exposed (FL 2). The upper part of the section is composed of corallinacean clay beds, bioclastic limestones and layers of corallinacean limestone (FL 3). Foraminiferal assemblage is dominated by epiphytic elphidia and *Asterigerinata*. Higher, thin layers of friable sands with small pebbles formed by solid calcareous sandstones with densely packed gastropod shells occur (FL 4), followed by beds of sandstones with pebbles and coarse-grained transgressive conglomerates with pebbles (diameter of 20–40 cm). Foraminiferal assemblage is dominated by small miliolides, mostly *Pseudotriloculina rotunda* and elphidia. Special feature is the great abundance of *Miniacina miniacea*, herewith recorded from the Vienna Basin for the first time. Nannofossils are very rare; the *Coccolithus pelagicus* is present. All samples contained also big spicules of sponges. The uppermost part of the section is composed of fine-grained friable sandstones and sands.

Stratigraphic age – Based on mollusc assemblages Švagrovský (1981) estimated the age as the Late Badenian. The foraminiferal assemblage from the lower part of the sequence (FL1–3) identified as CPN9 Velapertina Biozone corroborates with this age estimation. However, the foraminiferal assemblage from the upper part of the sequence (FL 4) contains *Elphidium reginum*, *E. josephinum*, *Sinuloculina consobrina sarmatica*, and *Pseudotriloculina rotunda*, and proves the Early Sarmatian age (lower part of the Elphidium reginum Range Zone).

Previous studies – The lithology, sedimentology and mollusc fauna were studied by Švagrovský (1981).

4.11 Štokeravská vápenka-Bonanza (ST) – Štokerau Limekiln-Bonanza site (11)

Other names – Devínska Nová Ves-Bonanza (Sabol & Kováč, 2006).

Geographical position – The locality is situated on the northern slope of Devínska Kobyla, at the easternmost border of Devínska Nová Ves borough.

GPS coordinates: N 48°12'07", E 16°59'60" (210 m).

Locality description – Several fissures in the Jurassic limestones are filled with terrestrial and marine sediments, the latter are represented with unconsolidated sands. For details on the sedimentology a reference is made to Holec (2001) and Sabol & Kováč (2006). Molluscan fauna is very poor in species (Sabol & Kováč, 2006).

Stratigraphic age – In the Central Paratethys *Oppenheimopecten aduncus* is known only from the Badenian (Steininger et al., 1978; Švagrovský, 1981). The age of the marine sediments at the locality has been previously estimated as the Late Badenian by Holec et al. (1987) and Sabol & Kováč (2006), however, without detailed discussion on the mollusc macrofauna.

Previous studies – Marine faunal elements (vertebrates) of the locality were studied by Holec et al. (1987), Holec (2001), and Sabol & Kováč (2006).

4.12 Devínska Nová Ves-Glavica (GV) (12)

Other names – Glavica (Obtočník) (Holec, 2001).

Geographical position – The locality is situated on the northern slope of Devínska Kobyla between Sandberg and Štokeravská vápenka-Bonanza site.

GPS coordinates: N 48°12'09", E 16°59'15" (175 m).

Locality description – The locality does not exist anymore. It was represented by a flat sand hill with very poor (in species and specimens) fossil fauna.

Stratigraphic age – Based on the impoverished bivalve assemblage, Holec (2001) estimated the age as the Late Badenian. However, he did not mention any taxa.

Previous studies – Holec (2001) reviewed the vertebrate fauna consisting of shark and bony fish remains. Invertebrate assemblage has never been studied in detail.

4.13 Devínska Nová Ves-Sandberg

Other names – Neudorf a. d. March (Bachmayer, 1962).

Locality description – The localities are situated in the former sandpits. Transgressive marginal sediments of the Sandberg Member (Baráth et al., 1994) are exposed here. Geographically, the area can be subdivided into three distinct localities (see below), where different lithofacies are present (Sandberg facies 1–4; Fig. 6).

