Geological Quarterly, 2005, **49** (3): 275–290

Mid-Cretaceous spicule-rich turbidites in the Silesian Nappe of the Polish Outer Carpathians: radiolarian and foraminiferal biostratigraphy

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Bąk M., Bąk K. and Ciurej A. (2005) — Mid-Cretaceous spicule-rich turbidites in the Silesian Nappe of the Polish Outer Carpathians: radiolarian and foraminiferal biostratigraphy. Geol. Quart., **49** (3): 275–290. Warszawa.

Spicule-rich turbidites are widespread in mid-Cretaceous deep-water flysch of the Subsilesian and Silesian units in the Polish Outer Carpathians. The spicule-rich material with an admixture of numerous radiolarian and foraminiferal particles was supplied, together with siliciclastic material, from shallow environments, mostly from the northern margin of the Carpathian Basin. We present new data on the age of these deposits in the Silesian Nappe, where they are distinguished as the Mikuszowice Cherts. This unit is composed of medium- and thick-bedded siliciclastic to calcareous turbidites including bluish cherts in their middle and upper parts and of thin non-calcareous hemipelagic shales. We have studied radiolaria and foraminifera from hemipelagic sediments and spicule-rich turbidites, from two continuous sections in the Barnasiówka Range (Beskid Wyspowy Mts.) that included the Mikuszowice Cherts (31 m thick) and their transition into the surrounding units. The age of the Mikuszowice Cherts was determined taking into account the following radiolarian datum events: (1) the occurrence of *Praeconocaryomma lipmanae* in the entire unit, (2) the FO (first occurrence) of *Hemicryptocapsa tuberosa* in the upper part of the unit, (3) the FO of *Amphipyndax stocki* close to the upper boundary of the unit, (4) the FO of *Hemicryptocapsa prepolyhedra* in the lowermost part of the overlying Barnasiówka Radiolarian Shale Formation. These datum events appear successively in the Western Tethys successions within the *Rotalipora cushmani* planktonic foraminiferal Zone, which corresponds to the middle and upper Cenomanian (except for its uppermost part). The foraminiferal assemblages, in which such taxa as *Rotalipora* cf. *cushmani*, *R*. cf. *greenhornensis*, whiteinellids and *Uvigerinammina praejankoi* successively appear, confirm the mid-late Cenomanian age of the spicule-rich turbidites in the Silesian Nappe.

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Key words: Outer Carpathians, middle-upper Cenomanian, spicule-rich turbidites, radiolaria, foraminifera, biostratigraphy.

INTRODUCTION

An oceanic anoxic event across the Cenomanian-Turonian boundary (OAE 2; Schlanger and Jenkyns, 1976), characterized by widespread deposition of marine sediments rich in organic carbon has been recognized in various basinal settings including, among others, the deep-water Outer Carpathian flysch Basin (for summary see Bąk *et al*., 2001). This organic-rich sedimentation, recorded in many sections of the Outer Carpathians, was preceded by widespread deposition of spicule-rich turbidites, recorded in the mid-Cretaceous flysch of the Subsilesian and Silesian units. The spicule-rich material with an admixture of numerous radiolarian and foraminiferal particles was supplied, together with siliciclastic material, from shallow environments, mostly from the northern margin of the Outer Carpathian Basin. The spicule-rich turbidites have been described as the Gaize Beds and spongiolites in the Subsilesian Nappe (*cf*. Sujkowski, 1933; Książkiewicz, 1936; Alexandrowicz, 1973) and as the Mikuszowice Cherts (Upper Lgota Beds) in the Silesian Nappe.

The position of these sediments in stratigraphical schemes has changed during the past 70 years (since Sujkowski's proposal in 1933) from upper Aptian to Cenomanian. The uncertainty in the age assignment was related to the predominance of the turbiditic siliceous sediments, practically devoid of hemipelagic intervals. Most shales at the tops of turbidites represent redeposited silts and clays. Moreover, hemipelagites, where present, include scarce long-ranging macro- and microfossils.

In this paper we discuss the age of deposition of the Mikuszowice Cherts, the unit that underlies the organic-rich deposits of the OAE 2 in the Silesian Nappe (Barnasiówka Radiolarian Shale Formation; Bąk *et al*., 2001). Previous data about the age of these deposits are inexact. Most findings of macro- and microfossils were obtained from underlying siliciclastic turbidites, named the Lower and Middle Lgota Beds. Only individual specimens of macrofossils (belemnites and inoceramids) and a few deep-water agglutinated foraminiferal assemblages, described by previous workers, were used in those biostratigraphical studies.

This paper presents new data on the biostratigraphy of the Mikuszowice Cherts, based on radiolaria and foraminifera. Our micropalaeontological studies are based not only on the microfossils from non-calcareous hemipelagic shales, but also include considerable data from the spicule-rich turbidites which contain many stratigraphically important microfossils.

PALAEOGEOGRAPHIC AND LITHOSTRATIGRAPHIC FRAMEWORK

The Polish part of the Outer (flysch) Carpathians comprises several nappes that are thrust over each other from the SSW to the NNE in the central part of the Polish Outer Carpathians. The internal structure of the Silesian Nappe (Fig. 1A, B) varies along its strike. In the western and central parts, the Silesian Nappe displays broad, gently folded structures, built up mostly of Cretaceous rocks (Książkiewicz, 1951, 1972).

The Cretaceous deposits of the Silesian Nappe were laid down in the Silesian sub-basin, located along the northern part of the Carpathian Basin and limited to the south by the Silesian ridge (cordillera) and in the north by the Subsilesian submerged ridge (Książkiewicz, 1962). Early Cretaceous sedimentation in the Silesian sub-basin developed in several stages (for a summary see Cieszkowski and Ślączka, 2001). This started from the Tithonian-Hauterivian rifting and local subsidence accompanied by calcareous flysch sedimentation (Cieszyn Beds). The second stage (Hauterivian-Aptian) is characterized by sedimentation of black clayey and siliceous shales (Verovice Shales) with locally distributed marine coarse clastics deposits (Grodziszcze Sandstones). The sediments of the Lgota Beds studied (Fig. 2) were deposited during the next stage, characterized by acceleration of siliciclastic turbiditic deposition, gradually replaced by deposition of spicule-rich turbidites. This directly preceded the worldwide oceanic anoxic event (OAE 2) in the latest Cenomanian-earliest Turonian, manifested by deposits rich in organic matter and Fe-Mn (Barnasiówka Radiolarian Shale Formation).

The Lgota Beds have been subdivided into three informal lithostratigraphic units: the Lower, Middle and Upper Lgota Beds (Książkiewicz, 1951). The lower unit (not studied here) consists of thick-bedded sandstones and conglomerates with thin intercalations of black and grey shales. The Middle Lgota Beds consist mostly of thin- and medium-bedded siliceous dark grey sandstones and siltstones, with distinct parallel and cross lamination. The sandstones and siltstones are interbedded with black, grey, green and spotty, mainly non-calcareous shales. The upper division, named the Mikuszowice Cherts (Szajnocha, 1884; Burtanówna, 1933) is a turbiditic sequence of alternating medium- and thick-bedded (up to 50 cm) sandstones consisting predominantly of siliciclastic or carbonate

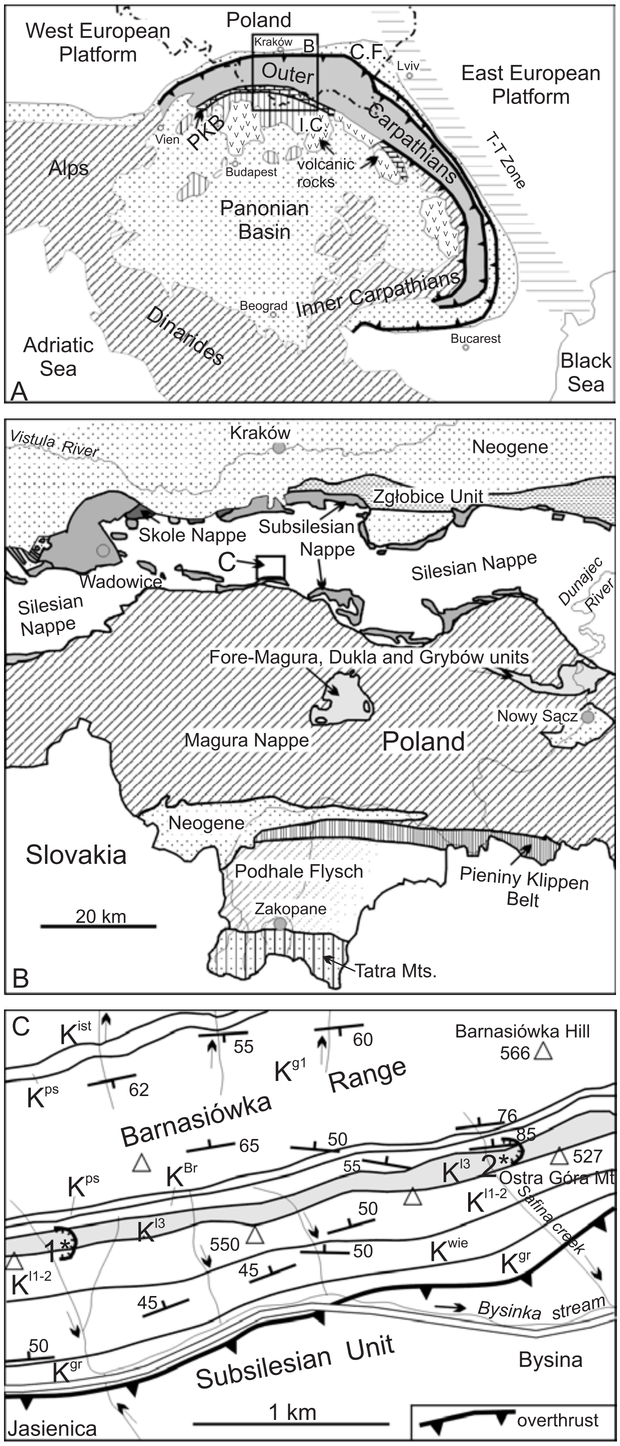

Fig. 1. Position of the sections studied in relation to the main geological units

