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Lower Badenian biostratigraphy and paleoecology: a case study from the Carpathian Foredeep (Czech Republic)

PAVLA TOMANOVÁ PETROVÁ[1] and LILIAN ŠVÁBENICKÁ[2]

[1]Czech Geological Survey, Leitnerova 22, 658 69 Brno, Czech Republic; pavla.petrova@cgu.cz
[2]Czech Geological Survey, Klárov 131/3, P.O.Box 85, 118 21 Praha, Czech Republic; lilian.svabenicka@geology.cz

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Abstract: The biostratigraphy and paleoecology of the Middle Miocene, Lower Badenian deposits were studied in two boreholes (Ivaň-1 and Vranovice-1) situated in the southern part of the Carpathian Foredeep, Czech Republic. Planktonic foraminifers document the M5b Zone of Berggren et al. (1995). Presence of *Uvigerina macrocarinata* Papp et Turnovsky and *Praeorbulina glomerosa circularis* (Blow) indicates "Lower Lagenid Zone" sensu Grill (1941). Calcareous nannofossils with *Helicosphaera waltrans*, *H. walbersdorfensis* and *Sphenolithus heteromorphus* give evidence for the NN5 Zone of calcareous nanoplankton (Martini 1971). Quickly changeable paleoenvironment, especially sea-level fluctuation and non-stable conditions are documented by five types of microfauna: 1. shallow-water foraminifers accompanied by fragments of molluscs and bryozoans — shallow sublittoral (infralittoral), 2. joint occurrence of agglutinated and calcareous benthic foraminifers — circalittoral to upper bathyal, 3. euryoxybiont foraminifers indicate low oxygen content in bottom water of the deeper sublittoral (circalittoral), 4. dominance of planktonic foraminifers with pyritized tests — low oxygen sea, circalittoral to upper bathyal, 5. mixed assemblages of shallow- and deep-water foraminifers document slumps. Generally, relatively shallow epicontinental sea of normal salinity with nutrient supply is supported by coastal nannoflora with higher numbers of *Reticulofenestra minuta*, *Coccolithus pelagicus*, and helicosphers. Low abundances of sphenoliths and scarce occurrence of discoasters may imply cooler surface waters. High numbers of reworked nannofossils reflect transgression.

Key words: Middle Miocene, Lower Badenian, Carpathian Foredeep, paleoecology, biostratigraphy, foraminifers, calcareous nannofossils.

Introduction

The problems of the biostratigraphic classification of the Middle Miocene, Lower Badenian (Langhian of the Mediterranean classification) deposits in the western part of the Central Paratethys, explicitly in the Carpathian Foredeep and adjacent area of the Alpine Molasse Basin have been under discussion for a long time and have not been satisfactorily solved yet. The specific development of these strata reflects an important phase in the genesis of the Alpine Molasse at the Lower-Middle Miocene boundary in the foreland of the Alpine-Carpathian chain and on the slopes of the Bohemian Massif in NE Austria and the SE part of the Czech Republic (that is in the southern Carpathian Foredeep). Different opinions on the evolution, definition and chronostratigraphic correlation of the individual lithostratigraphic units are represented by the Austrian and Czech schools. They relate to the genesis of deposits, their relationship to the underlying strata, and their fossil content including biostratigraphic and consequently chronostratigraphic correlation in the regional concept of the Central Paratethys. To obtain new information, two boreholes Ivaň IK-1 and Vranovice VK-1 were drilled in South Moravia, Czech Republic (Fig. 1). The sediments were investigated by means of study of foraminifers and calcareous nannofossils and provided data for further biostratigraphic and paleoenvironmental interpretations.

Geological setting

The Carpathian Foredeep is a peripheral foreland basin bordering the front of the Carpathian orogene belt. It was formed as a result of flexural down bending of the passive margin of the European Platform represented in this part by spur of the Bohemian Massif. The Foredeep is filled by Lower and Middle Miocene deposits of alternately marine, brackish and fresh-water origin.

Previous studies

The Lower Badenian sediments of the Carpathian Foredeep, Czech Republic and their biostratigraphic correlation according to foraminifers and calcareous nannoplankton have been presented by Švábenická & Čtyroká (1998, 1999), Čtyroká & Švábenická (2000), and Švábenická (2002). Similar problems has also been researched in the adjacent area of the Molasse Basin in Lower Austria by Rögl et al. (2002), Ćorić (2003), Ćorić & Švábenická (2004) and Ćorić & Rögl (2004) and the Styrian Basin (Spezzaferri et al. 2004). The paleoecology and biostratigraphy of foraminifers have been studied by Spezzaferri (2004). A summary of the stratigraphy and biostratigraphic correlation was published by Ćorić et al. (2004).

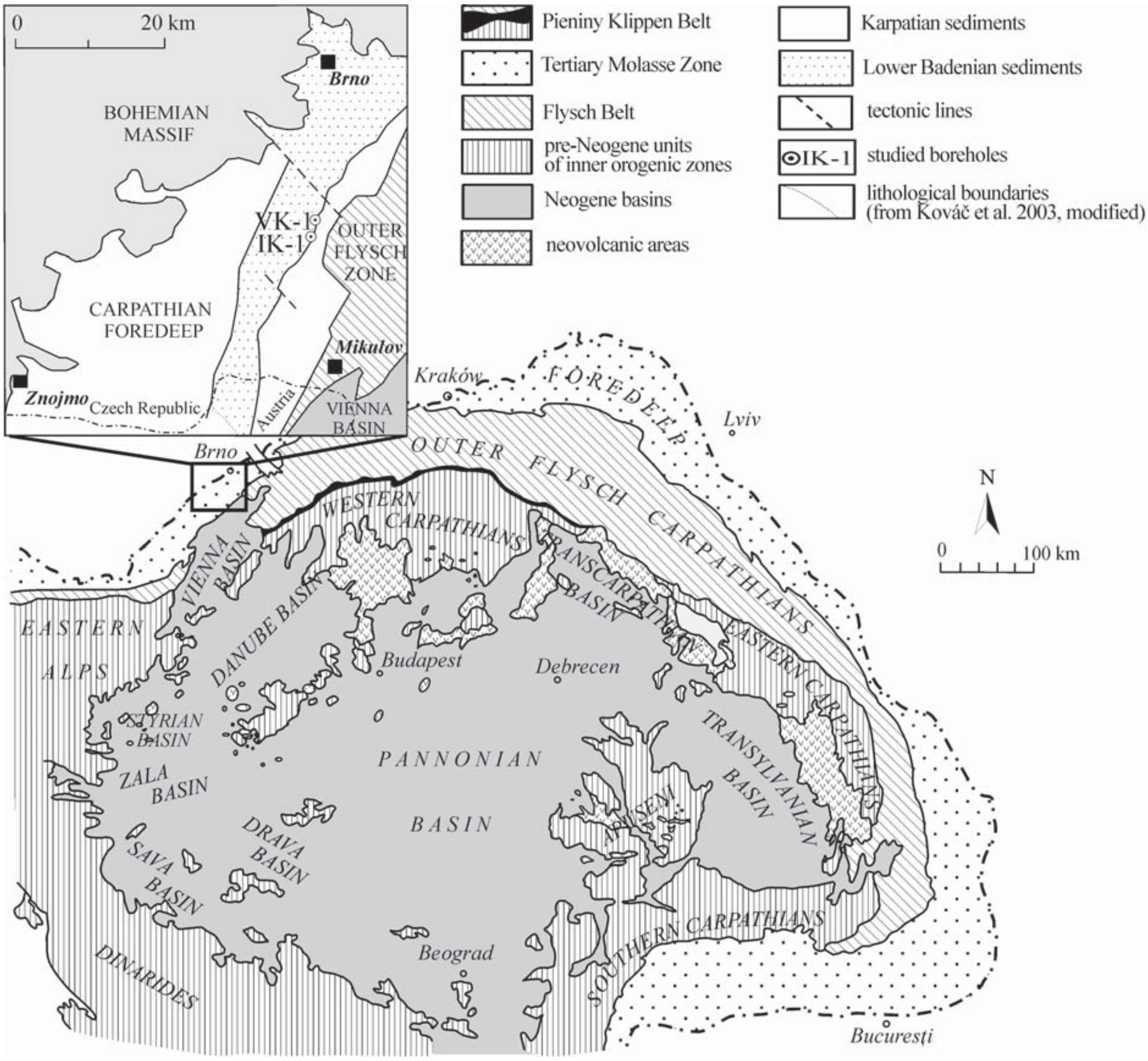

Fig. 1. Location of the Ivaň-1 and Vranovice-1 boreholes.

Material

Two boreholes, Ivaň IK-1 and Vranovice VK-1 were drilled in 2004. From the geological point of view, they were situated close to the Lower-Middle Miocene boundary that was recognized on the surface during geological mapping (Fig. 2). Boreholes were drilled at a distance of 3.7 km from each other in a NNE-SSW direction. They reached the depth of 60 m and the profiles were fully cored. Sediments were sampled approximately in 5 meters intervals with respect to their lithofacial character and sudden changes in lithology. For lithology of boreholes see Fig. 3.

Methods

The sediments were soaked in warm water with sodium carbonate for one day for dissaggregation, and then washed under running water through 63 μm mesh sieves. Foraminifers were picked from the fraction, identified with a binocular microscope WILD. Approximately 200 specimens were used for quantitative analyses. The ratio plankton/benthos (p/b) was counted as a percentage of planktonic specimens in the assemblage — p/(p+b)*100. Graphs of p/b were constructed as well as graphs of percentages of all species and graphs of percentages of benthic species. The graphs of constance of benthic and planktonic species were framed account on inclusive evaluation of the assemblages. Groups of agglutinated foraminifers, deep- and shallow-water foraminifers and euryoxybiont foraminifers were interpreted according to paleoecological studies of Murray (1991), Kaiho (1994), Spezzaferri & Ćorić (2001), and Spezzaferri et al. (2002, 2004).

Smear slides were prepared using a decantation method. Examination was carried out using an oil-immersion-objective Nikon light-polarized microscope at 1000× magnification. Quantitative data are based on approximately 500 specimens on each slide. Reworked nannofossils were omitted in proportional evaluation of the Miocene species in the assemblage.

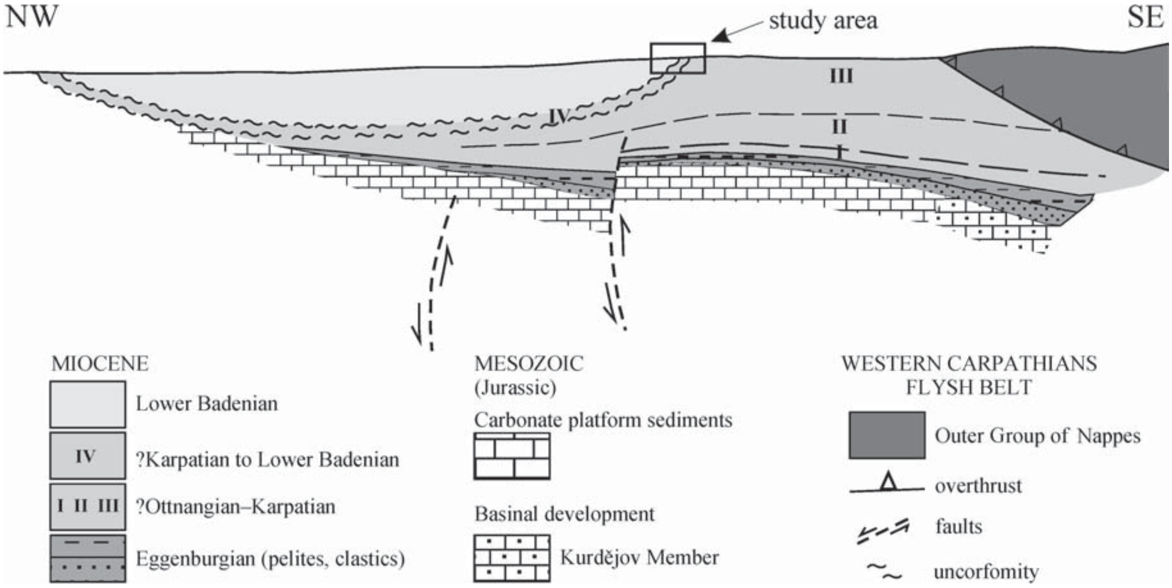

Fig. 2. Idealized structural-tectonic cross-section of the SE part of the Carpathian Foredeep, Czech Republic (from Adámek et al. 2003, modified).

