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RADIOLARIAN BIOSTRATIGRAPHY OF THE UPPER CENOMANIAN–LOWER TURONIAN DEPOSITS IN THE SUBSILESIAN NAPPE (OUTER WESTERN CARPATHIANS)

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Abstract: The Upper Cenomanian-Lower Turonian flysch deposits of the Subsilesian Unit of the Outer Western Carpathians include a characteristic interval of green and black, siliceous shales with manganese concretions, benthonites and tuff, with abundant radiolarian fauna. Thirty two species of Radiolaria have been identified. Spherical cryptothoracic and cryptocephalic Nassellaria dominate in the assemblage. Two radiolarian species: *Alievium superbum* and *Crucella cachensis* have been proposed as biomarkers for setting the Cenomanian–Turonian boundary interval in the deposits of the Subsilesian series of the Polish Outer Carpathians.

Key words: Cenomanian-Turonian boundary, Flysch Carpathians, Subsilesian Unit, Radiolaria.

Introduction

The Upper Cenomanian-Lower Turonian "Green radiolarian shales" represent the most distinctive horizon of the Outer Western Carpathians. They are present in the Skole Nappe (so-called "Dołhe Formation"), Silesian Nappe (the Barnasiówka Radiolarian Shale Formation), Subsilesian Nappe ("Green radiolarian shales") and Magura Nappe (the Hulina Formation) in the Polish part of the Outer Western Carpathians. The thickness of these deposits varies from dozens of centimeters to several meters in individual nappes. They mainly consist of green shales with intercalations of black, grey and olive, silty or calcareous shales, and they are partly intercalated with green and red cherts and radiolarites. Clastic intercalations are also present as thin-bedded, fine- and very fine-grained sandstone. The lower part of the "Green radiolarian shales" includes very characteristic layers of ferromanganese concretions (documented only from the Silesian and Subsilesian Nappes), and black shales with manganese incrustations, known in all the nappes. Moreover, the sediments of this age include benthonite intercalations and a tuff layer (a few centimeters thick), situated just below the layer with ferromanganese concretions.

The Upper Cenomanian-Lower Turonian deposits have been a subject of biostratigraphical studies since the early 1930's. Previous authors dealing with micropaleontological investigations focused their interests on foraminifers as the most useful tool for biostratigraphical purposes (e.g. Liszkowa 1956, 1962; Liszkowa & Nowak 1962; Bieda et al. 1963; Geroch et al. 1967; Geroch et al. 1985), however radiolarians are the most abundant group in these deposits.

The aim of the present study is to precisely determine the age of the "Green radiolarian shales" in the Subsilesian Nappe on the basis of radiolarian fauna. A special interest was given to the stratigraphic position of the ferromanganese concretions level in relation to the Cenomanian-Turonian boundary.

History of study

Uhlig, who carried out his geological investigations in Moravia, discovered the mid-Cretaceous deposits enriched in radiolarians in 1888. The first attempt at an age assignment was made by Sujkowski & Różycki (1930). These authors correlated the variegated shales with radiolarian cherts (cropping out in the Skole Nappe) with the radiolarite series of the Southern Alps, the Western Apennines and the Pieniny Klippen Belt. They assigned their age to the Late Jurassic on the basis of lithological similarities with the above mentioned deposits.

Later investigations were carried out in the Silesian Nappe, where the Upper Cenomanian-Lower Turonian deposits are much better exposed (Burtanówna et al. 1933; Nowak 1956; Koszarski et al. 1959; Koszarski & Liszkowa 1963; Geroch 1967; Geroch et al. 1967, 1985; Gzik 1990; Gzik & Koszarski 1990; M. Bąk 1994, 2000; K. Bąk & M. Bąk 2000; K. Bąk et al. 2001). The Early Albian age of the green shales with radiolarians in the Silesian series was suggested by Burtanówna et al. (1933), based on the superposition between the Lgota Beds and the Godula Beds. Koszarski et al. (1959) correlated the green shales with radiolarians from the Silesian, Subsilesian and Skole Nappes, and assigned them Cenomanian age, based on a few globotruncanids (Silesian series).

Radiolarian fauna was used as a stratigraphic tool in the early 1990's (M. Bąk 1994). Detailed studies were carried out in the Silesian Nappe (Międzybrodzie section near Sanok), where the radiolarian assemblage was correlated with the Cenomanian radiolarian *Holocryptocanium barbui–Holocryptocanium tuberculatum* Zone. The study of radiolarians was also made in other sections of the Silesian Nappe (M. Bąk 2000), where the Late Cenomanian-Early Turonian biozonation was proposed for these deposits.

Recently, the Upper Cenomanian-lowermost Turonian deposits in the Silesian Nappe have been distinguished as a for-

Fig. 1. Location of the section studied in the geological map of the Outer Western Carpathians (after Żytko et al. (1988) — simplified). *Abbreviations:* **Sk** — Skole Unit, **Zg** — Zgłobice Unit, **D + G** — undivided Dukla and Grybów Units, **G** — Grybów Unit, **Zas** — location of Zasań section.

mal lithostratigraphic unit, the Barnasiówka Radiolarian Shale Formation (Bąk et al. 2001). Its detailed stratigraphic position has been identified on the basis of the radiolarian fauna and deep-water agglutinated foraminifers.

The Upper Cenomanian-Lower Turonian deposits, enriched in radiolarians, are poorly exposed in the Subsilesian Nappe. One of the known localities is situated at Zasań near Myślenice (Fig. 1). The age of the deposits cropping out here was previously determined as Albian on the basis of the correlation with the Silesian and Skole series (Liszkowa in: Burtan & Turnau-Morawska 1978). Lately, Gedl & M. Bąk (2000) suggested a latest Cenomanian-Early Turonian age on the basis of dinocysts and radiolarian assemblages.

Geological setting

The Subsilesian series forms one of the Tertiary thrust-sheets of the Outer Western Carpathians. Its exposed part is represented by deposits of the Lower Cretaceous to Miocene age. The paleogeographic position of the Subsilesian Basin is interpreted as one of the subbasins of the Outer Carpathian basin, situated south of the North European plate on the submarine ridge, between the Silesian and Skole Subbasins (Książkiewicz 1962).

Nowadays, the Subsilesian Nappe occurs in the Polish part of the Western Carpathians as two parallel zones west of the Dunajec River (Fig. 1). The northern zone is visible to the north of the Silesian Nappe, between Brzesko and Cieszyn. The southern zone appears in a few tectonic windows between the Dunajec and Skawa Rivers and in the Żywiec Depression. The studied section is located in the Myślenice tectonic window, within the southern zone of the Subsilesian Nappe. The window is built of a few tectonic slices with highly tectonized Lower and Upper Cretaceous deposits.

The Albian-Turonian deposits of the Subsilesian Nappe (Fig. 2) in this area are represented by the Gaize Beds (mainly spongiolites with shale and siltstone intercalations), the "Green radiolarian shales" (highly correlative to the Barnasiówka Radiolarian Shale Formation from the Silesian Nappe) and the lower part of the "Variegated Shales" (red and green shales with single sandstone intercalations).

The studied section is situated at Zasań settlement, near the Trzemeśnia village, about 10 km east of Myślenice town. The Gaize Beds do not crop out in the Zasań section. The section includes sediments correlated with the Barnasiówka Radiolarian Shale Formation. It includes here (Fig. 3) green non-calcareous shales intercalated by black non-calcareous shales, and occasionally by green, pale green and spotty shales, partly covered by jarosite. Manganese shales with a layer of ferromanganese concrections (2–3 cm of diameter) occur higher up in the section. A few layers of thin benthonite intercalate them. One of the benthonite layers occurs just above the manganese shale. The manganese series with benthonites represents the middle part of this sequence. The higher part of the section studied is represented by: (1) thin layers of green radiolarian shales with ferrous coats intercalated with tuffites and benthonites, (2) light grey and light blue highly siliceous shales, with single intercalations of thin black shales and gaizes (thin- to medium-grained sandstones enriched in sponge spicules), and (3) green, blue-green and light grey clayey shales intercalated with light grey and black siliceous shales.

