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CALCAREOUS NANNOPLANKTON FROM THE EGGENBURGIAN STRATOTYPE AND FACIOSTRATOTYPES (LOWER MIOCENE, CENTRAL PARATETHYS)

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Abstract: Calcareous nannoplankton was studied at the Eggenburgian holostratotype and faciostratotypes of Loibersdorf, Achberg, Brunnstube, "Judenfriedhof", Burgschleinitz, Fels am Walgram, Vaďovce, Podkylava, Sverepec, Veľká Čausa and Lipovany. As sections with rich shallow-water molluscan fauna were chosen for Eggenburgian type sections, most of the samples are not favourable for the analysis of calcareous nannoplankton. Of 51 samples, 28 samples contain common to abundant calcareous nannoplankton which can be quantitatively analysed. Three bioevents were searched for in the type sections: FAD of *Discoaster druggii* (NN1/NN2 boundary), FAD of *Helicosphaera ampliaperta* (middle part of NN2 Zone, approximately Egerian/Eggenburgian boundary *sensu* Rögl 1998), FAD of *Sphenolithus belemnos* (NN2/NN3 boundary, upper part of the Eggenburgian). In areas with continuous sedimentation from the Egerian to Eggenburgian (the Outer Western Carpathians: Waschberg, Pouzdřany and Ždánice Units and the remnant flysch trough of the Skole-Skiba Zone; the Inner Western Carpathians: the Fiľakovo (Pétervására) Basin, all three events are successively observed while in areas with transgressive Eggenburgian sediments (Lower Austria, the Vienna Basin, the Danube Basin, the Váh River Valley and Horná Nitra Basin), sequences started with FAD of *Helicosphaera ampliaperta.* Two types of autochthonous assemblages were distinguished by multivariate statistical analysis (cluster and factor analysis): (1) abundant, dominated by *Coccolithus pelagicus,* (2) rare, dominated by reticulofenestrids. The third type of assemblage is dominated by reworked Cretaceous species.

Key words: Eggenburgian, holostratotype and faciostratotypes, Central Paratethys, calcareous nannoplankton, quantitative analysis, biostratigraphy.

Introduction

The regional Central Paratethys stages were defined in the large edition: "Chronostratigraphy and Neostratotypes of the Central Paratethys". Descriptions of biostratigraphically significant fossils represent a very important part of the characteristics of every stage. The "Eggenburgian" volume of this edition (Steininger & Seneš 1971) was published in the time when the study of calcareous nannoplankton in the Paratethys started. Eggenburgian biostratigraphy was based on molluscan and foraminiferal assemblages.

Meanwhile, calcareous nannoplankton has turned into the most important group for Tertiary biostratigraphy (Berggren et al. 1995). Data on calcareous nannoplankton assemblages from some faciostratotype localities were given later by Lehotayová & Molčíková (1975), Báldi (1986) and Müller (in Steininger & Roetzel 1991), but synthetic data about calcareous nannoplankton from the type sections of the Eggenburgian are missing.

The aim of this work is to update biostratigraphic data for the stratotype localities and most of the faciostratotype localities of the Eggenburgian with the analysis of calcareous nannoplankton assemblages.

Previous studies

The regional Central Paratethys stage of Eggenburgian was defined by Steininger & Seneš (1971). The positions of its boundaries were defined more precisely later (Steininger et al. 1990; Rögl 1998). The more recent stratigraphic study (Rögl 1998) correlated the base of the Eggenburgian with the base of the Burdigalian, dated approximately to 20.5 Ma. The upper boundary is less clear and is placed in the middle part of the Burdigalian (about 18.8 Ma). On the basis of the ranges of standard calcareous nannoplankton NN zones (Martini 1971) from Berggren et al. (1995), the time interval of the Eggenburgian (20.5–18.8 Ma) can be correlated with the upper part of NN2 Zone and lower part of NN3 Zone. Together with this concept of the Eggenburgian, the older one is still persisting, which correlated the Egerian/Eggenburgian boundary with the lower boundary of the NN2 Zone (Mărunțeanu 1992; Lehotayová 1984).

The following important bioevents in the calcareous nannoplankton assemblages were recorded around the analysed time interval, that is during the NN2 and NN3 Zones, in the world ocean (Berrgren et al. 1995) and in the Mediterranean (Fornaciari & Rio 1996):

(1) The FAD of *Discoaster druggii* indicates the base of the NN2 Zone. This event is dated to 23.2 Ma (Berggren et al. 1995). In the Central Paratethys, it was correlated with the base of the Eggenburgian (Lehotayová 1982; Mărunțeanu 1992). Based on the more recent correlation (Steininger et al. 1990; Rögl 1998), this bioevent is correlated with the Miocene part of the Egerian Stage.

(2) The FAD of *Helicosphaera ampliaperta*. This event is recognizable in the Indo-Pacific area and in the Mediterranean where it is dated to about 20 Ma (Fornaciari & Rio 1996). This event can be correlated with the middle part of NN2 Zone. In the Mediterranean area, the event defined the lower