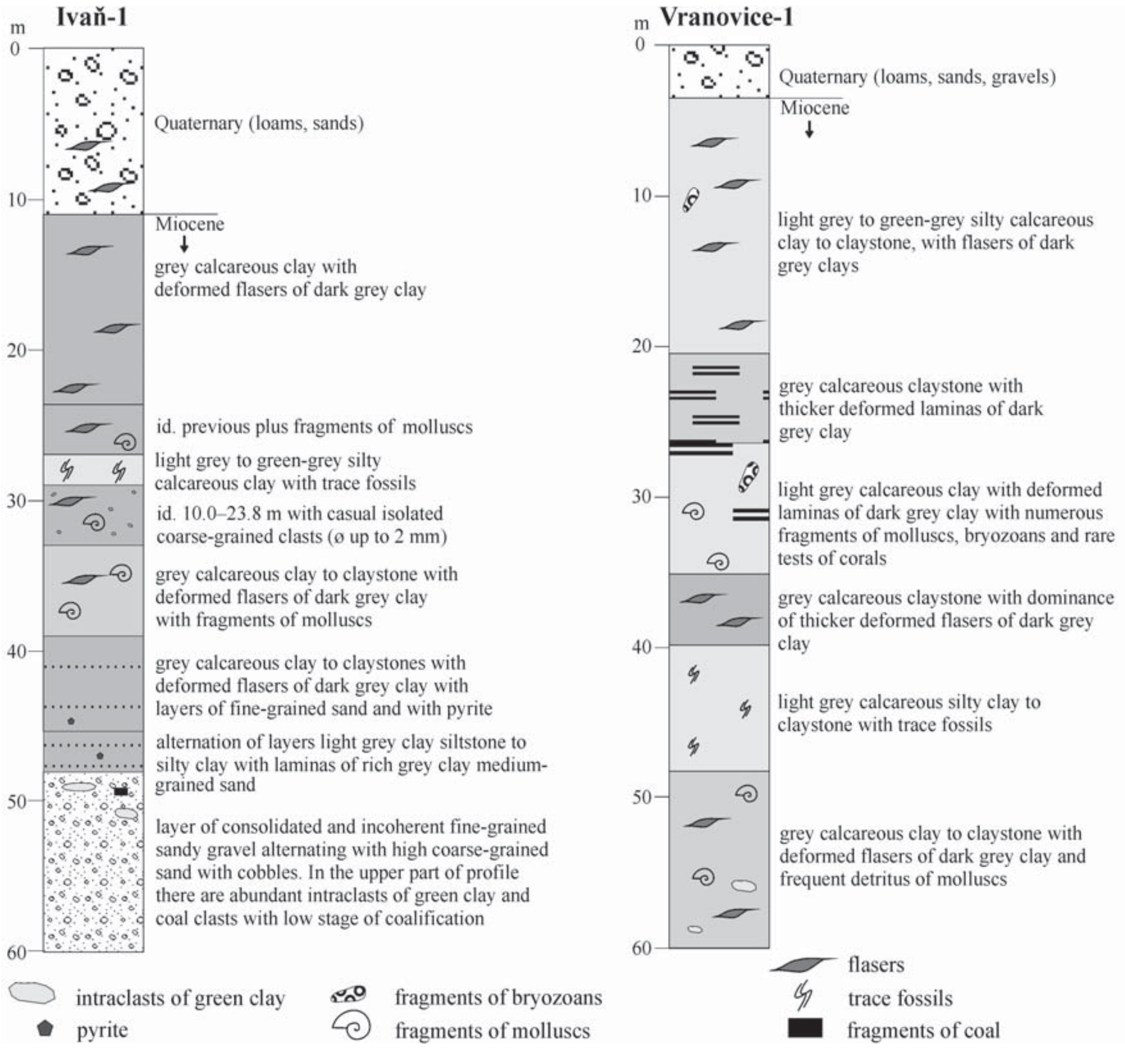

Fig. 3. Schematic lithology of the Ivaň-1 and Vranovice-1 boreholes.

Biostratigraphic data were correlated with planktonic foraminiferal zones by Berggren et al. (1995) and nannoplankton standard NN zones by Martini (1971) and MNN zones by Fornaciari et al. (1996). Central Paratethys regional stages and their comparison with nannoplankton NN zones (Table 1) and biostratigraphic evaluation of planktonic foraminifers are used according to Cicha et al. (1998).

Results

Ivaň IK-1 Borehole

Microfauna

Foraminifers are relatively well preserved and especially planktonic specimens are pyritized. Small tests dominate. The plankton/benthos ratio ranges between 60–92 % and usually reaches about 80 % (Fig. 4). Assemblages are characterized by rare occurrence of *Praeorbulina sicana* (de Stefani) accompanied by species *Praeorbulina glomerosa circularis*, *P. g. glomerosa* Blow, *Globorotalia bykovae* (Aisenstat), *Gl. peripheroronda* Blow et Banner, *Globigerinoides quadrilobatus* (d'Orbigny), *Glob. trilobus* (Reuss) and *Glob. bispehricus* Todd (Table 2). An interval with abundant specimens of *Globigerinoides* div. sp. was recognized in the interval 23.9–46.95 m. A diversified spectrum of benthic foraminifers is formed by the taxa *Uvigerina macrocarinata*, *U. semiornata* d'Orbigny, *U. acuminata* Hosius, *Bolivina hebes* Macfadyen, *Angulogerina esuriensis* Hornibrook, *Bulimina striata* d'Orbigny, *Amphimorphina haueriana* Neugeboren, *Pyramidulina raphanistrum* (Linne) and others. The taxa *Bolivina dilatata* Reuss, *Siphonodosaria scabra* (Reuss), *Globocassidulina oblonga* (d'Orbigny) and *Hansenisca soldanii* (d'Orbigny) reach higher values of constance.

Table 1: Correlation of Early and Middle Miocene with Central Paratethys stages by Cicha et al. (1998) and Gradstein et al. (2004), modified.

Ma	EPOCH	AGE	CENTRAL PARATETHYS STAGES	BIOZONES Berggren et al. 1995: Planktonic Foraminifera		Calcareous Nannoplankton
	Middle MIOCENE	SERRAVALLIAN	SARMATIAN	M11–M8		NN6
			BADENIAN	M7		
		LANGHIAN		M6		NN5
15	15.97			M5		
	Early MIOCENE	BURDIGALIAN	KARPATIAN	M4		NN4
			OTTNANGIAN	M3		
						NN3
			EGGENBURGIAN	M2		NN2
20		AQUITANIAN	EGERIAN (pars)	M1	b	
	23.03				a	NN1

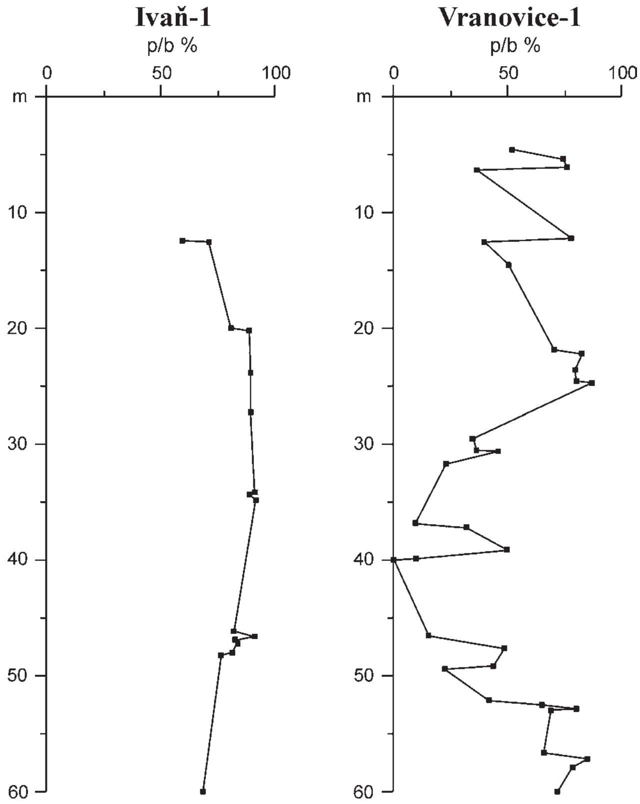

Fig. 4. Plankton/benthos ratio of the Ivaň-1 and Vranovice-1 boreholes.

Tests of foraminifers are pyritized practically in the whole profile up to 27.3 m. Autochthonous foraminifers are rarely accompanied by reworked, well preserved specimens from the Lower Miocene (Karpatian) strata such as *Globigerina ottnangiensis* Rögl (Cicha et al. 1998). Moreover, washing residues provided radiolarians, fragments of echinoid spines, molluscs, ostracods, fish bones and teeth, otoliths, numerous pyritized centric diatoms and rare fragments of sponge spicules. Crystalline pyrite was recorded in the depth of 60.0 m.

Calcareous nannofossils

Calcareous nannofossils were present in the interval of 48.25–12.45 m and the underlying strata were barren of this fossil group.

A smear slide prepared from an intraclast (48.25 m) contains abundant anorganic material and only rare and strongly damaged nannofossil oryctocoenoses — reworked specimens reach up to 90 % (Fig. 5). Autochthonous component is represented by *Helicosphaera carteri*, *H. waltrans, H. ampliaperta*, *Sphenolithus heteromorphus*, fragments of *Braarudosphaera bigelowii*, and others (Table 3).

The interval of 48.00–46.45 m also provided poor and poorly preserved nannofossils. Placoliths are strongly etched and mechanically damaged, while the distal rays of discoasters are usually broken. The assemblages are characterized by

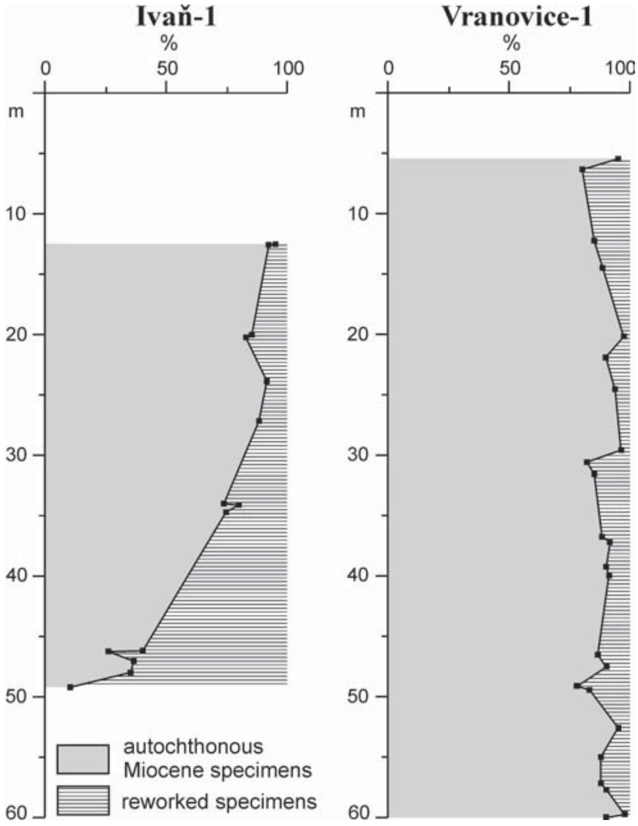

Fig. 5. Proportion of the autochthonous and reworked component in nannofossil oryctocoenoses, Ivaň-1 and Vranovice-1 boreholes.

the presence of *Helicosphaera waltrans* accompanied by *H. ampliaperta* and sporadic *Sphenolithus heteromorphus*, and by dominance of *Coccolithus pelagicus* (70–90 %). Helicosphers form about 15 %, and *Reticulofenestra minuta* occurs occasionally. Moreover, 5-rayed symmetrical discoasters are present on rare occasions. The Miocene part of oryctocoenoses fluctuates between 25–40 %, the rest is formed by reworked nannofossils from the Upper Cretaceous and Paleogene sediments. Anorganic material prevails.

The character of assemblages changes in the overlying strata. Nannofossil abundance is markedly higher and specimens are usually medium well preserved. The proportion of reworked specimens rapidly decreases and the percentage of the autochthonous part of oryctocoenoses fluctuates between 70–95 %. The assemblages are characterized by high numbers of *Reticulofenestra minuta* (55–20 %) and *Coccolithus pelagicus* (65–30 %). Helicosphers form 12–20 %. Species *Helicosphaera waltrans* and rare *Sphenolithus heteromorphus* occur continuously. The first specimens of *Helicosphaera walbersdorfensis* and *Umbilicosphaera jafari* were recorded in the depth of 46.20 m (Fig. 6).