Methods

Twenty eight samples have been collected from the studied section. Radiolarians were extracted using two methods. Siliceous shales were treated with 3–5% hydrofluoric acid. Clayey

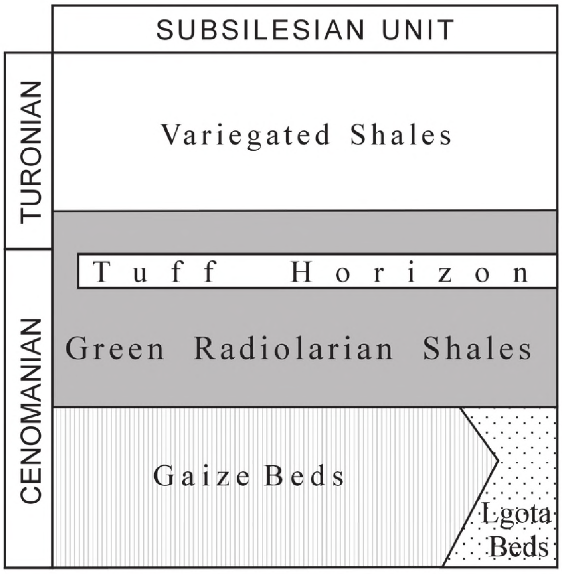

Fig. 2. Lithostratigraphy of the Cenomanian through Turonian deposits in the Subsilesian Unit (after Koszarski & Ślączka 1973).

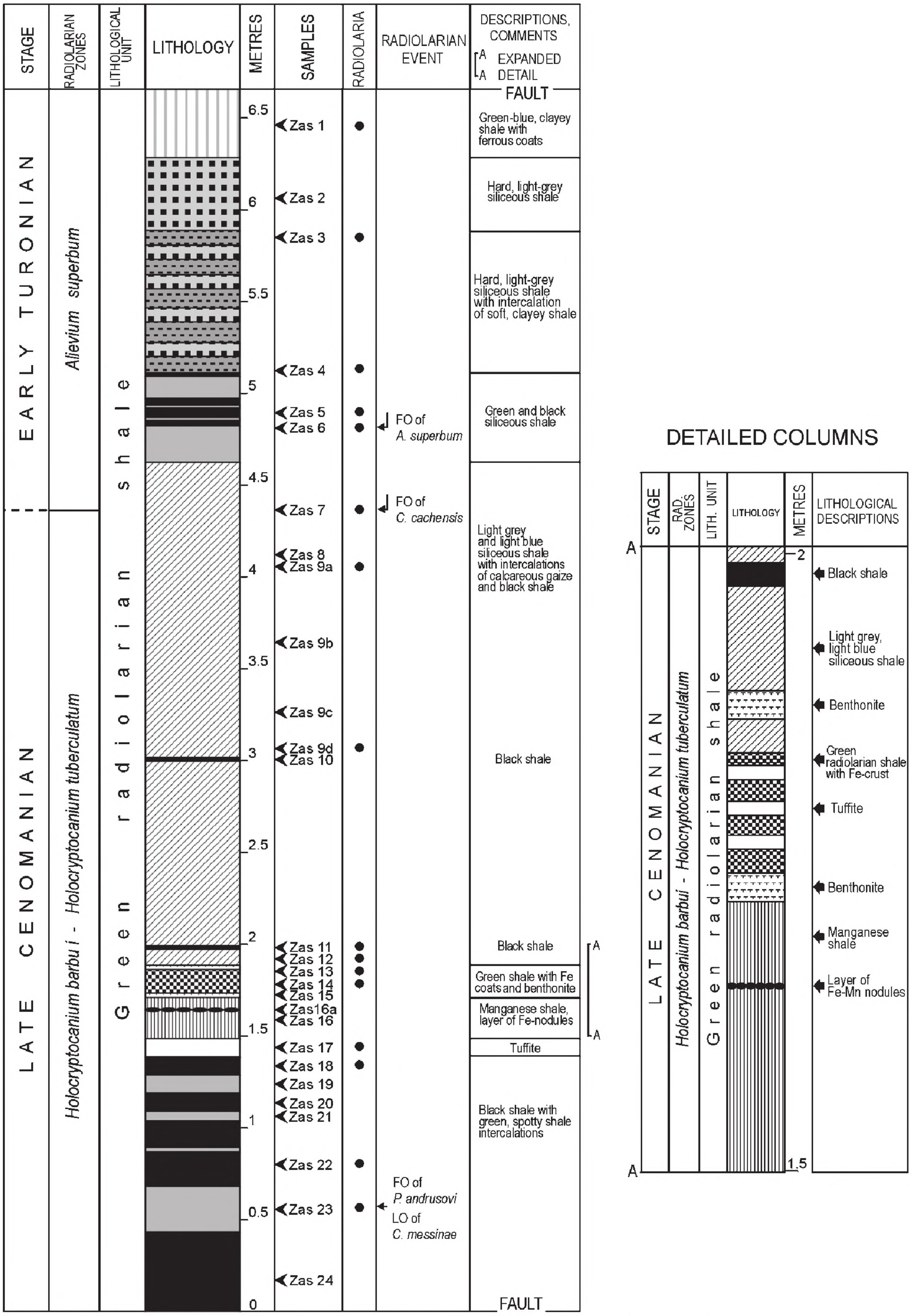

Fig. 3. Lithological columns of the Zasań section showing the lithology and position of radiolarian samples.

shales and benthonites were boiled in diluted Glauber's salt. The samples were sieved and the >63 μm fraction was examined. Selected samples with moderately to well-preserved radiolarians were studied under the scanning electron microscope (SEM), and the common faunal association is documented in Table 1 and Figs. 4–7.

Radiolarian fauna is abundant in all samples but, in general, poorly preserved, with few moderately to well-preserved specimens. In some cases a relatively intense recrystallization occurs. The poor preservation does not allow a statistical evaluation of the fauna because the assemblage composition and the differences reflect preservation rather than primary faunal composition. Nevertheless, enough specimens are sufficiently preserved for biostratigraphic analysis.

Radiolarian assemblage

The radiolarian association comprises twenty taxa of Spumellaria and twelve taxa of Nassellaria. According to the systematic framework of O'Dogherty (1994) and Dumitrică (1995) radiolarian taxa belong to six families of the order Spumellaria and five families of the order Nassellaria. Spumellaria include the following families and genera: Pseudoaulophacidae (genera *Alievium, Pseudoaulophacus* and *Patellula*), Patulibracchidae (genera *Paronaella* and *Halesium*), Actinommidae (genus *Praeconocaryomma*), Orbiculiformidae (genus *Crucella*), Cavaspongiidae (genus *Cavaspongia*) and Pyramispongidae (genus *Pyramispongia*). Nassellaria are mainly represented by Williriedellidae (genera

Table 1: Occurrence of the radiolarian specimens and local radiolarian zones in the Zasań section.