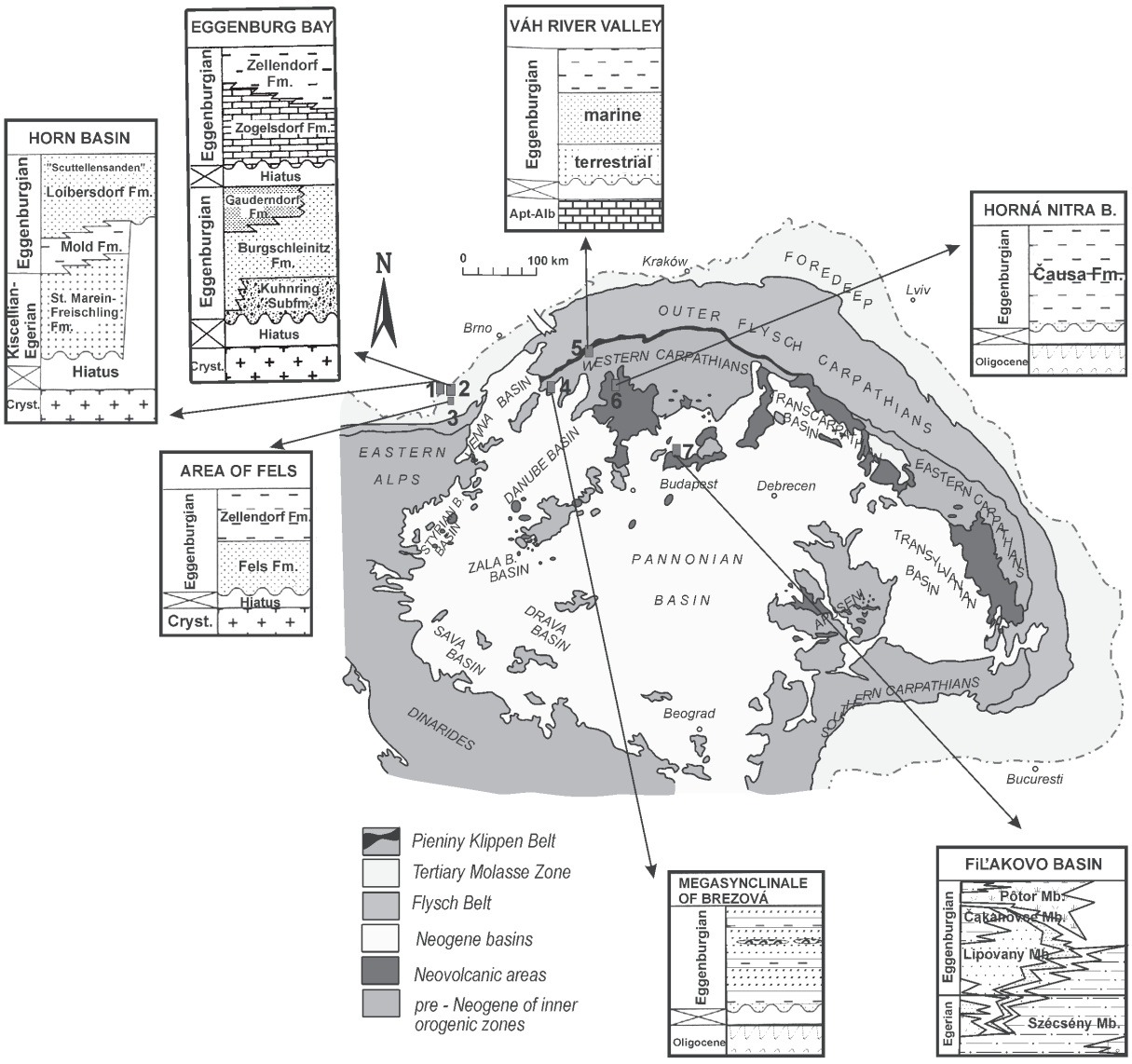

Fig. 1. Locations of the studied type sections and lithostratigraphy of the areas of interest. Lithostratigraphical schemes according to Roetzel et al. 1999 (Horn Basin, Fels area, Eggenburg Bay).

boundary of MNN2b Subzone correlated with the upper part of NN2 Zone (Fornaciari & Rio 1996). The type sections of Burdigalian (Pont-Pourqui Falunes and Montbrison-Fontbonau sections) contain assemblages with *H. ampliaperta* (Müller & Pujol 1979; Demarque & Perrieux 1984). The event can be correlated approximately with the Egerian/Eggenburgian boundary dated to 20.5 Ma (Rögl 1998) .

(3) The FAD of *Sphenolithus belemnos* is correlated with the base of the NN3 Zone and dated to 19.2 Ma (Berggren et al. 1995).

In the Central Paratethys, larger syntheses about the biostratigraphy of calcareous nannoplankton were published for the Western Carpathians (Lehotayová 1984), Romania (Mărunțeanu 1992) and Ukraine (Andreyeva-Grigorovich et al. 1997). Besides the events described from the world ocean, other events have been described for the Lower Miocene of the Central Paratethys. These events can be correlated with the Miocene part of the Egerian: the FAD of *Reticulofenestra pseudoumbilicus* (Mărunțeanu 1992); the FAD of the endemic species *Reticulofenestra excavata* (Lehotayová 1975); FAD of *Helicosphaera scissura* (Holcová 2001).

From the Eggenburgian, Lehotayová & Molčíková (1975) described poor calcareous nannoplankton assemblages with prevailing *Coccolithus pelagicus* which cannot be well correlated with the standard nannoplankton zones (Martini 1971). Lehotayová (1982) described calcareous nannoplankton assemblages of NN2 Zone with *Discoaster druggii* and *Helicosphaera ampliaperta* from the Slovak part of the Western Carpathians and correlated their occurrence with the Eggenburgian.

From Romania, Mărunțeanu (1992) described a successive appearance of *Discoaster druggii, Helicosphaera ampliaperta* and *Sphenolithus belemnos* correlable with the Mediterranean. *Helicosphaera ampliaperta* is absent from the Lower Miocene sediments of the Ukrainian Carpathians (Andreyeva-Grigorovich et al. 1997).

Müller (in Steininger & Roetzel 1991) correlated Eggenburgian sediments from Austria with the NN2–NN3 Zones, but provided no list of nannoflora.

Material

The Eggenburgian Stage of the Central Paratethys is defined at the Loibersdorf holostratotype in Lower Austria and at 19 faciostratotypes: of these, 9 are located in Austria, 9 in western and southern Slovakia and one in Hungary (Steininger & Seneš 1971). All these sections are described in detail by Steininger & Seneš (1971). Material from 11 of these type sections was available for study. Unfortunately, borehole material from the PB-1 borehole Sverepec (Váh River Valley) and ČČ-3 borehole Veľká Čausa (Horná Nitra Basin) has not been found and could not be studied.

The studied holostratotype and faciostratotype sections are located in the following areas (Fig. 1):

(1) Horn Basin: holostratotype — Loibersdorf (Loibersdorf Formation); faciostratotypes — Mold (Mold Formation, basal Loibersdorf Formation); Achberg — Scutellensande (Loibersdorf Formation). Eggenburgian sedimentary cycle started with the Mold Formation deposited in a brackish environment. This formation contains abundant euryhaline molluscs. Its stratigraphic position is not safely determined and varied from the Upper Egerian to the Lower Eggenburgian in different papers. Its sediments are overlain by marine, sublittoral deposits of the Loibersdorf Formation (Steininger & Roetzel 1991; Roetzel et al. 1999).

