

DINOFLAGELLATE CYST, PALYNOFACIES AND FORAMINIFERAL RECORDS OF ENVIRONMENTAL CHANGES RELATED TO THE LATE BADENIAN (MIDDLE MIOCENE) TRANSGRESSION AT KUDRYNTSI (WESTERN UKRAINE)

Przemysław GEDL¹ & Danuta PERYT²

¹ *Institute of Geological Sciences, Polish Academy of Sciences, Senacka 1, 31-002 Kraków, Poland, e-mail: ndgedl@cyf-kr.edu.pl*

² *Institute of Paleobiology, Polish Academy of Sciences, Twarda 51/55, 00-818 Warszawa, Poland, e-mail: d.peryt@twarda.pan.pl*

Gedl, P. & Peryt, D., 2011. Dinoflagellate cyst, palynofacies and foraminiferal records of environmental changes related to the Late Badenian (Middle Miocene) transgression at Kudryntsi (western Ukraine). *Annales Societatis Geologorum Poloniae*, 81: 331–349.

Abstract: Qualitative and quantitative characteristics of the palynological content of the Upper Badenian strata at Kudryntsi (western Ukraine) indicate that this succession was deposited in variable environments. The basal siliciclastic series shows a very low content of palynological organic matter and palynofacies, which indicate a restricted environment and/or unfavourable conditions for the palynomorph preservation. The presence of dinoflagellate cysts (and composition of their assemblages) in the upper part of organodetrital limestones and the overlying rhodoid limestones indicates a typical shelf environment. Taxonomically variable dinoflagellate cyst assemblages from particular samples reflect gradual environmental changes – from environments of slightly increased salinity of seawater (strata overlying the siliciclastic series) to open marine, more remote environments during deposition of the upper part of the section examined. The gradual deepening of the sea and decrease of salinity is supported also by the succession of foraminiferal assemblages, which undergo gradual changes from *Elphidium* spp. assemblages, through Miliolidae assemblage, *Lobatula lobatula* assemblage, *Neoconorbina* spp. assemblage to *Cibicides* assemblage. The Late Badenian foraminiferal assemblage from Kudryntsi contains two species common for the Sarmatian, *i.e.* *Elphidium reginum* and *Elphidium koberi*, the latter species known so far from the Sarmatian.

Key words: palaeoenvironment, dinoflagellate cysts, foraminifers, Upper Badenian, Middle Miocene, Paratethys, Carpathian Foredeep.

Manuscript received 3 June 2011, accepted 3 November 2011

INTRODUCTION

This paper deals with deposits related to the major Late Badenian transgression, which took place when the connection of the Carpathian Foredeep Basin with other Paratethyan basins was restored due to the sea level rise (Oszczypko *et al.*, 2006; Peryt, 2006). In places, as Kudryntsi in western Ukraine, the evidently marine deposits (limestones and intercalated marls with abundant faunal assemblage) forming the basal part of the Upper Badenian transgressive sequence are underlain by the pelites of the siliciclastic series occurring above the Badenian gypsum deposits (Peryt & Peryt, 2009). The earlier foraminiferal and geochemical study of these pelites showed that they formed in restricted environments (Peryt & Peryt, 2009).

The aim of the paper is to compare the dinoflagellate cyst and foraminiferal records obtained from the same set of

samples collected from the Upper Badenian transgressive section that is currently exposed at Kudryntsi gypsum quarry.

Dinoflagellates are unicellular, mainly autotrophic, organisms inhabiting almost all aquatic ecosystems, from freshwater to marine and hypersaline. During their life-cycle they produce resting cysts, which in some species are fossilizable. Studies on Recent dinoflagellate cyst distribution (*e.g.*, Dale, 1976; Wall *et al.*, 1977; Harland, 1983; McMinn, 1990; Edwards & Andrieu, 1992; Rochon *et al.*, 1999; Vink *et al.*, 2000; Marret & Zonneveld, 2003) allow for relative precise palaeoecological interpretation of Miocene forms, which in major part are also known from Holocene deposits. Therefore, their presence makes possible basic reconstructions of fossil material related to such factors

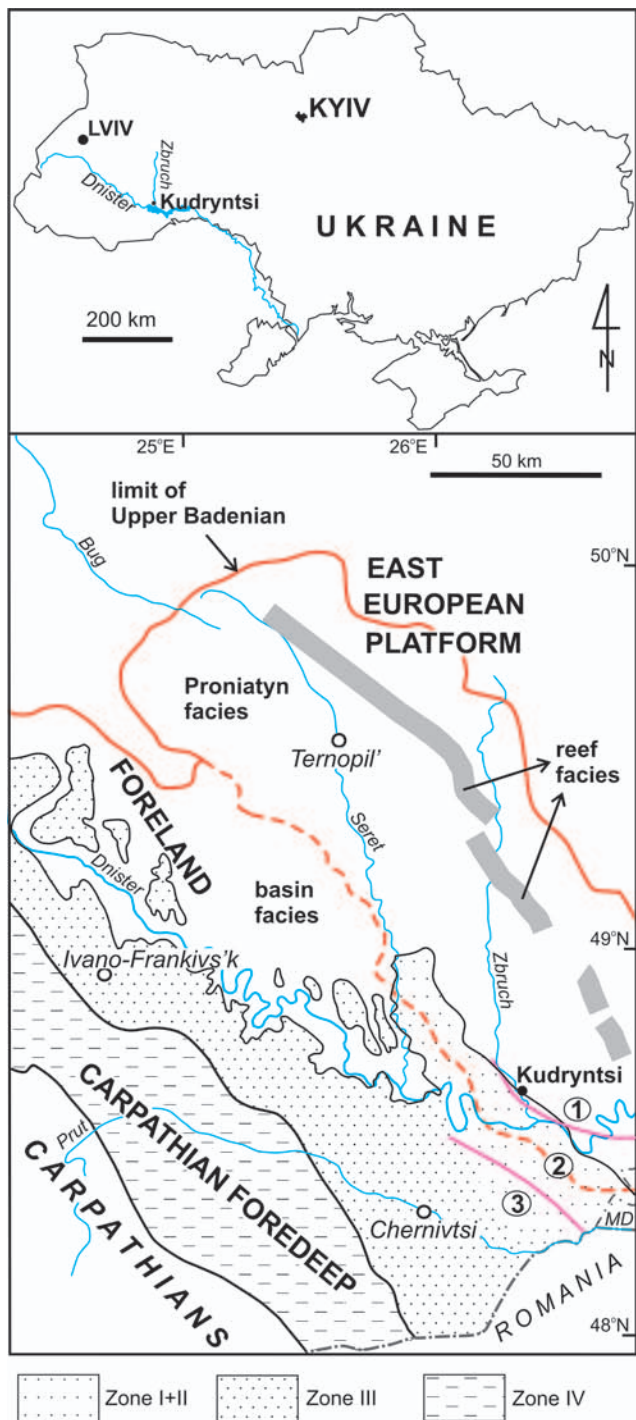


Fig. 1. Location map showing the general distribution of Upper Badenian facies (after Kudrin, 1966 and Siplivyy *et al.*, 1974); 1 – carbonate facies, 2 – clayey-sandy-carbonate facies, 3 – sandy-clayey facies. In addition, facies zones (I–IV) of the Badenian sulphate deposits (after Peryt, 2006) and the present NE gypsum limit are shown. Abbreviation: MD – Republic of Moldova

like water salinity, temperature, distance from shore, productivity (e.g. Dale, 1996). Dinoflagellate cysts have already been used for these purposes in studies of Miocene of the Carpathian Foredeep (Gedl, 1996).

However, dinoflagellate cysts are not the only organic fossils that occur in sedimentary rocks. Fossilizable are also

particular freshwater and marine algae, sporomorphs, and tissue remains of terrestrial plants. Association of these organic particles is known as palynofacies (Combaz, 1964; see also Tyson, 1995; Batten, 1996). Analysis of palynofacies element ratios, combined with sedimentological data, serves for further interpretation of environmental factors, including intensity of land influx and salinity level. They were also used for palaeoenvironmental reconstructions of the Miocene of the Carpathian Foredeep (Gedl, 1997, 1999) being particularly useful in case of the Middle Miocene (Badenian) evaporite deposits (Gedl *in* Peryt *et al.*, 1997).

Foraminifers are another group of microfossils commonly used in studies of the Miocene biostratigraphy and palaeoenvironment of the Carpathian Foredeep (e.g., Subbotina *et al.*, 1960; Pishvanova, 1969; Szczuchura, 1982; Czepiec, 1996; Gruzman & Trofimovich, 1996; Czepiec & Kotarba, 1998; Gonera, 2001; Peryt & Gedl, 2010; Garecka & Olszewska, 2011). Environmental requirements of recent benthic foraminifera have been the subject of many studies (e.g. Jorissen, 1987; Hottinger *et al.*, 1993; Langer, 1993; Hayward *et al.*, 1997; de Rijk *et al.*, 1999; Chendes *et al.*, 2004; Fiorini, 2004; Debeney *et al.*, 2005; Abbene *et al.*, 2006; Milker *et al.*, 2009). This makes that they are good bioindicators of marine environment changes (Murray, 2006), especially that some Miocene foraminiferal species still live in recent seas.

GEOLOGICAL FRAMEWORK

The Kudryntsi gypsum quarry is located on the left side of the Zbruch River Valley in the foreland of the Carpathian Foredeep Basin (Fig. 1). The stromatolitic gypsum (ca. 23 m thick) exploited in the quarry lies on the Cenomanian sandstones or on the Lower Badenian biodetrital (usually coralline algal) limestones (2 m thick); the latter are underlain by thin basal breccia that rests upon the Cenomanian (Peryt & Peryt, 2009). A unit of 4-m-thick fine siliciclastic deposits with intercalations of limestones and fine-grained sandstones (up to 15 cm thick) occurs above the gypsum (the Tyras Suite; Peryt & Peryt, 2009). In the northern part of the Kudryntsi quarry this unit is pervasively gypsified (Peryt *et al.*, 2008).

This siliciclastic unit is overlain by a limestone unit (1.3–1.4 m thick) composed of lithoclastic and fossiliferous limestones with minor intercalations of clays and marls (10–30 cm thick; Fig. 2), which is considered to be the marine facies of the Ratyn Limestone (Peryt & Peryt, 2009) typically overlying the gypsum deposits in this region (Siplivyy *et al.*, 1974). This limestone is covered by the Upper Badenian rhodoid limestones with minor intercalations of marls and claystones (Proniatyn facies of Teisseyre, 1900; cf. Siplivyy *et al.*, 1974). Eastwards, this carbonate facies is characterized by occurrence of coralline algae-vermetid reefs and a variety of bioclastic facies (Kudrin, 1966). These strata in the neighbourhood of Kudryntsi are more than 10 m thick when not eroded (Siplivyy *et al.*, 1974); in the Kudryntsi quarry the exposed section reaches 6 m. Further toward the southwest this carbonate facies is replaced by the clayey-sandy-carbonate facies that, in turn, passes

into sandy-clayey facies (Fig. 1) – a typical Kosiv Suite. The boundary between the carbonate and clayey-sandy-carbonate facies is located some 1.5 km SW of the Kudryntsi quarry (Fig. 1; Siplivyy *et al.*, 1974).

The Upper Badenian strata are covered by Lower Sarmatian strata that are clearly transgressive; farther eastwards they overlie the older Middle Miocene strata or they lie directly upon pre-Miocene substrate (Siplivyy *et al.*, 1974) (Fig. 1). The Lower Sarmatian deposits comprise bivalve coquinas, bioclastic or oolitic grainstones, marls or clays, breccias and conglomerates, as well as serpulid-microbialite reefs (Kudrin, 1966; Siplivyy *et al.*, 1974; Jasionowski *et al.*, 2003; Jasionowski, 2006).

The earlier study of the Kudryntsi section documented a major environmental change during the Late Badenian (Peryt & Peryt, 2009), following the marine invasion into southeastern Poland and western Ukraine from the Mediterranean (Andreyeva-Grigorovich *et al.*, 1997; Oszczytko *et al.*, 2006; Kovač *et al.*, 2007). The siliciclastic series overlying the gypsum was deposited in evaporitic lagoon influenced by large inflows of continental waters. The marine clay bed, which occurs below the limestone unit considered to be the Ratyn Limestone, originated in shallow subtidal environments of normal marine salinity and temperate to warm waters as indicated by requirements of *Elphidium crispum* association in recent seas (Peryt & Peryt, 2009).

MATERIAL AND METHODS

We have studied a new section available due to the progress of the exploitation in the quarry. The section is located in the south-central part of the Kudryntsi quarry (N48°37.185', E26°19.261'). It includes the upper part (2.2 m thick) of the siliciclastic unit (the Tyras Suite), the limestone unit (1.3–1.4 m thick; the Ratyn Limestone) and the 3.7-m-thick series of rhodoid limestones with intercalations of marls and claystones (the Kosiv Suite; Fig. 2). Nineteen samples collected from the section have been analysed for dinoflagellate cysts and palynofacies as well as foraminifers, except of sample O from which foraminifers have not been studied; the location of samples is shown in Figure 2.