CHRONOSTRATIGRAPHIC UNITS		CENOMANIAN										TURONIAN					
RADIOLARIAN ZONATION		*Holocryptocanium barbui - Holocryptocanium tuberculatum*										*Alievium superbum*					
SAMPLES		Zas-23	Zas-22	Zas-18	Zas-17	Zas-14	Zas-13	Zas-12	Zas-11	Zas-9d	Zas-9a	Zas-7	Zas-6	Zas-5	Zas-4	Zas-3	Zas-1
N A S S E L L A R I A	*Cryptamphorella conara* (Foreman)																●
	Diacanthocapsa euganea Squinabol							●									
	Dictyomitra napaensis Pessagno							●				●	●				
	Dictyomitra undata Squinabol											●					●
	Holocryptocanium barbui Dumitrică	●	●		●	●		●	●	●	●	●	●	●	●		●
	Holocryptocanium tuberculatum Dumitrică	●	●	●	●	●	●	●				●	●	●	●	●	●
	P. pseudomacrocephala (Squinabol)		●										●	●	●		●
	Pseudoeucyrtis pulchra (Squinabol)												●				
	Stichomitra communis Squinabol	●						●					●	●	●		●
	Stichomitra magna Squinabol	●															
	Nassellaria gen. et sp. indet. A												●				
	Nassellaria gen. et sp. indet. B												●				●
S P U M E L L A R I A	*Alievium superbum* (Squinabol)												●		●		●
	Archaeocenosphaera cf.? *mellifaera* O'Dogherty																
	Cavaspongia antelopensis Pessagno																●
	Cavaspongia euganea (Squinabol)												●				●
	Cavaspongia sphaerica O'Dogherty																●
	Crucella cachensis Pessagno											●	●				●
	Crucella messinae Pessagno	●															
	Dactyliosphaera maxima (Pessagno)		●									●					●
	Dactyliosphaera depressa (Wu)	●															
	Paronaella californiaensis Pessagno	●						●					●				
	Paronaella communis (Squinabol)												●				●
	Patellula andrusovi Ožvoldová	●	●					●				●	●	●	●	●	●
	Patellula cognata O'Dogherty												●				
	Patellula ecliptica O'Dogherty	●	●		●	●	●	●	●			●	●	●	●		●
	Patellula matura (Wu)	●															
	Patellula verteroensis (Pessagno)													●			
	Praeconocaryomma lipmanae Pessagno	●	●										●		●		●
	Praeconocaryomma universa Pessagno												●	●			●
	Pseudoaulophacus putahensis Pessagno											●			●		
	Pyramispongia glascockensis Pessagno	●															

Cryptamphorella, Hemicryptocapsa and *Holocryptocanium*), other species belong to the families Diacanthocapsidae (genus *Diacanthocapsa*), Archaeodictyomitridae (genus *Dictyomitra*), Pseudodictyomitridae (genus *Pseudodictyomitra*), and Amphipyndacidae (genus *Stichomitra*).

The analysed assemblage is dominated by spherical cryptothoracic and cryptocephalic Nassellaria, belonging mostly to the species *Holocryptocanium barbui* Dumitrică and *Holocryptocanium tuberculatum* Dumitrică. These species represent 60-99 % of the whole assemblage. Spumellarians are less common but more diversified. As the number of species, they represent up to 40 % of the radiolarian fauna.

Radiolarian biostratigraphy

Sixteen samples yielding radiolarians were studied from the interval investigated. The results are presented in Table 1. Biostratigraphically important species include *Alievium superbum* (Squinabol), *Crucella cachensis* Pessagno, *Patellula ecliptica* O'Dogherty, *Patellula andrusovi* Ožvoldová, *Holocryptocanium barbui* Dumitrică, *Holocryptocanium tuberculatum* Dumitrică, *Pyramispongia glascockensis* Pessagno, *Cavaspongia antelopensis* Pessagno, *Paronaella californiaensis* Pessagno, *Crucella messinae* Pessagno, *Stichomitra communis* Squinabol, *Praeconocaryomma universa* Pessagno, *Praeconocaryomma lipmanae* Pessagno, *Pseudodictyomitra pseudomacrocephala* (Squinabol), *Diacanthocapsa euganea* Squinabol, *Dictyomitra napaensis* Pessagno, *Pseudoaulophacus putahensis* Pessagno, *Dictyomitra undata* Squinabol, *Pseudoeucyrtis pulchra* (Squinabol), *Patellula cognata* O'Dogherty, *Paronaella communis* (Squinabol), *Cavaspongia euganea* (Squinabol) and *Cavaspongia sphaerica* O'Dogherty. This association is characteristic of the fauna around the Cenomanian-Turonian Boundary Event (CTBE), well described both from oceanic and land sections, for example, from the Pacific: Moore (1973), Foreman (1975); Atlantic Ocean: Thurow (1988); Carpathians: Dumitrică (1975), M. Bąk (1999a,b); Mediterranean: Marcucci et al. (1991), O'Dogherty (1994); Japan: Taketani (1982); Caucasus: Vishnievskaya (1993); Russian Pacific Rim: Vishnievskaya (1993); California: Pessagno (1976).

Several species occurring in the studied radiolarian assemblage are not influenced by the CTBE (long-ranging forms). These include *Halesium amissum* (Squinabol), *Holocryptocanium barbui* Dumitrică, *Holocryptocanium tuberculatum* Dumitrică, *Pyramispongia glascockensis* Pessagno, *Patellula helios* (Squinabol), *Patellula verteroensis* (Pessagno), *Pseudodictyomitra pseudomacrocephala* (Squinabol), and *Stichomitra communis* Squinabol. On the other hand, the CTBE is reflected in disappearance (LO) and the first appearance (FO) of some radiolarian species.

Crucella messinae Pessagno is one of the species which has its LO in the CTBE deposits. Its LO in uppermost Cenomanian is reported, from the California Coast Ranges (Pessagno 1976), Northern and Central Italy (Erbacher 1994), Northern Atlantic (Thurow 1988; Erbacher 1994) and elsewhere. According to O'Dogherty (1994) the last appearance data (LAD) of *C. messinae*, calculated on the basis of the unitary association method, took place in the earliest Turonian. In the studied section, this species has its LO about 1.1 m below the ferromanganese concretions level (sample Zas-23). It coincides with the first occurrences of *Paronaella californiaensis* Pessagno, *Patellula ecliptica* O'Dogherty, *Patellula andrusovi* Ožvoldová and *Praeconocaryomma universa* Pessagno, species which make their FOs in the CTBE.

Other important species for radiolarian biostratigraphy with relation to the Cenomanian-Turonian boundary (CTB) are *Alievium superbum* (Squinabol) and *Crucella cachensis* Pessagno. In the Zasań section, *A. superbum* appears in the highest part of the green shales (sample Zas-6), about 3.4 m above the ferromanganese concretions level. The FO of *C. cachensis* (sample Zas-7) is noted 0.5 m below the FO of *A. superbum.* Both species have their FAD very close to the CTB e.g., Pessagno (1976; Schaaf 1985; Thurow 1988). The authors mentioned above used these taxa to define the radiolarian *A. superbum* Zone, the lower boundary of which coincides with the CTB.

Pessagno (1976) was the first to discuss the FAD of *A. superbum* in the Boreal Province of the California Coast Ranges in relation to the CTB. According to this author, the lower part of *A. superbum* Zone lies in the lower part of the *Inoceramus labiatus* Zone, close to its lower limit and could also coincide with the first appearance of double-keeled Globigerinacea *(Helvetoglobotruncana helvetica).*

Recently, the Cenomanian-Turonian boundary was proposed in 1996 during the Second International Symposium on Cretaceous Stage Boundaries in Brussels. It coincides with the FO of the ammonite *Watinoceras devonense* at the base of Bed 86 in the stratotype section at Rock Canyon Anticline, west of Pueblo (Colorado). According to the inoceramid biozonation (see compilation made by Bengtson 1996) and ammonite zonations (Kennedy & Hancock 1976 and Kennedy et al. 1983; compiled by Robaszynski 1983), the lower part of the *I. labiatus* Zone coincides with the lower part of the *Watinoceras coloradoense* Ammonite Zone. The lower limit of the ammonite *W. coloradoense* Zone in Europe (biozonation of Cobban et al. 1994 and Obradovich 1993 in: Gradstein et al. 1995) could conceivably be correlative with the lower boundary of the *Watinoceras devonense* Zone of North America. The FO of *W. coloradoense* is placed in the stratotype section within Bed 97 (1.5 m above the base of *W. devonense*) (Kennedy & Cobban 1991). *H. helvetica* appears (FAD) less than 1 m above the base of Bed 86 in the stratotype section. In summary, according to the correlation presented above, the first appearance (FAD) of *A. superbum* could conceivably take place 1-1.5 m above the present Cenomanian-Turonian boundary.