A — the Outer Carpathians on a simplified geological map of the Alpine orogens and their foreland; I.C. — Inner Carpathians, C.F. — Carpathian Foredeep, PKB — Pieniny Klippen Belt; **B** — the Silesian Nappe in the western part of the Polish part of the Carpathians; **C** — geological map of the Silesian Nappe at the Barnasiówka Range (Beskid Wyspowy Mountains, Outer Carpathians, Poland) with location of the sections studied (after Burtan, 1964; Burtan and Szymakowska, 1964): K^{gr} — Grodziszcze Sandstones, K^{wie} — Verovice Shales, K^{l1-2} — Lower and Middle Lgota Beds, K^{l3} — Mikuszowice Cherts, K^{Br} — Barnasiówka Radiolarian Shale Formation, K^{ps} — Variegated Shales; K^{g1} — Lower Godula Beds; K^{ist} — Lower Istebna Sandstones, 1* — Jasienica section, 2* — Ostra Góra section

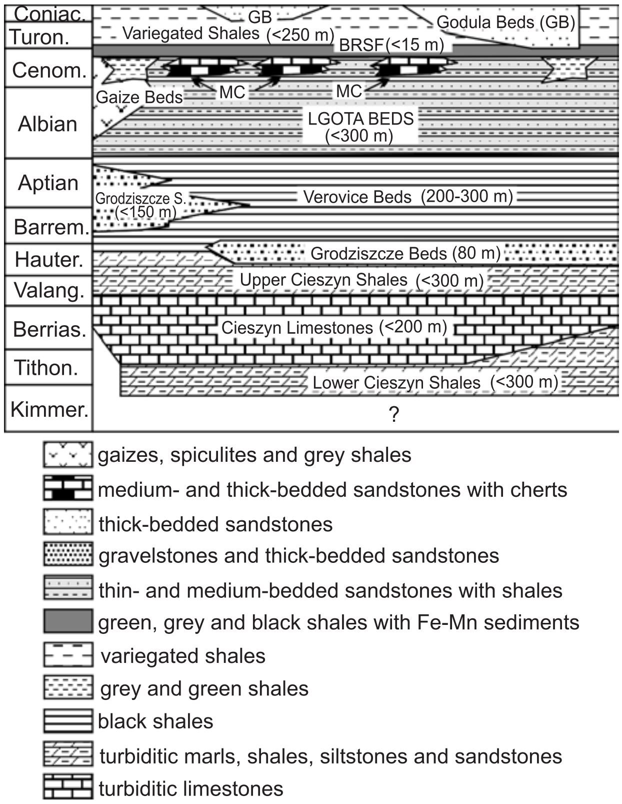

Fig. 2. Generalized stratigraphy of the Kimmeridgian-Coniacian of the Silesian Nappe after Koszarski and Ślączka (1973), slightly modified

MC — Mikuszowice Cherts, BRSF — Barnasiówka Radiolarian Shale Formation

grains and micrite, and siliceous-carbonate cement. Their characteristic feature is the presence of bluish cherts in the middle and upper parts of layers. In some places, the siliciclastics pass into carbonate sediments with a variable siliciclastic admixture.

The turbidites represent predominantly T_b, T_d, T_e (T_b — parallel laminated sand, T_d — laminated silt, T_e — pelagic and hemipelagic mud) Bouma intervals. The T_c (cross-laminated sand) interval is extremely rare. The most characteristic feature of these deposits, visible only in thin sections, is the high content of siliceous sponge spicules. Other biogenic particles are planktonic and benthic calcareous foraminifers, radiolarians, ostracods, fragmented coralline algae, inoceramid prisms and, sporadically, echinoid spines. The microfacies composition of the T_{bcd} intervals show the following types: (1) fine- to medium-grained greywackes with calcitic matrix/cement, sometimes with a biogenic admixture; (2) spicule-bearing greywackes with more than 5% of sponge spicules; (3) gaizes; (4) spiculites containing up to 90% of sponge spicules, usually recrystallized into chalcedonic quartz, rare foraminifers and radiolarians, and very rare detrital grains of quartz and glauconite; and (5) biomicrite with planktonic and benthic calcareous foraminifers, radiolarians and rare sponge spicules. The microfaunal composition indicates that the redeposited material was derived from an outer shelf and transported into a deep basin, below the carbonate compensation depth.

In the Eastern Carpathians, the well-developed Lower Lgota Beds are replaced by the lithotypes typical of the middle division; the Mikuszowice Cherts are there replaced by thin-bedded, siliciclastic turbidites (Książkiewicz, 1956). The Mikuszowice Cherts do not form a continuous horizon in the Western Carpathians (Koszarski *et al*., 1962; Książkiewicz and Liszkowa, 1978). They are present mainly in the NW part of the Silesian Nappe and they pass laterally into sandy and silty turbidites and grey and green shales (Książkiewicz and Liszkowa, 1978). The maximum thickness of the entire Lgota Beds reaches 400 m, whereas the average thickness of the Mikuszowice Cherts varies between 20 and 35 m, with the maximum values (130 m) reported from the Lanckorona Foothills by Książkiewicz (1951). Most probably, this unusual thickness is due to tectonic repetition of this succession in the strongly tectonized Lanckorona area.

The boundaries of the Mikuszowice Cherts are easily recognisable in the field. The lower boundary is placed at the sole of the first thick silicified layer showing laminae of bluish chert. The upper boundary is placed at the top of the uppermost sandstone bed with a chert layer in its middle part (Fig. 3; for details see Bąk *et al*., 2001).

The area studied is situated in the central part of the Silesian Nappe, within the Lanckorona–Żegocina tectonic zone (Fig. 1B, C), built of Cretaceous deposits. The Cretaceous deposits form here a tectonic slice (Fig. 1C), thrust southwards over Paleogene deposits (Burtan, 1964; Burtan and Szymakowska, 1964). The most resistant rocks of this slice build the Barnasiówka Range, which is a part of the Beskid Wyspowy Mountains.

PREVIOUS BIOSTRATIGRAPHIC STUDIES

Most of the existing biostratigraphic data concern the whole of the Lgota Beds rather than the Mikuszowice Cherts. The first data on the age of the Lgota Beds were based on the findings of the belemnite rostra *Neohibolites minimus* Lister (Liebus and Uhlig, 1902; Koszarski and Nowak, 1960). On the basis of an acme of this species, a middle Albian age was assigned for these strata by Koszarski and Nowak (1960). Inoceramids, such as *Inoceramus laubeii* Sow and *Inoceramus concentricus* Sow and an ammonite *Parahoplites (Acanthoplites) bigouretti* Seun (Liebus and Uhlig, 1902) suggest an early-middle Albian age for the Lgota Beds.

Later biostratigraphic studies were based mainly on deep-water agglutinated foraminifera (DWAF) from hemipelagic, non-calcareous shales (Geroch, 1960, 1966; Książkiewicz and Liszkowa, 1978; Geroch and Nowak, 1988). Olszewska (1997), in her composite zonation of the Outer Carpathian sequences, included the undivided Lgota Beds within three DWAF zones (*Haplophragmoides nonioninoides, Plectorecurvoides alternans* and *Bulbobaculites problematicus* zones) corresponding to the Albian-lowermost Cenomanian. Recently, Bąk *et al*. (2001) described DWAF assemblages from the Barnasiówka Radiolarian Shale Formation (BRSF). These data suggest a latest Cenomanian age for the lower boundary of the BRSF, on the basis of the presence of *Uvigerinammina praejankoi* Neagu, among others.

Findings of planktonic foraminifera have been rarely recorded from the Lgota Beds (Liszkowa and Nowak, 1963;

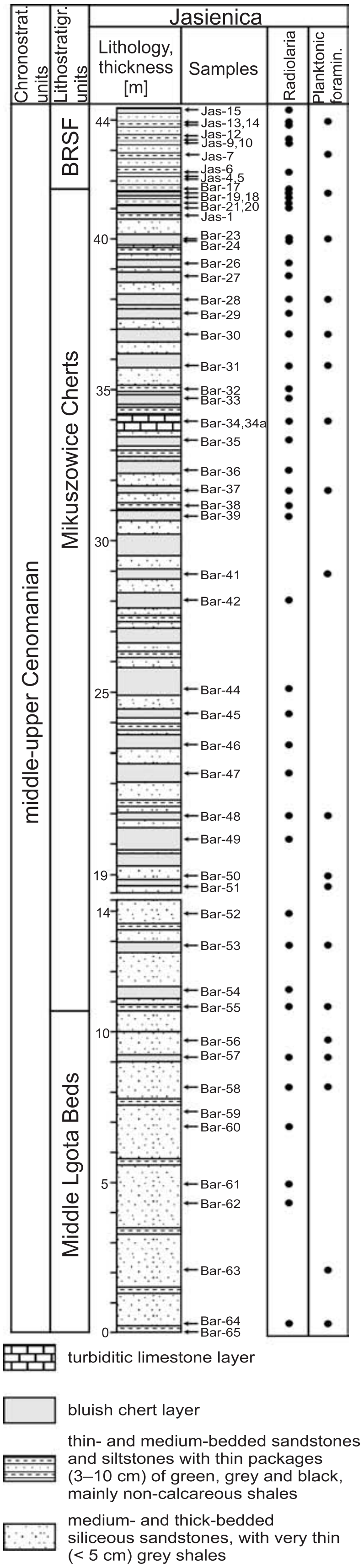

Fig. 3. Stratigraphic log of the Mikuszowice Cherts and the encompassing units at the Jasienica section, with positions of the samples studied and occurrences of radiolaria and planktonic foraminifera

Other explanations as on Figure 2

Książkiewicz and Liszkowa, 1978). Single rotaliporids and praeglobotruncanids from the Gaize Beds (an equivalent of the Lgota Beds in the Subsilesian Nappe) indicate a Cenomanian age for the Upper Lgota Beds. Individual specimens of *Rotalipora appenninica*, *Rotalipora greenhornensis* and *Whiteinella archeocretacea* in the lowermost part of the BRSF (Bąk *et al*., 2001) may suggest a late Cenomanian age for the top part of the Mikuszowice Cherts.

Geroch (1966), and Górka and Geroch (1989), described a few species of radiolarians from the Lgota Beds, however, without precise comments on their stratigraphic significance. Recently, taxonomically diverse assemblages (35 species), including some stratigraphically important species was used to established a radiolarian biostratigraphy in these deposits by the first author (Bąk, 1994, 2000, 2004; Bąk *et al*., 2001). The lower boundary of the BRSF was placed within the *Holocryptocanium barbui*-*Holocryptocanium tuberculatum* assemblage Zone, referred to the upper Cenomanian.