(2) The Eggenburg Bay: faciostratotypes of Brunnstubengraben bei Eggenburg (Kühnring Subformation); "Judenfriedhof" of Kühnring near Eggenburg (Kühnring Formation); Burgschleinitz–Kirchenburg (Burgschleinitz Formation and Gauderndorf Formation). Eggenburgian sedimentation started with the Kühnring Subformation containing fauna of intertidal molluscs. The overlying Burgschleinitz Formation is represented by sandstones with rich and diversified macrofauna, indicating a normal marine, sublittoral paleoenvironment. Foraminiferal assemblages were dominated by shallow-water cibicidoids, elphidiids and ammonias. The Eggenburgian succession in the Eggenburg Bay is topped by siltstone and fine-grained sandstone of the Gauderndorf Formation, which was deposited in a similar paleoenvironment to the underlying Burgschleinitz Formation (Steininger & Seneš 1971; Steininger & Roetzel 1991; Pervesler et al. 1998; stratigraphic data summarized by Roetzel et al. 1999).

(3) Area of Fels: faciostratotype Fels am Wagram (Fels Formation). Eggenburgian sedimentation started with the Fels Formation deposited under marine littoral conditions (Steininger & Seneš 1971).

All the formations described from Austria (with the exception of the Mold Formation) are dated to the Eggenburgian according to the molluscan fauna, and correlated with calcareous nannoplankton zones NN2–NN3 and planktonic foraminiferal zone N5 (Steininger & Roetzel 1991).

(4) Megasyncline of Brezová: faciostratotypes of Vaďovce and Podkylava. Eggenburgian sediments are represented by conglomerates, sandstones and detrital limestones (Buday et al. 1965) with rich sublittoral, marine molluscan fauna (Čtyroký 1959). Cicha (1957) described diversified sublittoral to neritic foraminiferal assemblages.

(5) Váh River Valley: faciostratotype of Sverepec. Lacustrine claystones are overlain by brackish pelites and normal marine sandstones and conglomerates. The succession is terminated by pelites. Coarser-grained sediments contain sublittoral molluscs; neritic molluscs were described from fine-grained sediments (Buday et al. 1965; Steininger & Seneš 1971). Foraminiferal assemblages from the Váh River Valley were studied by Cicha (1957) who described diversified sublittoral to neritic marine assemblages without planktonic foraminifers. Salaj & Zlinská (1991) described assemblages dominated by planktonic foraminifers. Lehotayová (1982) described poorly preserved calcareous nannoplankton assemblages of NN2 Zone (Martini 1971) with *Helicosphaera ampliaperta*.

(6) Horná Nitra Basin: faciostratotype Veľká Čausa. The Eggenburgian is represented by the Čausa Formation (Gašparík et al. in Steininger et al. 1985) formed by siltstones to claystones with sandstone intercalations (Gašparík 1969). The molluscan fauna indicates a sublittoral marine paleoenvironment. Poorly diversified shallow-water foraminiferal assemblages were described by Lehotayová (1959). Abundant calcareous nannoplankton assemblages of the NN2 Zone with abundant *Coccolithus pelagicus* and with *Helicosphaera ampliaperta* from the Horná Nitra Basin were recorded by Lehotayová (1982).

(7) The Fiľakovo Basin (faciostratotype of Lipovany): Lipovany Member represents sandstones with conglomerate and siltstone beds and tuffite beds (Vass et al. 1992). The Lipovany Member is characterized by common macrofauna (Ondrejíčková 1972). Foraminiferal assemblages contain shallow-water benthic foraminiferal assemblages dominated by the *Ammonia parkinsonia-tepida* group as well as assemblages dominated by cibicidoids (Holcová 2001). Both foraminifers and molluscs indicate a sublittoral paleoenvironment with normal salinity. The overlying Čakanovce Member is characterized by siltstones to fine-grained sandstones. It contains neritic molluscan fauna (Ondrejíčková 1972). Among benthic foraminiferal assemblages, stenohaline upper neritic assemblages appear (dominated by cibicidoids). Euryoxibiont foraminiferal assemblages with *Cassidulina* and *Bulimina* were recorded locally in the deepest part of the basin (Holcová 2001).

The analysis of the Eggenburgian type sections was completed by the study of the Miocene Egerian faciostratotype of Bretka for comparison of changes between the Lower Miocene calcareous nannoplankton assemblages in the Egerian and Eggenburgian. This locality is correlated with the Miocene on the basis of large foraminifers (Váňová 1975).

Methods

Calcareous nannoplankton was studied by standard methods using an optical microscope. The relative abundance of the taxa is related to the number of nannofossils. Therefore, taxa with a high number of coccoliths in coccosphaeras seem to be more abundant than those with low number of cocco-