Crucella cachensis Pessagno is another radiolarian species, which appears very close to the CTB. According to previous investigations (Górka 1996; M. Bąk 2000; Gedl & Bąk 2000; K. Bąk et al. 2001), this species is common in the Outer Western Carpathian deposits. The species first occurs in the studied section 0.5 m below the FO of *A. superbum* (sample Zas-7). The previous workers reported the presence of *C. cachensis* exclusively within the CTBE deposits (*Ibiden*). Thurow (1988) proposed a radiolarian *Crucella cachensis* Zone for the Northern Atlantic based on the first occurrence of the index

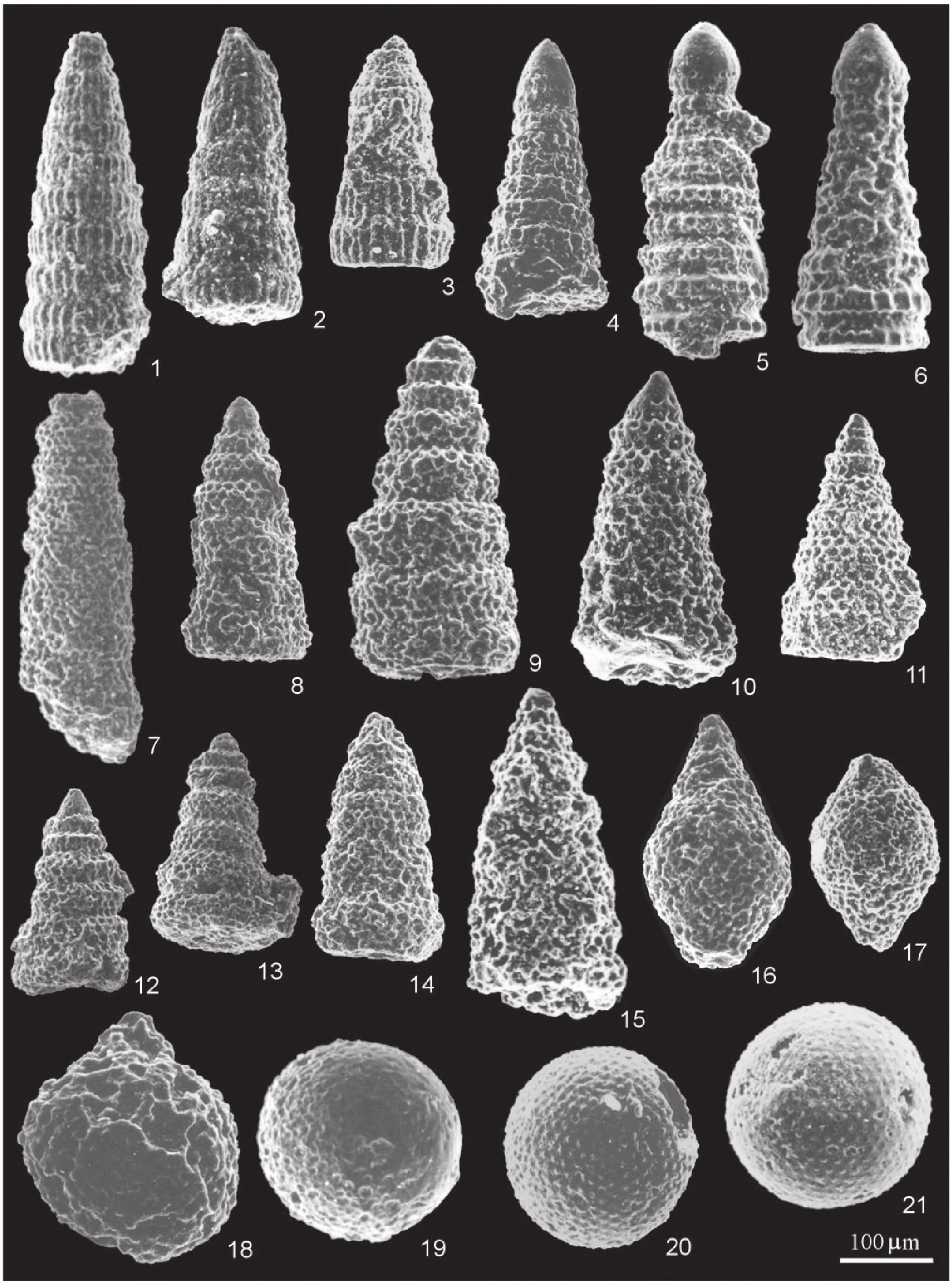

Fig. 4. Nassellaria from the uppermost Cenomanian–lowermost Turonian deposits of the Subsilesian series. **1.** *Dictyomitra napaensis* Pessagno — Zas-12. **2.** *Dictyomitra napaensis* Pessagno — Zas-7. **3.** *Dictyomitra undata* Squinabol — Zas-1. **4.** *Pseudodictyomitra pseudomacrocephala* (Squinabol) — Zas-1. **5.** *Pseudodictyomitra pseudomacrocephala* (Squinabol) — Zas-4. **6.** *Pseudodictyomitra pseudomacrocephala* (Squinabol) — Zas-1. **7.** *Stichomitra magna* Squinabol — Zas-23. **8.** *Stichomitra communis* Squinabol — Zas-6. **9.** *Stichomitra communis* Squinabol — Zas-6. **10.** *Stichomitra communis* Squinabol — Zas-1. **11.** *Stichomitra communis* Squinabol — Zas-1. **12.** *Stichomitra communis* Squinabol — Zas-1. **13.** *Stichomitra communis* Squinabol — Zas-1. **14.** *Stichomitra communis* Squinabol — Zas-6. **15.** *Stichomitra communis* Squinabol — Zas-6. **16.** *Pseudoeucyrtis pulchra* (Squinabol) — Zas-6. **17.** Nassellaria gen. et sp. indet. A — Zas-6. **18.** Nassellaria gen. et sp. indet. B — Zas-6. **19.** *Holocryptocanium barbui* Dumitrică — Zas-22. **20.** *Holocryptocanium barbui* Dumitrică — Zas-1. **21.** *Holocryptocanium barbui* Dumitrică — Zas-6.