The studied samples represent various lithologies. Samples from the lower part of the section (samples A, B, D, E) are pale-coloured (whitish-creamy), frequently banded, poorly calcareous light marly claystone. Sample C, collected from the same complex, is grey-greenish, non-calcareous sandy mudstone. Sample F, collected from organodetrital limestone complex, is hard pale-beige massive marl being more calcareous than underlying strata. Sample G represents very hard pelitic creamy limestone (highly calcareous). Sample H is very poorly calcareous soft dark-brown banded clay with rare fish remains. Two samples collected from conglomeratic slump layer represent white chalky limestone (sample I) and dark-brownish hard limestone (sample J). Sample K (top of the organodetrital limestone) is dark-beige massive and hard limestone with rhodoids.

Samples L–S collected from the rhodoid limestone complex represent two varieties. Samples M and O are

whitish-creamy hard organodetrital limestone, whereas the remaining samples consist of rhodoids with various amount of calcareous matrix. Samples N, Q and R are purely rhodoid, whitish-grey hard limestone, while samples L, P and S contain admixture of greyish-green (L, P) and willow-green clay (S).

The samples for palynology were processed in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków. Standard palynological procedure was applied, including 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid (ZnCl₂+HCl; density 2.0 g/cm³) separation, ultrasound for 10–15 s and sieving at 15 µm on a nylon mesh. No nitric acid (HNO₃) treatment was applied. The quantity of rock processed was approximately 40 g for each sample except of sample 4, whose quantity was 10 g. Microscope slides were made from each sample using glycerine jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

Low frequency of dinoflagellate cysts made that almost all residuum was used for slides, which have been scanned. Palynofacies were based on counting up to 1,000 elements.

Samples for foraminiferal study were processed in the laboratory of the Institute of Palaeobiology, Polish Academy of Sciences, Warszawa. Washed residues were obtained by disaggregation of samples using Na₂SO₄. An aliquot of about 200–300 specimens from the >100 µm size fraction was used for the faunal analyses. The figured specimens are deposited in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa (ZPAL F. 70). The palaeoenvironmental interpretation based on foraminifers applies the requirements of present-day representatives of recorded taxa.

RESULTS

Palynofacies and dinoflagellate cysts

All samples yielded palynological organic matter, which, however, differ in quantity and quality (Figs 3, 4). The palynofacies are shown in Figure 5 and the representative dinoflagellate cysts are shown in Figures 6 and 7. Siliciclastic (basal) part of the Kudryntsi section (samples A–E) contains very low amounts represented almost exclusively by black, opaque phytoclasts (95%), and highly degraded black and dark-brown, frequently elongated wood particles. There are almost no palynomorphs except of infrequent sporomorphs and some pale-coloured subspherical forms of uncertain origin (possibly Recent contamination). Qualitative differences refer to shape of black woody particles, which particularly in samples A and B are elongated, being strongly disintegrated in sample D.

Samples collected from organodetrital limestone exposed above (G and F) contain only trace amounts of palynological organic matter (small-sized black phytoclasts and single subspherical forms). A different palynofacies occurs in sample H taken from dark-brown clays: it consists of highly disintegrated small-sized particles of structureless organic matter; no palynomorphs have been found except of

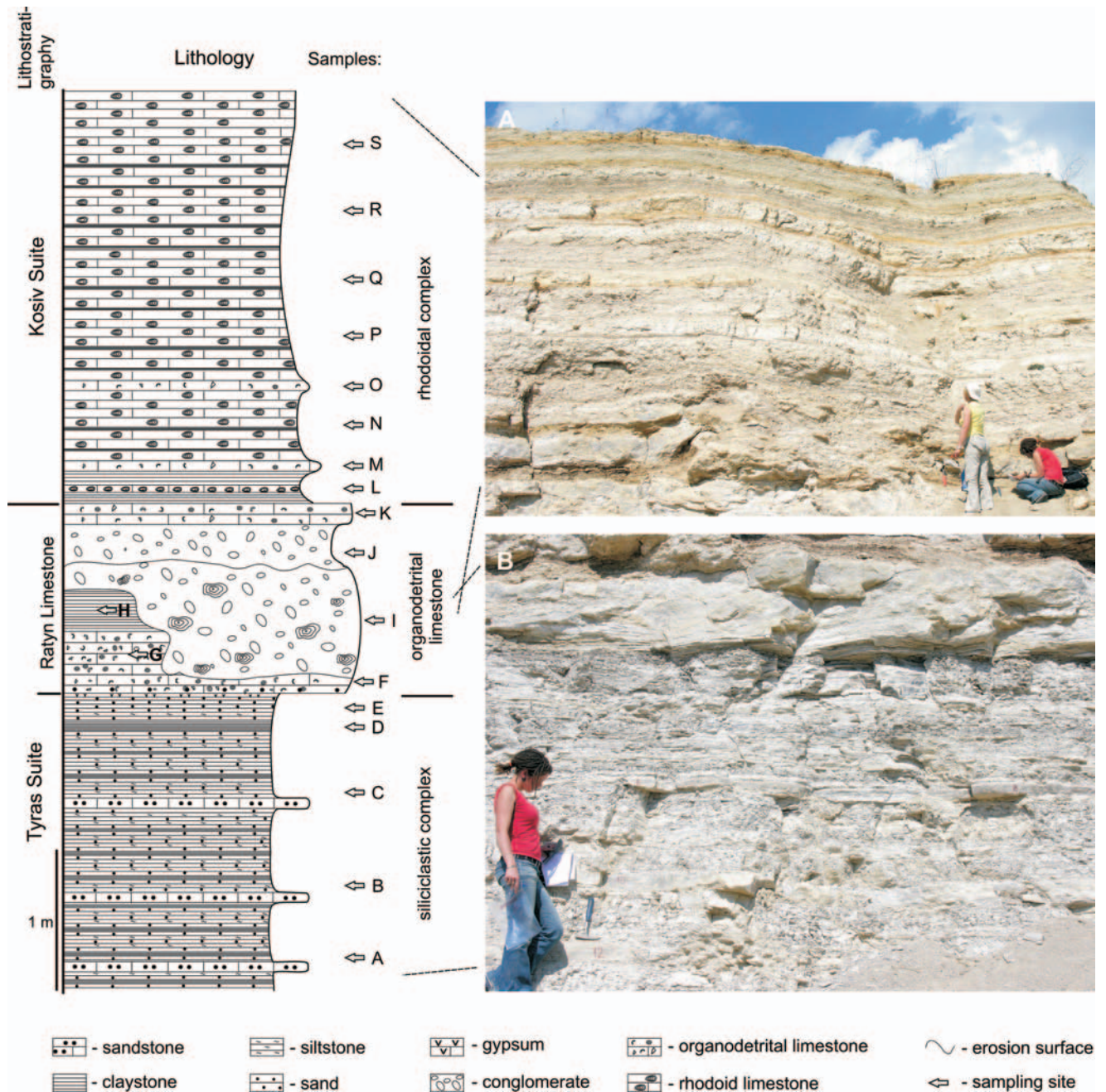


Fig. 2. Lithology and lithostratigraphy of the studied section and sample position; **A** – photograph of the upper part of the section; **B** – photograph of the lower part of the section

a single specimen of pale-coloured dinoflagellate cyst *Systematophora placacantha*.

Two samples from the conglomeratic slump layer yielded different palynofacies. Sample I contains high amounts of very well preserved Late Cretaceous dinoflagellate cysts (excluded from further studies in this paper), and sample J contains trace amounts of palynological organic matter (highly disintegrated small-sized black phytoclasts).

Sample K from the topmost layer of the organodetrital limestone complex is the first sample, which contains dinoflagellate cysts. It generally contains low amounts of palynological organic matter, which consists chiefly of small-sized black phytoclasts (70%), and pale-coloured phyto-

clasts palynodebris (30%). Dinoflagellate cysts are very rare; these are *Systematophora placacantha*, *Spiniferites ramosus* s. l., *Polysphaeridium subtile* and *Lingulodinium machaerophorum*, and a single specimen of *Pyxidiniopsis?* sp.

A characteristic feature of the rhodoid complex is occurrence of dinoflagellate cysts (except of the uppermost sample S), which are absent or very rare in underlying strata of the studied section. Their ratios range there from a few to several tens per cent. Palynofacies of samples from the rhodoid limestone complex shows relation to lithology: samples collected from organodetrital layers (M, O) contain a much higher amount of palynological organic matter than other samples from rhodoid layers. Moreover, the former

Lithostratigraphic unit		Tyras Suite										Kosiv Suite								
		siliciclastic complex					organodetrital limestone					rhodoïdal complex								
Number	Species	Lithology and lithologic unit																		
		Sample																		
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	<i>Systematophora placacantha</i>									1		5	21	17	28	35	24	31	36	
2	<i>Lingulodinium machaerophorum</i>											3	17	14	19	32	11	25	30	
3	<i>Pyxidinospis</i> sp.											1	6		9					
4	<i>Polysphaeridium subtile</i>											6	11				6	12	8	
5	<i>Spiniferites ramosus</i>											5	61	14	3	12	8			
6	<i>Dapsilidinium pseudocolligerum</i>											1								
7	<i>Pentadinium</i> sp.											14	5	1		6	3	3		
8	<i>Spiniferites</i> sp.											1	158	24	18	19	11	9		
9	<i>Nematosphaeropsis labyrinthus</i>												5	2						
10	<i>Operculodinium centrocarpum</i>												28	17	37	5				
11	<i>Operculodinium</i> sp.												13	12	84	8				
12	<i>Impagidinium</i> sp.												3			1				
13	<i>Areoligera?</i> sp.												1							
14	<i>Spiniferites pseudofurcatus</i>														1	3	3	7	10	
15	<i>Achomosphaera</i> sp.														3					
16	<i>Tectatodinium?</i> sp.																1			
17	<i>Polysphaeridium zoharyi</i>																5	4	3	
18	<i>Hystrichokolpoma rigaudiae</i>																7			
19	acritarch (<i>Svenkodium</i>)																		15	
	undetermined dinoflagellate cysts												12		9					

Fig. 3. Distribution of dinoflagellate cysts in Kudryntsi section. Abbreviations: d.c. – dark clay; o.l. – organodetrital layer

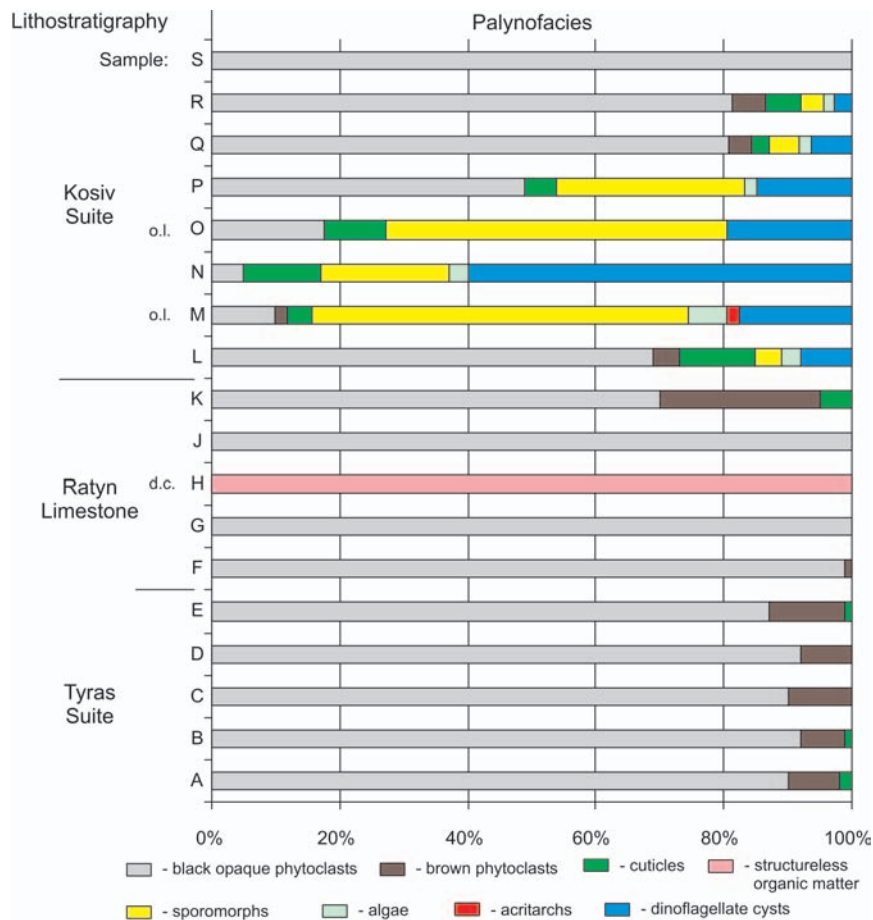


Fig. 4. Palynofacies changes in Kudryntsi section (Sample I with Cretaceous dinoflagellate cysts is excluded here). Abbreviations: d.c. – dark clay; o.l. – organodetrital layer