In summary, the only precise age data for the Mikuszowice Cherts based on planktonic microfossils are related to their boundary with the overlying BRSF and suggest a late Cenomanian age.

MATERIAL AND METHODS

Samples for micropalaeontological studies were collected from two continuous sections in two quarries in the Barnasiówka Range. The first of these quarries, the Barnasiówka–Jasienica quarry, is located 5 km west of Myślenice, on the SW slope of a tributary of the Bysinka stream, at an altitude of *ca*. 520 m (Fig. 1). The section consists of the entire sequence of the Mikuszowice Cherts (31 m thick) including its boundaries with the surrounding units. The second section crops out in the Barnasiówka–Ostra Góra quarry, 3.5 km west of Myślenice, on the SW slope of the Ostra Góra hill, at an altitude of *ca*. 500 m, west of the Safiana creek (Fig. 1C). The section includes the upper part of the Mikuszowice Cherts (7.5 m thick) and the boundary with the overlying Barnasiówka Radiolarian Shale Formation (Fig. 1C).

Seventy-eight samples of shales, cherts, siliciclastics, calcisiltites and calcilutites were collected for micropalaeontological studies (Figs. 3 and 4). Samples were taken every 50–80 cm, depending on sediment type. Microfossils (radiolaria and foraminifera) were extracted from dried and disintegrated samples that weighted about 750 g each. Argillaceous shales were disaggregated by repeated heating and cooling with sodium carbonate solution. Siliceous shales, cherts and siliceous sandstones were treated with 3–5% hydrofluoric acid. Calcareous shales and turbiditic limestone layers were treated with 5% hydrochloric acid. Residues were dried, weighed and washed through sieves of 63 μm mesh. At least 300 radiolarian tests and all foraminiferal tests were picked from fraction above 0.63 μm, except for the samples where microfossils were extremely rare.

The microfossils were additionally determined in thirty thin sections representing twenty layers. SEM micrographs of microfauna and of microfacies were made using a scanning microscope *HITACHI S-4700* and a stereoscopic microscope *Nikon SMZ1500* with a digital camera *Nikon Coolpix-4500*.

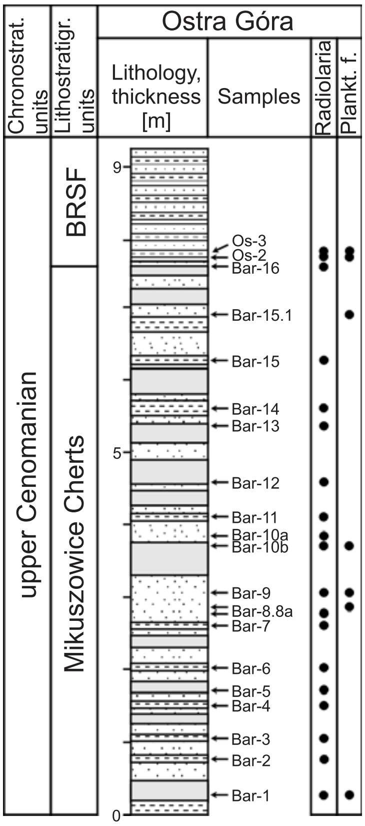

Fig. 4. Stratigraphic log of the upper part of the Mikuszowice Cherts and the lowermost part of the Barnasiówka Radiolarian Shale Formation (BRSF) at the Ostra Góra section with positions of the samples studied and occurrences of radiolaria and planktonic foraminifera

Other explanations as on Figure 3

Microfaunal slides with radiolaria are housed in the Institute of Geological Sciences, Jagiellonian University (collection Nr LG1) and slides with foraminifera in the Institute of Geography, Cracow Pedagogical University (collection Nr 11Sl).

RADIOLARIA AND FORAMINIFERA IN THE MIKUSZOWICE CHERTS AND SURROUNDING UNITS

Microfossils in the studied sediments occur in both green hemipelagic shales and muddy, silty to sandy turbidites. Generally, the shales are enriched in deep-water agglutinated foraminifers (DWAF) and they locally include radiolarians. Silty to sandy deposits include mainly sponge spicules; less common are radiolarians and foraminifers, inoceramid prisms, echinoderm ossicles and fragments of coralline red algae are rare.

RADIOLARIA

Most radiolarians are poorly and moderately preserved. Only 15% of skeletons may be identified; the best preserved radiolarians come from the cherts. Most of the radiolarian skeletons, especially those from the shales, have been recrystallized and replaced by pyrite or Fe-oxides, so that the external and internal wall structures are destroyed.

The radiolarian assemblage is moderately diverse, both in the uppermost part of the Middle Lgota Beds, the Mikuszowice Cherts and the lowermost part of the BRSF (Tables 1 and 3). Nassellarians dominate there, making up 50–80% of the radiolarian assemblage. The most frequent are representatives of the Williriedellidae, including forms belonging to *Holocryptocanium barbui* Dumitrica (Fig. 5J) and *H.* tuberculatum Dumitrica (Fig. 5L). Less frequent are specimens of *Holocryptocanium geysersensis* Pessagno (Fig. 5K), *Hemicryptocapsa tuberosa* Dumitrica, *Cryptamphorella conara* (Foreman), *Gongylothorax siphonofer* Dumitrica and *Trisyringium echitonicum* (Aliev) (Fig. 5G). Generally, skeletons of the Williriedellidae dominate in the entire radiolarian assemblage in the succession studied. Other nassellarians belong to the families: Amphipyndacidae, Archaeodictyomitridae, Eucyrtidae, Dorypylidae and Syringocapsidae, whose total number of specimens does not exceed 10% of the entire assemblage. Such forms have been identified as *Squinabollum fossile* (Squinabol) (Fig. 5F), *Pseudoeucyrtis spinosa* (Squinabol) (Fig. 5H, I), *Dictyomitra montisserei* (Squinabol) (Fig. 5E), *Stichomitra communis* Squinabol (Fig. 5B), *Spongostichomitra elatica* (Aliev) (Fig. 5C), *Amphipyndax stocki* (Campbell and Clark) (Fig. 5A) and *Thanarla veneta* (Squinabol) (Fig. 5D).

Spumellaria are less frequent than Nassellaria, making up 20–50% of the radiolarians. Species belonging to two families, Actinommidae (Fig. 6A–H) and Hagiastridae (Fig. 6I) are present. Representatives of the Actinommidae, such as *Praeconocaryomma lipmane* Pessagno (Fig. 6A–D), are the most frequent.

The numbers of radiolarian skeletons vary within the succession studied, depending on the type and source of the host sediments (Tables 1 and 3). In the entire section, green hemipelagic shales include low numbers of radiolarians. Only 20 specimens per 100 g of rock are present in the deposits around the boundary between the Middle Lgota Beds and the Mikuszowice Cherts. The dark-grey and black shales are devoid of radiolarians. By contrast, radiolarian skeletons are numerous, albeit as destroyed redeposited particles, in the sand fraction of the layers within the Mikuszowice Cherts and surrounding sediments. Most abundant radiolarian skeletons have been observed in the T_b–T_d intervals of the Mikuszowice Cherts. Their number exceeds 10 000 individuals per 100 g of rock. However, there are fluctuations in their number within this unit with a general trend to an increasing number of skeletons upwards. The most common are radiolarians belonging to the Williriedellidae. Their numbers range between 2 and 32 individuals per 100 g of rock in hemipelagic green shales, increasing to 80 specimens in the sandstone beds, and to more than 5000 specimens in the chert layers. Other species than those belonging to the Williriedellidae have not been found in the sandstones, and only a few occur in the cherts. This shows that skeleton shapes and wall thickness favoured preservation of specimens from the Williriedellidae among the redeposited particles of the sandstones and cherts.