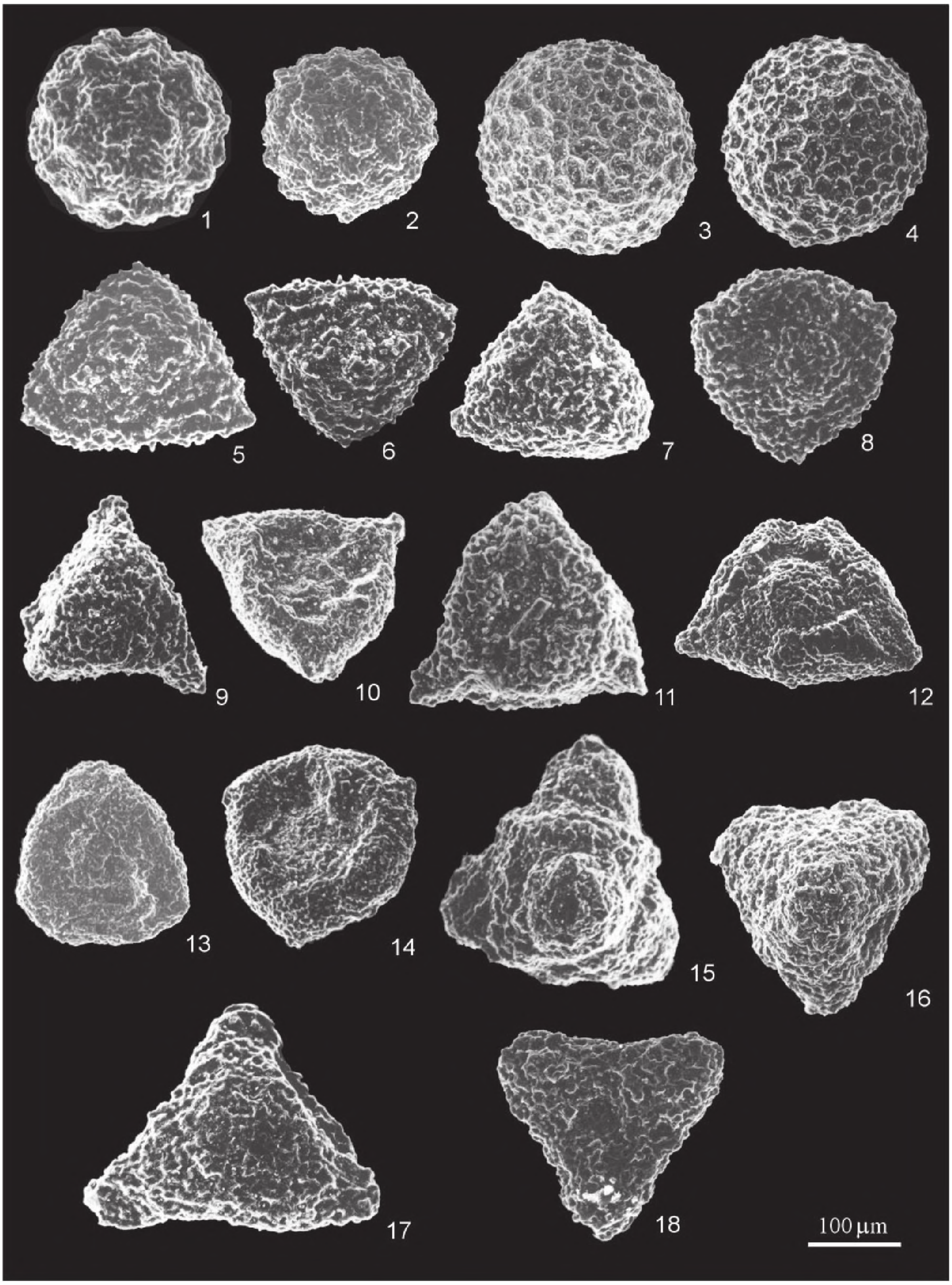

Fig. 5. Nassellaria and Spumellaria from the uppermost Cenomanian–lowermost Turonian deposits of the Subsilesian series. **1.** *Holocryptocanium tuberculatum* Dumitrică — Zas-6. **2.** *Holocryptocanium tuberculatum* Dumitrică — Zas-6. **3.** *Archaeocenosphaera*(?) cf. *mellifera* O'Dogherty — Zas-6. **4.** *Archaeocenosphaera*(?) cf. *mellifera* O'Dogherty — Zas-6. **5.** *Alievium superbum* (Squinabol) — Zas-4. **6.** *Alievium superbum* (Squinabol) — Zas-6. **7.** *Alievium superbum* (Squinabol) — Zas-1. **8.** *Pseudoaulophacus putahensis* Pessagno — Zas-4. **9.** *Cavaspongia sphaerica* O'Dogherty — Zas-1. **10.** *Cavaspongia euganea* (Squinabol) — Zas-6. **11.** *Cavaspongia euganea* (Squinabol) — Zas-1. **12.** *Cavaspongia euganea* (Squinabol) — Zas-6. **13.** *Cavaspongia euganea* (Squinabol) — Zas-6. **14.** *Cavaspongia euganea* (Squinabol) — Zas-6. **15.** *Pyramispongia glascockensis* Pessagno — Zas-23. **16.** *Pyramispongia glascockensis* Pessagno — Zas-23. **17.** *Cavaspongia antelopensis* Pessagno — Zas-1. **18.** *Paronaella communis* (Squinabol) — Zas-6.