Stratigraphic age – The presence of molluscs *Flabellipecten besseri*, *Oppenheimopecten aduncus*, *Aequipecten malvinae*, *A. elegans*, *Hinnites crispus*, *Codakia (C.) leonina*, *Acanthocardia* (*A.*) *turonica*, *Megacardita jouanneti*, *Conus* (*Ch.*) *fuscocingulatus*, and *Cryptoplax weinlandi* can be correlated with the Badenian (Švagrovský, 1981; Harzhauser et al., 2003; Kroh, 2003; Mandic, 2004). Švagrovský (1981) estimated the sediments to be of the Late Badenian age. The same age is indicated by the foraminifers and calcareous nannoplankton suggesting the Bulimina/Bolivina Zone, or CPN9 and NN6 biozones. The Early Sarmatian age of the uppermost part of the sequence (Sandberg facies 4, see below) is based on calcareous nannoplankton assemblage of NN6 Biozone (LCO *Calcidiscus premacintyrei*, FO and FCO *Calcidiscus macintyrei*).

Previous studies – Sandberg has been palaeontologically studied since the 19th century (Hörnes, 1848, 1851–1856, 1859–1870; Hörnes & Auinger, 1879–1891; Kornhuber, 1865; Schaffer, 1908; Horusitzky, 1917). Sieber (1934) correlated mollusc assemblages across the Vienna Basin including also the Sandberg area. According to him, the gastropod assemblage from Sandberg indicates shallow marine environment with sandy bottom near the coast. Koutek & Zoubek (1936) studied geological settings of the southern part of the Malé Karpaty Mts with the emphasis

on the Neogene sediments, giving also summary of the Sandberg mollusc fauna (mainly referring to older publications). Red algae from the corallinacean limestones of Sandberg were studied by Schaleková (1969). Švagrovský (1981) published an extensive systematic monograph on the molluscs of the Bratislava area including Sandberg locality. Molluscs were also studied by Ondrejičková (1987). Decapod crustaceans were reported by Lőrenthey & Beurlen (1929), Bachmayer (1962) and Hyžný (2011b). Seneš & Ondrejičková (1991) recognized three different benthic shelf environmental zones, mediolittoral M-1, infralittoral I-2, and circalittoral C-4. Baráth et al. (1994) defined a new lithostratigraphic unit here – the Sandberg Member. Many papers were dedicated to the vertebrates of Sandberg and its surroundings (Thenius, 1952; Holec, 1985, 2001, 2006; Holec & Sabol, 1996; Holec & Schlögl, 2000; Sabol & Holec, 2002; Holec & Emry, 2003; Schlögl & Holec, 2004). Palaeontologically, stratigraphically, palaeoclimatologically and palaeoecologically the locality Sandberg can be acknowledged as one of the most important Neogene localities of the former Central Paratethys because of the unique associations of terrestrial and marine faunas of the same age (Kováč et al., 2005).

Sandberg 1 (SA 1) (13)

Geographical position – The locality Sandberg 1 is the northernmost locality of the Sandberg area. It is situated very close to borough Devínska Nová Ves.

GPS coordinates: N 48°12'03", E 16°58'29" (205 m).

Locality description – Lowermost sediments consist of coarse-grained to medium-grained breccias and sandy conglomerates. These sediments are poor in macrofossils (shells of *Spondylus* can be rarely found). Higher, they are replaced by fine-grained pale-brown to rusty sands, at some places with thin lenses of gravel (or *Ophiomorpha* traces) (Sandberg facies 1). These beds are rather poor in macrofossils; molluscs are only represented by bivalves (*Cubitostrea digitalina*, *Flabellipecten solarium*). The section continues with pale-brown to pale-grey, fine-grained sands with sandstone beds and concretions (Sandberg facies 2). The macrofauna consists mainly of molluscs (bivalves and gastropods), typically with *Flabellipecten besseri*, *Oppenheimopecten aduncus*, *Aequipecten elegans*, *Cubitostrea digitalina*, *Lucinoma borealis*, *Megacardita jouanneti*, *Panopea (P.) menardi*, *Diloma orientalis*, *Turritella* sp., and *Conus* sp.