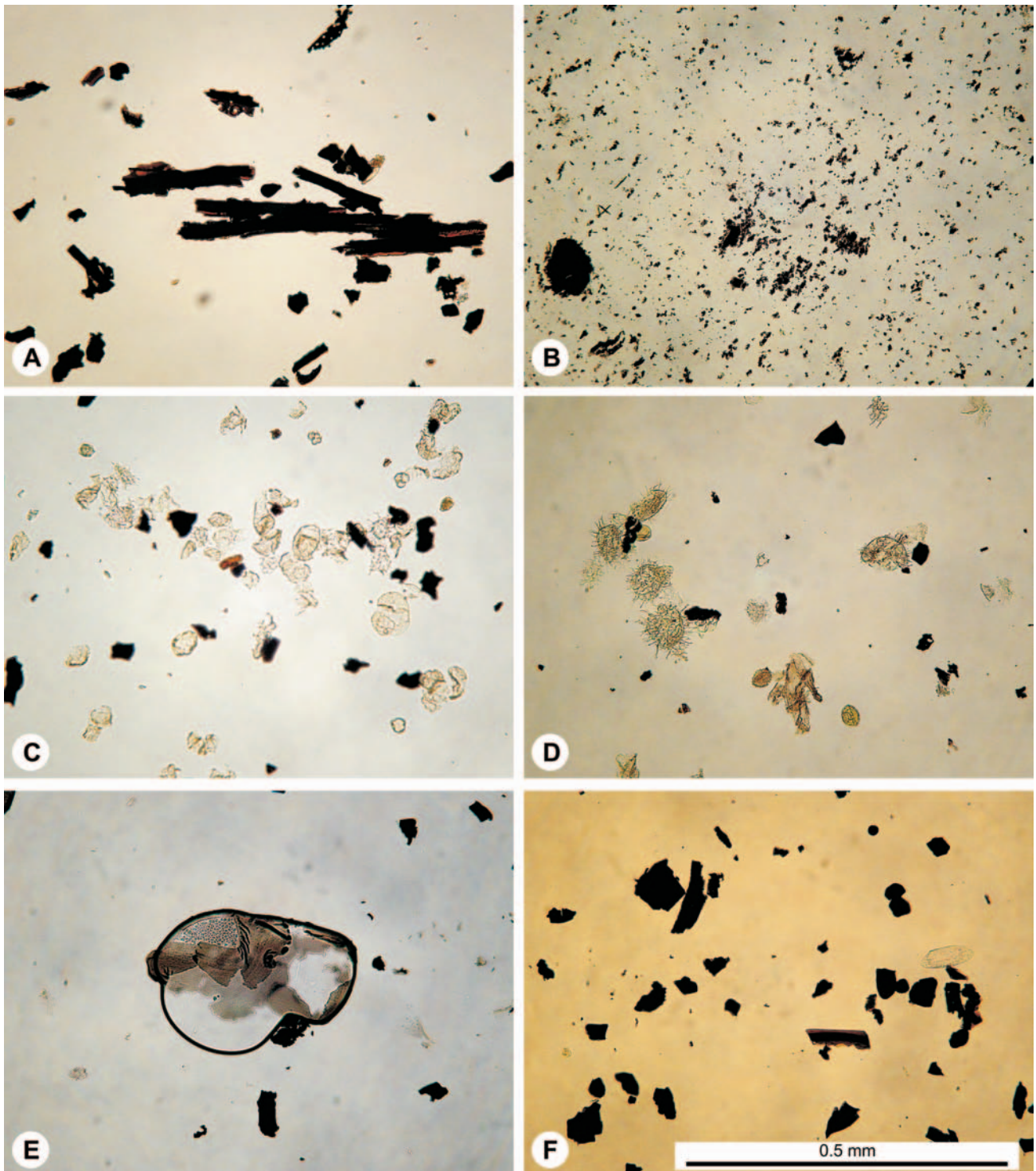


Fig. 5. Palynofacies of Badenian deposits from Kudryntsi (scale bar in F represents 0.5 mm and refers to all other photomicrographs): **A** – sample B (black and dark-brown elongated wood particles); **B** – sample H (palynofacies consists of highly disintegrated particles of structureless organic matter); **C** – sample M (palynofacies with common bisaccate pollen grains and dinoflagellate cysts); **D** – sample N (palynofacies with high ratio of dinoflagellate cysts); **E** – sample Q (palynofacies dominated by small-sized black palynodebris; large palynomorphs of uncertain origin [zooclasts?] occur); **F** – sample R (palynofacies composed of equidimensional black phytoclasts)

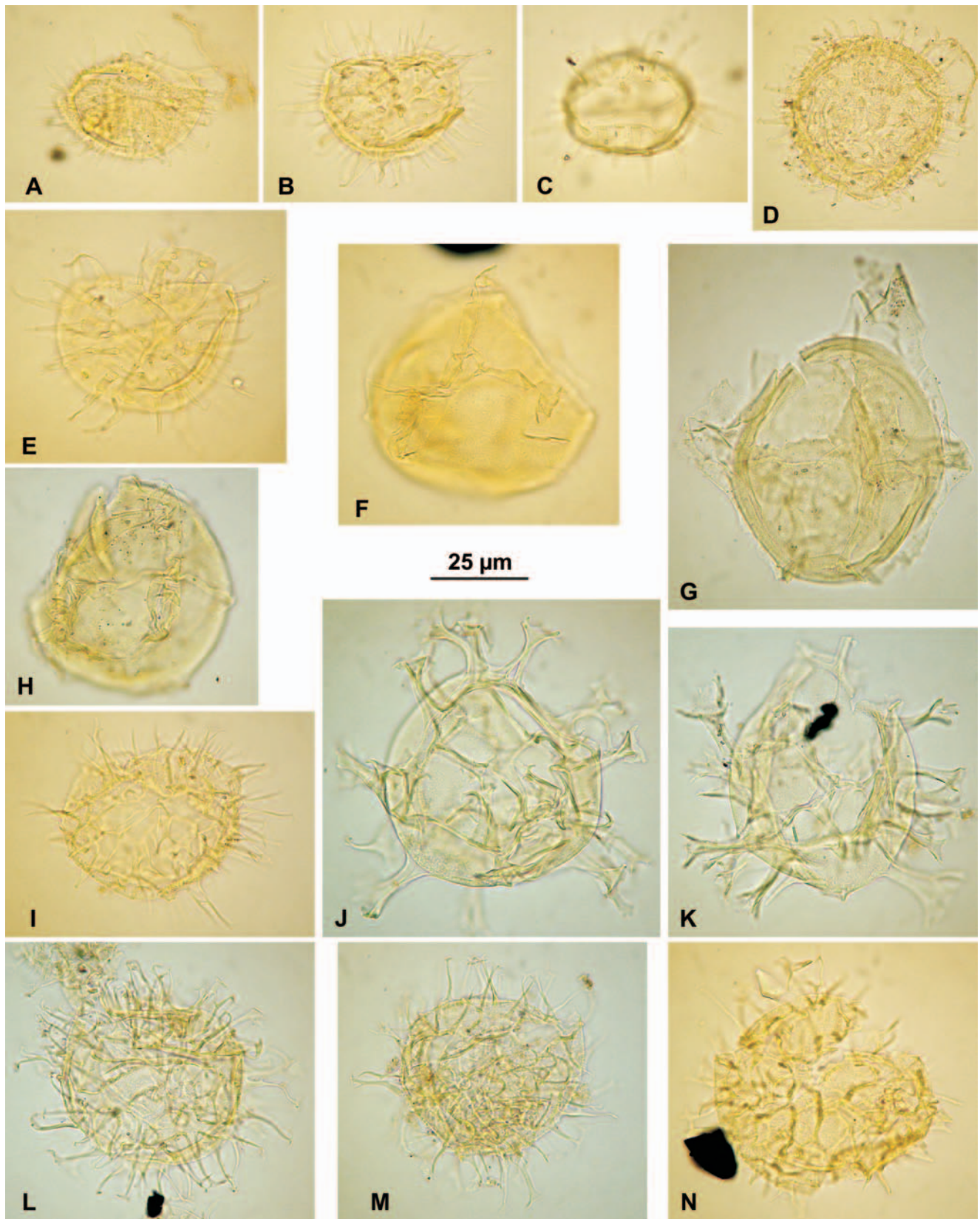


Fig. 6. Dinoflagellate cysts from Badenian sequence at Kudryntsi: **A–D** – *Lingulodinium machaerophorum* (A, B: specimens with scabrate cyst wall and long processes, sample L; C: specimen with relatively smooth cyst wall and 2P archaeopyle, sample R; D: specimen with thick and scabrate cyst wall and relatively short processes, sample R; E: specimen with 5P archaeopyle, sample L); **F–H** – *Pentadinium* sp. (F: sample L; G, H: sample P); **I** – *Systematophora placacantha* (sample L); **J, K** – *Spiniferites pseudofurcatus* (J: sample O; K: sample N); **L–N** – *Systematophora placacantha* (L, M: sample N; N: sample L)

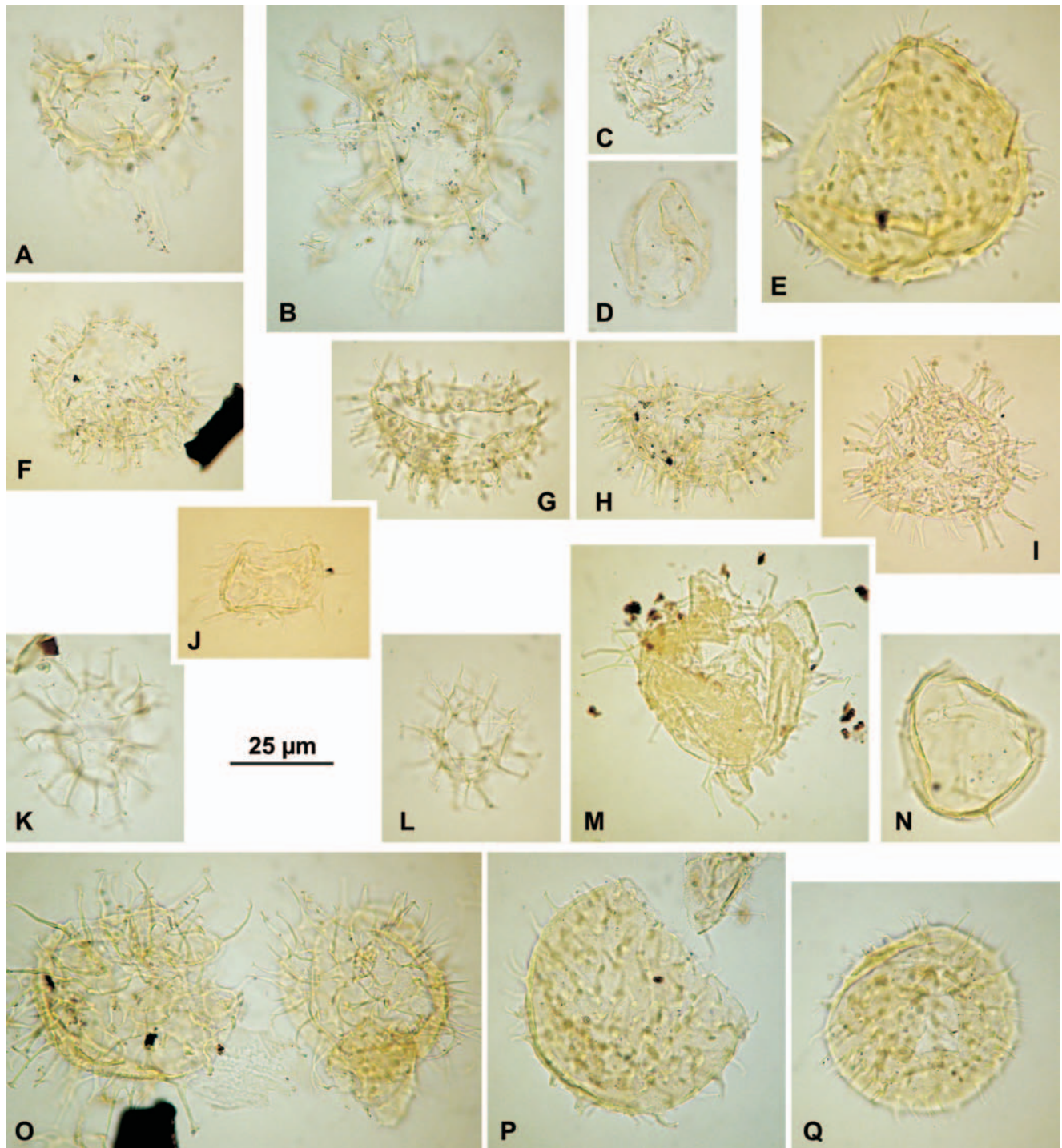


Fig. 7. Dinoflagellate cysts from Badenian sequence at Kudryntsi: **A, B** – *Hystrichokolpoma rigaudiae* (both specimens from sample P); **C** – *Impagidinium* sp. (sample P); **D** – *Pyxidiniopsis* sp. (sample K); **E** – *Operculodinium* sp. (sample M); **F–I** – *Polysphaeridium subtile* (all specimens sample R); **J** – *Dapsilidinium pseudocolligerum* (sample L); **K, L** – *Spiniferites* sp. (K: sample N, L: sample M); **M** – *Systematophora placacantha* (sample H); **N** – *Impagidinium* sp. (sample M); **O** – *Systematophora placacantha* (two specimens from sample N); **P, Q** – *Operculodinium* sp. (both specimens from sample N)

contain high ratios of sporomorphs (mainly bisaccate pollen grains) and dinoflagellate cysts. The latter yielded mainly black phytoclasts (particularly dominating in samples from upper part of rhodoid complex: Q and R), except of sample N, which contain high ratio of dinoflagellate cysts.