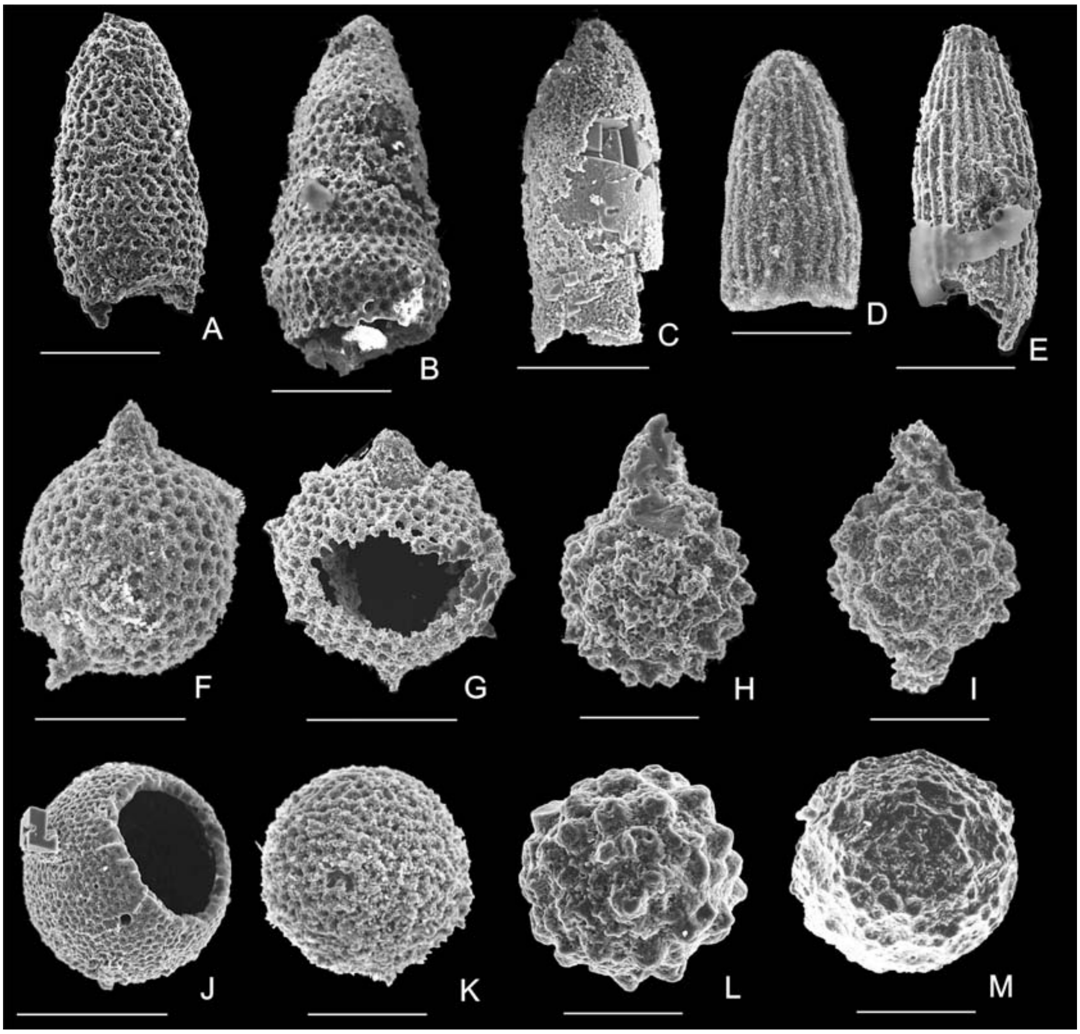

Fig. 5. Nassellaria from the Mikuszowice Cherts and surrounding units

A — *Amphipyndax stocki* (Campbell and Clark), Bar-21; **B** — *Stichomitra communis* Squinabol, Bar-10; **C** — *Spongostichomitra elatica* (Aliev), Bar-10; **D** — *Thanarla veneta* (Squinabol), Bar-28; **E** — *Dictyomitra montisserei* (Squinabol), Bar-10; **F** — *Squinabollum fossile* (Squinabol), Bar-33; **G** — *Trisyringium echitonicum* (Aliev), Bar-21; **H, I** — *Pseudoeucyrtis spinosa* (Squinabol), Bar-10; **J** — *Holocryptocanium barbui* Dumitrica, Bar-10; **K** — *Holocryptocanium geysersensis* Pessagno, Bar-29; **L** — *Holocryptocanium tuberculatum* Dumitrica, Bar-9; **M** — *Hemicryptocapsa prepolyhedra* Dumitrica, Jas-15; scale bar — 100 µm

FORAMINIFERA

Both planktonic and benthic foraminifera, including calcareous and deep-water agglutinated forms, have been determined in the deposits studied. The foraminifers were studied in thin sections and in residues (> 64 µm size fraction) in 62 samples, including 23 from green and olive non-calcareous shales, and 39 from cherts, sandstones, marl and limestones (Figs. 3 and 4; Tables 2 and 4).

THE UPPERMOST PART OF MIDDLE LGOTA BEDS

Foraminifera were found in non-calcareous, grey and olive shales and in sandstones. The low-diversity assemblage from the shales is dominated by DWAF belonging to *Recurvoides* spp. and small trochamminids. Characteristic species of this assemblage are *Plectorecurvoides alternans* Noth and *Thalmannammina neocomiensis* Geroch, described earlier from the Albian-Cenomanian deposits of the Outer Carpathians (e.g. Geroch, 1960; Geroch and Nowak, 1963; Olszewska, 1997). Quite different foraminifera, including calcareous benthic and planktonic forms, occur as redeposited particles in sandstones. Numerous small (partly juvenile) forms of *Hedbergella delrioensis* (Carsey) (Fig. 7B), *Globigerinelloides* cf. *ultramicra* (Subbotina) (Fig. 7C), *Heterohelix* cf. *moremani* (Cushman), *Guembelitria cenomana* (Keller) (Fig. 7A), small praeglobotruncanids and poorly preserved rotaliporids (Fig. 7E–G) were determined in thin section. Frequencies of planktonic foraminifera in some thin sections of sandstones exceed 150 specimens per 1 cm^2. Most of them are filled with authigenic quartz or pyrite, whereas the walls are calcareous. Besides plankton, the calcareous benthic foraminifera such as *Gavelinella, Lingulogavelinella, Gyroidinoides, Cibicides*, and

Table 1

Occurrence of radiolaria in the Mikuszowice Cherts and encompassing units at the Jasienica section versus lithostratigraphic units and types of deposit

Sample number	Bar-64	Bar-62	Bar-61	Bar-60	Bar-58	Bar-57	Bar-55	Bar-53	Bar-52	Bar-49	Bar-48	Bar-47	Bar-46	Bar-45	Bar-44	Bar-42	Bar-39	Bar-38	Bar-37	Bar-36	Bar-35	Bar-34	Bar-33	Bar-32	Bar-31	Bar-30	Bar29	Bar-28	Bar-27	Bar-26	Bar-24	Bar-23	Bar-21	Bar-20	Bar-19	Bar-18	Bar-17	Jas-4	Jas-6	Jas-7	Jas-9	Jas-10	Jas-12	Jas-13	Jas-14	Jas-15
Lithotype	sd	sd	sd	sd	sd	ch	sh	ch	sd	ch	ch	ch	ch	ch	ch	ch	ch	sh	ch	ch	ch	lms	ch	sh	ch	ch	ch	ch	ch	ch	ch	ch	ch	sh	sd	ch	sh	sh	sh	sh	sh	sh	sh	sh	sh	sh
Lithostratigraphic unit	Mid. Lgota						Mikuszowice Cherts																														Barn. Rad. Sh. Fm.									
Amphipyndax stocki																																	r													
Cryptamphorella conara																		r		r	r		r		r		r	r	r		r	r	r		r											r
Dictyomitra montisserei																											r				r		r													
Hemicryptcapsa prepolyhedra																																														f
Hemicryptocapsa tuberosa																									r			r		r		r	r													f
Holocryptocanium barbui	r	r	r	r		r		r	r	c	c	r	r	c	f	c	c	r	c	f	c	a	c	r	c	c	a	c	a	c	c	c	a	f	c	f	r		r	c		f	r	r	c	f
Holocryptocanium geysersensis											r										r							r					r													
Holocryptocanium tuberculatum	r	r	f	r	r		r	r	r	c	c	f	f	c	f	c	a	f	c	c	c		c		a	a	a	a	a	a	a	a	a	f	c	f	c			c	r			c	r	f
Praeconocaryomma lipmanae	r	r	f	r	r		r	r	r	c	c	r	f	c	f	c	c	r	a	c	c		c	f	a	c	a	a	a	a	a	a	a			r	f	r		f				c	f	
Pseudoeucyrtis spinosa																												r	r			r														
Quinquecapsularia parvipora											r																																			
Squinabollum fossile																	r	r		r	r		r		r		r	r			r															
Stichomitra communis																				r																										
Thanarla veneta																												r																		
Trisyringium echitonicum																																	r													

Number of specimens: r — rare (1–5), f — frequent (6–20), c — common (21–50), a — abundant (more than 50); sh — shale, sd — sandstone, ch — chert layer; lms — limestone; Mid. Lgota — Middle Lgota Beds, Barn. Rad. Sh. Fm. (BRSF) — Barnasiówka Radiolarian Shale Formation

Table 2

Occurrence of foraminifera in the Mikuszowice Cherts and the encompassing units at the Jasienica section versus lithostratigraphic units and types of deposit

Sample number		Bar-65	Bar-64	Bar-63	Bar-59	Bar-58	Bar-57	Bar-56	Bar-55	Bar-53	Bar-52	Bar-51	Bar-50	Bar-48	Bar-41	Bar-37	Bar-34a	Bar-32	Bar-31	Bar-30	Bar-29	Bar-28	Bar-26	Bar-24	Bar-23	Jas-1	Bar-18	Jas-4	Jas-5	Jas-6	Jas-7	Jas-9	Jas-10	Jas-12	Jas-13	Jas-14	Jas-15
Lithotype		sh	sd	sd	sh	sd	ch	sd	sh	ch	sd	sd	sd	ch	ch	ch	lms	sh	ch	ch	ch	ch	ch	ch	ch	sh	ch	sh	sh	sh	sh	sh	sh	sh	sh	sh	sh
Lithostratigraphic unit	Planktonic foraminifera	Middle Lgota							Mikuszowice Cherts																			Barn. Rad. Sh. Fm.									
Guembelitria cenomana						r							?			r																					
Heterohelix moremani				?												r																					
Heterohelix sp.				c		c	c			c			c			f	c										c										
Globigerinelloides bentonensis				r		r	r							r		r																					
Globigerinelloides cf. *ultramicra*						r								r																	r						
Hedbergella delrioensis			f	f		f	f	f						f		f	f		f	f		r			r						r						
Hedbergella planispira														r		r																					
Hedbergella simplex																						r														r	
Hedbergella sp.			a	a		a	a	a	a	a		a	a			a	a			a							a										
Whiteinella archaeocretacea																r									r						?						
Whiteinella baltica																r											r										
Praeglobotruncana delrioensis								r								r																					
Praeglobotruncana sp.				?		?		r					?		r	r	r			r																	
Dicarinella sp.																											?										
Rotalipora ex. gr. *appenninica*						r																									?						
Rotalipora cushmani										?																	?										
Rotalipora greenhornensis													?																		r						
Rotalipora reicheli																r																					
Rotalipora sp.							r			r			r			r				r							r										
Rhabdammina sp.						?																				r		r			r			r	r		r
Rhizammina sp.																										r											
Bathysiphon sp.																										r		r							r		
Hyperammina gaultina					r	r																						r	r								
Hyperammina sp.		r			r		?									r				r							?	r	r		r	?			r		r
Hippocrepina depressa																										r		r									
Hippocrepina sp.																r					r																
Saccammina sp.				?	r																																
Psammosphaera scruposa		r																																			
Psammosphaera sp.		f			r															r																	