Sandberg 2 (SA 2) (14)

Geographical position – The locality Sandberg 2 is situated approximately 100 m SE of Sandberg 1.

GPS: N 48°11'59", N 16°58'32" (218 m).

Locality description – The locality represents the largest exposed part of the marine sediments in the Sandberg area (Fig. 3C). Two distinctly different lithofacies occur here stratigraphically replacing the facies cropping out at Sandberg 1. The section begins with pale-grey sands with sandstone beds (Sandberg facies 3). The fauna is dominated with bivalves (*Cubitostrea, Anomia, Flabellipecten*, and *Oppenheimopecten*).

Foraminiferal assemblage consisting of *Bolivina dilatata maxima*, *Ammonia vienensis*, and *Cibicidoides ungerianus* identified the sediments to be of Middle to Late Badenian age.

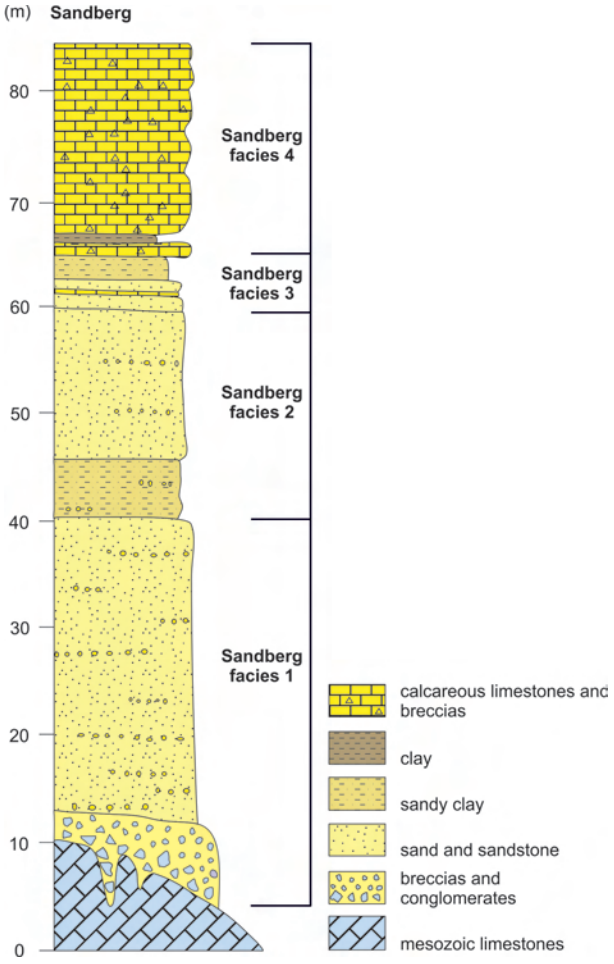

Fig. 6. Simplified lithological scheme of studied sections in the Sandberg area. The scheme was modified after Švagrovský (1981).

Massive beds of bioclastic and corallinacean limestones with sandy and clayey admixture and intercalations of bioclastic foraminiferal marls are present in the uppermost part of the sequence (Sandberg facies 4). They are exposed in the western wall of the quarry. Abundant macrofauna is composed of sponges, molluscs, bryozoans, brachiopods, polychaetes, echinoids, and decapod crustaceans. This fauna is the species-richest of all studied facies (see Appendix 1). The fauna is dominated by gastropods (*Jujubinus*, *Gibbula*, *Bolma*, *Bittium*, *Turritella*, *Eichwaldiella*). *Bolma meynardi* is a typical gastropod of these beds. Bivalves are mostly represented by *Gigantopecten*, *Manupecten*, *Plicatula*, *Spondylus*, *Glans*, and *Lutraria*. Several taxa of polyplacophorans have also been found (*Chiton*, *Acanthochitona*, and *Cryptoplax*). Foraminiferal assemblage consists mainly of *Amphistegina mammilla*. This genus is typical of back reef outer slope (Murray, 2006). The assemblage further consists of epiphytic taxa *Lobatula lobatula*, *Asterigerinata planorbis* and rare *Reussella spinulosa*. An assemblage of ostracods was also present in the residuum. A rich calcareous nannoplankton assemblage of NN6 zone was dominated by *Braarudosphaera bigelowii*, *Calcidiscus premacintyrei*, *C. tropicus macintyrei*, *Helicosphaera carteri*, *H. wallichii*, *Coccolithus pelagicus*, *Pontosphaera japonica*, *Holodiscolithus macroporus*, *Umbilicosphaera jafari*, and *Discoaster variabilis*.