	100 m bellow stratotype	50 m bellow stratotype	3 m bellow boundary Lip./Čak. Mbs	Lipovany																										
	Lipovany Mb.	Lipovany Mb.	Lipovany Mb.	boundary Lip./Čak. Mb.	base of Čak. Mb.	0.2 m above base	0.5 m above base	1 m above base	2 m above base	3 m above base	3.5 m above base	4 m above base	5 m above base	Bretka-stratotype 1	Bretka-stratotype 2	Sverepec-limestones	Sverepec - Somarica	Sverepec 42/1	Sverepec 42/2	Podkylava - sandstones 86	Podkylava - breccia	Podkylava	Vaďovce 1061	Vaďovce 93 - limestones	Vaďovce 26	Krajne	Veľká Čausa 1	Veľká Čausa 2		
	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Čakanovce Mb.	Bretka Mb.	Bretka Mb.												Čausa Mb.	Čausa Mb.		
Reticulofenestra minuta ROTH		6	17	9	74	12	5		18	6		7	3	7	12			26	10			1	2		5					
Reticulofenestra pseudoumbilica (GARTNER) GARTNER		1	12		7	12	2		9	6	2	4	5	2	8			6	13	1	3	1	5		1	1				
Reticulofenestra daviesi (HAQ) HAQ			1	5	3		1		6		1		1	1	2														
Reticulofenestra bisecta (HAY, MOHLER et WADE) ROTH		3		2	1					8	1							1	1							1			
Reticulofenestra bisecta (HAY, MOHLER et WADE) ROTH - small-sized																		1	7			1	5		4				
Reticulofenestra excavata LEHOTAYOVA		6	15		11	13	27		21	8	20	9	7					7	1	2	1	5	6		1				
Reticulofenestra lockeri MULLER		1		1		3	1		1	1								1	1				2						
Reticulofenestra ornata MULLER		1	1	1	1		2						3		2														
Reticulofenestra umbilica (LEVIN) MARTINI et RITZOWSKI						1				1	1			1	1			1			1								
Coccolithus pelagicus (WALLICH) SCHILLER		29	66	70	45	80	77		66		86	67	42	19	36			26	17	24	31	28		1	9	14				
Coccolithus miopelagicus BUKRY																							1		1				
Cyclicargolithus abisectus (MULLER) BUKRY			1		1					1	2		1	2	2		1	4					1	1					
Cyclicargolithus floridanus (ROTH et HAY) BUKRY		1	3	2	1	1				1	3	3	1	4	6			2	6				2						
Cribrocentrum reticulatum (GARTNER et SMITH) PERCH-NIELSEN						1	2												2			1	2	1						
Cricolithus ionesi COHEN				3		2			6	1	2									1		1				1				
Pontosphaera multipora KAMPTNER			2	2	1	1	5				1		1	3	3			5	8											
Transversopontis pulcher (DEFLANDRE) PERCH-NIELSEN			1								1																		
Braarudosphaera bigelowi (GRAN et BRAARUD) DEFLANDRE																		2	1	1	1								
Discolithina latelliptica BALDI-BEKE			2		1				1				1		1		1												
Helicosphaera ampliaperta BRAMLETTE et WILCOXON - narrow opening						4	4			3	5	2											2						
Helicosphaera ampliaperta BRAMLETTE et WILCOXON		1	4	1	3	4	2		1		2		6							1	1	6							
Helicosphaera carteri (WALICH) KAMPTNER		1		1	1		2		1	1		2			2			5	1				2						
Helicosphaera euphratis (HAQ) MARTINI			1			1			2			1			3														
Helicosphaera mediterranea MULLER																										5			
Helicosphaera recta (HAQ) MARTINI																													
Helicosphaera scissura MILLER					3								2					1	1	1	1	1							
Sfenolithus belemnos BRAMLETTE et WILCOXON			1		1																								
Sphenolithus disbelemnos FORNACIARI et RIO				1																2									
Sphenolithus moriformis (BRONNIMANN et STRADNER) BRAMLETTE et WILCOXON				1			2		2		1				1					1									
Discoaster barbadoensis (TAN SIN HOK) BRAMLETTE et RIEDEL																		1											
Discoaster druggii BRAMLETTE et WILCOXON											1																		
Discoaster sp. (broken specimen)																			2										
Thoracosphaera sp.		6	2	1					3			1	1						3	1									
Arkhangelskiella sp.																													
Watznaueria sp.			2				2					3					4	36	14	34	27	25	29	1	7	17				
Micula sp.																													
Isthmolithus recurvus DEFLANDRE												1																	
Chiasmolithus sp.																				3	1		1						
Eifelithus sp.												1								1		5				1			
Nannolith abundance	rare	very rare	common	rare	common	common	common	absent	abundant	common	abundant	rare	rare	rare	rare	absent	very rare	rare	rare	rare	rare	rare	common	very rare	rare	rare	absent	absent		

Fig. 2. *Continued on page 385.*

	Fels am Wagram - Dornergraben	Obernholz-Gemeindegrube	Mold-Kirchensteig bed 5	Mold-Kirchensteig bed 6	Mold-Kirchensteig Turritella bed	W-Nonndorf-am Waldrand bed 35	Loibersdorf - Hohlweg	Loibersdorf Süd	Achberg - Scutellensande	Kühnring - Judenfriedhof 12	Kühnring - Judenfriedhof 19	Kühnring - Judenfriedhof 21	Kühnring - Judenfriedhof 22	Kühnring - Judenfriedhof 23	Kühnring - Judenfriedhof 24	Maigen - Sandgrube Stranzl 2-2	Brunnstube-Raimundstollen	Burgschleinitz-Kirchenbruch 6	Maigen - Sandgrube Stranzl 2-15	Kühnring - Gemeindesandgrube	Burgschleinitz-Kirchenbruch 10	Maigen - Sandgruge Stranzl 2-31	Brunnstube-Raimundstollen	Brunnstube
	Fels Fm.	Fels Fm.	Mold Fm.	Mold Fm.	Loibersdorf Fm.	Loibersdorf Fm.	Loibersdorf Fm.	Loibersdorf Fm.	Loibersdorf Fm.	Kühnring Sfm.	Kühnring Sfm.	Kühnring Sfm.	Kühnring Sfm.	Kühnring Sfm.	Kühnring Sfm.	Kühnring Sfm.	Kühnring Sfm.	Burgschleinitz Fm.	Burgschleinitz Fm.	Gauderndorf Fm.	Gauderndorf Fm.	Gauderndorf Fm.	Gauderndorf Fm.	Gauderndorf Fm.
Reticulofenestra minuta ROTH				+			2	1					+				6			5	1		4	4
Reticulofenestra pseudoumbilica (GARTNER) GARTNER							3	11						+	+		10			9	5		1	15
Reticulofenestra daviesi (HAQ) HAQ							1	6									1			4				
Reticulofenestra bisecta (HAY, MOHLER et WADE) ROTH																	1							3
Reticulofenestra bisecta (HAY, MOHLER et WADE) ROTH - small-sized								3									6				1			2
Reticulofenestra excavata LEHOTAYOVA																								
Reticulofenestra lockeri MULLER																								
Reticulofenestra ornata MULLER																								
Reticulofenestra umbilica (LEVIN) MARTINI et RITZOWSKI																				1	1			
Coccolithus pelagicus (WALLICH) SCHILLER							5	74			+		+		+		20		+	29	27		8	61
Coccolithus miopelagicus BUKRY																								
Cyclicargolithus abisectus (MULLER) BUKRY								1									2			1				1
Cyclicargolithus floridanus (ROTH et HAY) BUKRY								2			+						6						1	3
Cribrocentrum reticulatum (GARTNER et SMITH) PERCH-NIELSEN							2	1									12				10			4
Cricolithus ionesi COHEN																								
Pontosphaera multipora KAMPTNER																								
Transversopontis pulcher (DEFLANDRE) PERCH-NIELSEN																					1			
Braarudosphaera bigelowi (GRAN et BRAARUD) DEFLANDRE																								
Discolithina latelliptica BALDI-BEKE																								
Helicosphaera ampliaperta BRAMLETTE et WILCOXON - narrow opening								2													5			
Helicosphaera ampliaperta BRAMLETTE et WILCOXON																				1				
Helicosphaera carteri (WALICH) KAMPTNER																					1			1
Helicosphaera euphratis (HAQ) MARTINI																								1
Helicosphaera mediterranea MULLER																								
Helicosphaera recta (HAQ) MARTINI																					10			
Helicosphaera scissura MILLER																								2
Sfenolithus belemnos BRAMLETTE et WILCOXON																								
Sphenolithus disbelemnos FORNACIARI et RIO																								
Sphenolithus moriformis (BRONNIMANN et STRADNER) BRAMLETTE et WILCOXON								1									1							
Discoaster barbadoensis (TAN SIN HOK) BRAMLETTE et RIEDEL																								
Discoaster druggii BRAMLETTE et WILCOXON																								1
Discoaster sp. (broken specimen)																					1			
Thoracosphaera sp.						+											1							
Arkhangelskiella sp.								1									2			2	1			1
Watznaueria sp.							1	9			+		+				14			10	15		3	5
Micula sp.								1									2			2	1		2	1
Isthmolithus recurvus DEFLANDRE																								
Chiasmolithus sp.																	1							
Eifelithus sp.					+															2				
Nannolith abundance	absent	absent	absent	very rare	very rare	very rare	rare	common	absent	absent	very rare	absent	very rare	very rare	very rare	absent	abundant	absent	very rare	abundant	common	absent	rare	common