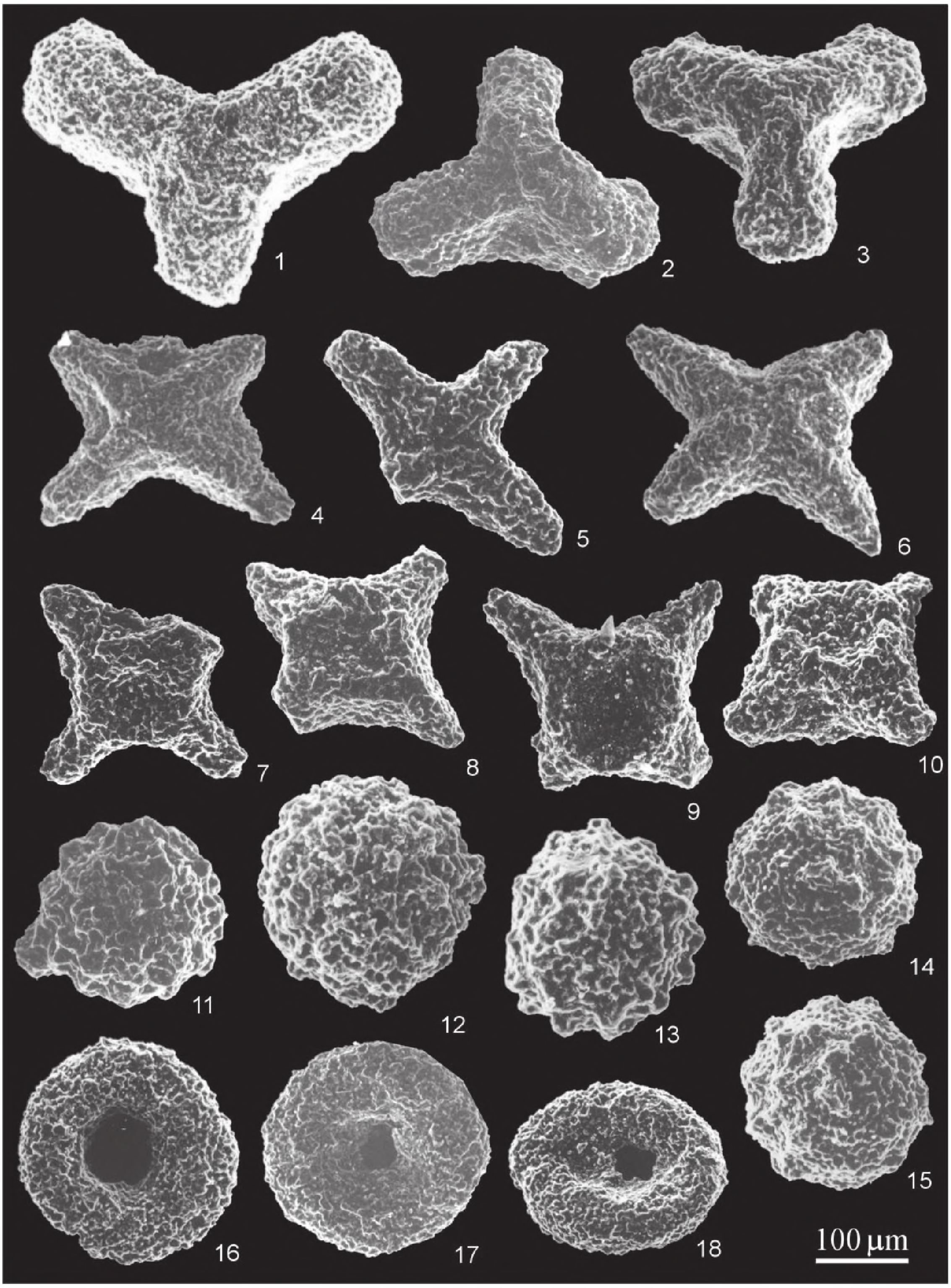

Fig. 6. Spumellaria from the uppermost Cenomanian–lowermost Turonian deposits of the Subsilesian series. **1.** *Paronaella californiaensis* Pessagno — Zas-23. **2.** *Paronaella californiaensis* Pessagno — Zas-23. **3.** *Paronaella californiaensis* Pessagno — Zas-6. **4.** *Crucella messinae* Pessagno — Zas-23. **5.** *Crucella messinae* Pessagno — Zas-23. **6.** *Crucella messinae* Pessagno — Zas-23. **7.** *Crucella cachensis* Pessagno — Zas-6. **8.** *Crucella cachensis* Pessagno — Zas-6. **9.** *Crucella cachensis* Pessagno — Zas-7. **10.** *Crucella cachensis* Pessagno — Zas-1. **11.** *Praeconocaryomma universa* Pessagno — Zas-6. **12.** *Praeconocaryomma universa* Pessagno — Zas-5. **13.** *Praeconocaryomma universa* Pessagno — Zas-1. **14.** *Praeconocaryomma lipmanae* Pessagno — Zas-23. **15.** *Praeconocaryomma lipmanae* Pessagno — Zas-23. **16.** *Dactyliosphaera maxima* (Pessagno) — Zas-1. **17.** *Dactyliosphaera maxima* (Pessagno) — Zas-1. **18.** *Dactyliosphaera maxima* (Pessagno) — Zas-1.

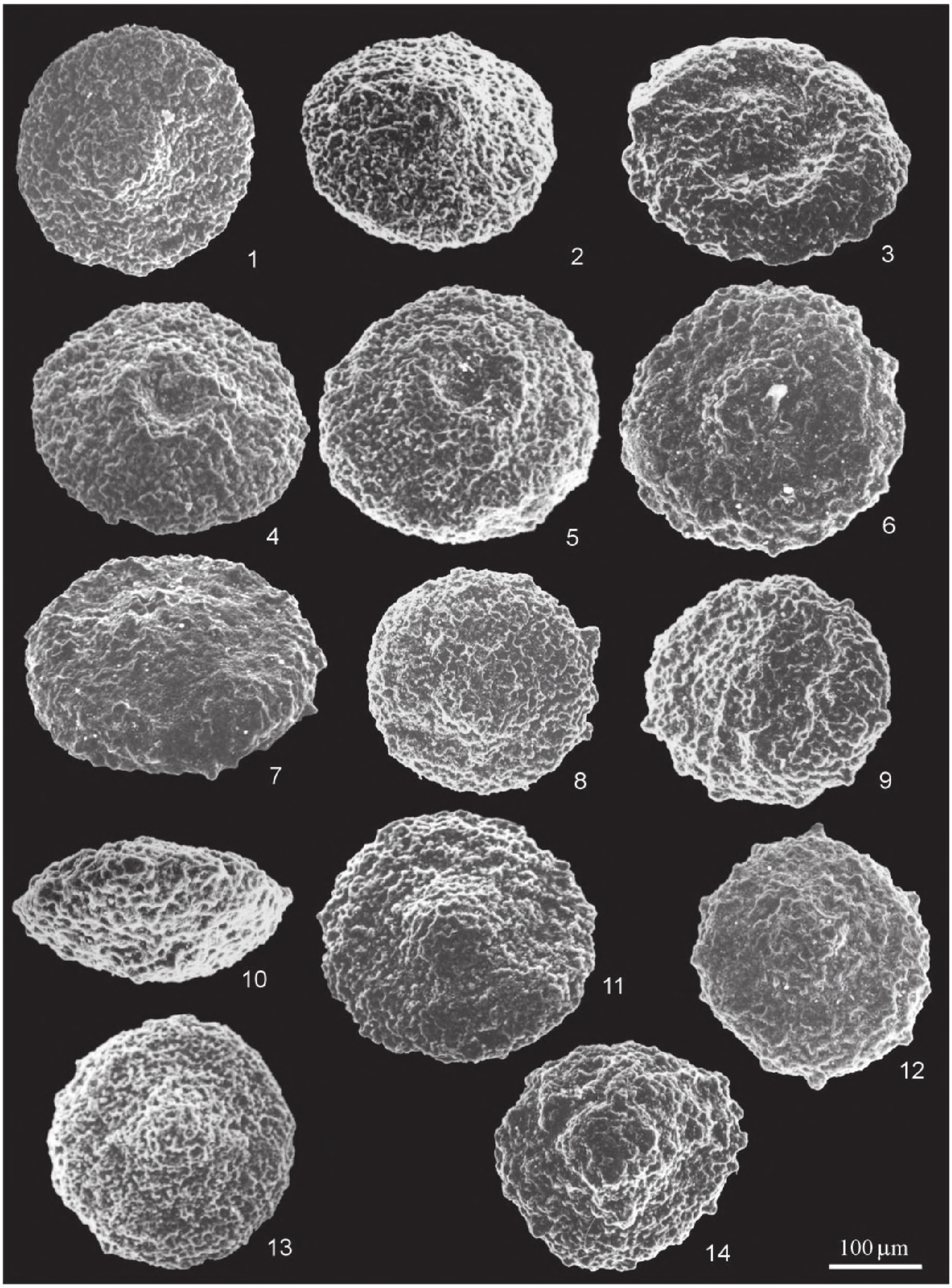

Fig. 7. Spumellaria from the uppermost Cenomanian–lowermost Turonian deposits of the Subsilesian series. **1.** *Patellula andrusovi* Ožvoldová, upper surface — Zas-1. **2.** *Patellula andrusovi* Ožvoldová, upper surface — Zas-1. **3.** *Dactyliosphaera depressa* (Wu) — Zas-23. **4.** *Patellula andrusovi* Ožvoldová, lower surface — Zas-1. **5.** *Patellula andrusovi* Ožvoldová, lower surface — Zas-1. **6.** *Patellula matura* (Wu) — Zas-23. **7.** *Patellula ecliptica* O'Dogherty — Zas-12. **8.** *Patellula ecliptica* O'Dogherty — Zas-6. **9.** *Patellula ecliptica* O'Dogherty — Zas-23. **10.** *Patellula ecliptica* O'Dogherty — Zas-22. **11.** *Patellula ecliptica* O'Dogherty — Zas-23. **12.** *Patellula ecliptica* O'Dogherty — Zas-22. **13.** *Patellula verteroensis* (Pessagno) — Zas-5. **14.** *Patellula cognata* O'Dogherty — Zas-6.

species. He noted that this species never occurs with planktonic foraminiferal species of the genus *Rotalipora* and its FO is always coeval with the onset of the planktonic foraminiferal *Whiteinella aprica* Zone.

In summary, both radiolarian species *A. superbum* and *C. cachensis*, present in the siliceous deposits of the Subsilesian series, are very useful biomarkers for placing the lower boundary of the Turonian. They make their FOs above the ferromanganese concretion level. Consequently, the stratigraphical position of the ferromanganese concretion level is within the uppermost Cenomanian.

