GEOLOGICA CARPATHICA, 50, 1, BRATISLAVA, FEBRUARY 1999
21–31

CRETACEOUS RADIOLARIAN ZONATION IN THE POLISH PART OF THE PIENINY KLIPPEN BELT (WESTERN CARPATHIANS)

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Project No. 362

(Manuscript received January 23, 1998; accepted in revised form December 9, 1998)

Abstract: The Albian to Turonian deposits in the Polish part of the Pieniny Klippen Belt comprise pelagic and shaly turbidite facies. They represent shallow (shelf) to deep-water environments, and they are relatively rich in radiolarian fauna. Over 70 radiolarian species of the Carpathian Tethyan low latitude realm were identified in over 200 samples from 18 sections in the deposits of the Pieniny, Branisko, Niedzica and Czorsztyn successions of the Pieniny Klippen Belt. 17 horizons containing abundant and well-preserved radiolarian fauna have been chosen for analysis. These data were processed with the BioGraph 2.02 computer program (Savary & Guex 1991) based on the Unitary Associations (U.A.) method. The program produced a sequence of 11 U.A. which were used for constructing the radiolarian zonal scheme. Three radiolarian zones and five subzones (Holocryptocanium barbui Zone with Stichomitra tosaensis, Squinabollum fossile, Thanarla pulchra, Torculum dengoi and Obeliscoites maximus subzones, Hemicryptocapsa prepolyhedra Zone and Hemicryptocapsa polyhedra Zone) have been proposed for the interval investigated.

Key words: Western Carpathians, Pieniny Klippen Belt, Cretaceous, Radiolaria, biostratigraphy.

Introduction

The Cretaceous deposits in the Polish part of the Pieniny Klippen Belt have been a subject of detailed lithological and biostratigraphical studies since the early 50s. The previous authors dealing with the micropaleontological investigations, focused their interests on foraminifers as the most useful microfauna for biostratigraphical purposes. Coccoliths and calpionellids were also used for dating of calcareous deposits. During these studies the presence of radiolarian fauna was observed in the different lithotypes of the Cretaceous deposits. Despite this, there was no paleontological description and application of the radiolarian fauna for the biostratigraphy.

The first investigations concerning the Radiolaria from the Cretaceous deposits of the Polish part of the Pieniny Klippen Belt were initiated by the author in the early 90s (M. Bąk 1993a,b).

This paper summarizes the researches which were first begun towards the end of 1992. Its aim is to present a radiolarian biostratigraphy in the Polish part of the Pieniny Klippen Belt.

Geological setting

The investigations of Cretaceous Radiolaria in the Polish part of the Pieniny Klippen Belt have been carried out in the Pieniny, Branisko, Niedzica and Czorsztyn successions.

Eighteen profiles with radiolarian fauna were chosen for analyses. These sections are located in the Niedzica, Krościenko, Szczawnica, Jaworki, Sromowce, Falsztyn, Dursztyn, Szaflary, and Stare Bystre areas (Fig. 1). These are:

Macelowa-Osice (McO), Magierowa Skałka Klippe (Mag), Orlica (Or) and Podskalnia Góra Mt. (Pg) sections in the Pieniny Succession; Kietowy stream (Ki), Stare Bystre (Sb) and Kapuśnica (Kp) sections in the Branisko Succession; Bukowiny Valley (Bw), Bukowiny Hill (Bd) and Kosarzyska Valley (Kos) sections in the Niedzica Succession, and Czerwona Skała Mt. (CSk), Lorencowe Klippes (Lor), Szaflary Quarry (Sz), Żłobowy creek (Zł), Falsztyn (Fl), Czorsztyn (Cz), Halka (H) and Niedziczanka creek (Nd) sections in the Czorsztyn Succession (for detail description of their location and lithology see Birkenmajer 1954, 1958, 1977; Birkenmajer & Jednorowska 1984, 1987; Gasiński 1988; K. Bąk 1992, 1993, 1995, 1998; M. Bąk 1995, 1996).

In the profiles examined, the radiolarian fauna has been recorded in the deposits of the Kapuśnica, Pomiedznik, and the Jaworki formations (M. Bąk 1993b, 1995, 1996) (Fig. 2).

The radiolarian fauna is present within both members of the Kapuśnica Formation. Within the Brodno Member which is scarcely represented among the deposits in the Polish part of the Pieniny Klippen Belt (Birkenmajer 1977), the radiolarian fauna is present but very rare. In the deposits of the Rudina Member, radiolarian skeletons are present in green and black marls and marly shales. They are abundant and generally well-preserved.

Abundant and well-preserved radiolarian fauna have been found in the Pomiedznik Formation, showing the high taxa diversification in both (lower and upper) members. These deposits consist of grey-green marly shales and marls intercalated with thin layers of green marly limestone containing lenticles of black cherts in its lower part (Gasiński 1988), and marly shales, marls and marly limestones without cherts in its upper part.