The basal sample from the rhodoid complex (L) contains low amounts of palynological organic matter domi-

nated by small-sized black phytoclasts (70%). Pale-coloured plant tissue remains, sporomorphs and palynomorphs of uncertain taxonomical position (presumably algae) are subordinate. Dinoflagellate cyst assemblage (8%) is taxonomically impoverished; it consists of four dominating taxa: *Systematophora placacantha*, *Pentadinium* sp., *Polysphaeridium subtile* and *Lingulodinium machaerophorum*, and sin-

gle specimens of *Spiniferites* sp. and *Dapsilodinium pseudo-colligerum*.

A higher sample M (organodetrital limestone layer) is composed of dominating sporomorphs (mainly bisaccate pollen grains – up to 60%) and aquatic palynomorphs representing dinoflagellate cysts (up to 20%), acritarchs and algae. The dinoflagellate cyst assemblage is dominated by the genus *Spiniferites* (app. 70%), relatively common are specimens of *Operculodinium* spp., *Systematophora placacantha* and *Lingulodinium machaerophorum*. Rare *Nematosphaeropsis labyrinthea*, *Impagidinium* sp., and *Pentadinium* sp. occur. Noteworthy is preservation of dinoflagellate cysts, which frequently are wrinkled or torn-off.

Palynofacies of sample N is distinguished by very high ratio of dinoflagellate cysts – up to 60%. Their assemblage is taxonomically similar to the one from sample B, but differs qualitatively. It consists of frequent specimens of *Systematophora placacantha*, *Operculodinium* spp., *Lingulodinium machaerophorum* and *Spiniferites* spp. (the latter genus is much less frequent than in sample M). *Nematosphaeropsis labyrinthea*, *Achomosphaera* spp. and *Pentadinium* sp. are represented by rare specimens.

Sample O yielded similar palynofacies as sample M, another sample representing organodetrital layer, dominated by pollen grains (up to 60%). Dinoflagellate cysts (20%) from this sample are also taxonomically impoverished: their assemblage is dominated by the genus *Operculodinium*, and, to a lesser degree, *Systematophora placacantha* and *Lingulodinium machaerophorum*. Representatives of the genus *Spiniferites* are subordinate, similarly as *Pyxidiniopsis?* sp.

Palynofacies of sample P containing low amount of palynological organic matter consists of black phytoclasts (up to 50%) and sporomorphs (30%; beside bisaccate grains, genus *Intratropollenites* is common). Dinoflagellate cysts are relatively common (app. 15%); their assemblage consists mainly of *Systematophora placacantha*, *Lingulodinium machaerophorum* and *Spiniferites* spp. An outstanding feature is low ratio of *Operculodinium* (frequent in underlying samples) and numerous occurrence of *Hystrichokolpoma rigaudiae*, which is absent in lower samples of the studied section. *Pentadinium* sp., *Polysphaeridium subtile* and *Polysphaeridium zoharyi* are infrequent. A single specimen of *Impagidinium* sp. has been found. Some palynomorphs of uncertain origin, possibly algae, have been found in this sample.

The two following samples Q and R contain low amounts of palynological organic matter. Their palynofacies is dominated by small-sized black phytoclasts (up to 90%). Additionally, small-sized plant tissue remains, sporomorphs (frequent spores) and dinoflagellate cysts occur. The latter are relatively rare (a few percent): their assemblages in both samples consist of dominating *Systematophora placacantha* and *Lingulodinium machaerophorum*; furthermore, *Spiniferites* spp., *Pentadinium* sp., *Polysphaeridium subtile*, *P. zoharyi* are also present. Infrequent small acritarchs occur in sample Q. Assemblage from sample R is characterized by lack of *Spiniferites ramosus*. Both samples contain no *Operculodinium*.

The topmost sample S, as the only one from the rhodoid complex, contains no dinoflagellate cysts. Its low amount of palynological organic matter consists of small-sized black

phytoclasts, and pale-coloured plant tissue remains and fungi (the two latter groups, similarly as single sporomorphs, are possibly recent contamination).

Foraminifers

The abundance fluctuations of foraminifers are shown in Figure 8 and selected species are shown in Figures 9 and 10. Samples from the siliciclastic unit yielded very rare and poorly preserved foraminifers. Taxonomic composition and their state of preservation suggest that they were probably reworked and redeposited (Peryt & Peryt, 2009). One sample (sample A) yielded a quite rich assemblage of Badenian foraminifers: single specimens of *Heterolepa dutemplei*, *Eponides repandus*, molds of *Quinqueloculina* spp. and *Triloculina* spp. and other strongly damaged tests. In addition, the following taxa occur: keeled elphidiids (*Elphidium fichtelianum*, *E. joukovi*, *E. macellum*), *Porosonion* spp., *Astronion perfossum*, *Lobatula lobatula*, *Cibicidoides pseudoungerianus*, *C. ungerianus*, *Semivulvulina* sp., *Bulimina aculeate*, *Rosalina* sp., *Siphotextularia* sp., *Neoponides* sp. and rare specimens of planktonic *Globigerina bulloides*. Most of tests show very distinct evidences of redeposition; some of them, however, are well preserved.

The lowest occurrence of *in situ* benthic foraminifers is recorded in sample E (Fig. 8). Seven foraminiferal assemblages (I–VII) have been recognised in the interval comprising samples E–S.

Assemblage I occurs in a clayey-sandy bed underlying the Ratyn Limestone (sample E; Fig. 8). This low diversity assemblage is characterized by dominance of elphidiids (more than 60%) represented mainly by *Elphidium koberi* and ?*Elphidium* sp. Another important component is *Neoconorbina* sp., which exceeds 20%. Rare specimens of *Elphidium aculeatum*, *Quinqueloculina* sp. and *Astronion perfossum* also occur.

Assemblage II is recorded in organodetrital limestone (samples F, G, J). This assemblage is dominated by thick-walled, large specimens of *Elphidium crispum* and *E. macellum* contributing 60–80% to the assemblage (Fig. 8). Minor components in these assemblage are miliolids and *Porosonion* spp.

Assemblage III occurs in dark-brown clays (sample H) and in topmost layer of the organodetrital limestone complex (sample K; Fig. 8). This assemblage differs significantly from assemblage II from organodetrital limestones. *Elphidium crispum* is not present in this assemblage. Instead, spiny elphidiids: *E. aculeatum* and *E. koberi* are dominant taxa. They form to 50% of the assemblage. Miliolids are also important contributors. Their ratio exceeds 40%: *Triloculina* spp. (25%), *Quinqueloculina* spp. (9%), *Pyrgo* spp. (4%) and *Articulina* sp. (3%). Rare large specimens of *E. reginum* are also recorded. *Rosalina* is common in this assemblage too. The tests show slightly damaged ornamentation possibly caused by bottom currents.

Assemblage IV occurs in basal samples from the rhodoid complex (L and M). The assemblage is dominated by miliolids (60–70%); common are *Porosonion* spp., *Guttulina* spp. and *Glandulina* spp. in sample L, and *Elphidium crispum* and *E. macellum* in sample M (Fig. 8).

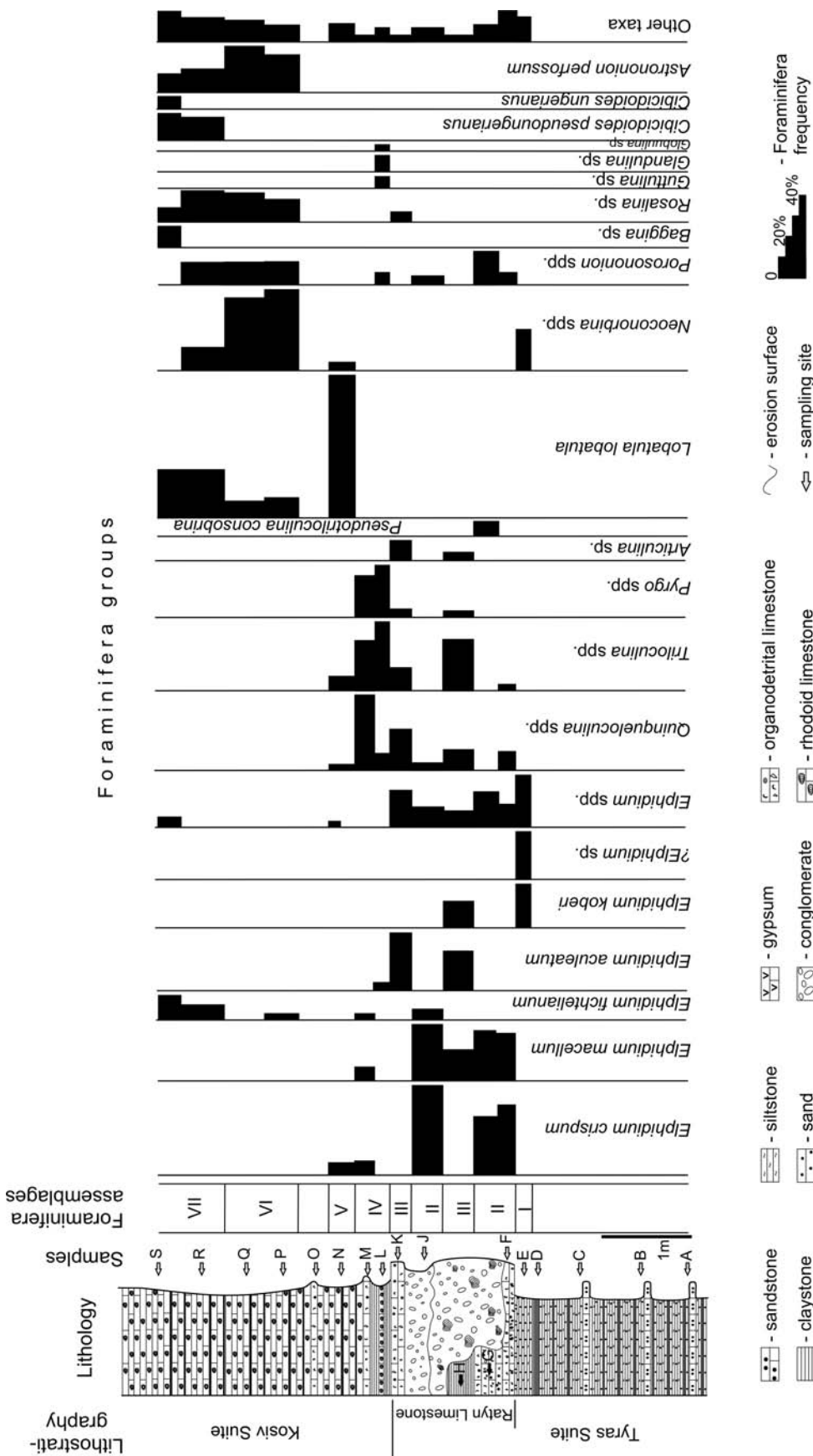


Fig. 8. Benthic foraminiferal assemblages and relative abundances of foraminifera groups within the Upper Badenian sequence at Kudryntsi