Tab. 2 continued

Lithostratigraphic unit: Middle Lgota

Sample number		Bar-65	Bar-64	Bar-63	Bar-59	Bar-58	Bar-57	Bar-56
Lithotype		sh	sd	sd	sh	sd	ch	sd
Ammodiscus cretaceus	Deep-water agglutinated foraminifera	r			r			
Ammodiscus tenuissimus								
Ammodiscus sp.								
Glomospira charoides								
Glomospira gordialis					r			
Glomospira serpens					r			
Glomospira sp.					r			
Glomospirella gaultina								
Pseudonodosinella troyeri								
Reophax sp.					r	r		
Ammobaculites cf. *crespinae*								
Bulbobaculites problematicus								
Haplophragmoides cf. *concavus*								
Haplophragmoides cf. *kirki*					r			
Haplophragmoides cf. *herbichi*								
Haplophragmoides nonioninoides								
Haplophragmoides cf. *walteri*								
Haplophragmoides sp.					r			
Trochammina sp.		f		r	r			
Plectorecurvoides alternans		r			r			
Recurvoides sp.		r			r			
Thalmannammina meandertornata					r			
Uvigernammina praejankoi								
Pseudobolivina variabilis					r			
Gerochammina stanislawii								
Gaudryina oblonga					r			
Verneuilinoides subfiliformis					r			
Lagena apiculata	Calcareous benthic foraminifera							
Lagena cf. *acuticostata*								
Pseudoglandulina mutabilis								
Dentalina cf. *guttifera*				r				
Dentalina sp.							r	
Laevidentalina gracilis								
Laevidentalina oligostegia								
Nodosaria cf. *obscura*								
Pseudonodosaria humilis								r
Lingulina cf. *nodosaria*								
Lageninidae gen. et sp. indet.				r				
Lenticulina sp.								
Marginulina sp.								
Vaginulina cf. *aricula*								
Vaginulina sp.								
Quinqueloculina cf. *kozlowskii*								
Bolivinitinae gen. et sp. indet.							f	f
Pleurostomella sp.								
Praebulimina sp.								
Berthelina berthelini								
Gavelinella baltica								
Lingulogavelinella globosa								
Lingulogavelinella orbiculata								
Lingulagavelinella sp.								
Orithostella formosa								
Orithostella jarzevae								
Valvulineria gracillima								
Valvulineria lenticula								
Valvulineria sp.								
Gavelinidae gen. et sp. indet.			a	a		a	a	a
Gyroidinoides infracretacea							r	
Gyroidinoides nitidus								
Gyroidinoides sp.			f	f		f	f	
Cibicides sp.			r			r	r	

Lithostratigraphic unit: Mikuszowice Cherts

Sample number	Bar-55	Bar-53	Bar-52	Bar-51	Bar-50	Bar-48	Bar-41	Bar-37	Bar-34a	Bar-32	Bar-31	Bar-30	Bar-29	Bar-28	Bar-26	Bar-24	Bar-23	Jas-1	Bar-18
Lithotype	sh	ch	sd	sd	sd	ch	ch	ch	lms	sh	ch	ch	ch	ch	ch	ch	ch	sh	ch
Ammodiscus cretaceus																		r	
Ammodiscus tenuissimus																		r	
Ammodiscus sp.																			
Glomospira charoides																			
Glomospira gordialis																			
Glomospira serpens																			
Glomospira sp.																			
Glomospirella gaultina																			
Pseudonodosinella troyeri												r						r	
Reophax sp.												r							r
Ammobaculites cf. *crespinae*																		r	
Bulbobaculites problematicus																			
Haplophragmoides cf. *concavus*																		r	
Haplophragmoides cf. *kirki*																			
Haplophragmoides cf. *herbichi*																		r	
Haplophragmoides nonioninoides																		r	
Haplophragmoides cf. *walteri*																			
Haplophragmoides sp.												r							
Trochammina sp.			r									r						r	r
Plectorecurvoides alternans																		r	
Recurvoides sp.												r							
Thalmannammina meandertornata												r							
Uvigernammina praejankoi																		r	
Pseudobolivina variabilis																			
Gerochammina stanislawii																		r	
Gaudryina oblonga												r							r
Verneuilinoides subfiliformis																			
Lagena apiculata																			r
Lagena cf. *acuticostata*														r					
Pseudoglandulina mutabilis																			r
Dentalina cf. *guttifera*																			
Dentalina sp.							r	r	r			r							
Laevidentalina gracilis																r			
Laevidentalina oligostegia																r			
Nodosaria cf. *obscura*															r				
Pseudonodosaria humilis																			
Lingulina cf. *nodosaria*																			r
Lageninidae gen. et sp. indet.																			
Lenticulina sp.					r			f			r		r						r
Marginulina sp.																?			?
Vaginulina cf. *aricula*			r																r
Vaginulina sp.								r				r							
Quinqueloculina cf. *kozlowskii*								r											
Bolivinitinae gen. et sp. indet.																			f
Pleurostomella sp.																?			
Praebulimina sp.								r				r							
Berthelina berthelini								r											
Gavelinella baltica								r											
Lingulogavelinella globosa								r						r					r
Lingulogavelinella orbiculata								r				r							
Lingulagavelinella sp.								r											
Orithostella formosa															r				r
Orithostella jarzevae																			?
Valvulineria gracillima														r					
Valvulineria lenticula								?											
Valvulineria sp.								r				r	r						r
Gavelinidae gen. et sp. indet.					a		a	a					r						a
Gyroidinoides infracretacea								r											
Gyroidinoides nitidus								r		r									
Gyroidinoides sp.					f	r		r				f		r	r				f
Cibicides sp.					r							r					r		r

Lithostratigraphic unit: Barn. Rad. Sh. Fm.

Sample number	Jas-4	Jas-5	Jas-6	Jas-7	Jas-9	Jas-10	Jas-12	Jas-13	Jas-14	Jas-15
Lithotype	sh	sh	sh	sh	sh	sh	sh	sh	sh	sh
Ammodiscus cretaceus	r	r		r			r		r	f
Ammodiscus tenuissimus	r			r					r	
Ammodiscus sp.			r	r	r	?			r	r
Glomospira charoides				r		r			r	r
Glomospira gordialis				r						r
Glomospira serpens										
Glomospira sp.										
Glomospirella gaultina				r						
Pseudonodosinella troyeri	r	r								r
Reophax sp.										
Ammobaculites cf. *crespinae*										
Bulbobaculites problematicus		r								
Haplophragmoides cf. *concavus*	r									
Haplophragmoides cf. *kirki*										
Haplophragmoides cf. *herbichi*		r								
Haplophragmoides nonioninoides									r	f
Haplophragmoides cf. *walteri*	r	f							r	f
Haplophragmoides sp.	r	r		r					f	r
Trochammina sp.	r				r	r	r	r	r	r
Plectorecurvoides alternans										
Recurvoides sp.	f	r		f	r	f	r	f	r	f
Thalmannammina meandertornata										
Uvigernammina praejankoi			r	r						
Pseudobolivina variabilis				r						
Gerochammina stanislawii	r	r	r	r	r	r			r	r
Gaudryina oblonga										
Verneuilinoides subfiliformis										
Lagena apiculata										
Lagena cf. *acuticostata*										
Pseudoglandulina mutabilis										
Dentalina cf. *guttifera*										
Dentalina sp.										
Laevidentalina gracilis										
Laevidentalina oligostegia										
Nodosaria cf. *obscura*										
Pseudonodosaria humilis										
Lingulina cf. *nodosaria*										
Lageninidae gen. et sp. indet.										
Lenticulina sp.										
Marginulina sp.										
Vaginulina cf. *aricula*										
Vaginulina sp.										
Quinqueloculina cf. *kozlowskii*										
Bolivinitinae gen. et sp. indet.										
Pleurostomella sp.										
Praebulimina sp.										
Berthelina berthelini										
Gavelinella baltica										
Lingulogavelinella globosa										
Lingulogavelinella orbiculata										
Lingulagavelinella sp.										
Orithostella formosa										
Orithostella jarzevae										
Valvulineria gracillima										
Valvulineria lenticula										
Valvulineria sp.										
Gavelinidae gen. et sp. indet.				f		r				
Gyroidinoides infracretacea										
Gyroidinoides nitidus										
Gyroidinoides sp.										
Cibicides sp.										

Explanations as on Table 1

Table 3

Occurrence of radiolaria in the Mikuszowice Cherts and the encompassing units at the Ostra Góra section versus lithostratigraphic units and types of deposit

Sample number	Bar-1	Bar-2	Bar-3	Bar-4	Bar-6	Bar-7	Bar-8	Bar-9	Bar-10	Bar-10	Bar-11	Bar-12	Bar-13	Bar-14	Bar-15	Bar-16	Bar-1	Os-2	Os-3
Lithotype	ch	sh	sh	sh	sh	sh	sh	ch	ch	sh	sh	sh	sh	sh	sh	sh	ch	sd	sd
Lithostratigraphic unit	Mikuszowice Cherts																BRSF		
Crucella messinae									r										
Cryptamphorella conara									r										
Dictyomitra montisserei									r										
Hemicryptocapsa tuberosa									r										
Holocryptocanium barbui	a	f	c	f	r	f	f	c	c	f	f	f	r	f	f	c	a		
Holocryptocanium geysersensis								f											
Holocryptocanium tuberculatum	c		r			f	f	a	a	r			r				c	c	r
Praeconocaryomma lipmanae	c		r				f	a	a			r					c		
Pseudoeucyrtis spinosa									r										
Spongostichomitra elatica									r										
Stichomitra communis									r										

Explanations as on Table 1

poorly preserved lageninids are numerous in the sandstones. Their numbers reach *ca*. 10 specimens per 1 cm^2 of thin section. DWAF occur occasionally in the sandstones. Tube-shaped forms of ?*Hyperammina* sp. and ?*Rhabdammina* sp., broken into fragments, have been found there.

MIKUSZOWICE CHERTS

Non-calcareous shales from the Mikuszowice Cherts include mostly DWAF and rare redeposited calcareous benthic foraminifera. Opportunistic forms, known from other deep-water flysch basins, are typical of these sediments and specimens of *Recurvoides* sp., *Thalmannammina neocomiensis* Geroch and *Trochammina* sp. are the most frequent among them. Some shales in the upper part of the Mikuszowice Cherts include a more diverse assemblage with infaunal forms such as *Gerochammina* spp. This genus is more frequent in the overlying sediments of the BRSF (Table 2).