Fig. 2. A list of nannoplankton taxa from the studied Eggenburgian type sections. Light grey hatching — samples from O. Mandic, dark grey hatching — samples from R. Roetzel.

liths. About 300 nannofossils were counted in each sample. The numbers of nannofossils in the assemblages were listed in a table and used as input data in multivariate statistical analysis (Fig. 3). Transposed matrixes were used for the computation: the taxa were arranged in rows (cases), samples in columns (variables).

Quantitative data were analysed by standard methods of multivariate statistics, computation was performed using statistical software BMDP (Dixon 1993). Before the analysis, samples with no or very rare calcareous nannoplankton were excluded from further computation. Cluster analysis of variables was used for clustering of samples. The correlation coefficient was used as a distance measure. For combined clusters, all three criteria were tested: single linkage, complete linkage and average linkage. Results of these three methods were compared (Fig. 4). Samples were also classified by factor analysis. Principal component analysis and varimax rotation were used for the computation. Variabilities in species composition of the assemblages in samples were reduced to three factors. Clusters of samples with a high factor score of the same factor were compared with results of cluster analysis (Fig. 4). High values of factor loading indicate which nannofossil taxa are decisive for the classification of samples.

Results

Characteristics of calcareous nannoplankton assemblages

As sections with rich shallow-water molluscan fauna were chosen for Eggenburgian type sections, most of the samples are not favourable for the analysis of calcareous nannoplankton. Calcareous nannoplankton assemblages are rare and poorly diversified at most of the localities. The assemblages are dominated by *Coccolithus pelagicus,* reticulofenestrids and helicoliths. A list of species of calcareous nannoplankton for the sections analysed is given in Fig. 2, relative abundances of selected taxa in Fig. 3.

No calcareous nannoplankton was recorded in the Fels, Mold and Burgenschleinitz formations. Foraminifers commonly occur in the Loibersdorf Formation at Loibersdorf holostratotype and in the Kühnring Formation at Brunnstube-Raimundstollen faciostratotype. Calcareous nannoplankton is most common in the Gauderndorf Formation, where it occurs in the sections at Brunnstube, Kühnring and Burgschleinitz. No or very rare occurrence of calcareous nannoplankton was recorded also at Sverepec (Váh River Valley). Calcareous nannoplankton is absent from our samples from Veľká Čausa (Horná Nitra Basin).

The following classification of calcareous nannoplankton assemblages was proposed on the basis of the occurrence of biostratigraphically significant taxa. Assemblages with very rare occurrence of calcareous nannoplankton were excluded from this classification because the absence/presence of stratigraphically significant species in this type of assemblages are random.

(1) Assemblages with the Miocene species *Reticulofenestra excavata, R. pseudoumbilicus* and *Helicosphaera scissura* without *Helicosphaera ampliaperta* were observed at Sverepec (Váh River Valley) and in the basal Eggenburgian sediments of the Kühnring Subformation (Brunnstube) in Lower Austria. Similar assemblages occur in the faciostratotype of Bretka in the Miocene part of the Egerian. The occurrence of *Discoaster druggii* in the Brunnstube section is indicative of the NN2 Zone. The absence of *Helicosphaera ampliaperta* indicates the lower part of the NN2 Zone, which cannot be correlated with the Eggenburgian sensu Rögl (1998). The occurrence of this type of assemblages at the faciostratotypes has two possible explanations: (i) faciostratotypes without *Helicosphaera ampliaperta* can be correlated with the lower part of NN2 Zone and may then validate the Egerian/Eggenburgian boundary at the boundary of the nannoplankton zones NN1/NN2, or confirm the validity of type sections such as the Eggenburgian ones. (ii) The absence of *Helicosphaera ampliaperta* may be caused by unfavourable paleoenvironmental conditions during its deposition, and the type sections may be also correlated with the upper part of NN2 Zone. This is very probable in the Kühnring Subformation and also in the section of Sverepec. This conception is confirmed by the scarce occurrence of *Helicosphaera ampliaperta* (missing in the section of the Sverepec faciostratotype) in other sections in the Váh River Valley (Lehotayová 1984).