Within the deposits of the Jaworki Formation, the radiolarian skeletons are present in the deposits of the Brynczkowa Marl Member, Skalski Marl Member, Magierowa Marl Member, Trawne Member, Snežnica Siltstone Mem-

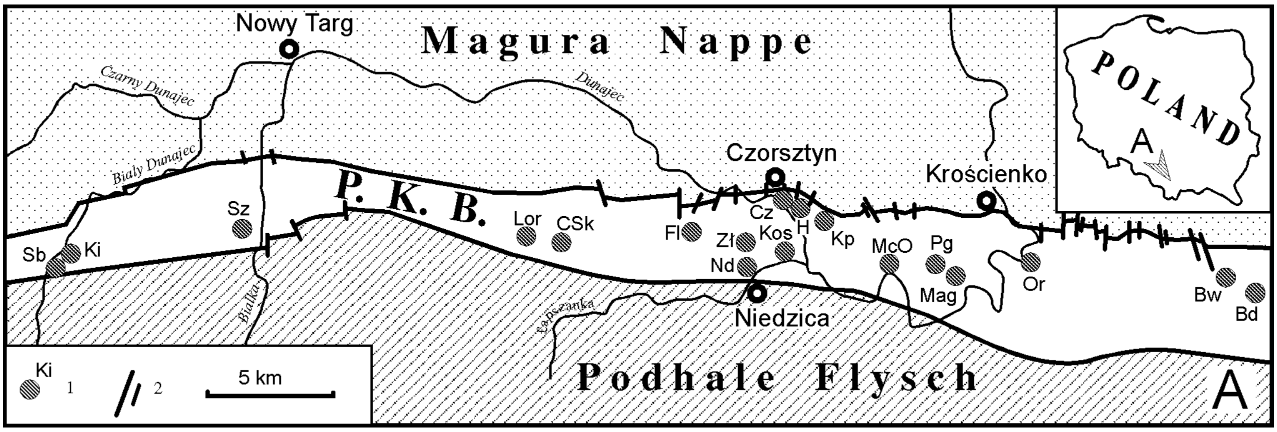


Fig. 1. Location of the sections investigated in the Pieniny Klippen Belt (geology after Birkenmajer (1977) — simplified): 1 — designation of the profile, 2 — faults.