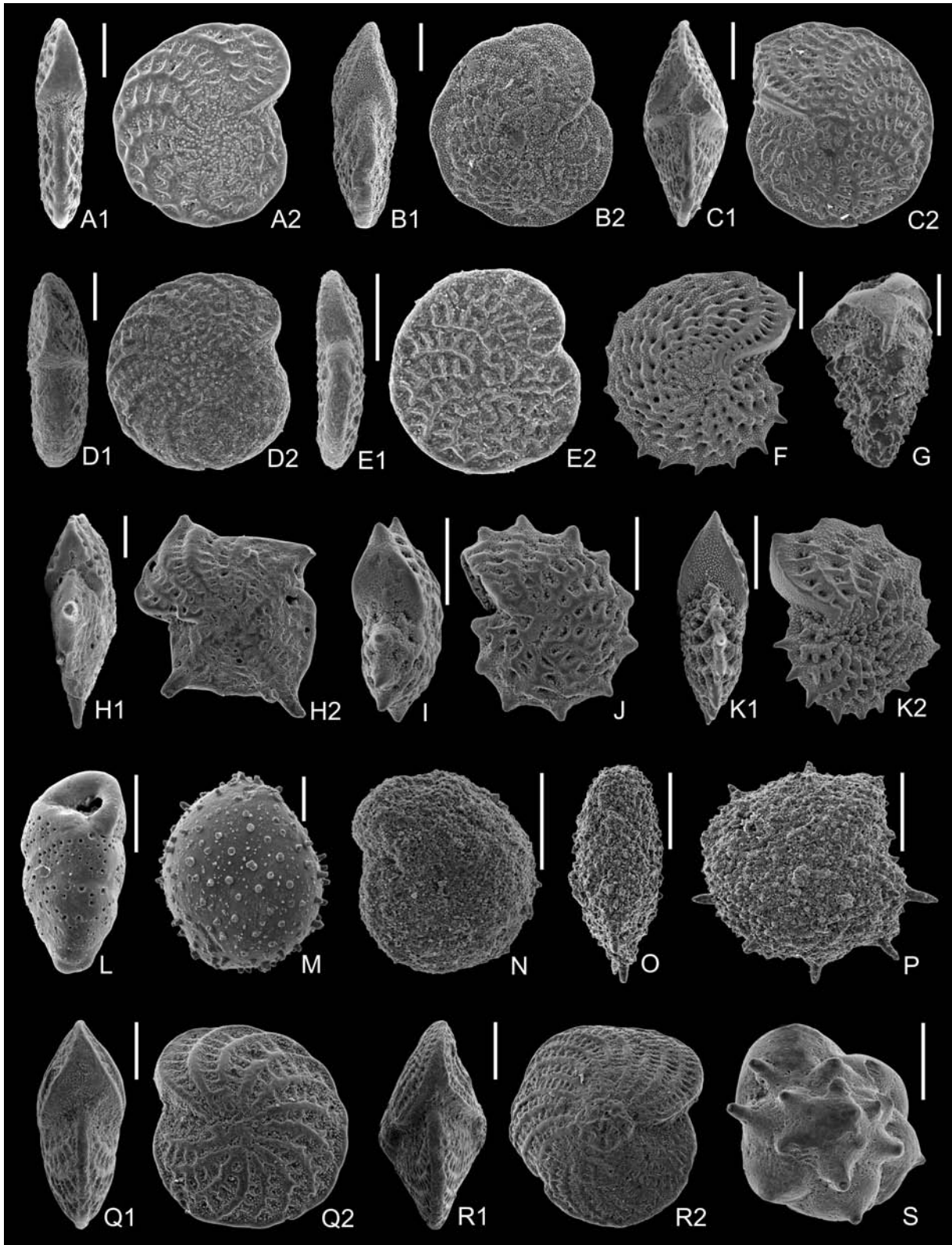


Fig. 9. Foraminifers from Badenian sequence at Kudryntsi (scale bars = 200 μm): **A** – *Elphidium fichtelianum* (d'Orbigny) (sample S); **B** – *Elphidium rugosum* (d'Orbigny) (sample J); **C** – *Elphidium crispum* (Linné) (sample J); **D** – *Elphidium joukovi* Serova (sample N); **E** – *Elphidium fichtelianum* (d'Orbigny) (sample P); **F** – *Elphidium aculeatum* (d'Orbigny) (sample K); **G** – *Reussella pulchra* Cushman (sample L); **H** – *Elphidium reginum* (d'Orbigny) (sample K); **I–K** – *Elphidium aculeatum* (d'Orbigny) (sample K); **L** – *Virgulinopsis* sp. (sample L); **M** – *Globulina spinosa* d'Orbigny (sample L); **N** – ?*Elphidium* sp. (sample H); **O, P** – *Elphidium koberi* Tollmann (sample H); **Q** – *Elphidium macellum* (Fichtel & Möll) (sample S); **R** – *Elphidium crispum* (Linné) (sample J); **S** – *Schackoinella imperatoria* (d'Orbigny) (sample K)

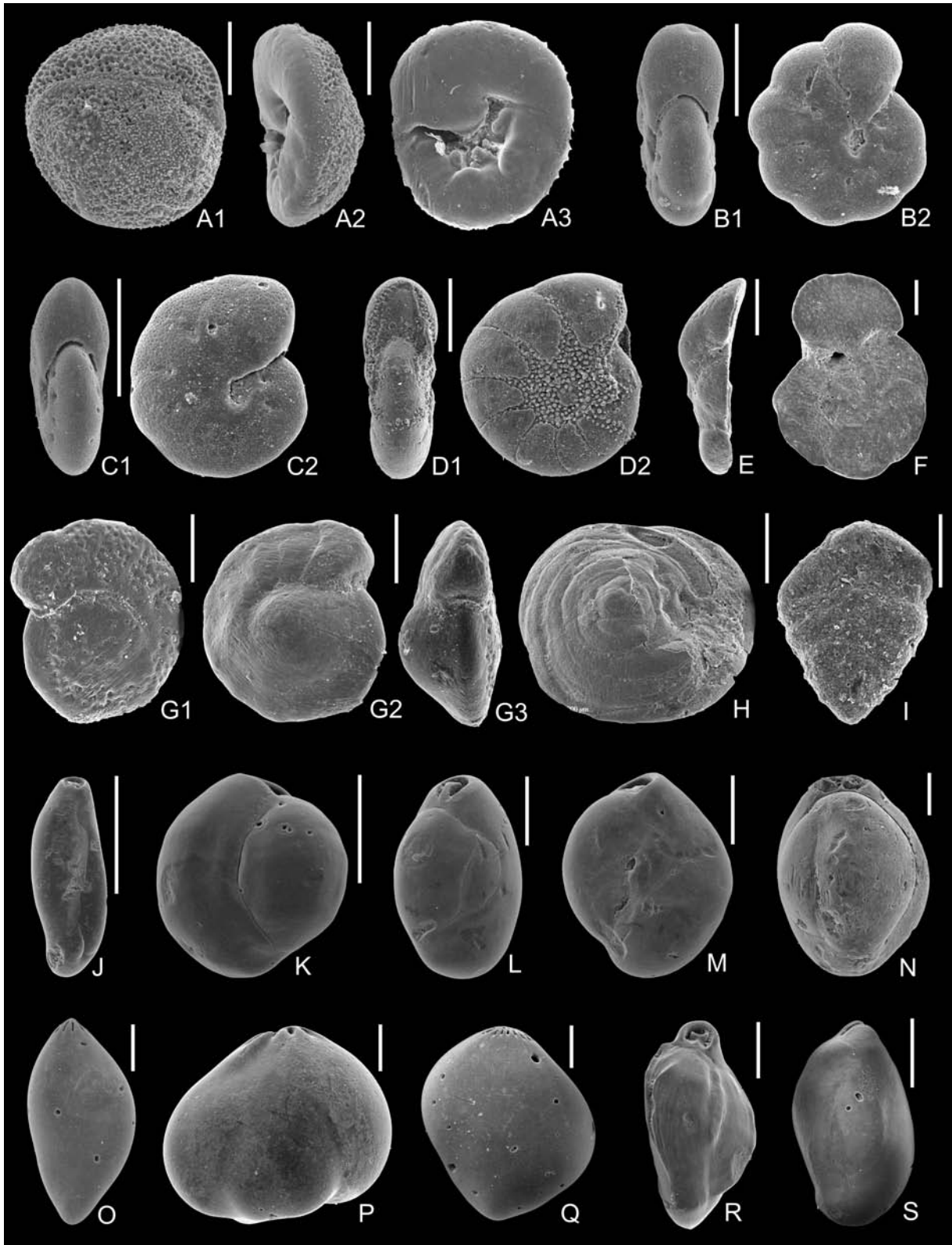


Fig. 10. Foraminifers from Badenian sequence at Kudryntsi (scale bars = 200 μ m): **A** – *Rosalina obtusa* d’Orbigny (sample L); **B**, **C** – *Astrononion perfossum* (Clodius) (sample L); **D** – *Porosononion martkobi* (Bogdanowicz) (sample L); **E** – *Lobatula lobatula* (Walker & Jacob) (sample S); **F** – *Lobatula lobatula* (Walker & Jacob) (sample N); **G** – *Cibicidoides pseudoungerianus* (Cushman) (sample S); **H** – *Neoconorbina* sp. (sample S); **I** – *Siphotextularia concava* (Karrer) (sample S); **J** – *Pseudotriloculina consobrina* (d’Orbigny) (sample L); **K**, **M**, **N** – *Triloculina gibba* d’Orbigny (sample K); **L** – *Triloculina* sp. (sample K); **O** – *Glandulina* sp. (sample L); **P** – *Guttulina communis* (d’Orbigny) (sample L); **Q** – *Guttulina gibba* (d’Orbigny) (sample L); **R** – *Quinqueloculina buchiana* d’Orbigny (sample K); **S** – *Quinqueloculina* sp. (sample K)

Assemblage V has been distinguished in sample N from the rhodoid complex. This almost monospecific assemblage is in 70% composed of *Lobatula lobatula*. Minor components are keeled elphidiids and miliolids (Fig. 8).

Assemblage VI occurs in samples P and Q of the rhodoid complex. In this assemblage, *Neoconorbina* spp. (35–40%) and *Astrononion perfossum* (18–22%) dominate. *Rosalina* spp. (11–14%), *Porosononion* spp. (11%) and *Lobatula lobatula* (8–10%) are also common. *Elphidium* is very rare in this assemblage (Fig. 8). The large tests are often damaged and their surfaces are smoothed due to current activity.

Assemblage VII has been found in the topmost part of the rhodoid complex (samples R and S). This assemblage is characterized by the highest diversity, and by the common presence of *Cibicidoides* spp., which is absent in other assemblages; *Neoconorbina* is much less abundant (10%) than in assemblage VI; *Elphidium* spp., *Baggina* sp., *Rosalina* spp., *Astrononion perfossum* are also common (Fig. 8).

INTERPRETATION AND DISCUSSION

A carbonate platform existed in western Ukraine (similarly as in a few places within the Central Paratethys) after the beginning of Late Badenian deposition characterized by transgression and formation of a normal marine environment (Schmid *et al.*, 2001; Vrsaljko *et al.*, 2006). Qualitatively and quantitatively diversified palynological and foraminiferal contents of the Badenian strata exposed in the Kudryntsi section located near the seaward margin of that platform indicate variable environmental conditions. Interpretation of these changes are supported by environmental preferences of particular genera of foraminifers, which occur in variable ratios within the Kudryntsi section.

Foraminiferal palaeoenvironmental preferences

Elphidiids are very common component of foraminiferal assemblages recorded in the Kudryntsi section. Salinity and water depth are important ecological factors that control abundance of this group. Particular *Elphidium* species show also relation to water depth and the degree of exposure to high wave and current energy (Langer, 1993; Hayward *et al.*, 1997). Keeled morphotypes, which are present in the described assemblages, are mostly herbivorous, epifaunal dwellers preferring sandy sediment, occurring in shallow marine environments (inner shelf) with warm to temperate and normal to hypersaline (35–70‰) waters (Hayward *et al.*, 1997; Murray, 2006). *Quinqueloculina* is an epifaunal dweller, living free or clinging on plants or sediment, preferring shallow normal marine to hypersaline (32–65‰) environments. Similar ecologic requirements possesses *Triloculina*, commonly occurring in combination with *Elphidium* and *Quinqueloculina* (Murray, 1991, 2006). The *Quinqueloculina* spp. association occurs in recent Mediterranean Sea in shallow environments (2–65 m), temperate to warm waters (10–25°C) and slightly elevated salinity (37–39‰). *Lobatula lobatula* is an epifaunal dweller, usually attached and immobile, especially in high energy; pre-

fering temperate – warm shallow normal marine environments (Murray, 1991, 2006). *Rosalina* and *Neoconorbina* are epifaunal dwellers, preferring temperate – warm shallow normal marine environments (Murray, 1991, 2006). *Cibicidoides* and *Astrononion* are an epifaunal dwellers, preferring cold normal marine environments (shelf – bathyal; Murray, 1991, 2006).

Palaeoenvironment reconstruction

The siliciclastic part of the exposure (samples A–E; Fig. 2) contains very low amounts of palynological organic matter. It consists almost exclusively of variously preserved black phytoclasts (Fig. 4A); there are no dinoflagellate cysts. Such palynofacies may reflect either restricted environment, unfavourable for aquatic phytoplankton (*e.g.* dinoflagellates), or specific sedimentary setting critical for preservation of palynomorphs. A rare occurrence of sporomorphs seems to opt for the first possibility. These strata were presumably deposited in very shallow environments, characterized by high hydrodynamic conditions. According to Batten (1996, p. 1033 and references therein), a high ratio of black phytoclasts is associated with proximal, high energy environments (it also occur in deep sea facies, but these can be excluded in case of Kudryntsi deposits).