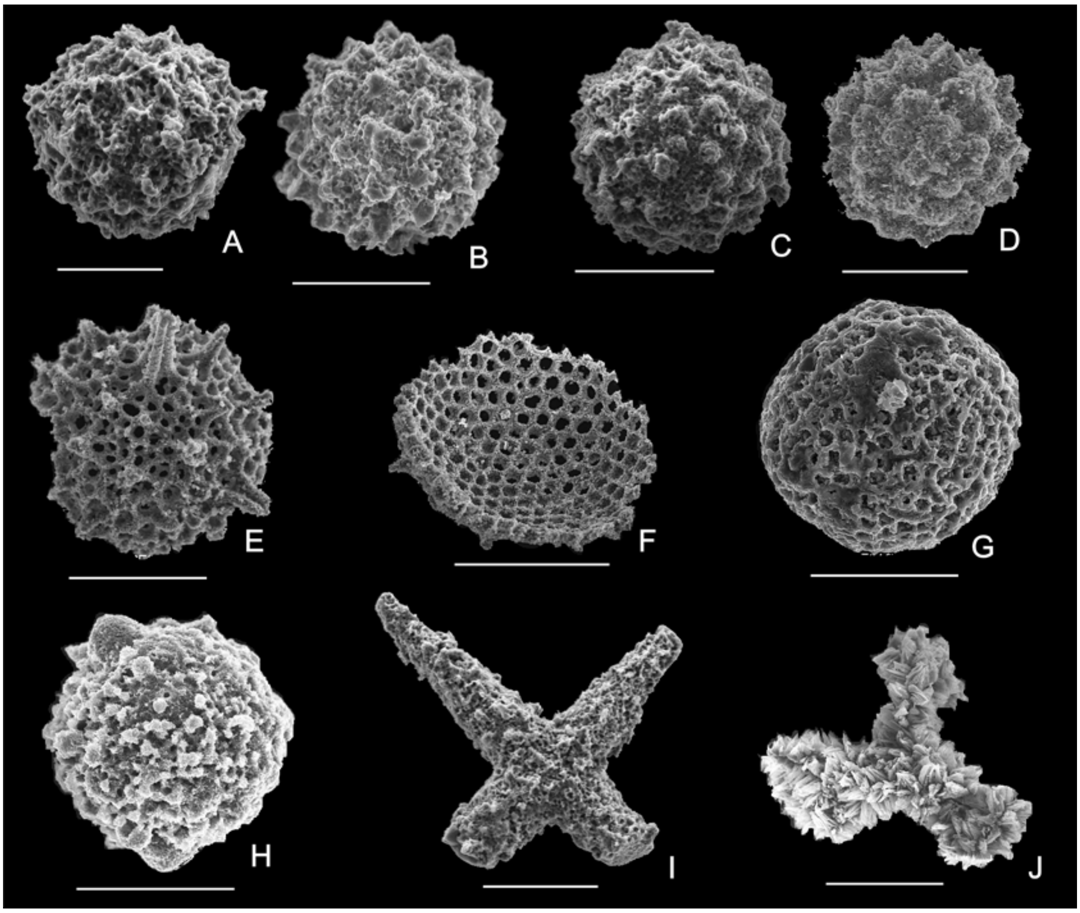

Fig. 6. Spumellaria from the Mikuszowice Cherts

A–D — *Praeconocaryomma lipmanae* Pessagno: **A** — Bar-21, **B** — Bar-28, **C** — Bar-23, **D** — Bar-29; **E** — *Quinquecapsularia parvipora* Squinabol, Bar-48; **F, G, J** — unidentified spumellarians: **F** — Bar-24, **G** — Bar-34; **H** — *Acaeniotyle* sp., Bar-34; **I** — unidentified hagiastrid, Bar-28; scale bar — 100 µm

Table 4

Occurrence of foraminifera in the Mikuszowice Cherts and the encompassing units at the Ostra Góra section versus lithostratigraphic units and types of deposit

Sample number		Bar-1	Bar-2	Bar-3	Bar-4	Bar-5	Bar-6	Bar-7	Bar-8a	Bar-9	Bar-10a	Bar-10b	Bar-11	Bar-15	Bar-15-1	Bar-16	Os-2	Os-3
Lithotype		ch	sh	sh	sh	ch	sh	sh	sd	sd	sh	ch	sh	sh	sd	sh	sd	sh
Lithostratigraphic unit		Mikuszowice Cherts														BRSF		
Guembelitria sp.	Plankt. foram.																r	
Heterohelix sp.	Plankt. foram.	f															c	a
Hedbergella delrioensis	Plankt. foram.	r							r	r		r			r			
Hedbergella sp.	Plankt. foram.																a	a
Globigerinelloides sp.	Plankt. foram.																f	c
Whiteinella sp.	Plankt. foram.																r	f
Praeglobotruncana delrioensis	Plankt. foram.	r																
Praeglobotruncana sp.	Plankt. foram.	r																
Rhizammina sp.	Deep-water agglutinated foraminifera					?		r		?								
Rhabdammina sp.	Deep-water agglutinated foraminifera					?												
Hippocrepina depressa	Deep-water agglutinated foraminifera									?								
Hippocrepina sp.	Deep-water agglutinated foraminifera					?												
Hyperammina gaultina	Deep-water agglutinated foraminifera					?					r							
Hyperammina sp.	Deep-water agglutinated foraminifera					?												
Saccammina placenta	Deep-water agglutinated foraminifera													r				
Saccammina sp.	Deep-water agglutinated foraminifera						r											
Psammosphaera sp.	Deep-water agglutinated foraminifera						r	r			r			r		r		
Ammodiscus cretaceus	Deep-water agglutinated foraminifera							r			r		r	r		r		
Glomospira serpens	Deep-water agglutinated foraminifera													r				
Glomospira sp.	Deep-water agglutinated foraminifera												r	r				
Haplophragmoides nonioninoides	Deep-water agglutinated foraminifera							f						r				
Haplophragmoides cf. *walteri*	Deep-water agglutinated foraminifera										r							
Haplophragmoides sp.	Deep-water agglutinated foraminifera													r				
Kutsevella implana	Deep-water agglutinated foraminifera															r		
Trochammina sp.	Deep-water agglutinated foraminifera			r	r		r	r	?					c				
Plectorecurvoides alternans	Deep-water agglutinated foraminifera		?															
Pseudonodosinella troyeri	Deep-water agglutinated foraminifera													r				
Reophax sp.	Deep-water agglutinated foraminifera							r		r		?	r	r				
Recurvoides sp.	Deep-water agglutinated foraminifera		r		c		c	r			f		r	c		r		
Thalmannammina meandertornata	Deep-water agglutinated foraminifera		r		f		r							c				
Gaudryina filiformis	Deep-water agglutinated foraminifera													r				
Gaudryina oblonga	Deep-water agglutinated foraminifera													c				
Dentalna debilis	Calcareous benthic foraminifera									r								
Dentalina sp.	Calcareous benthic foraminifera	r								r		r					r	r
Laevidentalina cf. *vistulae*	Calcareous benthic foraminifera									r								
Lingulina furcillata	Calcareous benthic foraminifera	r																
Nodosaria limbata	Calcareous benthic foraminifera										?							
Pseudonodosaria humilis	Calcareous benthic foraminifera	r																
Lagena apiculata	Calcareous benthic foraminifera	?								r								
Lagena sp.	Calcareous benthic foraminifera	?								r								
Vaginulina sp.	Calcareous benthic foraminifera									r		r						
Pleurostomella sp.	Calcareous benthic foraminifera	r				?												
Cibicides sp.	Calcareous benthic foraminifera	r				r						r			r			
Berthelina berthelini	Calcareous benthic foraminifera										?							
Lingulogavelinella globosa	Calcareous benthic foraminifera									?								
Gyroidinoides sp.	Calcareous benthic foraminifera									r							f	r
Gavelinidae gen. et sp. indet.	Calcareous benthic foraminifera	a				a			a	a		a			a		a	a
Bolivininitinae gen. et sp. indet.	Calcareous benthic foraminifera	r								r								

Explanations as on Table 1

A completely different assemblage occurs in sandstones, cherts and limestone. Mostly planktonic and calcareous benthic foraminifera have been identified in residues from dissolved cherts. Well-preserved, small hedbergellids (Fig. 8P) with numerous forms of *Hedbergella delrioensis* (Carsey) (Fig. 8B) are the most frequent among the planktonic foraminifera. They are associated with *Globigerinelloides ultramicra* (Subbotina) (Fig. 8A), *Heterohelix moremani* (Cushman) (Fig. 8H) and *Guembelitria cenomana* (Keller) (Fig. 8D). Larger planktonic forms are represented by *Praeglobotruncana delrioensis* (Plummer) (Fig. 8G), *Rotalipora appenninica* (Renz), *R. reicheli* (Mornod), *R.* cf. *greenhornensis* (Morrow) (Fig. 8K), *R. cushmani* (Morrow) (Fig. 8I), *Whiteinella archaeocretacea* Pessagno (Fig. 8E, F) and *W. baltica* Douglas and Rankin (Fig. 8C). Calcareous benthic foraminifera are represented mostly by *Gavelinella*, *Lingulogavelinella* and *Gyroidinoides*, with rare specimens belonging to *Cibicides*, *Dentalina, Globulina*, ?*Planularia*, ?*Marginulina*, *Praebulimina* and *Quinqueloculina*. The numbers of planktonic specimens observed in thin section range from 10 to 50 per 1 cm^2. Calcareous benthic forms are less frequent, from a few to 30 per 1 cm^2.

Planktonic and calcareous benthic foraminifera occur in each turbiditic layer studied, whereas the DWAF are sporadic. Few specimens of the DWAF, mainly tube-shaped ones, belonging to *Rhabdammina* sp., *Hyperammina* sp., *Bathysiphon* and *Hippocrepina* cf. *depressa* Vašiček and occasionally *Thalmannammina* sp., *Recurvoides* sp., *Saccammina* sp., *Gerochammina* sp., *Trochammina* sp., *Reophax* sp. (*Pseudonodosinella*? sp.), *Haplophragmoides* sp. and *Hormosina* sp. have been determined in thin sections of cherts.

BIOSTRATIGRAPHICAL RESULTS

RADIOLARIAN BIOSTRATIGRAPHY

The uppermost part of the Middle Lgota Beds, the Mikuszowice Cherts and the lowermost part of the Barnasiówka Radiolarian Shale Formation contain mostly long-ranging radiolarian species, known from the Albian and Cenomanian in the Tethyan realm. The radiolarian assemblage in all the sections studied includes abundant specimens of two taxa, *Holocryptocanium barbui* Dumitrica (Fig. 5J) and *H. tuberculatum* Dumitrica (Fig. 5L) which were used in other areas as the index species of an assemblage zone. Basing on these observations, we correlate the uppermost part of the Middle Lgota Beds, the Mikuszowice Cherts and the lowermost part of the BRSF with the *H. barbui-H. tuberculatum* Zone. The extent of this zone has been delimited by Dumitrică (1975) as middle Cenomanian-lower Turonian, based on his studies in the Romanian Carpathians. This was confirmed in the Polish part of the Outer Carpathians (Silesian and Subsilesian nappes; Bąk, 2000, 2004). In the Pieniny Klippen Belt, *Holocryptocanium barbui* and *H. tuberculatum* co-occur in the deposits (e.g. Bąk, 1995, 1996, 1999*b*) correlated with the *R. cushmani* and *P. delrioensis* zones (upper Cenomanian-lower Turonian).