Vranovice VK-1 borehole

Microfauna

Generally, foraminifers are well preserved and pyritized tests are found only on rare occasions (Table 4). Planktonic species *Praeorbulina glomerosa circularis* and *P. glomerosa glomerosa* are present in low numbers in the whole

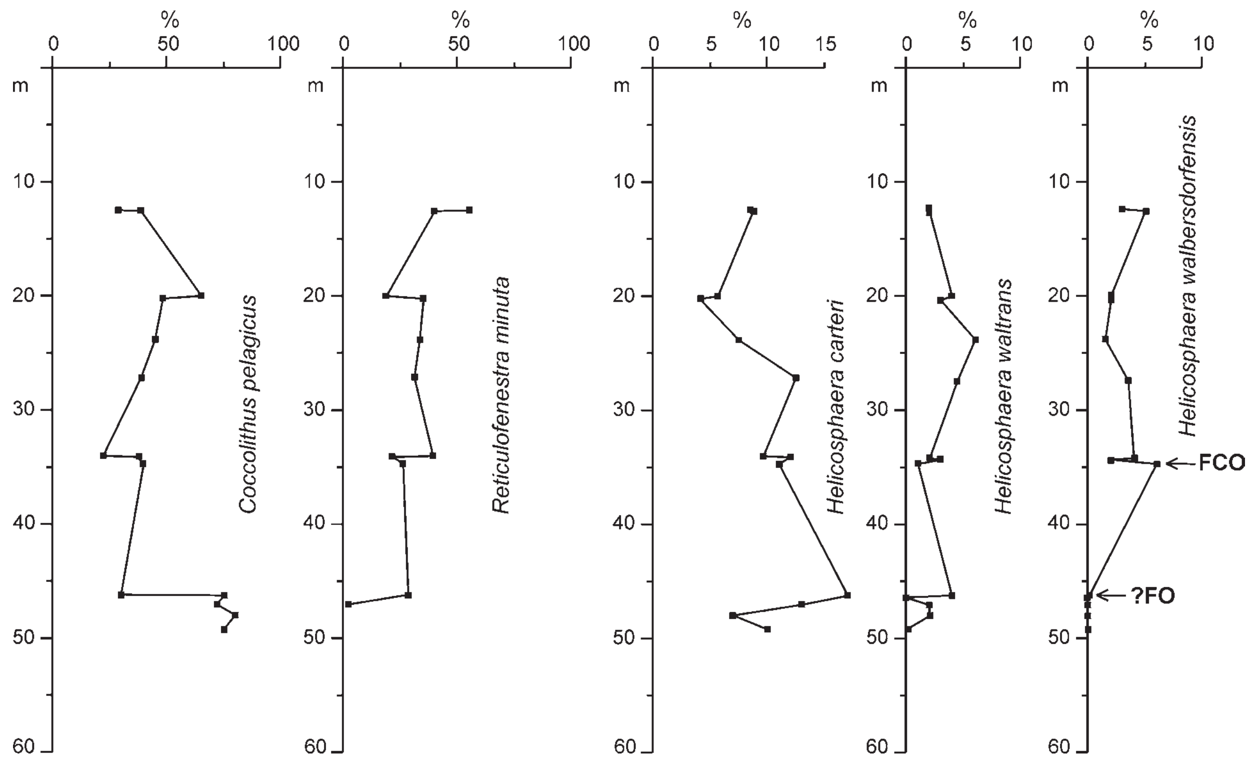

Fig. 6. Abundance patterns of selected calcareous nannofossils of the Ivaň-1 borehole. **FO** — first occurrence, **FCO** — first continuous occurrence.

Table 2: Distribution of foraminifers in the Ivaň-1 borehole. *Continued on next pages.*

TAXA \ depth [m]	12.47	12.55	20.05	20.35	23.90	27.30	34.20	34.30	34.80	46.20	46.70	46.95	47.10	48.00	48.25	49.15	60.00
Ammonia beccarii (Linne)											X						
Ammonia viennensis (d'Orbigny)											X		X		X		
Amphicoryna badenensis (d'Orbigny)												X		X			
Amphimorphina haueriana Neugeboren																	
Amphimorphina mucronata (Karrer)	X	X			X	X							X		X		
Amphimorphina sp.						X							X				
Amphistegina sp.													X				
Angulogerina esuriensis Hornibrook		X			X	X				X	X	X	X	X			
Angulogerina sp.					X		X	X					X				
Anomalinoides badenensis (d'Orbigny)						X											
Asterigerinata planorbis (d'Orbigny)			X	X		X				X					X		
Bathysiphon sp.																	X
Bolivina antiqua d'Orbigny						X							X		X		
Bolivina dilatata Reuss	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Bolivina hebes Macfadyen					X	X							X				
Bolivina plicatella Cushman	X		X		X	X					X		X	X	X		
Bolivina aff. *scalprata muscosa* Cicha et Zapletalova						X											
Bolivina cf. *vienensis* Marks					X												
Bolivina sp.	X	X		X	X	X	X		X	X	X		X				
Bulimina buchiana d'Orbigny	X		X		X								X	X			
Bulimina elongata d'Orbigny					X										X		
Bulimina schischinskayae Samoylova												X		X	X		
Bulimina striata d'Orbigny	X	X	X	X	X					X			X	X	X		
Bulimina subulata Cushman et Parker														X	X		
Cassidulina laevigata d'Orbigny						X	X	X			X	X	X	X	X		
Cibicidoides ungerianus (d'Orbigny)		X										X	X				
Coryphostoma digitalis (d'Orbigny)			X														
Cycloforina aff. *badensis* (d'Orbigny)															X		
Ehrenbergina serrata Reuss		X															
Elphidium crispum (Linne)												X		X	X		X
Elphidium fichtelianum (d'Orbigny)														X	X		
Elphidium flexuosum (d'Orbigny)																	X
Fissurina orbignyana Seguenza					X	X		X					X				
Fursenkoina acuta (d'Orbigny)		X			X	X		X				X		X			
Globocassidulina oblonga (Reuss)	X	X		X	X	X	X	X	X	X			X		X		
Globulina gibba d'Orbigny		X	X		X	X							X				
Grigelis pyrula (d'Orbigny)	X		X							X		X	X				
Guttulina communis (d'Orbigny)	X			X									X				
Hansenisca soldanii (d'Orbigny)		X	X		X	X	X	X	X			X	X	X	X		
Hanzawaia boueana (d'Orbigny)			X	X	X	X		X		X	X	X	X	X	X		X
Hanzawaia sp.					X		X										
Hemirobulina glabra (d'Orbigny)													X				
Hemirobulina sp.						X											
Heterolepa dutemplei (d'Orbigny)	X	X			X					X	X	X	X		X	X	X
Hoeglundina elegans (d'Orbigny)		X				X	X		X	X							
Islandiella cruissi (Marks)											X						
Karreriella sp.		X		X					X								
Laevidentalina communis (d'Orbigny)	X																
Laevidentalina elegans (d'Orbigny)	X		X	X											X		
Lagena striata (d'Orbigny)						X											
Lagena sp.							X										
Lapuguina schmidi Popescu					X												
Lenticulina calcar (Linne)														X			
Lenticulina cultrata (Montfort)	X		X		X	X					X						
Lenticulina gibba (d'Orbigny)		X			X												
Lenticulina inornata (d'Orbigny)	X		X		X						X	X	X	X			X
Lenticulina melvilli (Cushman et Renz)	X		X		X				X		X	X					
Lenticulina paulae (Karrer)					X												
Lenticulina similis (d'Orbigny)						X											
Lenticulina vortex (Fichtel et Moll)															X		X
Lenticulina sp.				X	X	X							X				
Marginulina hirsuta d'Orbigny	X		X									X					
Martinottiella karreri (Cushman)	X		X												X		
Melonis pompilioides (Fichtel et Moll)	X	X	X	X	X				X			X					
Neugeborina longiscata (d'Orbigny)		X			X	X	X		X			X					
Nodosaria hispida (Soldani)														X			
Nonion commune (d'Orbigny)	X				X	X					X			X	X		
Oridorsalis umbonatus (Reuss)													X				
Orthomorphina columella (Karrer)			X														
Pappina breviformis (Papp et Turnovsky)														X			
Pappina parkeri (Karrer)						X											
Pappina sp.								X									
Planularia moravica (Karrer)	X													X			
Plectofrondicularia sp.			X														
Porosononion granosum (d'Orbigny)						X											

Table 2: *Continued.*

TAXA \ depth [m]	12.47	12.55	20.05	20.35	23.90	27.30	34.20	34.30	34.80	46.20	46.70	46.95	47.10	48.00	48.25	49.15	60.00
Praeglobobulimina pupoides (d'Orbigny)	X									X			X				
Praeglobobulimina pyrula (d'Orbigny)	X	X	X	X	X												
Pseudonodosaria brevis (d'Orbigny)					X												
Psudotriloculina consobrina (d'Orbigny)		X						X									
Pullenia bulloides (d'Orbigny)	X	X	X					X	X		X				X		X
Pullenia quinqueloba (Reuss)				X							X				X		
Pyramidulina raphanistrum (Linne)	X	X			X	X	X						X		X		
Reussella spinulosa (Reuss)					X										X		
Saracenaria sp.							X										
Sigmoilinita tenuis			X		X	X		X	X				X				
Sinuloculina sp.					X												
Siphonodosaria consobrina (d'Orbigny)			X									X		X			
Siphonodosaria verneuilli (d'Orbigny)					X	X						X	X				
Siphonodosaria sp.					X	X			X				X				
Sphaeroidina bulloides (d'Orbigny)	X	X	X	X								X					
Spiroloculina canaliculata (d'Orbigny)													X				
Stilostomella adolphina (d'Orbigny)	X		X		X	X				X		X	X				
Stilostomella scabra (Reuss)	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	
Stilostomella verneuilli (d'Orbigny)				X													
Textularia aff. *laevigata* d'Orbigny												X					
Textularia sp.	X					X											
Uvigerina acuminata Hosius	X	X	X	X					X		X	X	X	X			
Uvigerina grilli Schmid													X				
Uvigerina macrocarinata Papp et Turnovsky												X	X	X			
Uvigerina pygmoides Papp et Turnovsky						X					X		X				
Uvigerina semiornata d'Orbigny	X	X	X	X					X	X		X	X	X			
Uvigerina uniseriata Jedlitschka	X											X					
Uvigerina sp.															X		
Vaginulinopsis hauerina (d'Orbigny)						X											
Vaginulinopsis pedum (d'Orbigny)												X					
Valvulineria complanata (d'Orbigny)	X	X	X							X			X	X			
Globigerina bulloides d'Orbigny		X		X	X		X			X	X	X	X	X			
Globigerina concinna Reuss						X							X				
Globigerina diplostoma Reuss	X	X		X	X	X	X			X	X	X	X	X	X		
Globigerina dubia Egger						X	X	X					X				X
Globigerina lentiana Rögl												X					
Globigerina praebulloides Blow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Globigerina tarchanensis Subbotina et Chutzieva					X	X							X				
Globigerina officinalis Subbotina						X											
Globigerina ottnangiensis Rögl			X		X						X			X			X
Globigerina sp.		X		X		X	X						X				X
Globigerinella obesa (Bolli)		X	X		X	X		X			X	X	X	X	X		
Globigerinella sp.									X								
Globigerinoides aff. *apertasuturalis* Jenkins						X											
Globigerinoides bisphericus Todd				X	X	X	X	X	X	X	X	X	X	X	X		
Globigerinoides quadrilobatus (d'Orbigny)	X				X	X		X	X	X	X		X	X	X		
Globigerinoides trilobus (Reuss)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Globorotalia bykovae (Aisenstat)	X	X	X	X	X	X	X	X	X	X	X		X		X		X
Globorotalia peripheroronda Blow et Banner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Globorotalia transsylvanica Popescu	X			X	X	X							X	X			
Globorotalia sp.				X	X	X		X					X				
Globoturborotalita druyi (Akers)							X		X	X			X				
Globoturborotalita woodi (Jenkins)			X									X		X			
Globoturborotalita sp.				X				X	X		X						
Paragloborotalia mayeri (Cushman et Ellisor)				X	X	X	X	X	X				X				
Paragloborotalia sp.		X															X
Praeorbulina glomerosa circularis (Blow)	X	X			X		X	X	X	X		X	X	X	X		
Praeorbulina glomerosa glomerosa Blow	X	X					X							X			
Praeorbulina sicana de Stefani		X								X				X			
Turborotalita quinqueloba (Natland)		X		X	X	X	X	X	X	X	X	X	X	X			

profile, *Praeorbulina sicana* and *Praeorbulina glomerosa curva* (Blow) scarcely in the lower part of the section in the intervals of 59.90 m, 52.95–52.80 m and 37.20 m. The taxa *Globorotalia bykovae*, *Gl. peripheroronda* Blow et Banner, *Globigerinoides quadrilobatus* (d'Orbigny), *Glob. trilobus* (Reuss), *Glob. bisphericus* Todd, *Tenuitellinata angustiumbilicata* (Bolli), *Globigerinella regularis* (d'Orbigny), *Globigerina bulloides* d'Orbigny, *G. praebulloides* Blow, *G. diplostoma* (Reuss) quantitatively prevail over other planktonic species. The percentage of *Globorotalia* div. sp. (about 40 %) dominates in the interval of 24.55–21.90 m. The benthic species *Uvigerina macrocarinata* occurs in the whole profile and at the depth of 12.60 m and 30.55 m was found in higher numbers. The constancy of taxa *Bolivina dilatata*, *B. plicatella* (Cushman), *Siphonodosaria scabra*, *Asterigerinata planorbis* (d'Orbigny), *Globocassidulina oblonga, Hansenisca soldanii* (d'Orbigny), *Hanzawaia boueana*

Table 3: Distribution of calcareous nannofossils in the Ivaň-1 borehole and the biostratigraphic interpretation. Abundance of Miocene nannofossil species and reworked nannofossil specimens: **A** — abundant (>10 specimens per 1 field of view of the microscope), **C** — common (10–5 specimens per 1 field of view), **F** — few (4–1 specimens per 1 field of view), **R** — rare (< 10 specimens per 10 fields of view), **VR** — very rare (< 1 specimens per 10 fields of view), **f** — fragments, **r** — reworked from the older Miocene strata. Preservation of calcareous nannofossils: **M** — moderate (etching or mechanical damage is apparent but majority of specimens are easily identifiable), **P** — poor (etching and especially mechanical damage is intensive making identification of some specimens difficult), **VP** — very poor (etching and mechanical damage is very intensive, specimens mostly in fragments). Estimates of the abundance of nannofossils in samples: **VH** — very high (>50 specimens per 1 field of view of the microscope), **H** — (50–30 specimens per 1 field of view), **M** — moderate (30–10 specimens per 1 field of view), **L** — low (10–1 specimens per 1 field of view), **VL** — very low (<10 specimens per 10 fields of view). * zones (Martini 1971) attributed to interval Karpatian-Badenian of the Central Paratethys stages (see Table 1).