The presence of foraminifers in the siliciclastic unit *ca.* 2 m below the undoubtedly marine deposits limestone is enigmatic. One possible explanation is that the siliciclastic unit related so far with the final stage of evaporite deposition in the Carpathian Foredeep Basin (Peryt & Peryt, 2009), should be rather associated with the Late Badenian transgression. However, other samples from this unit are barren (except for the redeposited Cretaceous forms). The alternative explanation is that during terminal stages of evaporitic basin, the deposition of the siliciclastic unit took place in a lagoon, which was periodically flooded by short-lived marine incursions. Similar situation has been described from the Upper Miocene evaporites of the Eastern Betics, SE Spain, where scarce and poorly preserved foraminifera are recorded in various gypsum units (Playà *et al.*, 2000, table 2); planktonic foraminifera are scarce, small and usually poorly preserved, and the benthic foraminifera seem to have adapted to a wide range of salinity (Playà *et al.*, 2000, table 2). The composition of foraminifers in sample A strongly argues for redeposition from older Badenian strata. The Kudryntsi section is located very close to the original limit of the Badenian gypsum basin (Peryt *et al.*, 2004; Peryt & Peryt, 2009), and towards the east the Upper Badenian rests upon the Lower Badenian strata (Siplivyy *et al.*, 1974).

A monospecific assemblage I with *Elphidium koberi* from the clayey marly bed from the topmost part of the siliciclastic unit (sample E) indicates a very restricted marine environment; probably with elevated salinity.

Shallow water environments (0–20 m deep) of normal marine to slightly elevated salinity, and characterized by high hydrodynamic conditions, are suggested for deposition of organodetrital carbonates characterized by foraminiferal assemblage II with *Elphidium crispum* and *E. macellum* (samples F, G, J).

The occurrence of dark-brown clay with fish remains (sample H) may indicate a period of a calm, stagnant environment – palynofacies of this sample consists exclusively of structureless organic matter, which is typical for the bacterial decay of organic matter in the oxygen depleted, especially anoxic environments (Batten, 1996). Foraminiferal assemblage III with dominant elphidiids with spines, *i.e.* *Elphidium aculeatum* and *E. koberi* and common miliolids, characterizes shallow-marine environment with low hydrodynamic conditions and slightly increased salinity.

Occurrence of dinoflagellate cysts in the topmost part of the organodetrital limestone complex (sample K) and in the overlying rhodoid limestone indicates a change of environment that might be related to the appearance of marine conditions favourable for motile stages of dinoflagellates, or it may reflect a change of sedimentary setting responsible for the preservation of terrestrial and aquatic palynomorphs. A high ratio of sporomorphs and cuticles points at a terrestrial influx into the marine basin. The influx intensity was rather limited, since dinoflagellate cysts are a significant component of palynofacies, being indicative for hemipelagic mode of sedimentation. Such a change may be related to a gradual widening of the basin, possibly associated with deepening, and the appearance of more offshore, less dynamic, quiet bottom environment, which led to accumulation and preservation of both terrestrial and marine palynomorphs. Dinoflagellate cyst assemblages are rather taxonomically not diversified. They consist exclusively of gonyaulacoids, which in majority are represented by chorate and proximochorate specimens. The lack of peridinioids might be related either to primary conditions not suitable for this group of dinoflagellates (*e.g.* low nutrient conditions of the surface water) but also unfavourable syn- and post depositional conditions related to aerobic conditions at the bottom and in the sediment, which are particularly hostage for their preservation (see *e.g.*, Zonneveld *et al.*, 1997).

A general composition of dinoflagellate cyst assemblages suggests marine environment during deposition of the rhodoid complex. The majority of species are typical for shelf environment. Some of them, like *Polysphaeridium zoharyi* and *P. subtile*, are characteristic for inner shelf or lagoonal environments, being tolerant to increased salinity. However, these species never occur as dominant in the studied material. On the other hand, rare specimens of taxa typical for offshore, oligotrophic waters have been found in samples M and N (single specimen of *Impagidinium* occurs also in sample P). Their presence may indicate either influences of offshore waters, limited nutrient availability in near-shore surface waters, or deepening of the basin.

Foraminiferal assemblages from the rhodoid complex (IV–VII) also support marine environments of their origination.

A different composition of dinoflagellate cyst assemblages in particular samples reflects presumably slightly diverse environmental conditions. Sample L contains *Polysphaeridium zoharyi* and *P. subtile*. According to several authors, these species (especially *P. zoharyi*) are typical for littoral embayment in tropical to subtropical settings and are tolerant for increased salinity (Wall & Dale, 1969; Dale, 1976; Wall *et al.*, 1977; Morzadec-Kerfourn, 1979, 1983;

Bradford & Wall, 1984; Edwards & Andrieu, 1992). However, Marret and Zonneveld (2003) reported *P. zoharyi* from low saline environments and suggested euryhaline nature of this species.

The assemblage IV with Miliolidae (samples L and M) supports the interpretation of elevated salinity during the deposition of the lowermost part of the rhodoid complex, in shallow water environment. The next, monospecific assemblage V with *Lobatula lobatula* (sample N) suggests shallow-marine, very high-energy environment. Dinoflagellate cyst assemblages from samples M–O contain no *Polysphaeridium zoharyi*: this change might be interpreted as transition from higher saline regime during deposition of the basal part of the rhodoid complex, into normal marine environment in its higher part. The occurrence of some offshore taxa (*Nematosphaeropsis labyrinthus* and species of *Impagidinium*) in the middle part of the rhodoid complex (samples M and N) coincides with the highest ratio of dinoflagellate cysts (up to 60% in sample N). Both *N. labyrinthus* and *Impagidinium* are treated by several authors as “oceanic” species, which motile stages inhabited offshore waters (*e.g.*, Morzadec-Kerfourn, 1977; Wall *et al.*, 1977; Harland, 1983; Brinkhuis, 1994). The other common species in the middle part of the rhodoid complex – *Operculodinium* sp. (mainly *O. centrocarpum*) and *Lingulodinium machaerophorum* are cosmopolitan species (*e.g.*, Marret & Zonneveld, 2003). *Lingulodinium machaerophorum* is a euryhaline species, which may possess shorter processes in lower saline conditions (*e.g.*, Wall & Dale, 1973; Dale, 1996; Ellegaard, 2000): in our material specimens of *L. machaerophorum* have rather long processes, which may suggest normal salinity. *Operculodinium centrocarpum*, which is a very frequent species in samples M–O, is regarded a cosmopolitan species, which motile stage can flourish in a wide range of environments. Also in case of this species a process length reduction related to lower salinity was suggested (de Vernal *et al.*, 1989; Ellegaard, 2000), but in Kudryntsi material species with “normal” processes predominate.

Samples P–R from the higher part of the rhodoid complex contain dinoflagellate cyst assemblages, which are dominated by cosmopolitan species *Systematophora placacantha* and *Lingulodinium machaerophorum*. Qualitative fluctuation of taxonomical composition may be related to water depth: assemblages with common or dominating *Operculodinium* (samples M–O) may reflect slightly deeper (offshore) environment than the ones inhabited by motile stages of *Lingulodinium machaerophorum* and *Systematophora placacantha* (samples P–R). Possibly similar changes were described by Morzadec-Kerfourn (1983) who described *Lingulodinium machaerophorum* Association from the inner coastal zone with water depth of 10–30 m, and *Operculodinium centrocarpum*-*O. israelianum* Association from the deeper outer coastal zone (30–50 m water depth). More proximal environment for samples P–R may be supported by the occurrence of *Polysphaeridium* in these samples, and the absence of this genus in samples suggests more offshore environment for samples M–O with common *Operculodinium*. However, common occurrence of *Hystriochokolpoma rigaudiae* in sample P may also indicate offshore conditions since this genus, although commonly be-

lied to be cosmopolitan (*e.g.*, Brinkhuis, 1994) is related by some authors as an offshore one (*e.g.*, Rassmussen *et al.*, 2003). On the other hand, it cannot be excluded that appearance of *H. rigaudiae* in our material is associated with other environmental changes like water temperature.

The foraminiferal assemblages VI and VII occurring in that part of the section characterize the highest diversity and taxa preferring temperate-warm to cold shelf to bathyal normal marine environments. The assemblage VI, composed of taxa preferring temperate – warm shallow normal marine environments (*Lobatula*, *Neoconorbina*, *Rosalina*, *Porosonion*, *Astrononion*), confirms suggestions of lowering of salinity to normal marine in the middle part of the rodoid complex. The assemblage VII with *Cibicidoides* and *Lobatula*, *Neoconorbina*, *Rosalina*, *Baggina*, *Porosonion*, *Elphidium* and *Astrononion* suggests temperate to cold normal marine shelf environment.

A NOTE ON *ELPHIDIUM REGINUM* OCCURRENCE

We focused in this paper on palaeoenvironmental aspects of our micropalaeontological assemblages from Kudryntsi. However, one biostratigraphical aspect, which is announced here, deserves a separate discussion. It refers to the occurrence of *Elphidium reginum* in the Upper Badenian succession at Kudryntsi. This species is regarded as the index species of the Lower Sarmatian biozone (Grill, 1941; Łuczowska, 1972; Czepiec, 1996; Harzhauser & Piller, 2004a; Toth *et al.*, 2010). In Podolia, *Elphidium reginum* occurs in the Buglovian and Volhynian (Pishvanova, 1958; Krashennnikov, 1960), but Krashennnikov (1958, p. 296 and 302; 1960, fig. 6) noted that it appears already in the uppermost Badenian (his horizon G). Szczuchura (1982) also reported single specimens of this species in the Badenian profile of Józefów and Hamernia in Roztocze Hills (SE Poland). Other typically Sarmatian foraminifera appearing in the *Anomalinoidea dividens* Zone (*e.g.*, Czepiec, 1996) are lacking and therefore we relate the appearance of *Elphidium reginum* in the Upper Badenian of Kudryntsi to specific environmental conditions which in that particular area have been very similar to those in which the Sarmatian assemblages lived (*cf.* Szczuchura, 1982). The same reasoning may be applied to *Elphidium koberi*, another elphidiid species that so far was described from the Sarmatian strata (Tollmann, 1955; Brestenska, 1974; Papp & Schmid, 1985; Cicha *et al.*, 1998; Görür *et al.*, 2000; Paruch-Kulczycka, 2007; Schütz *et al.*, 2007) and which occurs in samples E and H in the Kudryntsi section. Harzhauser and Piller (2004b) recorded reworked coralline limestone and abundant coralline fragments in the Lower Sarmatian deposits of the Vienna Basin and interpreted them as due to intense reworking of Badenian deposits. In addition, Harzhauser (written information, 2011) has seen several other outcrops in Austria and Hungary in which the Badenian/Sarmatian boundary is expressed as hiatus, and the earliest Sarmatian deposits are usually reworked Badenian coralline limestone, which bear the entire suite of Badenian taxa, including molluscs (this kind of deposits has an own

lithostratigraphic term in Austrian geology referred to as detrital Leitha Limestone). However, although undoubtedly there is some reworking within the studied section at Kudryntsi, we do not see the convincing arguments in favour of the massive reworking of the Upper Badenian strata and the incorporation of reworked rhodoids and molluscs diagnostic for the Badenian into the Sarmatian succession in the case of the Kudryntsi outcrop.

SUMMARY

Diversified palynological and foraminiferal assemblages recorded in strata exposed in the Kudryntsi section above the gypsum indicate variable environmental conditions during the Late Badenian transgression. Analysis of changes of microfossil assemblages suggests restricted environment during beginning of the transgression, and gradual passage into marine environment during later stages of Late Badenian deposition (Fig. 11).

The basal part of the Upper Badenian succession (siliciclastic complex) at Kudryntsi is barren – this points at highly restricted environmental conditions not suitable neither for dinoflagellate cysts (absent) nor foraminifera (rare – presumably reworked). It was presumably high-energy shallow environment (palynofacies of this part of section contains frequent elongated woody particles), possibly associated with hypersaline conditions as indicated by foraminifera assemblage from topmost part of the siliciclastic unit (Assemblage I).