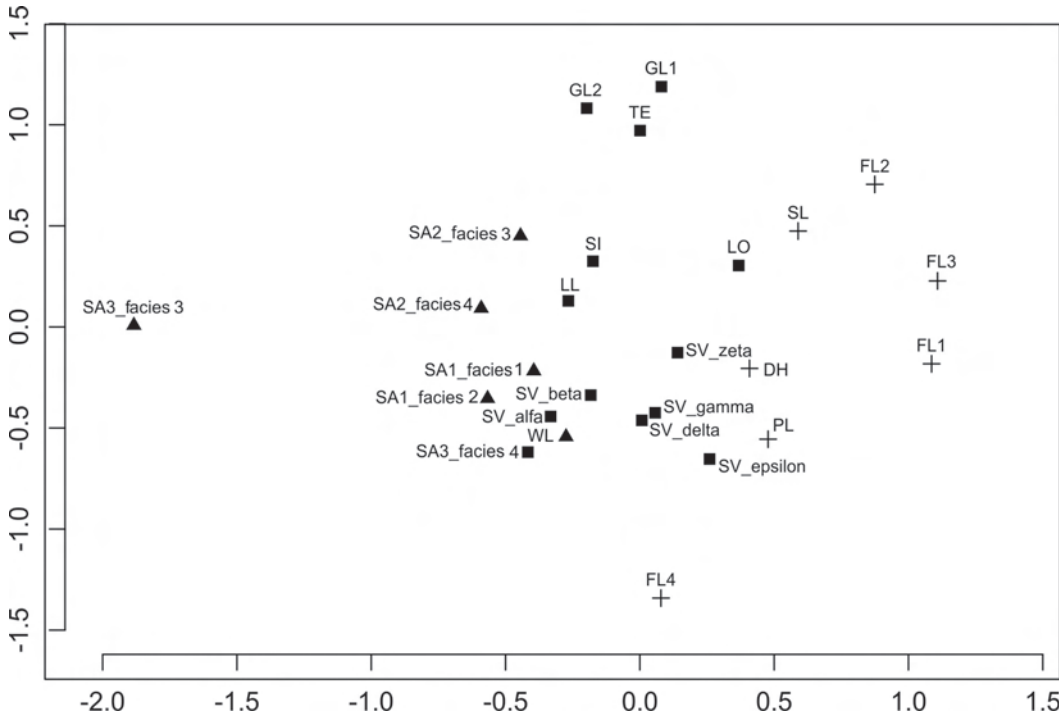

Fig. 7. NMDS analysis of all faunal components of studied localities clearly demonstrates that three geographic areas (Dúbravka area – cross; Devín area – rectangle; Devínska Nová Ves – triangle) are distinct also from the palaeoenvironmental point of view.

Malý Sandberg (SA 3) (15)

Geographical position – The locality is situated approximatelly 250 m SE of Sandberg 2.

GPS coordinates: N 48°11'51", E 16°58'38" (235 m)

Locality description – Two lithofacies of Neogene sediments are exposed in an abandoned quarry. This locality is very similar to Sandberg 2 with pale-grey sands with sandstone beds (Sandberg facies 3) in the lower part of the section and massive bioclastic and corallinacean limestones with sandy and clayey admixture (Sandberg facies 4) in the upper part. In contrast to Sandberg 2, fossil assemblages are poor in species (see Appendix 1); however a collecting bias cannot be ruled out in this case.

4.14 Devínska Nová Ves-Waitov lom (WL) – Wait's quarry (16)

Geographical position – The locality is an abandoned quarry on the western slope of Devínska Kobyla, approximatelly 400 m SE of the Malý Sandberg locality.