Ivaň–1

Age	Central Paratethys stage	Nannofossil zones (Martini 1971)*	Carpathian Foredeep (Švábenická 2002)	Depth (m)	sample abundance	nannofossil preservation	*Braarudosphaera bigelowii*	*Calcidiscus premacintyrei*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus floridanus*	*Discoaster deflandrei*	*Discoaster exilis*	*Discoaster* sp. (5-rayed, symmetrical)	*Helicosphaera ampliaperta*	*Helicosphaera carteri*	*Helicosphaera mediterranea*	*Helicosphaera waltrans*	*Micrantholithus* sp.	*Pontosphaera multipora*	*Reticulofenestra pseudoumbilicus*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Calcidiscus leptoporus*	*Reticulofenestra minuta*	*Rhabdosphaera sicca*	*Thoracosphaera* sp.	*Helicosphaera intermedia*	*Umbilicosphaera rotula*	*Coccolithus* cf. *miopelagicus*	*Helicosphaera scissura*	*Helicosphaera walbersdorfensis*	*Sphenolithus conicus*	*Umbilicosphaera jafari*	*Helicosphaera euphratis*	*Sphenolithus dissimilis*	*Discoaster adamanteus*	*Pontosphaera discopora*	% of reworked nannofossils
Middle Miocene	Lower Badenian	NN5	horizon *Helicosphaera waltrans*	12.45–12.50	VH	M		VR	A		R	VR	R			C		F		R	F	R	VR	R		VA	R	VR		R			F	r	F	VR		cf.		6.1
				XII.55	VH	M		VR	A		R		VR			F		F		R	F	VR	VR	VR		A	F		VR	F			F		F					8.1
				20.05–20.09	L	VP			C				VR			R		R		VR	R	VR	R			F							R							15
				20.35	VH	M		VR	A	VR	F		R		VR	F		F		R	R	VR	VR	R	VR	A			VR	R			R		R	VR			VR	18
				23.90	H	M		VR	A		R		R		VR	F		F		R	R	R	VR	R	VR	A	VR			R			R		R					10
				27.30	M	M	VR	R	A		R		VR			F	VR	F		R	R	VR	VR	R	R	A				VR		R	R		R					12
				34.20	M	M	VR	R	C		R				R	F		R		R	F	R	VR	VR		A			VR	VR		VR	R		F	VR	r			27
				34.20–34.30	H	M	R	VR	A		R	VR	VR			F	VR	R		F	F	R	R	R	VR	C	VR	R	VR	R	R	VR	R	r	F		r	VR	VR	21
				34.80	H	M		F	C		F	R	R			F		R		R	R	VR	R	VR	VR	C			VR	R			F		F	VR	r			26
				46.20	M	P		VR	C		R		R		VR	F		F			R	R	VR	VR		C			VR	R		VR	cf.	r	VR					60
				46.45	L	VP									VR	F				VR		VR	VR	VR		VR		VR			VR									74
				47.10	M	VP	VR	VR	C		R		R	VR	VR	F	f	F		R	R	VR	R	R	VR	R			VR	VR										64
				48.00–48.10	L	VP			C		VR		VR		R	F	VR	R		VR	VR	R		VR	VR	VR	VR	VR												57
				48.25	L	VP	f	VR	F	VR	R	VR	f	VR	R	F	VR	VR	VR	R		VR	VR	VR																72
			?	49.15	barren of nannofossils																																			
				60.00																																				

(d'Orbigny) and *Melonis pompilioides* (Fichtel et Moll) rises above 80 %. The character of assemblages and plankton/benthos ratio varies between 0.45–85.20 % and quickly changes during the whole profile. According to the character of foraminiferal assemblages four intervals have been recognized: 1. abundance of plankton taxa (60.0–52.50 m), 2. dominance of benthic taxa (52.0–29.65 m), 3. abundance of plankton taxa (24.70–21.90 m), 4. fluctuating, rather higher values of the plankton/benthos ratio (12.60–4.60 m). The next negligible variations were observed in shorter intervals. Distinctive divergences of several centimeters were recorded in the plankton/benthos ratio and total pattern of assemblages (see Fig. 4).

Reworked taxa of foraminifers *Globigerina ottnangiensis* Rögl, *Pappina* div. sp. and *Cassigerinella* sp. were scarcely recorded. Foraminifers were complemented by fragments of molluscs, bryozoans, ostracods, sponge spicules, echinoid spines and locally radiolarians, pyritized centric diatoms and fish bones.

Calcareous nannofossils

Calcareous nannofossils were abundant and medium well preserved through the whole profile. Except in the intervals 52.50–49.40 m, 40.05 m, and 31.80–29.65 m where the quantity of specimens strongly decreases and the mode of nannofossil preservation is very poor. The assemblages are characterized by abundance of *Reticulofenestra minuta* forming up to 70 % of the autochthonous Miocene component (Fig. 7). The percentage of *Coccolithus pelagicus* fluctuates between 10–35 %. The lowermost part of profile (60.00–59.90 m) provided high numbers of excellently preserved *Micrantholithus* sp. and few *Braarudosphaera bigelowii* (Table 5). In the overlying strata these pentaliths were found in low numbers and especially the genus *Micrantholithus* only in fragments. The species *Helicosphaera waltrans* occurred continuously up to 31.60 m (see Fig. 7), higher it was found sporadically. *Sphenolithus heteromorphus* was present in almost the whole profile but in very low numbers. Usual part of assemblages is represented by *Helicosphaera walbersdorfensis*, *H. carteri* and other helicosphers, *Reticulofenestra pseudoumbilicus* (<5 μm), genera *Calcidiscus* and *Umbilicosphaera* including the relatively common *U. jafari*, and others. Discoasters are almost absent. The Miocene part of the oryctocoenoses forms about 90 % and it is complemented by reworked specimens from the Upper Cretaceous, Paleogene and older Miocene strata (see Fig. 5).

Table 4: Distribution of foraminifers in the Vranovice-1 Borehole. *Part 1 of 4.*

TAXA \ depth [m]	4.60	5.40	6.10	6.30	12.20	12.60	14.40	21.90	22.20	23.60	24.55	24.70	29.65	30.50	30.55	31.60	36.80	37.20	39.20	39.80	40.05	46.45	47.50	49.20	49.40	52.20	52.50	52.80	52.95	56.65	57.20	57.80	59.90	60.00
Ammodiscus sp.																						X												
Ammonia beccarii (Linne)																	X			X	X													
Ammonia viennensis (d'Orbigny)					X	X									X	X	X	X	X	X	X				X	X		X						X
Amphicoryna badenensis (d'Orbigny)	X	X	X				X	X				X					X	X	X	X		X			X	X								
Amphimorphina mucronata (Karrer)	X	X	X	X		X	X	X				X			X		X		X		X	X	X	X	X	X					X	X		X
Amphimorphina haueriana Neugeboren			X				X															X	X		X		X							
Amphistegina mammilla (Fichtel et Moll)	X		X	X	X	X	X								X	X		X		X	X	X		X	X	X			X					
Angulogerina esuriensis Hornibrook		X			X				X	X			X															X			X	X		
Angulogerina sp.					X					X	X															X								
Asterigerinata planorbis (d'Orbigny)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Baggina sp.												X																			X			
Bitubulogenerina aff. *reticulata* Cushman								X																		X								
Bolivina antiqua d'Orbigny		X			X		X		X	X	X	X	X	X	X	X						X				X	X	X		X		X	X	X
Bolivina dilatata Reuss	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X	X	X	X	X	X	X	X	X	X	X	X
Bolivina fastigia Cushman																																	X	
Bolivina hebes Macfadyen	X		X		X	X	X	X	X	X	X		X		X			X	X		X		X		X	X	X	X			X	X	X	X
Bolivina plicatella Cushman	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X					X		X		X		X	X	X	X	X
Bolivina aff. *sarmatica* Didkovskiy						X																												
Bolivina scalprata miocenica Macfadyen																										X	X							
Bolivina scalprata muscosa Cicha et Zapletalova					X																							X		X				
Bolivina vienensis Marks																																	X	
Bolivina sp.		X			X	X	X		X		X				X					X				X		X	X	X	X	X				X
Borelis sp.							X																											
Bulimina buchiana d'Orbigny		X			X		X	X			X								X				X		X			X						
Bulimina elongata d'Orbigny	X	X	X		X		X	X			X	X	X				X	X	X		X	X	X	X	X	X		X				X		
Bulimina schischinskayae Samoylova	X	X			X					X													X	X	X		X				X		X	
Bulimina striata d'Orbigny	X		X		X	X	X	X	X	X	X		X	X	X		X		X		X		X	X	X	X	X	X	X			X	X	X
Bulimina subulata Cushman et Parker	X	X	X	X			X	X					X		X				X				X	X		X		X		X	X		X	X
Bulimina sp.		X				X		X		X																	X	X						
Cassidulina laevigata d'Orbigny	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X		X				X	X		X	X			X	X	X	X	X
Cassidulina sp.		X		X			X																											
Ceratocancris eximus (Rzehak)																																	X	
Cibicidoides ungerianus (d'Orbigny)		X		X		X	X			X	X		X	X	X											X		X		X		X	X	X
Cibicidoides sp.							X		X		X																							
Coryphostoma digitalis (d'Orbigny)					X																													
Cycloforina badensis (d'Orbigny)																															X			
Cycloforina sp.			X																															
Dentalina acuta d'Orbigny	X																																	
Dimorphina akneriana (Neugeboren)							X			X																								
Elphidium crispum (Linne)	X			X	X	X	X	X				X				X			X	X	X	X			X	X	X			X			X	X
Elphidium fichtelianum (d'Orbigny)	X			X		X	X						X													X	X							
Elphidium flexuosum (d'Orbigny)					X			X	X													X												
Elphidium hauerianum (d'Orbigny)				X																														
Elphidium sp.			X	X			X	X		X			X		X													X			X	X		
Fissurina orbignyana Seguenza		X	X	X		X	X			X	X	X	X	X	X									X		X				X		X		
Fissurina sp.		X																																X
Frondicularia annularis d'Orbigny									X																									
Frondicularia sp.					X		X			X	X												X											
Fursenkoina acuta (d'Orbigny)	X	X			X					X		X	X				X	X	X								X	X	X			X	X	
Glandulina ovula d'Orbigny							X			X																								
Globocassidulina oblonga (Reuss)		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X		X		X	X	X	X	X	X	X	X	X	X	X	X