(2) Assemblages with *Helicosphaera ampliaperta* can be correlated with the upper part of NN2 Zone and with the Eggenburgian and Burdigalian. These assemblages occur in the Loibersdorf Formation including the holostratotype area, in the Gauderndorf Formation in the Eggenburg Bay and at the faciostratotypes of Podkylava and Vaďovce from the Megasyncline of Brezová. At the locality of Podkylava, *Helicosphaera ampliaperta* is accompanied by *Sphenolithus disbelemnos.* Although no nannofossils were recorded in the analysed material from the Veľká Čausa section, Lehotayová (1984) described this type of calcareous nannoplankton assemblage from another faciostratotype section from the Horná Nitra Basin (borehole ČČ-3).

(3) Assemblages with *Sphenolithus belemnos* which can be correlated with zone NN3 were found at the faciostratotype of Lipovany in the Fiľakovo Basin.

Multivariate statistical analysis

All the tested multivariate statistical methods give comparable results (Fig. 4) although some differences were observed in the obtained results. The results of cluster analysis by complete linkage based on minimum similarity, it is the maximum distance of variables can be best interpreted. The results of this method are similar to average linkage. All methods including factor analysis enable us to distinguish the following types of assemblages:

(1) Assemblages dominated by *Coccolithus pelagicus* are the most frequent type. They occur in the Lipovany and Loibersdorf Formation, and dominate the Čakanovce Member and Gauderndorf Formation. The high similarity of samples shown in dendrograms in Fig. 4 reflects small differences in the species composition of clustered assemblages.

(2) Assemblages dominated by reworked Cretaceous *Watznaueria* sp. occur in the Váh River Valley and in the Megasyncline of Brezová. Samples from the sections at Brunnstube and Burgschleinitz were also classified to this group by some methods (factor analysis, cluster analysis us-

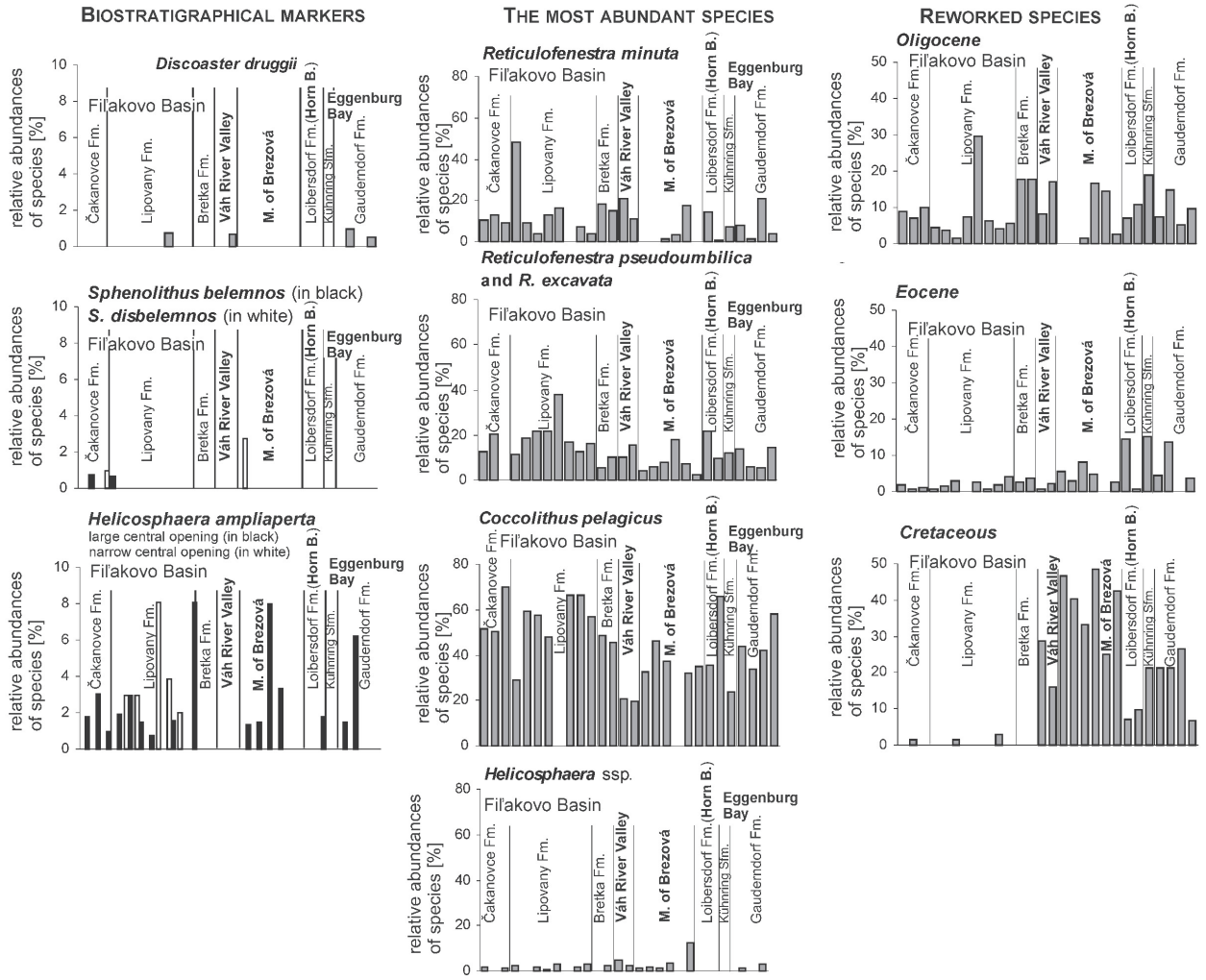

Fig. 3. Relative abundances of the most abundant taxa, biostratigraphically significant taxa and reworked taxa in the studied sections.

ing average linkage). Two "subgroups" of this type of assemblages can be distinguished by cluster analysis using average or complete linkage: (i) assemblages dominated by *Coccolithus pelagicus* among autochthonous taxa (Podkylava and Krajné sections); (ii) assemblages dominated by reticulofenestrids in autochthonous parts of the assemblages (mainly the Sverepec section).

(3) A small group is represented by samples dominated by *Reticulofenestra minuta* from certain levels of the Čakanovce Member in the Fiľakovo Basin.

Reworked nannofossils

Three groups of reworked nannofossils can be distinguished in the Eggenburgian type sections on the basis of their stratigraphic range: (1) Cretaceous, (2) Eocene, (3) Oligocene.

Their occurrences reflect stratigraphical ranges of the underlying sediments which can be reworked and embedded in the Eggenburgian sediments. Reworked taxa are included in the list of taxa (Fig. 2); relative abundances of reworked taxa are given in Fig. 3.