GPS coordinates: N 48°11'41", E 16°58'52" (254 m).

Locality description – Middle Miocene sands are transgressively deposited on the Lower Jurassic limestones, dolomites, and carbonate breccias. Invertebrate fauna is poor (Zágoršek, 1985).

Stratigraphic age – Based on rather poor mollusc assemblage the age has been estimated as the Late Badenian (Zágoršek, 1985).

Previous studies – Zágoršek (1985) studied sedimentology and palaeoecology of a small cave in Waitov lom. Holec & Sabol (1996), Holec (2001), and Holec & Sabol in Majzlan et al. (2005) reviewed the vertebrate assemblages consisting mostly of sharks, bony fish and seals.

5. DISCUSSION

5.1 Stratigraphy

Before this contribution, in the studied area and its vicinity, dating based on microfaunal or nannofloral assemblages was limited to Devínska Nová Ves-Brickyard (Hudáčková et al., 2003; Kováčová & Hudáčková, 2009). The age estimation of the Miocene sediments exposed at Devínska Kobyla has been so far made on the presence of molluscs only (cf. Švagrovský, 1981; Ondrejičková, 1987). Our results can be considered as the first age determinations of the long-time recognized localities at Devínska Kobyla Hill on the basis of foraminifers and calcareous nannoplankton. The analyses clearly show differences in age between individual localities; both Upper Badenian and Lower Sarmatian sediments crop out here.

On the basis of foraminiferal assemblages and calcareous nannoplankton the Lower Sarmatian strata have been identified in Dúbravka area (DH, PL, FL, SL) and also in the uppermost parts of the sequences exposed at other localities (LL, SV, FL, SA 2). Such a discrepancy in interpreting data (estimating stratigraphic age on the basis of different groups of organisms) can be explained with the change in ecological conditions during the late Middle Miocene. This was rather significant in such marginal parts as was the northern Vienna Basin because in isolated bays and pools different faunas can be represented. Due to these special contrasts in living conditions for microfaunal assemblages, the lack of planktonic foraminifers in the studied area at that time can lead to the inequality in the stratigraphic control (Hudáčkova in Andrejeva-Grigorovich et al., 2001). A

survey of literature has shown that numerous mollusc taxa (e.g. *Flabellipecten besseri*, *Codakia (C.) leonina*, *Acanthocardia (A.) turonica*) which are usually treated as biostratigraphically significant for the Badenian stage in the area of Central Paratethys were documented in other regions (Mediterranean, Atlantic) also from younger sediments (cf. Studencka et al., 1998). *Flabellipecten leythajanus* seems to be the only bivalve which has been documented so far only from the Badenian of the Central Paratethys (Studencka et al., 1998). *Flabellipecten lilli* and *F. scissus* are known also from the Eastern Paratethys (Studencka et al., 1998). If following the age determination based on foraminifers the occurrence of *F. leythajanus* at DH and PL (localities identified here as of the Lower Sarmatian age) is the youngest report of the species. It is, however, questionable whether at all Paratethyan localities, where the presence of *F. leythajanus* was documented, also the independent biostratigraphical tool was used (e.g. foraminifers or calcareous nannoplankton). In general, molluscs comprise rather long-ranging taxa in comparison with foraminifers and we argue that in marginal parts of the Central Paratethys foraminifers can be used for biostratigraphy more successfully. Therefore in cases with conflicting results from the biostratigraphic analyses we consider those from foraminifers as more reliable.

Concerning the presence of the Sarmatian sediments in the studied area and its closest surroundings, already Mišík (1966) mentioned *Nubecularia* and corralinacean limestones of the Sarmatian age from the Dúbravka area, however, without detailed location. These sediments may actually be correlated with the Lower Sarmatian strata in the Dúbravka area localities as presented herein (DH, PL, FL, SL).