Table 4: *Part 2 of 4.*

TAXA \ depth [m]	4.60	5.40	6.10	6.30	12.20	12.60	14.40	21.90	22.20	23.60	24.55	24.70	29.65	30.50	30.55	31.60	36.80	37.20	39.20	39.80	40.05	46.45	47.50	49.20	49.40	52.20	52.50	52.80	52.95	56.65	57.20	57.80	59.90	60.00
Globulina gibba d'Orbigny	X	X	X			X	X		X		X							X		X	X	X	X		X		X					X		
Grigelis pyrula (d'Orbigny)					X							X																X	X		X			X
Guttulina communis (d'Orbigny)											X	X			X		X																X	
Hansenisca soldanii (d'Orbigny)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hanzawaia aff. *hořčici* (Cicha et Zapletalova)							X																								X			
Hanzawaia boueana (d'Orbigny)	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Hanzawaia sp.		X		X			X				X																	X						
Hemirobulina glabra (d'Orbigny)	X	X							X																									
Heterolepa dutemplei (d'Orbigny)	X			X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hoeglundina elegans (d'Orbigny)					X	X							X			X											X						X	
Hyalinonetrion clavatum (d'Orbigny)																			X									X				X		
Karreriella badensis (Reuss)							X																											
Karreriella chilostoma (Reuss)					X		X																											
Karreriella sp.					X				X	X																	X			X	X	X		X
Laevidentalina communis (d'Orbigny)	X		X																															
Laevidentalina elegans (d'Orbigny)					X					X		X													X	X		X			X		X	
Lagena striata (d'Orbigny)								X	X	X												X			X									
Lagena sp.										X		X																						
Lenticulina calcar (Linne)	X	X	X	X			X											X			X	X		X	X									X
Lenticulina cultrata (Montfort)	X			X				X		X	X					X	X	X			X	X	X			X	X							
Lenticulina gibba (d'Orbigny)											X															X				X				
Lenticulina inornata (d'Orbigny)		X	X	X			X	X	X	X	X	X		X		X	X						X				X	X	X	X	X		X	X
Lenticulina melvilli (Cushman et Renz)										X																X				X		X		
Lenticulina cf. *similis* (d'Orbigny)																												X						
Lenticulina vortex (Fichtel et Moll)																										X	X							
Lenticulina sp.			X						X	X				X	X	X	X			X						X	X	X		X		X	X	
Lobatula lobatula (Walker et Jacob)														X																	X			
Marginulina hirsuta d'Orbigny		X	X		X					X	X																X	X		X			X	
Martinottiella communis (d'Orbigny)											X																							
Martinottiella hirsuta d'Orbigny																																		X
Martinottiella karreri (Cushman)										X																X					X		X	
Melonis pompilioides (Fichtel et Moll)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X		X
Neoeponides schreibersi (d'Orbigny)						X	X				X			X												X								
Neugeborina longiscata (d'Orbigny)					X				X	X	X																X		X		X	X	X	X
Nodosaria hispida (Soldani)			X																															
Nonion commune (d'Orbigny)	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X		X	X	X	X	X	X			X	
Nonion sp.		X					X			X	X			X	X									X		X				X	X	X		X
Oridorsalis umbonatus (Reuss)																			X				X											
Pappina breviformis (Papp et Turnovsky)							X	X				X							X															
Pappina parkeri (Karrer)		X	X																		X													X
Pappina primiformis (Papp et Turnovsky)											X																							
Pappina sp.												X			X																			
Planularia dentata (Karrer)														X																				
Planularia moravica (Karrer)					X																													
Planularia sp.								X	X	X																X			X					
Plectofrondicularia sp.																	X													X				
Porosononion granosum (d'Orbigny)	X			X																													X	
Praeglobobulimina pupoides (d'Orbigny)	X	X		X				X		X					X									X		X					X	X		X
Praeglobobulimina pyrula (d'Orbigny)	X													X				X	X				X			X							X	
Praeglobobulimina sp.									X																									
Pseudonodosaria brevis (d'Orbigny)		X																					X					X				X		

Table 4: *Part 3 of 4.*

TAXA \ depth [m]	4.60	5.40	6.10	6.30	12.20	12.60	14.40	21.90	22.20	23.60	24.55	24.70	29.65	30.50	30.55	31.60	36.80	37.20	39.20	39.80	40.05	46.45	47.50	49.20	49.40	52.20	52.50	52.80	52.95	56.65	57.20	57.80	59.90	60.00
Pseudonodosaria sp.									X																									
Pseudotriloculina consobrina (d'Orbigny)																			X															
Pullenia bulloides (d'Orbigny)	X	X	X	X		X		X			X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Pyramidulina raphanistrum (Linne)	X	X			X		X			X	X	X				X							X	X		X			X		X			
Quinqueloculina akneriana d'Orbigny				X												X																X		
Quinqueloculina buchiana d'Orbigny				X												X																		
Quinqueloculina sp.	X					X	X						X							X														
*Reussella spinulosa (*Reuss)				X		X	X	X	X	X		X	X	X	X			X						X	X	X				X			X	
Semivulvulina pectinata (Reuss)	X	X	X	X							X				X		X	X	X	X			X			X	X	X					X	
Semivulvulina deperdita (d'Orbigny)	X																X	X	X			X			X									
Sigmoilinita tenuis (Czjzek)	X		X		X			X	X	X	X	X			X								X				X	X	X	X	X	X	X	
Siphonia reticulata (Czjzek)																														X				
Siphonodosaria consobrina (d'Orbigny)	X																					X						X	X					
Sphaeroidina bulloides d'Orbigny									X		X	X			X					X														
Spiroloculina canaliculata d'Orbigny						X				X	X									X							X					X		X
Spirorutilus carinatus (d'Orbigny)	X	X	X	X		X	X	X	X			X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		
Stilostomella adolphina (d'Orbigny)	X	X	X	X	X	X		X	X	X	X	X	X		X		X		X				X	X	X	X		X		X	X			
Stilostomella scabra (Reuss)	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X
Stilostomella verneuilli (d'Orbigny)	X			X	X	X		X			X		X		X		X						X			X	X	X		X		X	X	
Stilostomella sp.				X		X	X	X	X	X	X				X	X										X		X		X	X		X	X
Textularia gramen d'Orbigny	X						X			X				X	X	X	X					X			X			X						
Textularia pala Czjzek	X	X		X	X	X	X	X	X			X		X	X	X	X		X				X	X			X	X					X	
Textularia sp.				X	X		X						X	X					X				X			X		X		X	X			X
Uvigerina aculeata d'Orbigny												X																						
Uvigerina acuminata Hosius	X					X			X					X				X										X						
Uvigerina cf. *grilli* Schmid												X																						
Uvigerina macrocarinata Papp et Turnovsky	X				X	X	X	X	X	X	X	X	X	X	X							X	X			X	X	X	X				X	
Uvigerina pygmoides Papp et Turnovsky				X												X											X		X					X
Uvigerina semiornata d'Orbigny					X		X					X													X	X	X			X				
Uvigerina sp.					X				X		X					X			X													X		
Vaginulinopsis legumen (Linne)							X																					X	X		X	X		
Vaginulinopsis pedum (d'Orbigny)					X					X		X																						
Vaginulinopsis sp.		X								X	X																							
Valvulineria complanata (d'Orbigny)						X		X	X	X	X	X	X						X						X	X					X	X		
Valvulineria sp.														X										X			X				X			
Beela sp.		X																																
Cassigerinella sp.															X															X				
Globigerina bulloides d'Orbigny	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X		X	X		X	X	X	X		X
Globigerina concinna Reuss		X	X		X		X		X		X																			X				
Globigerina diplostoma Reuss	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X				X	X	X	X	X	X		X	X	X	X	X
Globigerina dubia Egger	X																																	
Globigerina officinalis Subbotina				X					X															X							X		X	
Globigerina ottnangiensis Rögl							X		X	X												X											X	
Globigerina praebulloides Blow	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X
Globigerina tarchanensis Subbotina et Chutzieva		X		X	X	X	X	X	X	X	X			X	X									X		X	X	X		X	X	X		X
Globigerina sp.		X		X		X	X	X	X		X			X	X		X	X		X				X		X	X	X		X				X
Globigerinella obesa (Bolli)	X		X	X				X		X					X		X					X							X	X	X		X	
Globigerinoides bisphericus Todd					X		X		X	X	X	X		X	X	X			X										X				X	
Globigerinoides quadrilobatus (d'Orbigny)			X		X				X	X				X																	X			
Globigerinoides trilobus (Reuss)	X	X			X	X	X			X	X	X	X	X	X	X										X		X	X	X				X
Globigerinoides sp.														X													X							

Table 4: *Part 4 of 4.*

TAXA \ depth [m]	4.60	5.40	6.10	6.30	12.20	12.60	14.40	21.90	22.20	23.60	24.55	24.70	29.65	30.50	30.55	31.60	36.80	37.20	39.20	39.80	40.05	46.45	47.50	49.20	49.40	52.20	52.50	52.80	52.95	56.65	57.20	57.80	59.90	60.00
Globorotalia bykovae (Aisenstat)	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X			X	X	X	X		X	X	X	X	X	X	X	X
Globorotalia peripheroronda Blow et Banner	X	X	X	X	X	X	X	X	X	X	X	X	X		X			X				X	X	X		X	X	X	X	X	X	X		X
Globorotalia transsylvanica Popescu		X	X	X		X	X		X		X	X			X						X		X	X		X	X	X		X	X	X		X
Globorotalia sp.		X		X	X	X	X	X	X	X				X	X			X						X	X	X	X	X		X	X	X	X	X
Paragloborotalia mayeri (Cushman et Ellisor)		X			X	X	X	X	X	X	X			X	X											X					X	X		X
Praeorbulina glomerosa circularis (Blow)			X		X					X				X	X											X	X	X	X	X	X	X		X
Praeorbulina glomerosa curva (Blow)																		X																
Praeorbulina glomerosa glomerosa Blow							X																					X	X					X
Praeorbulina sicana de Stefani																												X					X	
Turborotalita quinqeloba (Natland)	X	X			X	X	X	X	X	X	X			X	X	X										X	X	X	X	X	X	X		X

Table 5: Distribution of calcareous nannofossils in the Vranovice-1 borehole and the biostratigraphic interpretation. For explanation see Table 3.

Vranovice-1																																									
Age	Central Paratethys stage	Nannofossil zones (Martini 1971)*	Carpathian Foredeep (Švábenická 2002)	Depth (m)	sample abundance	nannofossil preservation	*Braarudosphaera bigelowii*	*Calcidiscus leptoporus*	*Calcidiscus premacintyrei*	*Coccolithus* cf. *miopelagicus*	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Helicosphaera carteri*	*Helicosphaera scissura*	*Helicosphaera walbersdorfensis*	*Helicosphaera waltrans*	*Micrantholithus* sp.	*Pontosphaera multipora*	*Reticulofenestra pseudoumbilicus*	*Reticulofenestra minuta*	*Rhabdosphaera sicca*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Umbilicosphaera jafari*	*Umbilicosphaera rotula*	*Helicosphaera ampliaperta*	*Triquetrorhabdus carinatus*	*Coronocyclus nitescens*	*Discoaster adamanteus*	*Discoaster exilis*	*Calciosolenia murrayi*	*Helicosphaera intermedia*	*Helicosphaera euphratis*	*Discoaster deflandrei*	*Helicosphaera mediterranea*	*Sphenolithus conicus*	*Pontosphaera discopora*	% of reworked nannofossils	remnants of diatoms	remnants of plant tissues
Middle Miocene	Lower Badenian	NN5	horizon *S. heteromorphus*	4.X	VH	M	f		F	VR		F	F	VR	F	VR		F	F	A	F	R	R	F	F	F	R		VR		R		R	R	VR			R	8	VA	VA
				V.40	VH	M	f	VR	VR	VR	A	R	R		F			R	F	A		VR	VR	R	F	R	VR				f		R				VR		5	VA	VA
				VI.30	M	P	R	VR	VR		A	F	F		F		f	R	F	A	R	VR	VR	R	F	VR	VR									VR			20	A	A
				XII.20	VH	P	f		VR		A	F	F	VR	R	VR	f	R	C	A	VR	VR	R	R	F	R	VR							VR	VR				15	A	A
				14.40	VH	M	f		VR		C	VR	F		F		f	R	F	A	R	VR	VR	R	C	F											VR		13	C	C
				20.20	VH	M	R	R	VR	R	A	F	F		F	VR	f	R	F	VA	R			R	F	C	VR		VR		R			VR				VR	3	F	C
				21.90	H	P	R	R	R	VR	A	R	C	VR	F		f	R	C	A		VR	VR	R	R	F	VR				f		VR	VR	VR			VR	10	R	F
				24.55	VH	M	R	R	VR	R	A	F	C	VR	C	VR	f	R	F	A	R	VR	VR	R	F	F			VR		f		VR	VR	VR				6	C	A
				29.65	L	VP	R	R	VR		F		R		R	VR	f	R		F		VR	VR		R	R	VR						VR	VR	VR			VR	5	R	F
				30.55–30.58	H	VP	f				C	R	C		F		f	f	F	A		R	VR	VR	F	R	VR		R				VR	VR					18	VR	F
			horizon *Helicosphaera waltrans*	31.60	M	VP	f	VR	VR		C	VR	F		R	R		R	F	C					R	VR							VR	VR					15		F
				36.80	H	M	R	VR	VR	VR	A	VR	C	R	F	R		R	F	A		VR	VR	R	F	R	VR			VR		R		R		VR			12	F	C
				37.20	H	P	f				A		F		R	VR		VR	F	A		VR	VR	R	R	VR					f								8	R	F
				39.20	M	VP	R	R			F	VR	R	R	F	R		R	F	C		VR		R	R	VR													8	R	F
				40.05	M	VP	f			R	F		F		R	VR			F	C	R			VR	R	R			VR				VR	R					9	R	R
				46.45	H	M	R			VR	C	VR	F		F	R	f	VR	F	A				VR	F	R	VR							R	VR	VR	VR		14	F	C
				47.50	H	P	R	VR		VR	C	VR	R	VR	R	R		VR	F	A		VR		R	R	R	VR		VR					VR	VR	VR			10	C	A
				49.20	L	VP	R				F		F	R	F	VR		R	F	C			VR	VR	R								VR	VR					22	F	C
				49.40	H	VP	VR			VR	A	VR	F	R	F	VR		R	F	A	VR		VR	VR	F								VR	VR					17	C	C
				52.50	L	VP	VR		R		F		F		VR	VR	VR	R	R	F				VR	R														5		F
				55.05	H	M	R		R		A	VR	C		F	R	R	VR	R	A		R	VR	VR	F	R	VR		VR				VR						13	F	C
				57.20	VH	P	VR		VR		A	R	F	VR	F	R	VR	R	C	A	R	VR	R	R	F	VR	VR				VR	VR	VR						13	A	A
				57.80	VH	M	R	R		R	A	F	C	R	F	F	R	F	R	A		R	VR	R	F	R	VR		VR	VR	f								10	C	A
				59.90	VH	M	F	R	R	VR	C	F	C		C	F	C	F	F	A	R	F	F	F	C	C	VR	VR											7	VA	A
				60.00	VH	M	R	VR	R	VR	C	R	C	R	F	R	F	R	F	A	VR	F	VR	VR	C	F													10	A	A