Reworked species are generally scarce in the Fiľakovo Basin (below 15 %). They are dominated by Oligocene redepositions. This sufficiently documents the marked dominance of Oligocene sediments below the Lower Miocene sediments (Vass et al. 1992).

Abundant reworked nannofossils in the Megasyncline of Brezová and the Váh River Valley are dominated by Cretaceous redepositions (about 50 %). This is in agreement with the widespread occurrence of Cretaceous sediments in this area. Remarkable is the occurrence of reworked Oligocene species although Oligocene sediments have not been reported from these areas.

Reworked nannofossils are also common in the Austrian type sections. They are dominated by Cretaceous redepositions, but Eocene and Oligocene taxa are also relatively abundant (Fig. 4).

Discussion

Eggenburgian calcareous nannoplankton was also studied in other areas of the Central Paratethys. The results of these studies (e.g., Krhovský et al. 1995; Lehotayová 1982, 1984; Andreyeva-Grigorovich et al. 1997; Andreyeva-Grigorovich & Halásová 2000) were used for the classification of the Lower Miocene sediments of the Central Paratethys. The division

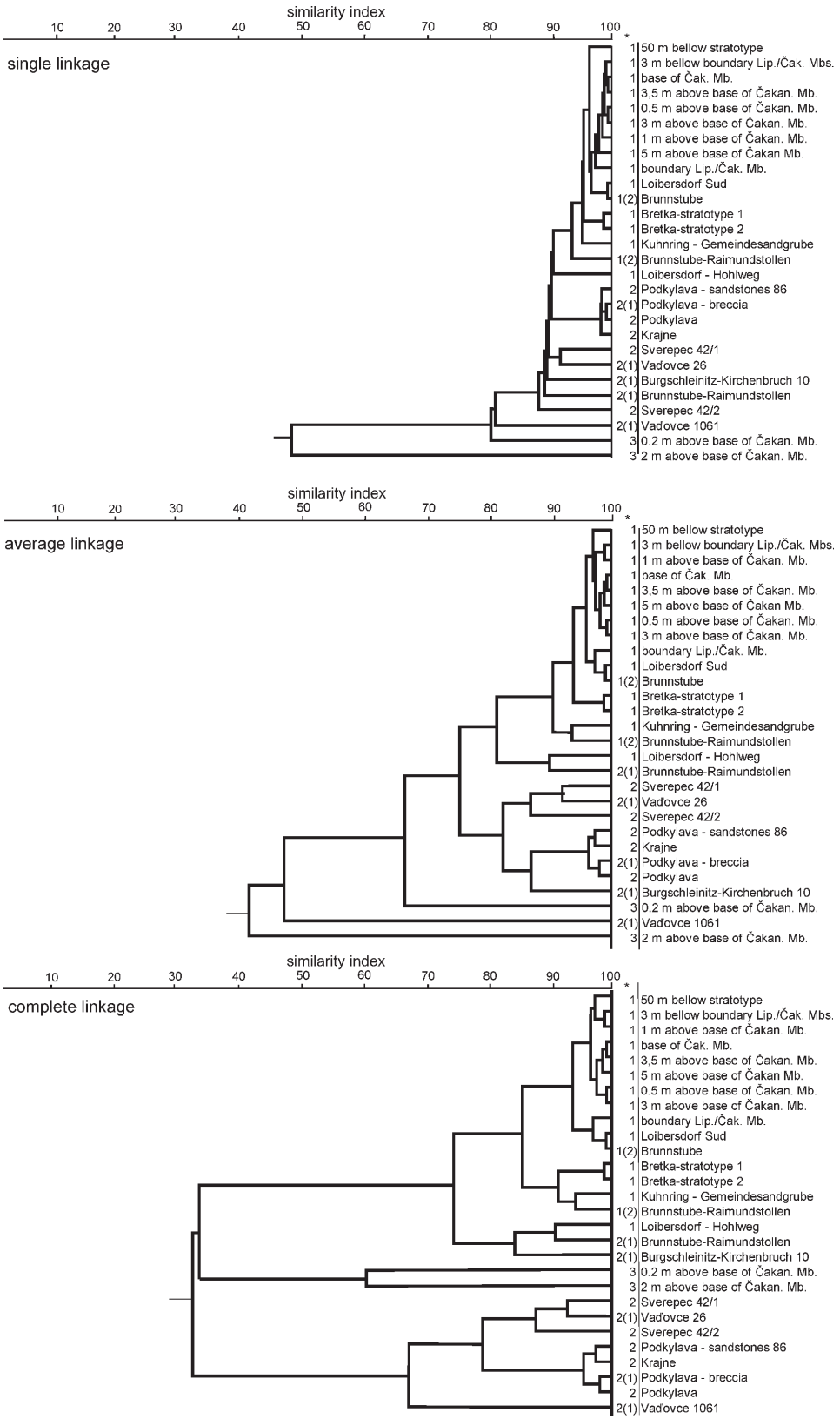

Fig. 4. Classification of calcareous nannoplankton assemblages using cluster and factor analysis.

is based on their stratigraphical ranges assessed by the calcareous nannoplankton bioevents (FAD of *Discoaster druggii* and *Helicosphaera scissura*; FAD of *Helicosphaera ampliaperta*, FAD of *Sphenolithus belemnos*) (Fig. 5):

(1) The area with sediments where all three events were recorded, and the stratigraphic range of the sediments continues above and below these events: Pouzdřany Unit (Krhovský et al. 1995); Ždánice Unit (Molčíková & Straník 1987);