The succession of the FOs of a few radiolarian taxa observed in the sections studied yields additional, more detailed data, related to the age of the Mikuszowice Cherts and the surrounding units. Four species such as *Praeconocaryomma*

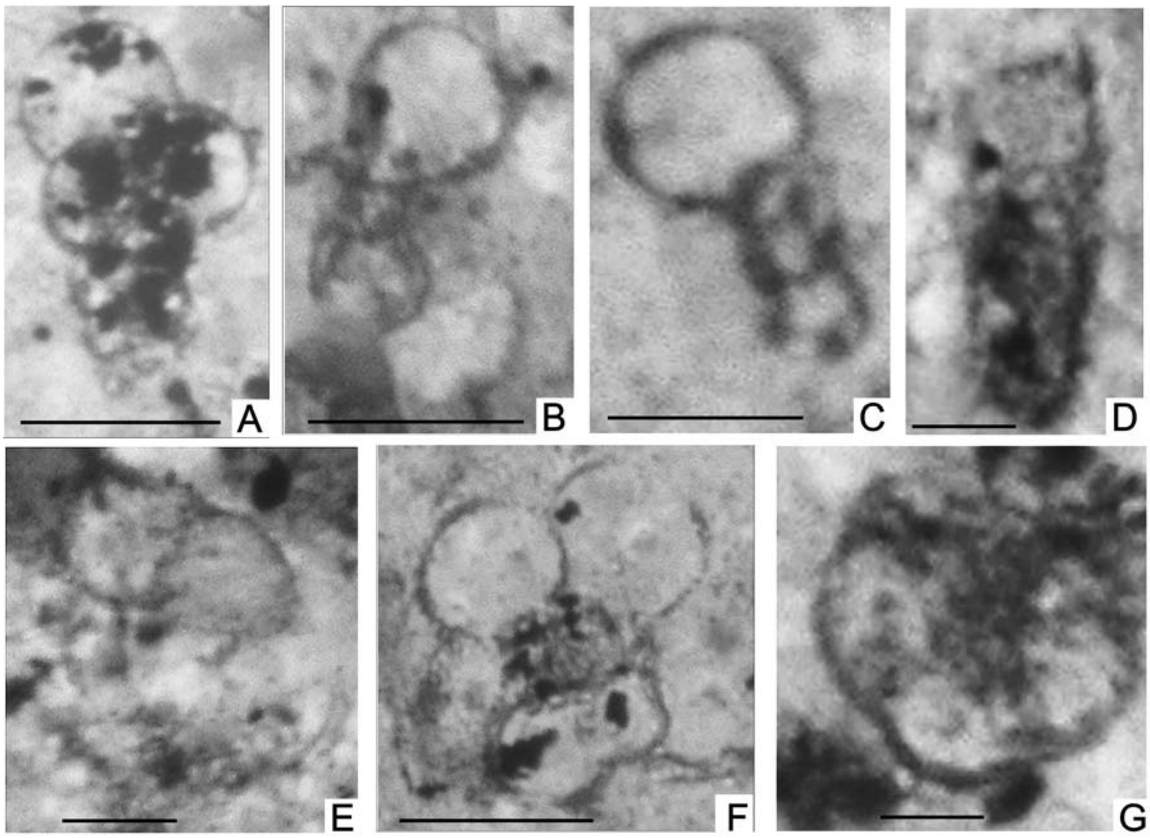

Fig. 7. Redeposited planktonic foraminifera from the uppermost part of the Middle Lgota Beds

A — *Guembelitria cenomana* (Keller), Bar-58; **B** — *Hedbergella delrioensis* (Carsey), Bar-57; **C** — *Globigerinelloides* cf. *ultramicra* (Subbotina), Bar-58; **D** — *Rotalipora*? sp., Bar-57; **E** — *Rotalipora* ex gr. *appenninica* (Renz)?, Bar-58; **F** — *Praeglobotruncana*? sp. (*Rotalipora*? sp.), Bar-63; **G** — *Praeglobotruncana*? sp. (*Rotalipora*? sp.), Bar-58; scale bar — 100 µm

lipmanae Pessagno, *Hemicryptocapsa tuberosa* Dumitrica, *Amphipyndax stocki* (Campbell and Clark) and *Hemicryptocapsa prepolyhedra* Dumitrica had their FADs (first appearance datum) in the middle and late Cenomanian.

Praeconocaryomma lipmanae Pessagno (Fig. 6A–D) appears first in the uppermost part of the Middle Lgota Beds (Table 1) and is present throughout the entire section studied, including the Mikuszowice Cherts and the lowermost part of the BRSF (Fig. 9). In the Middle Lgota Beds, *P. lipmanae* was found in the redeposited layers. Starting from the middle part of the Mikuszowice Cherts, it appears sporadically also in hemipelagites, becoming common to abundant there. The stratigraphic range of *P. lipmanae* has been delimited as late Cenomanian to early Turonian by Pessagno (1976) in the deep-water flysch facies of the California Coast Range, where it co-occurs with planktonic foraminifera. The FO of this species is noted there in the lower part of the *Quinquecapsularia spinosa* radiolarian Subzone, correlated with the *Rotalipora cushmani-R. greenhornensis* planktonic foraminiferal Subzone (Pessagno, 1969, 1976). In the pelagic facies of the Pieniny Klippen Belt, the earliest appearance of *P. lipmanae* is recorded in the *R. cushmani* Zone (Bąk, 1999*a*). *P. lipmanae* is one of the radiolarian species which constrain the age of the uppermost part of the Middle Lgota Beds as not earlier than the base of the *Rotalipora cushmani* Zone (middle Cenomanian).

Another radiolarian taxon that confirms the mid-late Cenomanian age of the section studied is *Hemicryptocapsa tuberosa* Dumitrica. Its FO was observed here in the middle part of the Mikuszowice Cherts (Table 1; Fig. 9). Its earliest appearance in the Pieniny Klippen Belt has been noted within the *R. cushmani* Zone (Bąk, 1995).

Another radiolarian species *Amphipyndax stocki* (Campbell and Clark) (Fig. 5A), which was found higher in the section, in the uppermost part of the Mikuszowice Cherts (Table 1; Fig. 9), indicates a late Cenomanian age for these sediments. This species has been recently recorded from the upper Cenomanian deposits of the Tethys (e.g. O'Dogherty, 1994). In the Outer Carpathians, *A. stocki* appears close to the Cenomanian–Turonian boundary (Bąk, 2000, 2004). A similar age of its FO was indicated from the Pieniny Klippen Belt (e.g. Bąk, 1999*a*, *b*), where this datum event was correlated with the uppermost Cenomanian–lowermost Turonian *Praeglobotruncana delrioensis* planktonic foraminiferal Zone (Bąk, 1998).

Another radiolarian species which has its FAD in the late Cenomanian is *Hemicryptocapsa prepolyhedra* Dumitrica (Fig. 5M). This species appears in the upper part of the *Rotalipora cushmani* Zone in pelagic environments (Bąk, 1999*a*, *b*). In the sections studied, this species has its FO within the BRSF, *ca*. 2.8 m above its boundary with the Mikuszowice Cherts (Table 1; Fig. 9).