Radiolarian correlation

The studied radiolarian assemblage, including all radiolarians recovered in the deposits of the Subsilesian Nappe, has been used for comparison with radiolarian zonal schemes from different regions, especially from the Carpathians and Mediterranean.

The radiolarian association from the lower part of the Zasań section (below the FO of *C. cachensis* and *A. superbum*) correlates well with the *Holocryptocanium barbui-Holocryptocanium tuberculatum* assemblage proposed by Dumitrică (1975) for the radiolarian-bearing deposits of the Romanian Carpathians. This radiolarian assemblage shows great similarity with the association presented herein, based on the co-occurrence of *H. barbui* and *H. tuberculatum*, and other cryptocephalic and cryptothoracic Nassellaria. Moreover, some multi-segmented Nassellaria from the genera *Dictyomitra, Pseudodictyomitra* and *Stichomitra* also occur together. A high percentage of cryptothoracic and cryptocephalic Nassellaria, especially *H. barbui* and *H. tuberculatum* is one of the outstanding features of the radiolarian assemblages from the Late Cenomanian to Early Turonian interval in the Carpathians. This feature has been reported from many sections investigated in the Polish Outer Carpathians: in the Silesian (M. Bąk 1994, 2000; K. Bąk et al. 2001) and Skole Units (Górka 1996). It is also character of the radiolarian assemblages reported from all successions in the Polish part of the Pieniny Klippen Belt (M. Bąk 1993, 1995, 1996a,b, 1999a,b).

The FO of *A. superbum* in sample Zas-6 marks the base of the radiolarian *Alievium superbum* Zone of Pessagno (1976), which includes the radiolarian assemblage from the upper part of the section. This radiolarian biozone was also recognized in the Mediterranean region (*superbum* Zone of O'Dogherty 1994). The *A. superbum* Zone can be well distinguished only in the Outer Western Carpathians (Subsilesian, Silesian and Skole Units). In the Slovak part of the Pieniny Klippen Belt, the species *A. superbum* has been found only within the Czorsztyn Succession (Sýkora et al. 1997).

This interval is also well correlated with the radiolarian *Crucella cachensis* Zone of Thurow (1988) distinguished in the North Atlantic. O'Dogherty (1994) also reported *Crucella cachensis* from the Mediterranean region. This species is common in the Outer Carpathian deposits, especially in the Subsilesian and Skole Nappes, but it is rare in the Polish part of the Pieniny Klippen Belt. Up to now, it has been found only within the *superbum* Zone in the Czorsztyn Succession in the Slovak part of the Pieniny Klippen Belt (Sýkora et al. 1997).

Conclusions

The results presented here are based on micropaleontological analysis of twenty-eight samples collected from one section (Zasań section) of mid-Cretaceous deposits of the Subsilesian Unit, in its Polish part. The studied deposits are very rich in radiolarians. Lithologically, they consist mainly of green shales with black shale intercalations, including manganese concretions level, benthonites and tuff layers. These deposits represent a characteristic correlation horizon, present in the whole Carpathian arc.

A systematic study of all radiolarian species occurring in the investigated samples allowed us to evaluate the diversity of the radiolarian fauna. Twenty species of Spumellaria and twelve species of Nassellaria have been recognized. The radiolarian assemblage is dominated by spherical cryptocephalic Nassellaria, belonging mainly to the species *Holocryptocanium barbui* Dumitrică and *H. tuberculatum* Dumitrică. These species make up 60 to 99 percent of the assemblage. Spumellarians are less common but more diversified. They represent up to 40 percent of the radiolarian fauna, and are represented mainly by the genera *Patellula, Crucella, Paronaella, Praeconocaryomma* and *Alievium*. This association is characteristic of the fauna around the Cenomanian-Turonian Boundary Event (CTBE).

Two radiolarian species: *Alievium superbum* (Squinabol) and *Crucella cachensis* Pessagno, present in the siliceous deposits of the Subsilesian series have been used as biomarkers to place the Lower Turonian boundary. They make their first occurrence above the ferromanganese concretions level (*A. superbum* — 3.4 m and *C. cachensis* — 0.5 m). Consequently, the age of the ferromanganese concretion level was determined as the uppermost Cenomanian.

All radiolarian taxa recorded in the studied deposits have been used for comparison with the radiolarian zonal schemes of previous authors in different areas of the Carpathians and the Mediterranean Basin.

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References

Bąk K. & Bąk M. 2000: The Cenomanian-Turonian Boundary Event in deep-water flysch sediments of the Silesian Unit (Polish Western Carpathians) — agglutinated foraminifera and radiolaria record. *Abstracts of the 6th International Cretaceous Symposium August 27 to September 4, 2000,* Vienna, Austria, 1–12.

Bąk K., Bąk M. & Paul Z. 2001: Barnasiówka Radiolarian Shale Formation — a new lithostratigraphic unit in the Upper Cenomanian–lowermost Turonian of the Polish Outer Carpathians

(Silesian Series). *Ann. Soc. Geol. Pol.* 71, 75–103.

Bąk M. 1993: Late Albian–Early Cenomanian Radiolaria from the Czorsztyn Succession, Pieniny Klippen Belt, Carpathians. *Stud. Geol. Pol.* 102, 177–207.

Bąk M. 1994: Radiolaria from Cenomanian deposits of the Silesian Nappe near Sanok, Polish Carpathians. *Bull. Polish Acad. Sci. Earth Sci.* 42, 145–153.

Bąk M. 1995: Mid Cretaceous Radiolaria from the Pieniny Klippen Belt, Carpathians, Poland. *Cretac. Research* 16, 1–23.

Bąk M. 1996a: Cretaceous Radiolaria from the Niedzica Succession, Pieniny Klippen Belt, Polish Carpathians. *Acta Paleont. Pol.* 41, 1, 91–110.

Bąk M. 1996b: Late Cretaceous Radiolaria from the Czorsztyn Succession, Pieniny Klippen Belt, Polish Carpathians. *Stud. Geol. Pol.* 109, 69–85.

Bąk M. 1999a: Cretaceous Radiolaria from the Pieniny Succession, Pieniny Klippen Belt, Polish Carpathians. *Stud. Geol. Pol.* 115, 91–115.

Bąk M. 1999b: Mid-Cretaceous Radiolarian zonation in the Polish part of the Pieniny Klippen Belt (Carpathians). *Geol. Carpathica* 50, 1, 21–31.

Bąk M. 2000: Radiolaria from the Upper Cenomanian-Lower Turonian deposits of the Silesian Unit (Polish Flysch Carpathians). *Geol. Carpathica* 51, 309–324.

Bengtson P. 1996: The Turonian stage and substage boundaries. *Bull. Inst. Roy. Sci. Natur. Belg.* 66, 69–79.

Bieda F., Geroch S., Koszarski L., Książkiewicz M. & Żytko K. 1963: Stratigraphie des Karpates externes polonaises. *Biul. Inst. Geol.* 181, 5–174.

Burtan J. & Turnau-Morawska M. 1978: Biochemical siliceous rocks of the West Carpathian Flysch. *Prace Geol. Pol. Akad. Nauk — Oddział w Krakowie Komisja Nauk Geologicznych* 111, 1–36 (in Polish, English summary).

Burtanówna J., Książkiewicz M. & Sokołowski S. 1933: Über das Auftreten der Radiolaritschiefer in der mittleren Kreide der West-Beskiden. *Ann. Soc. Géol. Pol.* 9, 96–99 (in Polish, German summary).

Dumitrică P. 1975: Cenomanian Radiolaria at Podul Dîmdoviței In: Micropaleontological Guide to the Mesozoic and Tertiary of the Romanian Carpathians; 14th European Micropaleontological Colloquium Romania. *Institute of Geology and Geophysics,* Buchurest, 87–89.