A shallow subtidal warm-temperate restricted environment with increased salinity and changing hydrodynamic intensity is suggested for the topmost siliciclastic unit and the organodetrital limestone. The former yielded a monospecific foraminiferal assemblage I with *Elphidium koberi*, whereas the organodetrital limestone contains foraminiferal assemblages II (with *Elphidium crispum* and *E. macellum*) and III (Elphidiids with spines, *i.e.* *Elphidium aculeatum* and *E. koberi*); the latter assemblage characterizes shallow water marine environment with low hydrodynamic conditions and slightly elevated salinity. The lowering hydrodynamic conditions that periodically appeared in Late Badenian sea during deposition of organodetrital complex gave rise to anoxic bottom conditions as presumed from palynofacies (sample H). Environmental conditions during deposition of the organodetrital limestone were sufficient for foraminifera, but crucial for dinoflagellates. The latter appeared for the first time in the topmost part of the organodetrital complex. Their appearance is related with further salinity decrease (although infrequent dinoflagellate cyst assemblage from the topmost part of organodetrital limestone contains rare specimens typical for hypersaline environments) and gradual remoting of the sedimentary setting exposed at Kudryntsi, which led to slightly deeper setting, with normal marine salinity and temperate-water environment during deposition of the rhodoid complex. However, appearance of dinoflagellate cysts may be related to sedimentological factors reflecting increase of water depth and the appearance of less dynamic, quiet bottom environment, which led to accumulation and preservation of both terres-

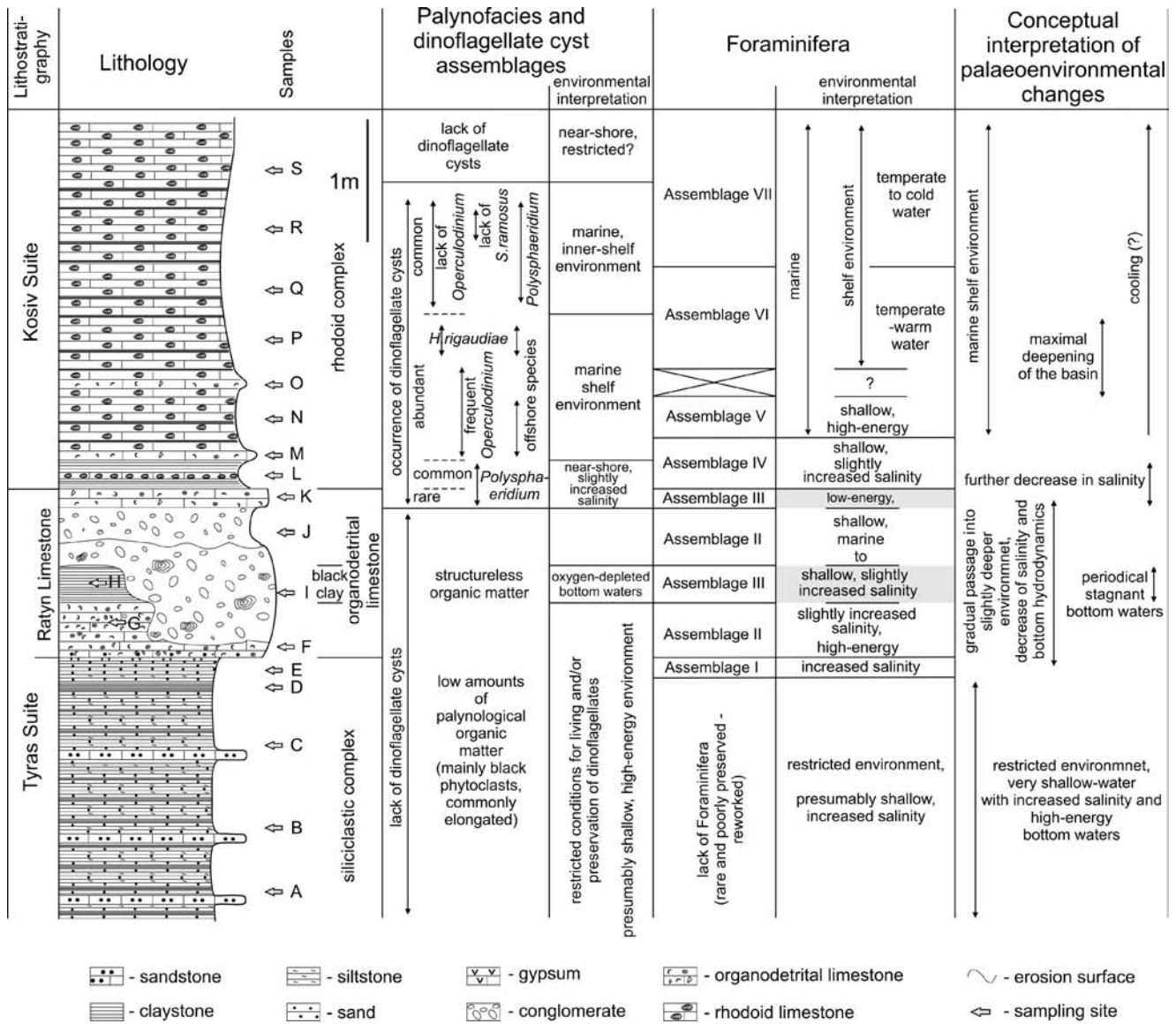


Fig. 11. Conceptual palaeoenvironmental changes in the Late Badenian basin at Kudryntsi based on interpretation of dinoflagellate cyst and foraminifera assemblages

trial and marine palynomorphs. The beginning of the deposition of the rhodoid complex was presumably still under slightly restricted conditions related to slightly increased water salinity (assemblage IV in the basal part of the rhodoid complex with Miliolidae – typical for shallow water environment with slightly increased salinity); interestingly, this part of the section yielded dinoflagellate cyst assemblage typical for normal salinity regime. Sample M yielded a dinoflagellate cyst assemblage dominated by *Spiniferites*, and single specimens of an offshore genus *Impagidinium*. This may indicate various sensitivity of both microfossil groups, or bottom waters inhabited by foraminifera were characterized by increased salinity compared to the surface marine waters.

The higher part of the rhodoid complex was deposited in marine, more offshore, but still rather near-shore environment. Dinoflagellate cyst assemblages from the rhodoid complex suggest the transition from slightly higher saline

regime characteristic for the deposition of its basal part (sample L – occurrence of *Polysphaeridium subtile*) and normal marine environment in its higher part (samples M–R – taxonomically rich and diversified assemblages). The monospecific assemblage V with *Lobatula lobatula* from the lower part of the rhodoid complex (sample N) indicates shallow-marine environment with normal salinity, but characterized by very high-energy hydrodynamic conditions. Dinoflagellate cyst assemblage from the same sample is characterized by high frequency and relative diversity – this points at optimal living conditions related to shelf waters. The foraminiferal assemblages VI and VII characterize the highest taxonomical diversity; they include taxa preferring temperate-warm to cold shelf to bathyal marine environments. Associated dinoflagellate cysts from the same interval (samples P–R) are generally diversified; a characteristic feature of their assemblages is lack of *Operculodinium*, which commonly occur in underlying strata. This change

may reflect some palaeoenvironmental variation, possibly related to minor cooling of marine waters as induced from foraminifera record (the assemblage VI consists of taxa preferring temperate-warm shallow marine environments, whereas the assemblage VII suggests temperate to cold marine shelf environment).

The latter interpretation of changes of foraminiferal assemblages is related to water temperature decline. This may reflect a slight cooling during the Late Badenian, but it may be also linked to deepening of the basin and appearance of colder bottom waters.

The foraminiferal assemblages from Kudryntsi contain *Elphidium reginum* and *Elphidium koberi* common for the Sarmatian; *Elphidium reginum* is regarded as the index species of the Lower Sarmatian biozone, although it was earlier reported from the uppermost Badenian. Other typically Sarmatian foraminifera of the *Anomalinoidea dividens* Zone are lacking and the occurrence of *Elphidium reginum* and *Elphidium koberi* in the Upper Badenian of Kudryntsi is related to specific environmental conditions which were very similar to those characteristic for the Sarmatian.

Acknowledgements

We would like to thank Barbara Słodkowska for reading the manuscript and critical remarks. Special thanks are due to Mathias Harzhauser for his helpful comments and inspiring suggestions. The research was undertaken as a research project No. UKRAINA/193/2006 of the Ministry of Science and Higher Education carried out at the AGH University of Science and Technology and the Polish Geological Institute – National Research Institute and was financed from the scientific fund of 2007–2010. We thank Zofia Dubicka for the field assistance.

REFERENCES

- Abbene, I. J., Culver, S. J., Reide Corbett, D., Buzas, M. A. & Tully, L. S., 2006. Distribution of foraminifera in Pamlico Sound, North Carolina, over the past century. *Journal of Foraminiferal Research*, 36: 135–151.
- Andreyeva-Grigorovich, A. S., Kulchytsky, Y. O., Gruzman, A. D., Lozynyak, P. Y., Petrashkevich, M. I., Portnyagina, L. O., Ivanina, A. V., Smirnov, S. E., Trofimovich, N. A., Savitskaya, N. A. & Shvareva, N. J., 1997. Regional stratigraphic scheme of Neogene formations of the Central Paratethys in the Ukraine. *Geologica Carpathica*, 48: 123–136.
- Batten, D. J., 1996. Palynofacies and palaeoenvironmental interpretation. In: Jansonius, J. & McGregor, D. C. (eds), *Palynology: principles and applications*, 3. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, p. 1011–1064.
- Bradford, M. R. & Wall, D. A., 1984. The distribution of Recent organic-walled dinoflagellate cysts in the Persian Gulf, Gulf of Oman, and northwestern Arabian Sea. *Palaeontographica, Abt. B*, 192: 16–84.
- Brestenská, E., 1974. Die Foraminiferen des Sarmatien s. str. In: Brestenská, E. (ed.), *Chronostratigraphie und Neostatotypen – Miozän der Zentralen Paratethys*, 4, M5 Sarmatien, p. 243–293.
- Brinkhuis, H., 1994. Late Eocene to Early Oligocene dinoflagellate cysts from the Priabonian type-area (northeast Italy): biostratigraphy and palaeoenvironmental interpretation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 107: 121–163.
- Chendes, C., Kaminski, M. A., Filipescu, S., Aksu, A. E. & Yasar, D., 2004. The response of modern benthic foraminiferal assemblages to water-mass properties along the southern shelf of Marmara Sea. *Acta Palaeontologica Romaniaae*, 4: 69–80.
- Cicha, I., Rögl, F., Rupp, Ch. & J. Ctyroka, J., 1998. Oligocene–Miocene foraminifera of the Central Paratethys. *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft*, 549: 1–325.
- Combaz, A., 1964. Les palynofaciès. *Revue de Micropaléontologie*, 7: 205–218.
- Czepiec, I., 1996. Biostratigraphy and palaeoenvironment of Sarmatian marginal zone of Poland. (In Polish, English summary). *Kwartalnik AGH, Geologia*, 22: 309–338.
- Czepiec, I. & Kotarba, M. J., 1998. Paleocology and organic matter in the Late Badenian and Early Sarmatian marine basin of the Polish part of the Carpathian Foredeep. *Przegląd Geologiczny*, 46: 732–736.
- Dale, B., 1976. Cyst formation, sedimentation and preservation: factors affecting dinoflagellate assemblages in Recent sediments from Trondheimsfjord, Norway. *Review of Palaeobotany and Palynology*, 22: 39–60.
- Dale, B., 1996. Dinoflagellate cyst ecology: modelling and geological applications. In: Jansonius, J. & McGregor, D. C. (eds), *Palynology: principles and applications*, 3. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas, p. 1249–1275.
- Debenedy, J.-P., Millet, B. & Angelidis, M., 2005. Relationships between foraminiferal assemblages and hydrodynamics in the Gulf of Kalloni, Greece. *Journal of Foraminiferal Research*, 35: 327–343.
- de Rijk, S., Troelstra, S. & Rohling, E. J., 1999. Benthic foraminiferal distribution in the Mediterranean Sea. *Journal of Foraminiferal Research*, 29: 93–103.
- de Vernal, A., Goyette, C. & Rodrigues, C. G., 1989. Contribution palynostratigraphique (dinokystes, pollen et spores) à la connaissance de la Mer Champlain: coupe de Saint-Césaire, Québec. *Canadian Journal of Earth Sciences*, 26: 2450–2464.
- Edwards, L. E. & Andrieu, V. A. S., 1992. Distribution of selected dinoflagellate cysts in modern marine sediments. In: Head, M. J. & Wrenn, J. H. (eds), *Neogene and Quaternary Dinoflagellate Cysts and Acritarchs*. American Association of Stratigraphic Palynologists Foundation, p. 259–288.
- Ellegaard, M., 2000. Variations in dinoflagellate cyst morphology under conditions of changing salinity during the last 2000 years in the Limfjord, Denmark. *Review of Palaeobotany and Palynology*, 109: 65–81.
- Fiorini, F., 2004. Benthic foraminiferal associations from Upper Quaternary deposits of southeastern Po Plain, Italy. *Micropalaeontology*, 50: 45–58.
- Garecka, M. & Olszewska, B., 2011. Correlation of the Middle Miocene deposits in SE Poland and West Ukraine based on foraminifera and calcareous nannoplankton. *Annales Societatis Geologorum Poloniae*, 81: 309–330.
- Gedl, P., 1996. Middle Miocene dinoflagellate cysts from the Korytnica clays (Góry Świętokrzyskie Mountains, Poland). *Annales Societatis Geologorum Poloniae*, 66: 191–218.
- Gedl, P., 1997. Palynofacies of the Miocene deposits in the Gliwice area (Upper Silesia, Poland). *Bulletin of the Polish Academy of Sciences, Earth Sciences*, 45: 191–201.
- Gedl, P., 1999. Palaeoenvironmental and sedimentological interpretations of the palynofacies analysis of the Miocene deposits from the Jamnica S-119 borehole (Carpathian Foredeep,