According to Harzhauser & Piller (2004) in marginal settings a characteristic Lower Sarmatian lithology is represented by bryozoan-serpulid-algae bioconstructions, whereas Late Sarmatian is characterized by oolites and coquinas. Corralinacean limestones exposed at localities (see below) where Early Sarmatian age is estimated herein are in agreement with the statement of Harzhauser & Piller (2004). Besides the lithology, we argue that at Devínska Kobyla, a boundary between the Badenian and Sarmatian stages can be determined on the basis of foraminifers and calcareous nannoplankton. For now it can be said that it is present at some several studied localities (see above) although we are not able to determine its exact position yet. Table 1 summarizes the estimated ages of studied localities based on different groups of organisms (calcareous nannoplankton, foraminifers, and molluscs).

The Sarmatian sediments were identified also in the area of Karlova Ves borough, situated a few kilometres SE of Devínska Kobyla Hill. From the locality Záluhy (Hrubý breh nad Záluhami) Nagy et al. (1993) described the Karlova Ves Member interpreted as the Sarmatian marginal sediments. The mollusc assemblage (*Irus gregarious*, *Sarmatimactra vitaliana*) from these sediments points to the Late Sarmatian age, thus, they are significantly younger than the Sarmatian strata exposed at Devínska Kobyla. Harzhauser & Piller (2004) argued that the Karlova Ves Member is not valid lithostratigraphic term and should be abandoned due to mixing Lower Sarmatian carbonates with the Upper Sarmatian oolites and coquinas.

5.2 Palaeoenvironment

According to their geographical position at the slopes of Devínska Kobyla, the studied localities can be divided into three groups (cf. Švagrovský, 1981). Interestingly, they constitute three more-less separate groups with only minor overlap also from the palaeoecological point of view (Fig. 7). The first group is represented by outcrops situated on the western slopes of Devínska Kobyla, i.e. localities of the Sandberg area (SA 1–3) and Waitov lom. Based on foraminifers (herein) the age of the Sandberg facies 1–3, which are generally of sandy character is the Late Badenian. Basal transgressive facies are preserved at the base of the Sandberg section (cf. Baráth et al., 1994; Švagrovský, 1981). The environment can be characterized as shallow marine under a fairweather wave base or close to it (presence of e.g. *Turritella* (*H.*) *tricincta*, *Cerithium* sp., *Conolithus dujardini*, *Scaphander lignarius*) with normal salinity (presence of stenohaline taxa), typified with rather high energy (presence of *Cubitostrea digitalina*, *Crassadoma multistriata*, *Spondylus* (*S.*) *crassicosta*, *Anomia* (*A.*) *ephippium rugulosostriata*, *Chama* (*P.*) *gryphoides*, *Patella anceps*) with the slight decrease of hydrodynamics in the Sandberg facies 2. The uppermost part of the sequence (Sandberg facies 4) characterized by the presence of the corallinacean limestones represents a change in the sedimentation as reflected by 3rd order eustatic cycle (corresponding to the TB 2.6 cycle of Haq et al., 1988) correlated across the Central Paratethys (Harzhauser & Piller, 2004). Its age has been estimated as Early Sarmatian (see above).

In the Devín area most probably dysoxic conditions prevailed during the Upper Badenian as exemplified by the presence of *Corbula gibba* which thrives well under such conditions, and is present in the entire sequences of the localities Lomnická, Terasy, and the lower part of Glosusová lavica (GL 1). *Corbula* is usually distributed from low intertidal zones to considerable depths of several hundred metres (Švagrovský, 1981; Salas, 1996). Great abundances of *C. gibba* point to unstable conditions (Mandic & Harzhauser, 2003); this species is a typical opportunistic colonizer of disrupted habitats with reduced number of accompanied taxa which is able to become quickly a dominant faunal element (Hoffman, 1977, 1979; Mandic & Harzhauser, 2003). At Glosusová lavica the bottom was soft, sandy to clayey; the deposition of fine-sands and clays occurred in greater depths than at other localities of Devínska Kobyla (Fig. 8). This can be supported by diverse and abundant foraminiferal assemblage at Glosusová lavica pointing to relatively deep-water environment documented by prevalence of co-occurrence of biconvex trochospiral and rounded trochospiral morphogroups of benthic foraminifers (Corliss & Chen, 1988). The productive genera (*Melonis*, *Cassidulina*, and *Uvigerina*) dominate, documenting high nutrient influx and the oxygen depletion (Corliss & Chen, 1988; see also Table 2). The foraminiferal assemblage at Glosusová lavica can be correlated with those of Devínska Nová Ves-Tehelňa, where the environment has been interpreted as deeper neritic in the depth-range 100–200 m with stratified water column (Švagrovský 1981; Seneš & Ondrejičková 1991; Tomašových 1998; Hudáčková et al., 2003; Kováčová & Hudáčková 2009).