Dumitrică P. 1995: Systematic framework of Jurassic and Cretaceous Radiolaria. In: Baumgartner P.O. et al. (Eds): Middle Jurassic to Lower Cretaceous Radiolaria of Tethys: occurrences, systematics, biochronology. *Mémoires de Géologie (Lausanne)* 23, 19–36.

Erbacher J. 1994: Entwicklung und Paläoozeanographie mittelkretazischer Radiolarien der westlichen Tethys (Italien) des Nordatlantiks. *Tübinger Mikropaläontologische Mitteilungen* 12, 1–120.

Foreman H.P. 1975: Radiolaria from the North Pacific Deep Sea Drilling Project Leg 32. In: Larson R.L. & Moberly R. et al. (Eds): Initial Reports of the Deep Sea Drilling Project 32, 579–676.

Gedl E. & Bąk M. 2000: Mid-Cretaceous dinocysts and Radiolaria from the Zasań section (Subsilesian Unit, Polish Outer Carpathians) — a CTBE problem. *Abstracts of 6th International Cretaceous Symposium, August 27 to September 4, 2000,* Vienna, Austria, 1–36.

Geroch S. 1967: A some assemblages of microfauna from the Silesian Series of the Western Polish Carpathians. *Biul. Inst. Geol.* 211, 369–381.

Geroch S., Gucwa I. & Wieser T. 1985: Manganese nodules and other indications of regime and ecological environment in lower part of the Upper Cretaceous — exemplified by Lanckorona profile. In: Wieser T. (Ed.): 13th Congress of Carpatho-Balkan Geological Association: Fundamental researches in the western part of the Polish Carpathians Guide to Excursion I. *Geological Institute,* Cracow, 88–100.

Geroch S., Jednorowska A,. Książkiewicz M. & Liszkowa J. 1967: Stratigraphy based upon microfauna in the Western Polish Carpathians. *Biul. Inst. Geol.* 211, 185–282.

Górka H. 1996: Cenomanian Radiolaria from Spława, Polish Carpathians. *Geological Quarterly* 40, 555–574.

Gradstein F.M., Agterberg F.P., Ogg J.G., Hardenbol J., Van Veen P., Thierry J. & Huang Z. 1995: A Triassic, Jurassic and Cretaceous Time Scale. In: Berggren et al. (Eds): Geochronology, time scales and global stratigraphic correlation. *SEMP (Society for Sedimentary Geology) Spec. Publ.* 54.

Gzik M. 1990: Micropaleontological analysis of the radiolarite series near Lanckorona. *Unpublished MSc. Thesis Institute of Geological Sciences, Jagiellonian University,* Kraków, 1–99 (in Polish).

Gzik M. & Koszarski L. 1990: The sedimentation and microfauna of a series of Cretaceous radiolarites from the vicinity of Lanckorona in the Carpathians. *Spraw. Posiedz. Kom. Nauk Geol. Pol. Akad. Nauk, Kraków* 34, 220–223.

Kennedy W.J. & Cobban W.A. 1991: Stratigraphy and interregional correlation of the Cenomanian-Turonian transition in the Western Interior of the United States near Pueblo, Colorado, a potential boundary stratotype for the base of the Turonian stage. *Newslett. Stratigr.* 24, 1–33.

Koszarski L. & Liszkowa J. 1963: New data about the Cenomanian in the Carpathians. *Kwart. Geol.* 7, 557–558 (in Polish).

Koszarski L., Nowak W. & Żytko K. 1959: Notes on the age of the Godula Beds (Carpathians Flysch). *Kwart. Geol.* 3, 127–151 (in Polish, English summary).

Koszarski L. & Ślączka A. 1973: Outer Carpathians (Flysch). The Lower Cretaceous and the Upper Cretaceous. In: Sokołowski S. (Ed.): Geology of Poland. *Instytut Geologiczny, Wydawnictwa Geologiczne,* Warszawa, 647-660 (in Polish).

Książkiewicz M. 1962: Geological atlas of Poland. Stratigraphical-facial problems. Cretaceous and older Palaeogene in Polish Outer Carpathians. *Instytut Geologiczny,* Warszawa (in Polish).

Liszkowa J. 1956: Microfauna of the Subsilesian series. *Przegl. Geol.* 4, 463–468 (in Polish).

Liszkowa J. 1962: Classification du Cretace de la serie subsilesienne des Carpates Polonaises basee sur la presence microfaune. *Ann. Inst. Geol. Publ. Hung.* 69, 889–902.

Liszkowa J. & Nowak W. 1962: Older Cretaceous members of the Frýdek Subsilesian series. *Kwart. Geol.* 6, 235–255.

Marcucci-Passerini M., Bettini P., Danielli J. & Sirugo A. 1991: The "Bonarelli Horizon" in the Central Apennines (Italy): radiolarian biostratigraphy. *Cretac. Research* 12, 321–331.

Moore T.C. 1973: Radiolaria from Leg 17 of the Deep Sea Drilling Project. In: Winterer E.L., Ewing J.I. et al. (Eds): Initial Reports of the Deep Sea Drilling Project. *U.S. Printing Office,* Washington, 17, 797–869.

Nowak W. 1956: Subsilesian Unit in the Bielsko-Biała region. *Przegl. Geol.* 4, 460–461 (in Polish).

O'Dogherty L. 1994: Biochronology and paleontology of Mid-Cretaceous radiolarians from Northern Apennines (Italy) and Betic Cordillera (Spain). *Memoires de Geologie (Lousanne)* 21, 1–413.

Pessagno E.A. 1976: Radiolarian zonation and stratigraphy of the Upper Cretaceous portion of the Great Valley Sequence, California Coast Ranges. *Micropaleontology Spec. Publ.* 2, 1–95.

Robaszynski F. (compiler) 1983: Conclusions au Colloque sur le Turonien: Échelles biostratigraphiques intégrées et cartes de faciès et contrées limitrophes. *Mém. Mus. Nat. Hist. Natur. N.*

S. Sér. C. Sci. Terre 49 (for 1981), 209–241.

Schaaf A. 1985: Un nouveau canevas biochronologique du Crétacé inférieur et moyen: les biozones a radiolaires. *Bull. Sci. Géol., Strasbourg* 38, 3, 227–269.

Sujkowski Z. & Różycki S.Z. 1930: Trouvaille de Radiolarites typiques dans les Karpates orientales. *Posiedz. Nauk. Państw. Inst. Geol.* 25, 14–15 (in Polish).

Sýkora M., Ožvoldová L. & Boorová D. 1997: Turonian silicified sediments in the Czorsztyn Succession of the Pieniny Klippen Belt (Western Carpathians, Slovakia). *Geol. Carpathica* 48, 243–261.

Taketani Y. 1982: Cretaceous radiolarian biostratigraphy of the Urakawa and Obira areas, Hokkaido. *Sci. Rep. Tohoku Univ., Ser. 2. Geol.* 52, 1–75.

Thurow J. 1988: Cretaceous Radiolarians of the North Atlantic Ocean: ODP Leg 103 (Sites 638 640 and 641) and DSDP Legs 93 (Site 603) and 47B (Site 398). *Proceedings of the Ocean Drilling Program Scientific Results* 103, 379–418.

Uhlig V. 1888: Vorlage des Kartenblattes Teschen-Mistek-Jablunkau. *Verh. Geol. Reichsanst.* 2, 1–129.

Vishnevskaya V. 1993: Jurassic and Cretaceous radiolarian biostratigraphy in Russia. In: Blueford J. & Murchey B. (Eds): Radiolarian of giant and subgiant fields in Asia. *Micropaleontology Spec. Publ.* 6, 175–200.