- Poland). *Geological Quarterly*, 43: 479–492.
- Gonera, M., 2001. Foraminiferida and paleoenvironment of the Badenian formations (Middle Miocene) in the Upper Silesia. (In Polish, English summary). *Studia Naturae*, 48: 1–211.
- Görür, N., Çağatay, N., Sakiç, M., Akkök, R., Tchapylyga, A. & Natalin, B., 2000. Neogene Paratethyan succession in Turkey and its implications for the palaeogeography of the Eastern Paratethys. *Geological Society, London, Special Publication*, 173: 251–269.
- Grill, R., 1941. Stratigraphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen. *Oel und Kohle*, 37: 595–602.
- Gruzman, A. D. & Trofimovich, N. A., 1996. Organichni reshtki neogenovykh vkladiv. Foraminifery. (In Ukrainian). *Paleontologichnyi Zbirnik*, 31: 14–20.
- Harland, R., 1983. Distribution maps of recent dinoflagellate cysts in bottom sediments from the North Atlantic Ocean and adjacent seas. *Palaeontology*, 26: 321–387.
- Harzhauser, M. & Piller, W. E., 2004a. Integrated stratigraphy of the Sarmatian (Upper Middle Miocene) in the western Central Paratethys. *Stratigraphy*, 1: 65–86.
- Harzhauser, M. & Piller, W. E., 2004b. The Early Sarmatian – hidden seesaw changes. *Courier Forschungsinstitut Senckenberg*, 246: 89–111.
- Hayward, B. W., Hollis, C. J. & Grenfell, H. R., 1997. Recent Elphidiidae (Foraminiferida) of the South-west Pacific and fossil Elphidiidae of New Zealand. *Institute of Geological & Nuclear Sciences Monographs*, 16, 170 pp., Lower Hutt.
- Hottinger, L., Halicz, E. & Reiss, Z., 1993. Recent Foraminiferida from the Gulf of Aqaba, Red Sea. *Opeara Sazu*, 33, 179 pp.
- Jasionowski, M., 2006. Facies and geochemistry of Lower Sarmatian reefs along the northern margin of the Paratethys in Roztocze (Poland) and Medobory (Ukraine) region: paleoenvironmental implications. (In Polish, English summary). *Przegląd Geologiczny*, 54: 445–454.
- Jasionowski, M., Poberezhskyy, A. V., Studencka, B., Peryt, D. & Hara, U., 2003. Serpulid-microbialite Lower Sarmatian reefs of the Miodobory region (Volhyn-Podolian margin of the East-European Platform). (In Ukrainian with English summary). *Geologiya i Geokhimiya Horyuchykh Kopalyn*, 2: 85–91.
- Jorissen, F., 1987. The distribution of benthic Foraminifera in the Adriatic SEA. *Marine Micropaleontology*, 12: 21–48.
- Kováč, M., Andreyeva-Grigorovich, A., Bajraktarević, Z., Brzobohatý, R., Filipescu, S., Fodor, L., Harzhauser, M., Nagymarosy, A., Oszczykko, N., Pavelić, D., Rögl, F., Saftić, B., Sliva, L. & Studencka, B., 2007. Badenian evolution of the Central Paratethys Sea: paleogeography, climate and eustatic sea-level changes. *Geologica Carpathica*, 58: 579–606.
- Krashennikov, V. A., 1958. Stenofatsialnyye i evrifatsialnyye vidy foraminifer. (In Russian). *VNIGNI Trudy, Paleontologicheskii sbornik*, 9: 285–305.
- Krashennikov, V. A., 1960. Elfidiidy miotsenovykh otlozheniy Podolii. (In Russian). *Trudy Geologicheskogo Instituta*, 21: 1–142.
- Kudrin, L. N., 1966. *Stratigrafiya, fatsii i ekologicheskii analiz fauny paleogenovykh i neogenovykh otlozheniy Predkarpats'ya*. (In Russian). Izdaniya Lvovskogo Universiteta, Lvov.
- Langer, M. R. 1993. Epiphytic foraminifera. *Marine Micropaleontology*, 20: 235–265.
- Łuczowska, E., 1972. Miliolidae (Foraminifera) from Miocene of Poland. Part 1. Revision of the classification. *Acta Palaeontologica Polonica*, 17: 341–377.
- Marret, F. & Zonneveld, K. A. F., 2003. Atlas of modern organic-walled dinoflagellate cyst distribution. *Review of Palaeobotany and Palynology*, 125: 1–200.
- McMinn, A., 1990. Recent dinoflagellate cyst distribution in eastern Australia. *Review of Palaeobotany and Palynology*, 65: 305–310.
- Milker, Y., Schmiidl, G., Betzler, C., Römer, M., Jaramillo-Vogel, D. & Siccha, M., 2009. Distribution of Recent benthic foraminifera in neritic carbonate environments of the Western Mediterranean Sea. *Marine Micropaleontology*, 70: 207–225.
- Morzadec-Kerfourn, M.-T., 1977. Les kystes de dinoflagellés dans les sédiments récents le long des côtes Bretonnes. *Revue de Micropaléontologie*, 20: 157–166.
- Morzadec-Kerfourn, M.-T., 1979. Indicateurs écologiques du domaine littoral: végétation et plancton organique. *Océanis*, 5: 207–213.
- Morzadec-Kerfourn, M.-T., 1983. Intérêt de dinoflagellés pour l'établissement de reconstruction paléogéographique: exemple du Golfe de Gabes (Tunésie). *Cahiers de Micropaléontologie*, 4: 15–22.
- Murray, J. W., 1991. *Ecology and palaeoecology of benthic foraminifera*. Longman, Avon, 397 pp.
- Murray, J. W., 2006. *Ecology and applications of benthic foraminifera*. Cambridge University Press, Cambridge, 426 pp.
- Oszczykko, N., Krzywicz, P., Popadyuk, I. & Peryt, T., 2006. Carpathian Foredeep Basin (Poland and Ukraine): Its sedimentary, structural and geodynamic evolution. *American Association of Petroleum Geologists Memoir*, 84: 293–350.
- Papp, A. & Schmid, M. E., 1985. Die fossilen Foraminiferen des Tertiären Beckens von Wien – Revision der Monographie von Alcide d'Orbigny (1846). *Abhandlungen der Geologischen Bundesanstalt*, 37: 1–311.
- Paruch-Kulczycka, J., 2007. Pozycja biostratygraficzna zespołów mikrofauny z odsłoneń w Gałuszczyńcach i Kołubajowcach (NW Ukraina). (In Polish). In: Żylińska, A. (ed.), *Granice paleontologii. Materiały konferencyjne*, p. 104.
- Peryt, D. & Gedl, P., 2010. Palaeoenvironmental changes preceding the Middle Miocene Badenian salinity crisis in the northern Polish Carpathian Foredeep Basin (Borków Quarry) inferred from foraminifers and dinoflagellate cysts. *Geological Quarterly*, 54: 487–508.
- Peryt, D. & Peryt, T. M., 2009. Environmental changes in the declining Middle Miocene Badenian evaporite basin of the Ukrainian Carpathian Foredeep (Kudryntsi section). *Geologica Carpathica*, 60: 505–517.
- Peryt, T. M., 2006. The beginning, development and termination of the Middle Miocene Badenian salinity crisis in Central Paratethys. *Sedimentary Geology*, 188–189: 379–396.
- Peryt, T. M., Karoli S., Peryt, D., Petrichenko, O. I., Gedl, P., Durkovičová, J. & Dobieszyńska, Z., 1997. Westernmost occurrence of the Middle Miocene Badenian gypsum in Central Paratethys (Kobeřice, Moravia, Czech Republic). *Slovak Geological Magazine*, 3: 105–120.
- Peryt, T. M., Poberezhskyy, A. V., Jasionowski, M., Peryt, D., Petrychenko, O. Y., Lyzun, S. O. & Turchinov, I. I., 2004. Correlation of Badenian sulphatic deposits in the Dnister river region. (In Ukrainian, English summary). *Geologia i Geokhimiya Horyuchykh Kopalyn*, 1: 56–69.
- Peryt, T. M., Peryt, D. & Poberezhskyy, A. V., 2008. Badenian (Middle Miocene) laminated gypsum facies from Kudryntsi on Zbruch River (West Ukraine). (In Ukrainian with English summary). In: Gozhyk, P.F. et al. (eds), *Suchasni problemy litologii i mineragenii osadovykh baseyniv ta sumizhnykh terytoriy*, 140–145, Kyiv.
- Pishvanova, L. S., 1958. Novyye dannyye o verkhnetortoniskikh i nizhnesharmatskikh otlozheniyakh Predkarpats'ya. (In Russian). *VNIGNI Trudy, Paleontologicheskii sbornik*, 9: 251–284.

- Pishvanova, L. S., 1969. Stratigraphical and facial distribution of Foraminifera in Miocene deposits of the western part of Ukrainian SSR. *Rocznik Polskiego Towarzystwa Geologicznego*, 39: 335–349.
- Playà, E., Ortí, F. & Rosell, L., 2000. Marine to non-marine sedimentation in the upper Miocene evaporites of the Eastern Betics, SE Spain: sedimentological and geochemical evidence. *Sedimentary Geology*, 133: 135–166.
- Rochon, A., de Vernal, A., Turon, J.-L., Matthiessen, J. & Head, M. J., 1999. Distribution of recent dinoflagellate cysts in surface sediments from the North Atlantic and adjacent seas in relation to sea-surface parameters. *American Association of Stratigraphic Palynologists, Contributions Series*, 35: 1–146.
- Schmid, H. P., Harzhauser, M. & Kroh, A., 2001. Hypoxic events on a Middle Miocene carbonate platform of the Central Paratethys (Austria, Badenian, 14 Ma). *Annalen des Naturhistorischen Museums in Wien*, 102A: 1–50.
- Schütz, K., Harzhauser, M., Rögl, F., Dorić, S. & Galović, I., 2007. Foraminiferen und Phytoplankton aus dem unteren Sarmatium des südlichen Wiener Beckens (Petronell, Niederösterreich). *Jahrbuch der Geologischen Bundesanstalt*, 147: 449–488.
- Siplivyy, Y. F., Shevchenko, O. E. & Dudnische, A. A., 1974. *Geologicheskaya karta SSSR masshtaba 1:200 000, Seriya volyno-podolskaya, Listy M-35-XXXIII, L-35-III, Ob'yasnitelnaya zapiska*. (In Russian). Moskva, 114 pp.
- Subbotina, N. N., Pishvanova, L. S. & Ivanova, L. V., 1960. Stratigrafiya oligotsenovykh i miotsenovykh otlozheniy Predkarpat'ya po foraminiferam. (In Russian). *Trudy VNIGRI, Mikrofauna SSSR, Sbornik*, 11: 5–122.
- Szczechura, J., 1982. Middle Miocene foraminiferal biochronology and ecology of SE Poland. *Acta Palaeontologica Polonica*, 27: 3–44.
- Teisseyre, W., 1900. *Atlas Geologiczny Galicyi. Tekst do zeszytu ósmego*. (In Polish). Wydawnictwo Komisji Fizjograficznej Akademii Umiejętności, Kraków: 1–330.
- Tollmann, A., 1955. Die Foraminiferenentwicklung im Torton und Untersarmat in der Randfazies der Eisenstädter Bucht. *Sitzungsberichte der Österreichischen Akademie der Wissenschaften: Mathematisch-Naturwissenschaftlichen Klasse, Abteilung I*, 164: 193–202.
- Tóth, E., Görög, A., Lécuyer, C., Moissette, P., Balter, B. & Monostori, M., 2010. Palaeoenvironmental reconstruction of the Sarmatian (Middle Miocene) central Paratethys based on palaeontological and geochemical analyses of foraminifera, ostracods, gastropods and rodents. *Geological Magazine*, 147: 299–314.
- Tyson, R. V., 1995. *Sedimentary organic matter. Organic facies and palynofacies*. Chapman & Hall, London, xvii + 615 pp.
- Vink, A., Zonneveld, K. A. F. & Willems, H., 2000. Organic-walled dinoflagellate cysts in western equatorial Atlantic surface sediments: distribution and their relation to environment. *Review of Palaeobotany and Palynology*, 112: 247–286.
- Vrsaljko, D., Pavelić, D., Miknić, M., Brkić, M., Kovačić, M., Hećimović, I., Hajek-Tadesse, V., Avanić, R. & Kurtanjek, N., 2006. Middle Miocene (Upper Badenian/Sarmatian) palaeoecology and evolution of the environments in the area of Medvednica Mt. (North Croatia). *Geologia Croatica*, 59: 51–63.
- Wall, D. & Dale, B., 1969. The “hystrichosphaerid” resting spore of the dinoflagellate *Pyrodinium bahamense* Plate, 1906. *Journal of Phycology*, 5: 140–149.
- Wall, D., Dale, B., 1973. Paleosalinity relationships of dinoflagellates in the Late Quaternary of the Black Sea – a summary. *Geoscience and Man*, 7: 95–102.
- Wall, D., Dale, B., Lohmann, G. P. & Smith, W. K., 1977. The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the north and south Atlantic Oceans and adjacent seas. *Marine Micropaleontology*, 2: 121–200.
- Zonneveld, K. A. F., Versteegh, G. J. M. & De Lange, G. J., 1997. Preservation of organic walled dinoflagellate cysts in different oxygen regimes: a 10,000 years natural experiment. *Marine Micropaleontology*, 29: 393–405.