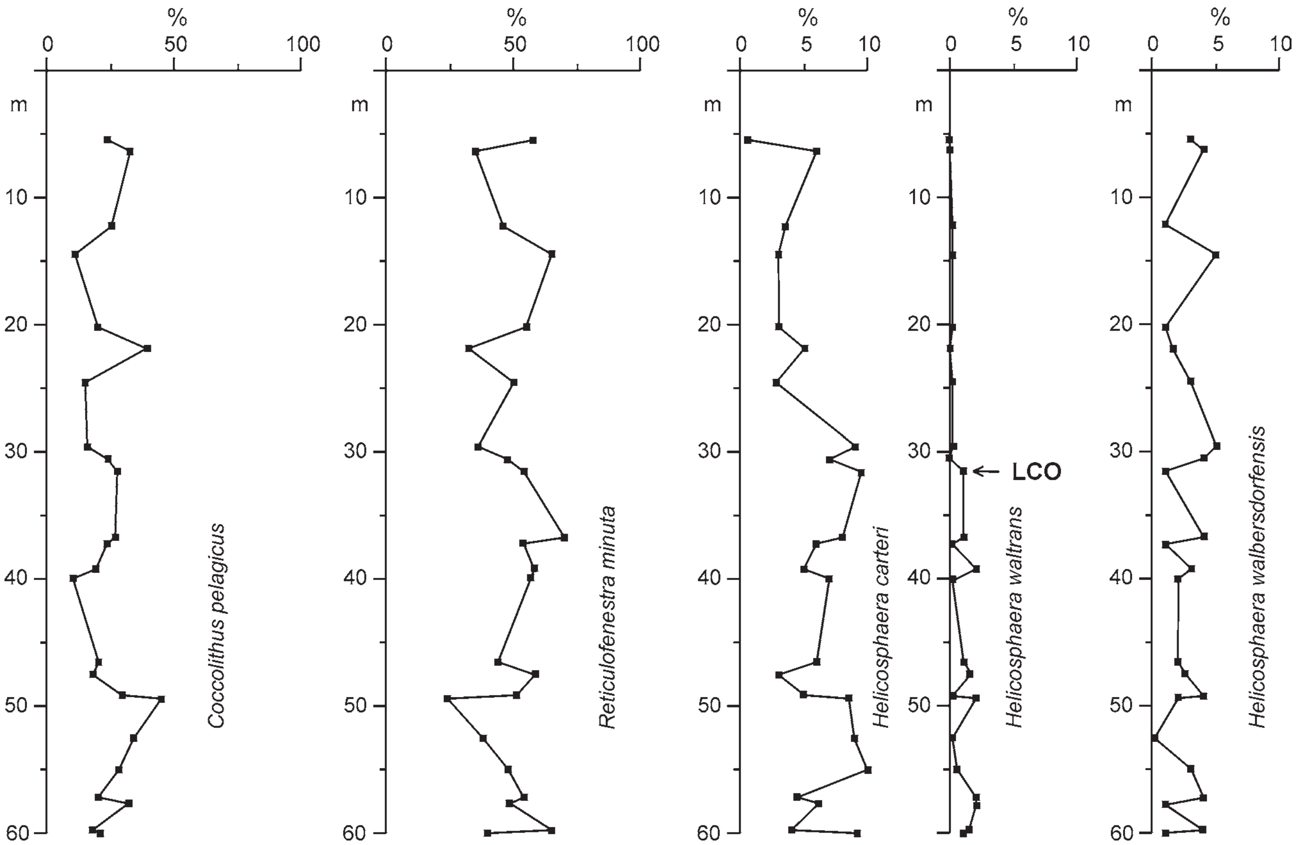

Fig. 7. Abundance patterns of selected calcareous nannofossils in the Vranovice-1 borehole. **LCO** — last continuous occurrence.

Moreover, slides provided high numbers of remnants of diatoms, sponge spicules and plant tissues.

Biostratigraphy

Foraminifers with *Praeorbulina sicana* and *Praeorbulina glomerosa circularis* document the Middle Miocene, M5b Zone of planktonic foraminifers sensu Berggren et al. (1995) that is correlated with the Lower Badenian in the Central Paratethys regional stages (see Table 1). This interval corresponds to deposition of the Grund Formation sensu Roetzel & Pervesler (2004) and the "Lower Lagenidae Zone" that was defined by Grill (1941) in the Molasse Basin and Carpathian Foredeep.

Joint occurrence of *Helicosphaera waltrans* (Fig. 9.1–3) and *Sphenolithus heteromorphus* (Fig. 10.19–22) indicates Zone NN5. The short interval of the horizon with *H. waltrans* (Švábenická 2002) is correlated with the lower Middle Miocene, Lower Badenian of Central Paratethys stage (Ćorić & Švábenická 2004).

The correlation with the Langhian stratotype section of the Mediterranean (Fornaciari et al. 1997) is rather problematic because of the following phenomena: 1. joint occurrence of *Helicosphaera waltrans* and *H. walbersdorfensis* (continuous and relatively common) that was observed both in the Ivaň-1 and Vranovice-1 boreholes (see Figs. 6 and 7), 2. absence of genus *Orbulina*. According to Fornaciari et al. (1997) the first occurrence of common *H. walbersdorfensis* indicates the base of Subzone MNN5b and this event is described chronologically higher, after the last occurrence of *H. waltrans* and first occurrence of *Orbulina suturalis* Brön.

On the other hand this correlation corresponds to the results presented from the Roggendorf-1 borehole, Molasse Basin, Lower Austria (Ćorić & Rögl 2004) where the first occurrence of *Helicosphaera waltrans* is mentioned at the depth of 280 m together with *H. walbersdorfensis*, whereas the first occurrence of *Orbulina suturalis* and *Praeorbulina glomerosa circularis* follows in the overlying strata at 7–10 m.

Paleoecological interpretation

Foraminiferal assemblages including the plankton/benthos ratio indicate a marine paleoenvironment of the middle to outer shelf (Murray 1976).

The following microfaunal taphocoenoses reflecting paleoenvironmental changes of depositional area have been recognized:

1. The dominance of shallow water foraminifers with *Asterigerinata planorbis*, *Amphistegina mammilla* (Fichtel et Moll), *Elphidium fichtelianum* (d'Orbigny), *E. crispum* (Linne), *Nonion communis* (d'Orbigny), *Quinqueloculina akneriana* d'Orbigny, *Q. buchiana* d'Orbigny, *Borelis* sp.

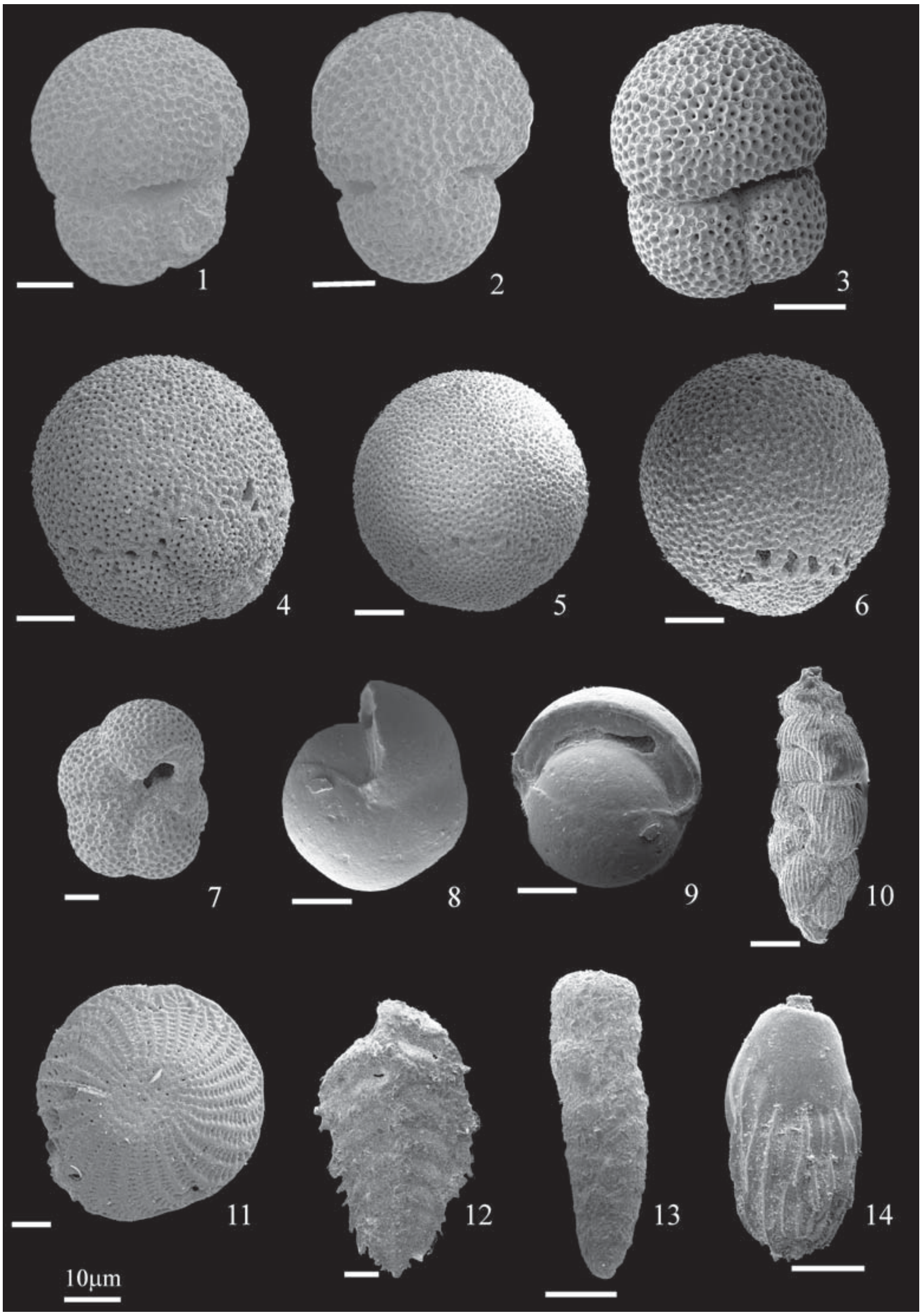

Fig. 8. Biostratigraphically significant foraminifers in the Ivaň IK-1 and Vranovice VK-1 boreholes, Middle Miocene (Lower Badenian), Carpathian Foredeep. **1,2** — *Globigerinoides bisphericus* Todd, Ivaň-1, 46.0 m. **3** — *Globigerinoides trilobus* (Reuss), Ivaň-1, 46.5 m. **4** — *Praeorbulina glomerosa circularis* (Blow), Ivaň-1, 12.55 m. **5** — *Praeorbulina gl. circularis* (Blow), Ivaň-1, 47.1 m. **6** — *Praeorbulina gl. glomerosa* Blow, Ivaň-1, 12.47 m. **7** — *Paragloborotalia mayeri* (Cushman et Ellisor), Ivaň-1, 46.7 m. **8, 9** — *Pullenia bulloides* (d'Orbigny), Vranovice-1, 4.6 m. **10** — *Pappina breviformis* (Papp et Turnovsky), Ivaň-1, 48.25 m. **11** — *Elphidium crispum* (Linne), Vranovice-1, 6.3 m. **12** — *Spirorutilus carinatus* (d'Orbigny), Vranovice-1, 6.3 m. **13** — *Martinottiella karreri* (Cushman), Ivaň-1, 48.25 m. **14** — *Uvigerina macrocarinata* Papp et Turnovsky, Vranovice-1, 12.6 m.

accompanied by fragments of bryozoans and molluscs (Vranovice-1 borehole in the depths 6.3 m, 12.6 m, 14.4 m, 39.8 m, 40.05 m, 52.2 m and 52.95 m) gives evidence for shallower sublittoral (infralittoral) after Pokorný et al. (1992). Foraminifers indicate well-oxygenated warmer waters of normal salinity. Pioneer assemblages of bryozoans reflect time-limited suitable conditions for their life run (Zágoršek et al. 2005). Bryozoans lived in warm and shallow (infralittoral) sea water with high energy waves.