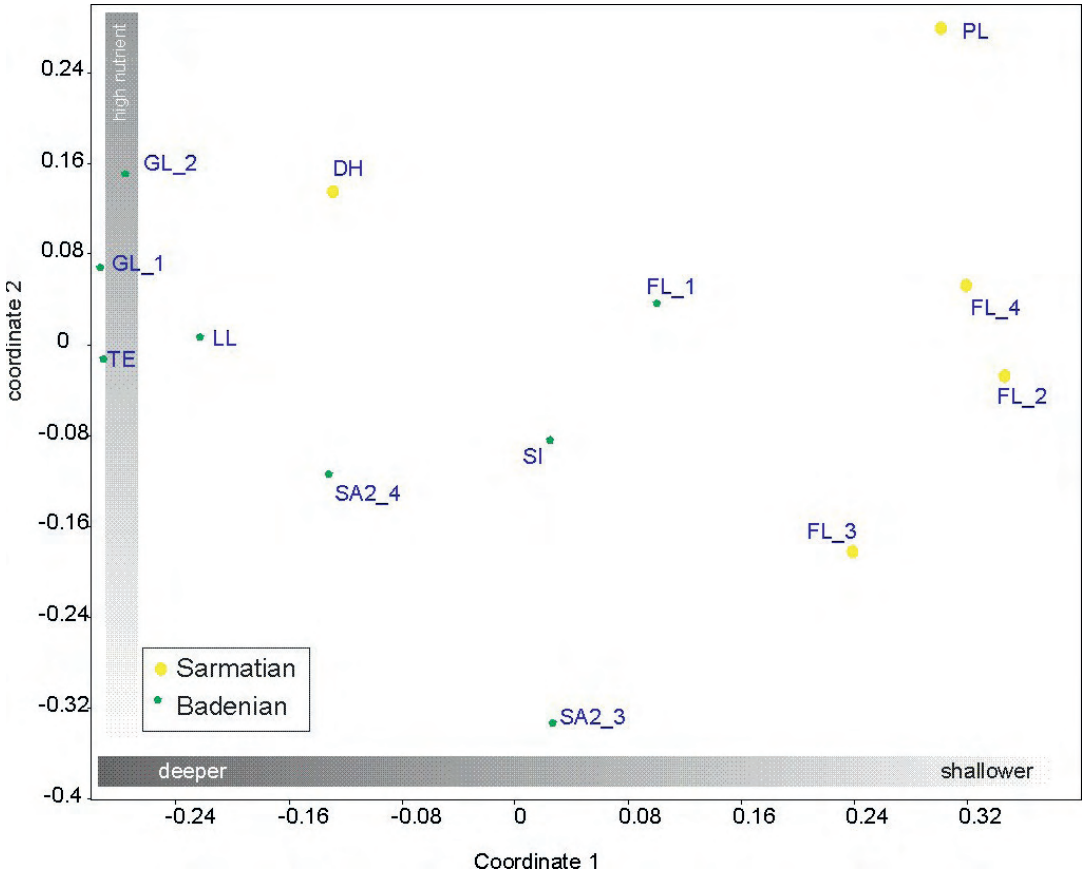

Fig. 8. NMDS analysis of the foraminiferal distribution in the studied samples.