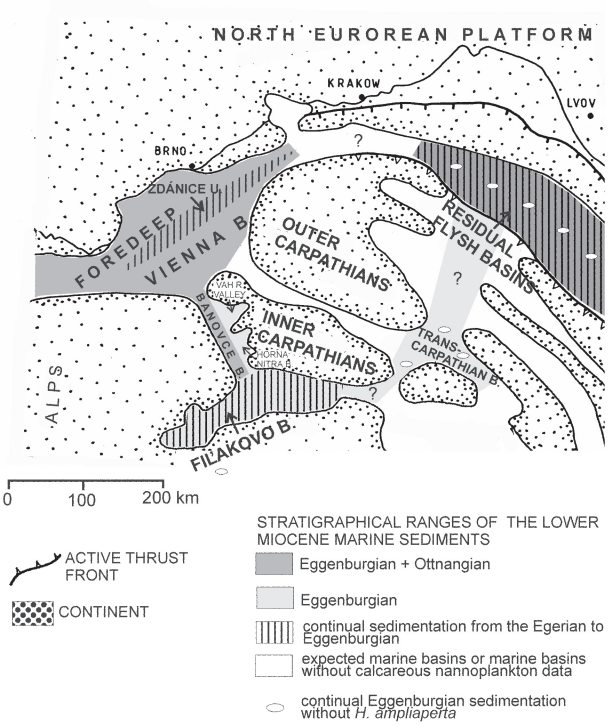

Fig. 5. Distribution of the Lower Miocene sediments with different stratigraphic ranges in the Central Paratethys. General paleogeographical scheme modified after Kováč et al. (1993) and Kováč (2000).

Fiľakovo (Pétervására) and Novohrad (Nógrád) Basin in southern Slovakia and northern Hungary (Vass et al. 1992; Báldi 1986; Sztanó 1994; Holcová 2001). This stratigraphical range of the Lower Miocene sediments is expected also for the Ukraine although *Helicosphaera ampliaperta* has not been recorded in this area (Andreyeva-Grigorovich et al. 1997).

(2) The oldest deposits of the Eastern Slovak Basin are claystone to sandstone of the Prešov Formation (Vass 2000). From the index nannoplankton taxa, only *Helicosphaera scissura* was recorded in this formation. Therefore, the Prešov Formation may be correlated with the time interval to the FAD of *Helicosphaera ampliaperta*. The more probable interpretation also correlates the Prešov Formation with the time interval above the FAD of *H. ampliaperta.* The index species did not penetrate to the Eastern Slovak Basin or to the Ukraine.

(3) Transgressive sediments with *Helicosphaera ampliaperta* initiate the Lower Miocene sedimentation in the Vienna Basin (Andreyeva-Grigorovich & Halásová 2000), Megasyncline of Brezová (this work), Danube Basin — Bánovce Depression (Fordinál et al. 2001) and Horná Nitra Basin (Lehotayová 1982).

(4) Transgressive sediments with the absence of *Helicosphaera ampliaperta* at the base have been described from Lower Austria (Horn Basin and Eggenburg Bay) and from the Váh River Valley. The absence of *H. ampliaperta* at the base of the transgressive sediments is probably caused by the not fully marine character of these sediments (Roetzel et al. 1999).

The following paleogeographic conclusions can be drawn from these data:

Continuous sedimentation from the Egerian to the Eggenburgian is characteristic for the Waschberg Zone, Pouzdřany and Ždánice units and for the residual flysch trough of the Skole-Skiba Zone. The index species of *Helicosphaera ampliaperta* did not penetrate into the eastern unit (Ukrainian Carpathians) and probable also not into the Eastern Slovak Basin. In the Fiľakovo (Pétervására) Basin, sedimentation also continued from the Egerian, but came to an end during the time corresponding to the NN3 Zone.

Transgressive Eggenburgian sediments in Lower Austria, in the Vienna Basin, Danube Basin, the Váh River Valley and Horná Nitra Basin start with the FAD of *Helicosphaera ampliaperta*, which can be correlated with the base of the Burdigalian *sensu* Berggren et al. (1995) and Eggenburgian *sensu* Rögl (1998). Here, the Eggenburgian sedimentary cycles may be topped by the deposition of terrestrial or brackish sediments.

Conclusions

(1) Calcareous nannoplankton from the Eggenburgian holostratotype and faciostratotypes of Loibersdorf, Achberg, Brunnstube, "Judenfriedhof", Burgschleinitz, Fels am Wagram, Vaďovce, Podkylava, Sverepec, Veľká Čausa and Lipovany, as well as from other sections in the vicinity of the type sections (Mold-Kirchensteig, Maigen-Sandgrube Stranzl, Kühnring-Gemeindesandgrube, Krajné) was studied quantitatively.

(2) First appearances of the following biostratigraphically significant species were recorded at the holostratotype and faciostratotypes: *Discoaster druggii* (NN1/NN2 boundary), *Helicosphaera ampliaperta* (middle part of NN2 Zone, Egerian/Eggenburgian boundary *sensu* Rögl 1998), *Sphenolithus belemnos* (NN2/NN3 boundary, upper part of the Eggenburgian). Stratigraphical range of the Eggenburgian type sections can be correlated with the upper part of NN2 Zone; NN3 Zone was recorded in the Lipovany section of the Fiľakovo Basin. This stratigraphical range is in agreement with the present concept of the Eggenburgian boundary (Rögl 1998). Eggenburgian sediments may start with a level without *Helicosphaera ampliaperta*: unfavourable living conditions for calcareous nannoplankton are interpreted for this level.

(3) Multivariate statistical analysis (cluster and factor analysis) enabled us to distinguish two types of autochthonous assemblages: most assemblages are dominated by *Coccolithus pelagicus*, the second rare type of assemblage is dominated by reticulofenestrids. The type of assemblages with high relative abundances of reworked Cretaceous species can be distinguished with high statistical significance.

(4) Two different types of Lower Miocene depositional area were distinguished in the Central Paratethys on the basis of the occurrence of calcareous nannoplankton bioevents (FAD of *Discoaster druggii*; FAD of *Helicosphaera ampliaperta*, FAD of *Sphenolithus belemnos*): (i) Continuous sedimentation from the Egerian to the Eggenburgian with all three events is characteristic for the Waschberg, Pouzdřany and Ždánice Units and for the remnant flysch trough of the Skole-

Skiba Zone in the Outer Western Carpathians. Continuous sedimentation from the Egerian also occurred in the Fiľakovo (Pétervására) Basin (the Inner Western Carpathians) but stopped during the time corresponding to the NN3 Zone. (ii) Transgressive Eggenburgian sediments in Lower Austria, in the Vienna Basin, the Danube Basin, the Váh River Valley and Horná Nitra Basin started with the FAD of *Helicosphaera ampliaperta* which can be correlated with the base of the Burdigalian *sensu* Berggren et al. (1995) and Eggenburgian *sensu* Rögl (1998).

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