2. A higher number of agglutinated foraminifers *Semivulvulina pectinata* (Reuss), *S. deperdita* (d'Orbigny), *Textularia gramen* d'Orbigny, *T. pala* Czjzek, *Spirorutilus carinatus* (d'Orbigny) accompanied by calcareous benthos with *Melonis pompilioides* (Fichtel et Moll), *Pullenia bulloides* (d'Orbigny), *Nonion communis* and *Heterolepa dutemplei* (d'Orbigny) (Vranovice-1 in the depths 6.1 m, 36.8 m, 37.2 m, 39.2 m, 47.5 m and 49.4 m) indicates deeper and colder sea, circalittoral to upper bathyal. Foraminifers show sea of normal salinity without dysoxic indicators.

3. The dominance of deep water euryoxybiont foraminifers *Uvigerina macrocarinata* Papp et Turnovsky, *U. semi-*

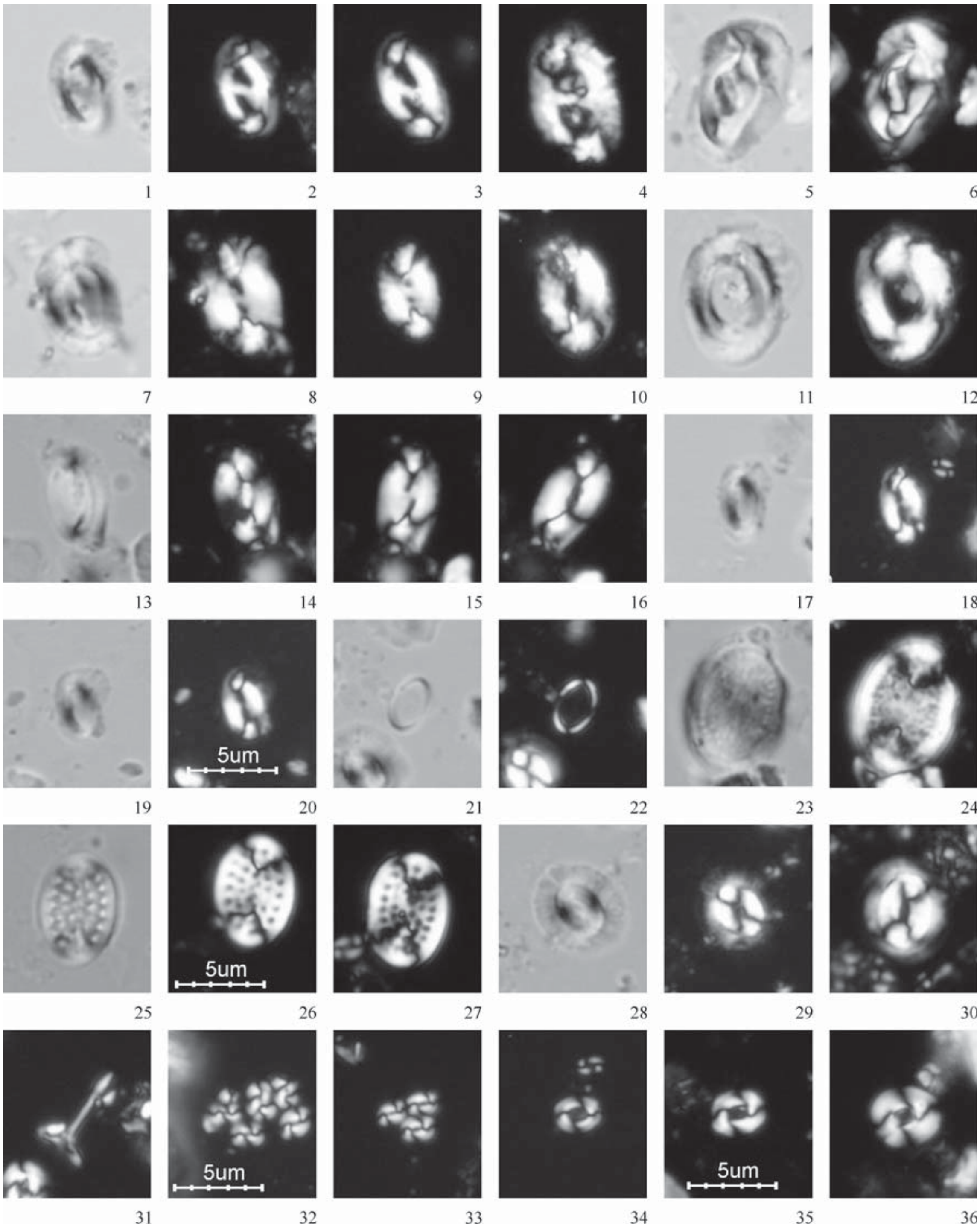

Fig. 9. Calcareous nannofossils in the Ivaň IK-1 and Vranovice VK-1 boreholes, Middle Miocene (Lower Badenian), Carpathian Foredeep. **PPL** — plane-polarized light, **XPL** — cross-polarized light. **1–3** — *Helicosphaera waltrans*, 1, 2 — Ivaň-1, 47.10 m, 3 — Vranovice-1, 47.50 m; 1 — PPL, 2, 3 — XPL. **4** — *Helicosphaera mediterranea*, Vranovice-1, 47.50 m, XPL. **5, 6** — *Helicosphaera euphratis*, Ivaň-1, 34.20 m; 5 — PPL, 6 — XPL. **7–9** — *Helicosphaera carteri,* Vranovice-1, 7, 8 — 31.60 m, 9 — 4.10 m; 7 — PPL, 8, 9 — XPL. **10** — *Helicosphaera scissura,* Vranovice-1, 47.50 m, XPL. **11, 12** — *Helicosphaera ampliaperta*, Vranovice-1, 47.50 m; 11 — PPL, 12 — XPL. **13–16** — *Helicosphaera intermedia*, Ivaň-1, 34.80 m; 13 — PPL, 14–16 — XPL at 0°, 15° and 30°. **17–20** — *Helicosphaera walbersdorfensis*, Vranovice-1, 47.50 m; 17, 19 — PPL, 18, 20 — XPL. **21, 22** - *Syracosphaera pulchra*, Ivaň-1, 47.10 m; 21 — PPL, 22 — XPL. **23, 24** — *Pontosphaera discopora,* Vranovice-1, 21.90 m; 23 — PPL, 24 — XPL. **25–27** — *Pontosphaera multipora,* Vranovice-1, 57.80 m; 25 — PPL, 26, 27 — XPL. **28–30** — *Coccolithus pelagicus*, Vranovice-1, 49.25 m; 28 — PPL, 29, 30 — XPL. **31** — *Rhabdosphaera sicca,* Ivaň-1, 5.40 m, XPL. **32, 33** — *Reticulofenestra minuta*; 32 — Ivaň-1, 12.55 m; 33 — Vranovice-1, 24.55 m, XPL. **34, 35** — *Reticulofenestra pseudoumbilicus* <5 μm, XPL; 34 — Iváň-1, 34.20 m; 35 — Vranovice-1, 12.20 m. **36** — *Cyclicargolithus floridanus,* Ivaň-1, 34.80 m, XPL.

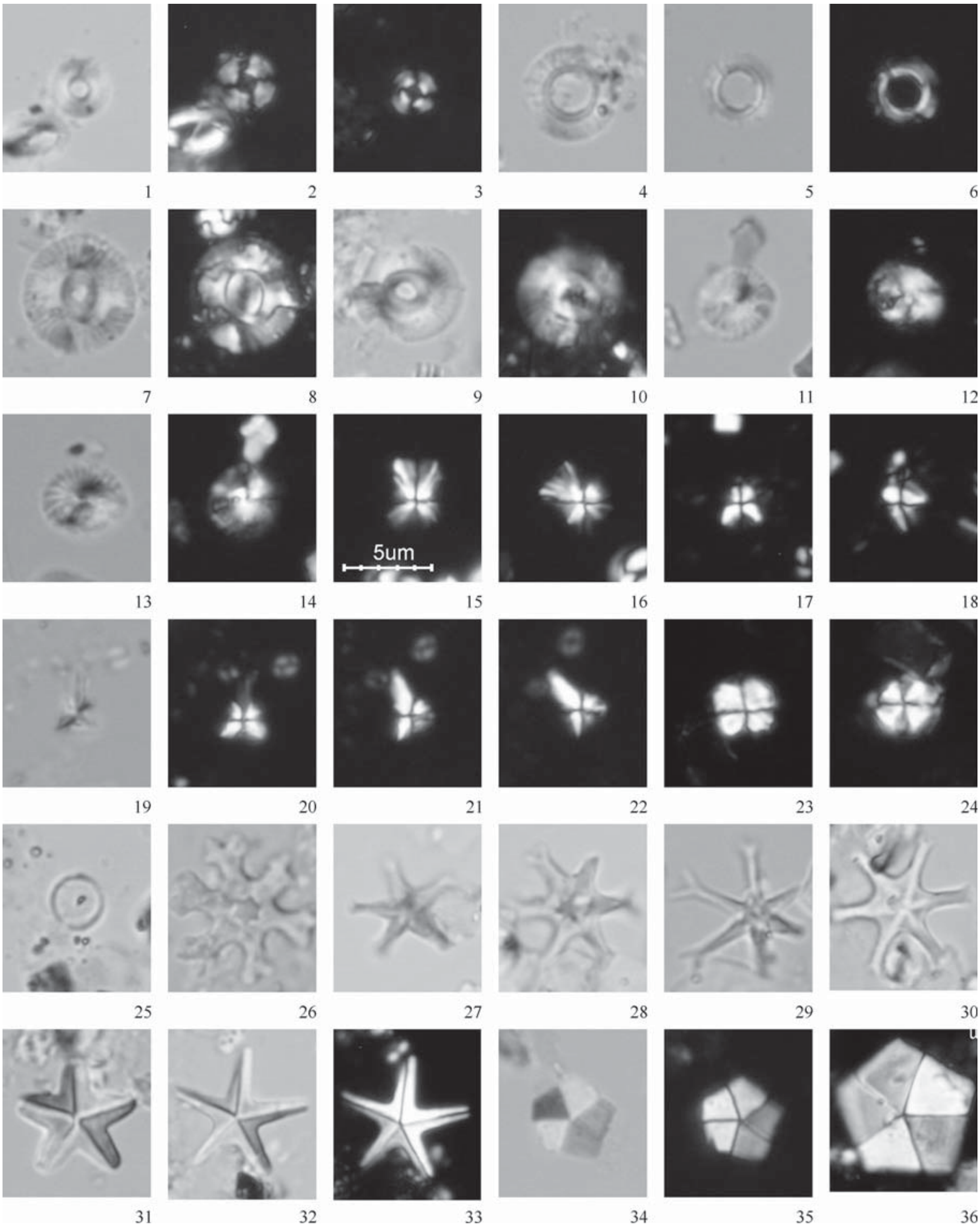

Fig. 10. Calcareous nannofossils in the Ivaň-1 and Vranovice-1 boreholes, Middle Miocene (Lower Badenian), Carpathian Foredeep. **PPL** — plane-polarized light, **XPL** — cross-polarized light. **1–3** — *Umbilicosphaera jafari*; 1 — Ivaň-1, 12.55 m, PPL; 2, 3 — Vranovice-1, 14.40 m; 2 — PPL, 3 — XPL. **4–6** — *Umbilicosphaera rotula*, Vranovice-1; 4 — 57.20 m, PPL; 5, 6 — 21.90 m; 4 — PPL, 6 — XPL. **7–10** — *Calcidiscus premacintyrei*; 7, 8 — Vranovice-1, 55.5 m; 7 — PPL, 8 — XPL; 9, 10 — Ivaň-1, 34.80 m. **11–14** — *Calcidiscus leptoporus*; 11, 12 — Vranovice-1, 55.05 m; 11, 13 — PPL, 12, 14 — XPL. **15, 16** — *Sphenolithus dissimilis*, Ivaň-1, 34.20 m, XPL at 0° and 45°. **17, 18** — *Sphenolithus conicus*, Ivaň-1, 46.20 m, XPL at 0° and 45°. **19–22** — *Sphenolithus heteromorphus*, Vranovice-1, 21.90 m; 19 — PPL, 20–22 — XPL at 0°, 15° and 45°. **23, 24** — *Sphenolithus moriformis*, Vranovice-1, 57.20 m, XPL at 0° and 45°. **25** — *Coronocyclus nitescens*, Vranovice-1, 47.50 m, PPL. **26** — *Discoaster deflandrei*, Ivaň-1, 34.80 m, PPL. **27** — 5-rayed symmetrical discoaster, Ivaň-1, 47.10 m, PPL. **28–30** — *Discoaster exilis*, PPL; 28 — Vranovice-1, 57.20 m; 29, 30 — Ivaň-1, 46.20 m. **31–33** — *Micrantholithus* sp., Vranovice-1, 59.90 m; 31 — PPL, 32, 33 — XPL. **34–36** — *Braarudosphaera bigelowii*, Vranovice-1, 59.90 m; 34, 35 — "small form" < % µm, 36 — "large form" >µm; 34 — PPL, 35, 36 — XPL.

ornata d'Orbigny, *Pappina breviformis* (Papp et Turnovsky), *Bolivina dilatata* Reuss, *B. plicatela* Cushman, *B. antiqua* d'Orbigny, *Bulimina elongata* d'Orbigny, *B. striata* d'Orbigny, *B. buchiana* d'Orbigny, accompanied by deep water species *Melonis pompilioides* and *Pullenia bulloides*, higher number of planktonic foraminifers, and by pyritized centric diatoms (Vranovice-1 in the depths 5.4 m, 12.2 m, 24.55 m, 24.7 m, 29.65 m, 49.2 m, 57.2 m, 57.8 m, 59.9 m, 60.0 m and in Ivaň-1 in 12.47 m, 20.35 m and 46.95 m) indicates low oxygen bottom conditions of deeper sublittoral (circalittoral) (Kaiho 1994; Mullins et al. 1985).