The lower part of the sequence at Lingulová lavica is rich in flattened elongated forms of foraminifers representing mainly deep infauna and typifying dysoxic environments (Kaiho, 1994). In the upper part of the sequence at Lingulová lavica, the sediments are coarser and foraminiferal assemblage dominated by unkeeled *Elphidium* and *Ammonia* suggests shallower eutrophic environment because these genera are able to absorb nutrients even in dysoxic (*Ammonia* even in anoxic) conditions (Murray, 2006).

In the Dúbravka area the Upper Badenian sediments are exposed only at Fuchsov lom. Upper part of the sequence clearly corresponds to the Lower Sarmatian on the basis of foraminifers. In the mollusc assemblage, gastropod genera *Cerithium* and *Turritella* dominate, whereas stenohaline bivalves (e.g. Pectinidae) and echinoids are completely missing indicating lower salinity.

At Dúbravská hlavica, Pektenová lavica and Starý lom Sarmatian sediments are exposed. All these localities correspond to very shallow environment (infralittoral to eulittoral – thus, the algal dominated zone to ca. 5 metres below the low water mark) with seagrass meadows covering muddy to sandy bottom. Distinct salinity fluctuations (from brackish to hypersaline) at all three localities are documented with change of foraminiferal assemblages dominated by keeled *Elphidium* which is able to survive 30–70‰ salinity caused by seasonal fluctuation (Murray, 2006; see also Table 2), and *Ammonia* [salinity 10–31‰, common in sediments with highly variable TOC content (Murray, 2006) and may be facultative anaerobe (Pawlowski et al., 1995)]. Keeled elphidia recently live on the rhizomes of seagrasses; thus, its predominance suggests presence of dense arborescent seagrass substrate (Langer, 1993) during the earliest Sarmatian in the hypersaline environment here. Abundant callianassid shrimp remains reported by Hyžný (2012) and Hyžný & Hudáčková (2012) are in accord with this interpretation because callianassids are able to tolerate large salinity fluctuations (Dworschak, 2000) and many taxa (e.g. *Biffarius filholi*, *Corallianassa coutierei*, *Neotrypaea californiensis*) interact closely with seagrasses (Berkenbusch & Rowden, 2003; Berkenbusch et al., 2007; Kneer et al., 2008). Similarly, keeled elphidia dominate at Pektenová lavica.

At Fuchsov lom the facies FL 1–2 contained foraminiferal assemblage with *Miniacina*. This taxon usually inhabits rigid substrates (seashells, calcareous algae and others) in places of attenuated brightness (Balatta et al., 2007; see also Table 2).

The foraminiferal association from the upper part of Fuchsov lom (FL 3–4) is dominated by epiphytic genera (*Lobatula*, *Asterigerinata*, and *Cibicides*). These taxa suggest the presence of the soft bottom covered with algae or sea-grasses. The uppermost part of the sequence (FL 4) contains a mollusc assemblage with dominance of euryhaline taxa (*Bittium reticulatum*, *Cerithium* sp., *Acteocina* cf. *lajonkaireana*, *Retusa* sp., *Loripes dujardini*, *Ervilia* sp.) indicating brackish environment. Thus, the facies FL 3–4 can be correlated with the sequences exposed at Dúbravská hlavica, Pektenová lavica and Starý lom.

6. CONCLUSIONS

16 studied localities at Devínska Kobyla with the Middle Miocene strata contain species-rich assemblages of micro- and macrofauna, as well as nannoflora, and can be divided into three groups, both sedimentologically and faunistically: Devín area, Dúbravka area, and Devínska Nová Ves area. Closer correlation between these areas is obscure mainly because most of them are just few meters thick, although in all three areas one section with thicker (tens of metres) sedimentary sequence has been studied. We found out that stratigraphic results obtained from the analyses of foraminifers, calcareous nannoplankton and molluscs can differ significantly. On the basis of foraminifers, most of the localities of Dúbravka area can be assigned to the Lower Sarmatian. More detailed sampling is needed to solve the relationships between distinct areas as presented herein. Thus, we aim for the more detailed correlation between studied sedimentary sequences as the next step in new studies of the Middle Miocene strata exposed at and around the Devínska Kobyla Hill.

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