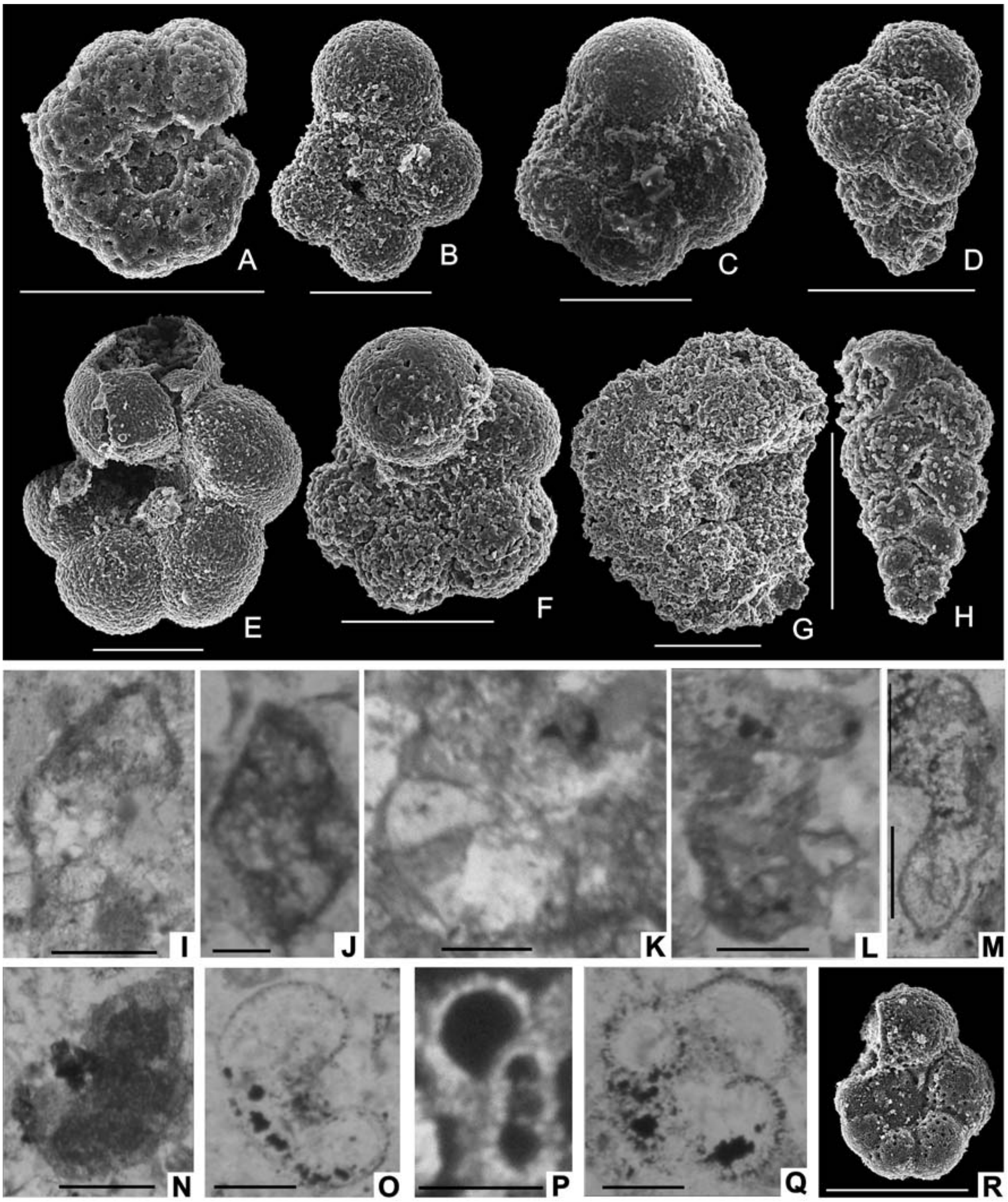

Fig. 8. Redeposited planktonic foraminifera from the Mikuszowice Cherts

A — *Globigerinelloides ultramicra* (Subbotina), Bar-48; **B** — *Hedbergella delrioensis* (Carsey), Bar-37; **C** — *Whiteinella baltica* Douglas and Rankin, Bar-37; **D** — *Guembelitria cenomana* (Keller), Bar-37; **E, F** — *Whiteinella archaeocretacea* Pessagno, Bar-37; **G** — *Praeglobotruncana delrioensis* (Plummer), Bar-37; **H** — *Heterohelix moremani* (Cushman), Bar-37; **I** — *Rotalipora cushmani* (Morrow), Bar-53; **J** — *Rotalipora cushmani* (Morrow)?, Bar-18; **K** — *Rotalipora* cf. *greenhornensis* (Morrow), Bar-50; **L** — *Rotalipora* cf. *reicheli* Mornod, Bar-37; **M** — *Praeglobotruncana*? sp., Bar-1; **N** — *Dicarinella*? sp., Bar-18 (crossed nicols); **O** — *Whiteinella baltica* Douglas and Rankin, Bar-18; **P, Q** — *Hedbergella* sp., Bar-18; **R** — *Hedbergella planispira* (Tappan) (with last chamber broken), Bar-48; scale bar — 100 μm

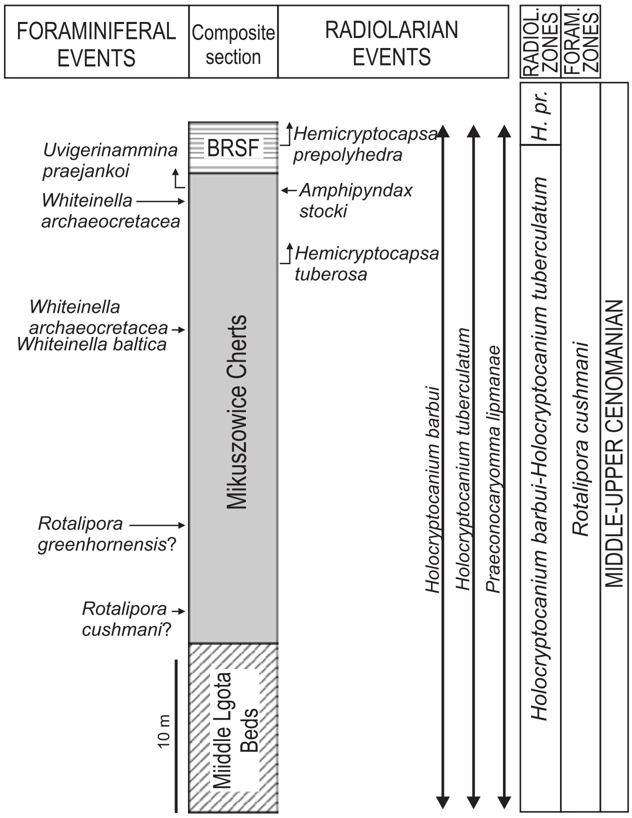

Fig. 9. Composite section of the Mikuszowice Cherts and the encompassing adjoining units at the Barnasiówka Range (Silesian Nappe, Outer Carpathians) with the stratigraphically important radiolarian and foraminiferal datum events. Note that the planktonic foraminiferal zone is here approximately indicated based on comparisons of radiolarian ranges from pelagic, calcareous facies

FORAMINIFERAL BIOSTRATIGRAPHY

Foraminifera determined from the sections studied are of low biostratigraphical value, mainly because of the scarcity of planktonic forms. Benthic calcareous and deep-water agglutinated foraminiferal (DWAF) assemblages include only individual taxa useful for the biostratigraphy of the mid-Cretaceous strata. However, even these taxa have longer stratigraphic ranges than the planktonic forms and the radiolarians mentioned above.

Hemipelagic shales in the uppermost part of the Middle Lgota Beds are dominated by long-ranging DWAF. The only species used in the former zonal schemes is *Plectorecurvoides alternans* Noth (*cf.* Geroch and Nowak, 1984; Olszewska, 1997), represented in the sections studied by a single specimen. The FAD of this species was recorded from the middle Albian (e.g. Geroch and Nowak, 1984; Olszewska, 1997). Redeposited „keeled” planktonic foraminifera belonging to *Praeglobotruncana* cf. *delrioensis* (Plummer) and *Rotalipora* cf. *appenninica* (Renz), found in the sandstone layers of the Middle Lgota Beds, show that their age could not be older than late Albian (Caron, 1985; Robaszynski and Caron, 1995).

Hemipelagic shales of the Mikuszowice Cherts include a more diversified DWAF assemblage. Some of these, for example *Haplophragmoides* cf. *concavus* (Chapman), *H. nonioninoides* (Reuss), *Hippocrepina depressa* Vašiček and *Plectorecturvoides alternans* Noth are stratigraphical markers in both Albian and Cenomanian deep-water flysch sediments. However, two species *Gerochammina stanislawii* Neagu and *Uvigerinammina praejankoi* Neagu, that occur at the top of the Mikuszowice Cherts have their FADs in the upper Cenomanian, close to the Cenomanian-Turonian boundary (Neagu, 1990; K. Bąk, 2000; Bąk *et al*., 2001).

Some information about the age of the Mikuszowice Cherts comes also from redeposited planktonic foraminifera, found in the chert, sandstone and limestone layers. Most planktonic species determined in these sediments are typical of upper Albian through Cenomanian stages, though some of them have shorter stratigraphic ranges. This concerns *Rotalipora* cf. *reicheli* (Mornod), *R.* cf. *greenhornensis* (Morrow), *R.* cf. *cushmani* (Morrow), *Whiteinella archaeocretacea* (Pessagno) and *W. baltica* (Douglas and Rankin). All these rotaliporids appeared in the Tethyan realm in the middle and late Cenomanian; whiteinellids have their FADs in the upper Cenomanian (e.g. Caron, 1985; Robaszynski and Caron, 1995). In the succession studied, whiteinellids have been found in the upper part of the Mikuszowice Cherts (Table 2; Fig. 9).

Calcareous benthic foraminifera, abundant in sandy turbidites, are another useful tool for local biostratigraphy. *Lingulogavelinella globosa* (Brotzen), determined in a few samples (Tables 2 and 4), has its FAD in the middle Cenomanian in the epicontinental Polish-German Basin (Gawor-Biedowa, 1972; Heller, 1975; Hiss, 1983; Peryt, 1983). This species was found in the middle part of the Mikuszowice Cherts as redeposited particles in the chert layers (Table 2). Other calcareous benthic forms found in the studied sections have longer stratigraphic ranges, but these taxa were also noted from the Cenomanian in the neighbouring epicontinental facies (*cf.* Gawor-Biedowa, 1972; Peryt, 1983; Pożaryska and Wytwicka, 1983; Hradecká, 1993).

The lowermost part of the BRSF includes stratigraphically important DWAF, such as *Uvigerinammina praejankoi* Neagu, *Haplophragmoides* cf. *walteri* and *Gerochammina stanislawii* Neagu, all of them recorded as appearing in the *Whiteinella archeocretacea* Zone (uppermost Cenomanian; Neagu, 1990; K. Bąk, 2000; Bąk *et al*., 2001).

CONCLUSIONS

The age of the Mikuszowice Cherts is here determined taking into account such radiolarian data as: (1) the co-occurrence (in the entire section) of numerous *Holocryptocanium barbui* and *H. tuberculatum*, recorded from the middle Cenomanian, (2) the occurrence (in the whole section) of *Praeconocaryomma lipmanae*; (3) the FO of *Hemicryptocapsa tuberosa* in the upper part of the unit (*ca*. 6 m below the upper boundary); (4) the FO of *Amphipyndax stocki* close to the upper boundary of the unit (*ca*. 1 m below the upper boundary); (5) the FO of *Hemicryptocapsa prepolyhedra* in the lowermost part of the Barnasiówka Radiolarian Shale Formation (*ca*. 2.8 m above the boundary with the Mikuszowice Cherts). All these taxa (except for both species of *Holocryptocanium*) appear in the Western Tethyan realm successively within the *Rotalipora cushmani* planktonic foraminiferal Zone, which is correlated with the middle-upper Cenomanian, except for its uppermost part.

The foraminiferal taxa confirm a middle-late Cenomanian age for the Mikuszowice Cherts. An example of this is the occurrence of redeposited whiteinellids (a group known since the late Cenomanian), which were found *ca*. 10 m below the upper boundary of the unit. Other stratigraphic markers, such as redeposited specimens of *Rotalipora* cf. *cushmani* and *R*. cf. *greenhornensis* have been found close to the lower boundary of the Mikuszowice Cherts (*ca*. 2 m and 8 m above the lower boundary, respectively). On the other hand, the DWAF species *Uvigerinammina praejankoi*, with its FAD in the uppermost Cenomanian, was found close to the upper boundary of the unit studied (*ca*. 1 m below the upper boundary).

To summarise, the deposition of the spicule-rich turbidites in the Silesian sub-basin, represented by a 31 m thick succession of the Mikuszowice Cherts, took place during the middle-late Cenomanian (*Holocryptocanium barbui-H. tuberculatum* radiolarian Zone), preceding the organic-rich sedimentation during OAE 2.

Acknowledgements. B. Olszewska and L. O'Dogherty are gratefully acknowledged for reviewing of the manuscript. Special thanks are due to G. Haczewski for improving the English of the manuscript and to M. Narkiewicz for editorial comments. This research was partly supported by the Committee for Scientific Research (grant No 3PO4D 001 25 to K.B.).

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