4. Dominance of planktonic foraminifers (predominance of pyritized tests) accompanied by *Siphonodosaria* div. sp., *Bolivina* div. sp., *Pyramidulina raphanistrum* (Linne), *Amphimorphina mucronata* (Karrer), *Uvigerina* div. sp. and *Lenticulina* div. sp. (Vranovice-1 in the depths of 21.9 m, 22.2 m, 23.6 m, 30.55 m, 52.8 m, Ivaň-1 in the depths of 12.55 m, 20.05 m, 23.9 m, 27.3 m, 34.2 m, 34.3 m, 34.8 m, 46.2 m, 46.7 m, 47.1 m and 48.0 m). Pyritized tests of foraminifers, especially globigerinas, dysoxic indicators (Kaiho 1999; Spezzaferri & Ćorić 2001) and pyritized centric diatoms reflect lower oxygen supply in bottom water. The assemblages document deeper sea environment (circalittoral to upper bathyal) after Pokorný et al. (1992).

The presence of *Globorotalia bykovae* and *Praeorbulina glomerosa circularis* and higher numbers of specimens *Globigerinoides* div. sp. recorded especially in the middle and upper part of the Ivaň-1 borehole indicate sea of higher temperature in the Lower Badenian in comparison with the Karpatian stage (Spezzaferri & Ćorić 2001).

5. Mixed assemblages of shallow-water (*Asterigerinata planorbis* and *Amphistegina mammilla*) and deep-water (*Melonis pompilioides* and *Pullenia bulloides*) benthic foraminifers (Vranovice-1 borehole, depths 4.6 m, 31.6 m and 46.45 m). Shallow-water specimens were probably reworked from the inner- and middle shelf into a deeper part of the depositional area. This interpretation corresponds to conclusions of Spezzaferri (2004). In her opinion sediments of the Grund Formation from the Grund area, Lower Austria, paleobathymetrically belong to the outer shelf. In contrast, Zuschin et al. (2001) non vidi, fide Spezzaferri (2004) assumes a shallow-water environment much less than 100 meters in depth based on molluscan assemblages and shell-beds geometry suggesting proximal tempestites. Foraminiferal assemblages similar to those of nos. 3, 4 and 5 (see above) were mentioned by Spezzaferri (2004) in the Grund area of the Austrian Molasse Basin.

Foraminifers found in intraclasts (Ivaň-1 borehole, 48.25 m) can be compared with taphocoenose no. 5 and from the depth 49.15 m (same borehole) with impoverished microfauna.

The microfauna of the Ivaň-1 borehole gives evidence for the deeper marine environment of the outer shelf whereas the Vranovice-1 borehole provided more shallow-water indices (Murray 1976).

To compare nannofossils, three types of oryctocoenoses were recognized:

1. Nannoflora with helicosphers, umbilicosphers and small placoliths of Prinsiaceae. *Reticulofenestra minuta* quantitatively prevails over *Coccolithus pelagicus*. These usually abundant and diversified assemblages reflect epicontinental waters with higher nutrient supply (Spezzaferri & Ćorić 2001). Abundance of *R. minuta* can be a signal of changes in nutrient dynamics (Gartner et al. 1983, 1984). Reworked species from the older strata form up to 10 %. Rare *Sphenolithus heteromorphus* and scarce presence or absence of discoasters may indicate cool surface waters.

2. Higher numbers of pentaliths *Micrantholithus* sp. and *Braarudosphaera bigelowii* (Fig. 10.31–36). *Reticulofenestra minuta* quantitatively prevails over *Coccolithus pelagicus*, specimens of genera *Helicosphaera* and *Umbilicosphaera* are relatively common. Reworked species from the older strata form about 10 %. Generally, representatives of the Braarudosphaeraceae are supposed as shallow depth indicators, document epicontinental sea and large shelf areas (Perch-Nielsen 1985).

3. *Coccolithus pelagicus* quantitatively prevails over *Reticulofenestra minuta*, helicosphers including *Helicosphaera carteri* occur in higher numbers. Reworked species from older strata quantitatively prevail over the autochthonous Miocene component. Abundance of *C. pelagicus* documents a coastal environment with nutrient supply, intense upwelling and unstable stratified water column (Spezzaferri & Ćorić 2001).

The data mentioned above show that both microfauna and calcareous nannofossils indicate similar paleoenvironmental conditions. Nevertheless, in some cases interpretations are different. For instance, intervals 6.3–14.4 m and 52.20–52.95 m of the Vranovice-1 borehole provided shallow water foraminifers accompanied by pioneer assemblages of bryozoans and molluscs that reflect warmer marine infralittoral environment of higher energy of waves.

Poor nannoflora (interval 52.20–52.95 m) where *Coccolithus pelagicus* quantitatively prevails over *Reticulofenestra minuta* documents a similar coastal environment to the microfauna, intense upwelling and unstable stratified water column, but the extremely rich and diversified nannoflora from interval 6.3–14.4 m where *R. minuta* quantitatively prevails over *C. pelagicus* indicates a shallow epicontinental sea. Moreover, rare sphenoliths and near absence of discoasters indicate cooler surface waters in both intervals.

Reworked nannofossils originate from the Upper Cretaceous and Paleogene strata. Coccoliths from the older Miocene strata (zone interval NN2–NN4) were observed rarely. In contrast, tests of reworked foraminifers come from the Lower Miocene (Karpatian) strata exclusively and form a negligible component of microfauna oryctocoenoses.

Nannofossil species *Helicosphaera amliaperta* was observed in low numbers and continuously in association with *Helicosphaera waltrans,* namely Zone NN5 especially in the Ivaň borehole (see Table 3).

The percentage of reworked nannofossils in Vranovice-1 borehole is relative low and stable (3–10 % — see Fig. 5)

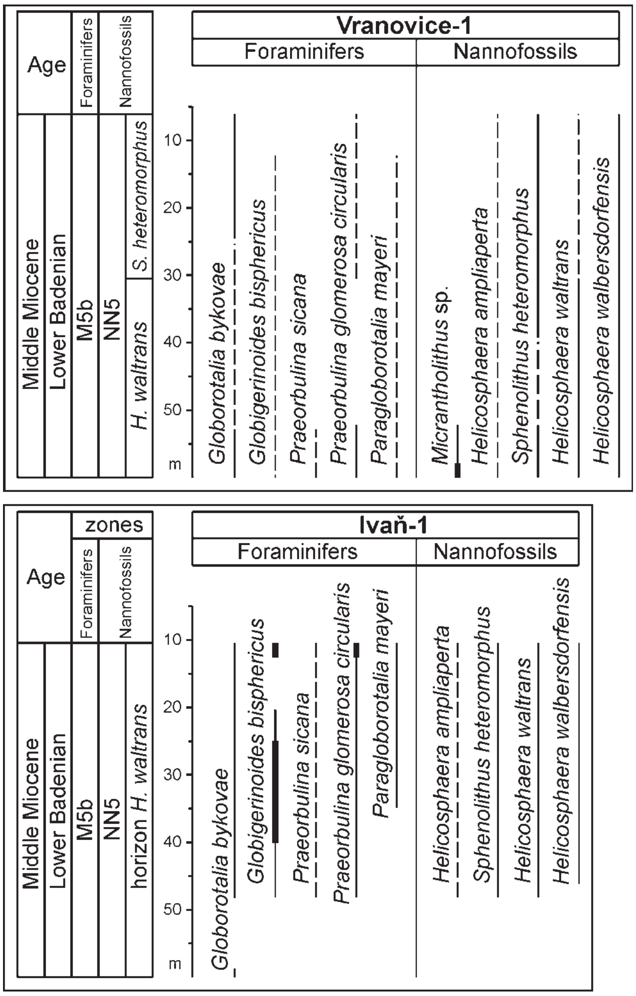

Fig. 11. Correlation schema of foraminifers and nannofossils, Ivaň-1 and Vranovice-1 boreholes. Foraminiferal zones after Berggren et al. (1995), nannofossil zones after Martini (1971), nannofossil horizons after Švábenická (2002).

although nearby land and quickly changeable paleoenvironment are indicated by the presence of remnants of plant issues, diatoms, sponge spicules, in some intervals also by bryozoans, molluscs and shallow water foraminifers s.s. On the other hand, intraclasts and the overlying deposits in a short interval of the Ivaň-1 borehole (46.20–48.10 m — see Fig. 5) provided higher numbers of reworked nannofossils fluctuating between 60–90 %. Therefore, the number of reworked nannofossil specimens may reflect rather marine transgression and the mobility of depositional area than shallow water conditions. This observation does not agree with Spezzaferi & Ćorić (2001) that relatively shallow water depths can be documented by the presence of high numbers of reworked nannofossils.

Conclusions

The foraminifers indicate the Middle Miocene (Lower Badenian of Central Paratethys regional stages), Zone M5b, species *Uvigerina macrocarinata* and *Praeorbulina glomerosa circularis* "Lower Lagenidae Zone" sensu Grill (1941). Calcareous nannofossils with *Helicosphaera waltrans*, *H. walbersdorfensis* and *Sphenolithus heteromorphus* give evidence for Zone NN5 (Fig. 11).

The first occurrence of nannofossil *Helicosphaera walbersdorfensis* precedes the first occurrence of foraminiferal marker species *Orbulina suturalis.*

Generally, plankton/benthos ratio and benthic foraminifers document paleodepths of the middle to outer shelf.

Changeable paleoenvironment, especially sea-level fluctuation and unstable conditions are documented by five types of microfauna: 1. shallow water foraminifers accompanied by fragments of molluscs and bryozoans — well-oxygenated warmer waters, infralittoral, probably lagoons, 2. joint occurrence of agglutinated and calcareous benthic foraminifers — circalittoral to upper bathyal, 3. euryoxybiont foraminifers indicate low oxygen bottom water of sublittoral (circalittoral), 4. dominance of planktonic foraminifers — lower oxygen supply, circalittoral to upper bathyal, 5. mixed assemblage of shallow- and deep-water foraminifers reflects slumping eventually storm events in depositional area.

A relatively shallow sea of normal salinity with nutrient supply is also indicated by nannoflora with higher numbers of *Reticulofenestra minuta*, *Coccolithus pelagicus*, and helicosphers. Low abundances of sphenoliths and near absence of discoasters may imply cooler surface waters.

High numbers of reworked nannofossils may reflect marine transgression.

In some cases, interpretations based on microfauna, or foraminifers and calcareous nannofossils may offer different paleoenvironmental conclusions.

On the basis of lithology and biostratigraphy sediments of the Ivaň-1 borehole are stratigraphically older and were deposited in the deeper marine environment in comparison with the Vranovice-1 borehole.

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Appendix

List of nannofossil species in alphabetical order of genera epiteths.

Braarudosphaera bigelowii (Gran et Braarud) Deflandre
Calcidiscus leptoporus (Murray et Blackman) Loeblich et Tappan
Calcidiscus premacintyrei Theodoridis
Coccolithus miopelagicus Bukry
Coccolithus pelagicus (Wallich) Schiller
Coronocyclus nitescens (Kamptner) Bramlette et Wilcoxon
Cyclicargolithus floridanus (Roth et Hay) Bukry
Discoaster adamanteus Bramlette et Wilcoxon
Discoaster deflandrei Bramlette et Riedel
Discoaster exilis Martini et Riedel
Helicosphaera ampliaperta Bramlette et Wilcoxon
Helicosphaera carteri (Wallich) Kamptner
Helicosphaera euphratis Haq
Helicosphaera intermedia Martini
Helicosphaera mediterranea Müller
Helicosphaera scissura Müller
Helicosphaera walbersdorfensis Müller
Helicosphaera waltrans Theodoridis
Micrantholithus sp.
Pontosphaera discopora Shiller
Pontosphaera multipora (Kamptner) Roth
Reticulofenestra minuta Roth
Reticulofenestra pseudoumbilicus (Gartner) Gartner
Rhabdosphaera sicca Stradner
Sphenolithus conicus Bukry
Sphenolithus dissimilis Bukry et Percival
Sphenolithus heteromorphus Deflandre
Sphenolithus moriformis (Brönnimann et Stradner) Bramlette et Wilcoxon
Syracosphaera pulchra Lohmann
Umbilicosphaera jafari Müller
Umbilicosphaera rotula (Kamptner) Varol