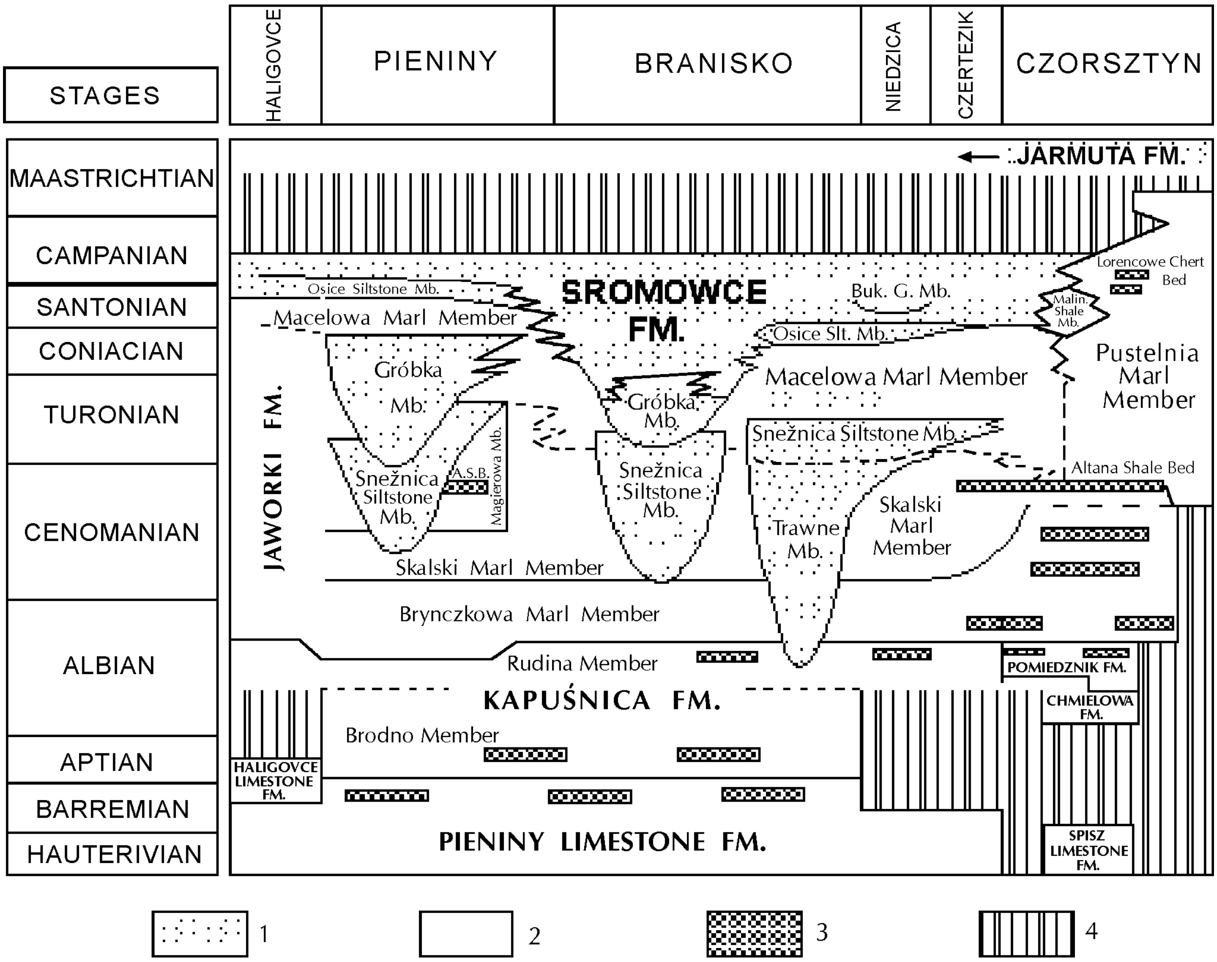


Fig. 2. Age and mutual relationships of Cretaceous lithostratigraphic units in the Pieniny Klippen Belt, Poland (after Birkenmajer & Jednorowska (1987)): 1 — flysch and flyshoid development, 2 — marl and limestone, 3 — radiolaria shale and chert, 4 — hiatus.

ber, Macelowa Marl Member, and the Pustelnia Marl Member.

The Radiolaria within the Brynczkowa Marl Member, Skalski Marl Member (excluding Altana Shale Bed) and also within Trawne Member deposits are rare and moderately to poorly preserved. The radiolarians found within the Altana Shale Bed deposits (black-blue, greenish and black shales and marls) are abundant but low in diversity and poorly preserved.

The radiolarian fauna is abundant in the Magierowa Marl Member deposits which correspond to the Altana Shale Bed

(Birkenmajer 1977). Well-preserved siliceous specimens are present in green and grey shales and marly shales. Radiolarians in black shales are also abundant but often difficult to recognize because of ferritization and pyritization processes.

The radiolarians are generally rare also in the deposits of the Snežnica Siltstone Member. Only the Upper Cenomanian deposits (blue-grey and green shale marls) are especially enrich in well-preserved radiolarian skeletons, also pyritized.

The radiolarian skeletons within the Macelowa Marl Member deposits are rare and mostly poorly preserved because of calcification processes. Well preserved and diversified radiolarian fauna is present only in the red marls corresponding to the Lower Turonian.

The deposits belonging to the Pustelnia Marl Member contain only very scarce poorly preserved, mostly calcified radiolarian skeletons.

The radiolarian skeletons are also scarce, poorly preserved and mostly calcified within the Lorencowe Chert Bed deposits.

Radiolarian assemblage

Seventy seven radiolarian species have been recorded within the Cretaceous deposits of the Pieniny Klippen Belt ranging from Lower Albian to Santonian age. Twenty genera and 53 species of Nassellaria, and 11 genera and 24 species of Spumellaria were recognized (M. Bąk 1993, 1995, 1996).

The assemblages, in all successions investigated, are dominated by cryptocephalic and cryptothoracic Nassellaria belonging to the genera *Holocryptocanium, Hemicryptocapsa, Cryptamphorella, Dorypyle, Hiscocapsa, Trisyringium* and *Squinabollum.* Multisegmented Nassellaria are also common and are represented by the genera *Dictyomitra, Thanarla, Pseudodictyomitra, Stichomitra, Xitus, Obeliscoites* and *Torculum* (Plate I). Spumellaria are less common in the studied deposits. The most abundant are the specimens belonging to the families Actinommidae, Praeconocaryommidae, Xiphostylidae (genera *Staurosphaeretta* and *Triactoma*), and Dactyliosphaeridae (*Dactyliodiscus*, *Godia* and *Dactyliosphaera*). The remaining Spumellaria belong to the genera *Hexapyramis, Cavaspongia, Pseudoaulophacus, Patellula, Paronaella* and *Crucella.*

Among all successions investigated, the radiolarians are most abundant and diversified within the deposits of the Czorsztyn Succession, and generally scarce in the deposits of the Pieniny Succession.

The content of radiolarian specimens is not uniform in the deposits investigated. One of the reasons might be the lithology which predestines the preservation of the siliceous microfossils, and the second could be the radiolarian faunas radiation, and turnovers. Both might reflect the ecological response of the biota to global climatic and sea level changes which occurred during mid-Cretaceous times.

Two great changes in the radiolarian assemblage can be recorded within the studied deposits. The beginning of an important radiation of Radiolaria is observed in the Middle Albian (Ticinella primula foraminiferal Zone; K. Bąk 1998). Many of new species had their first appearance in the Middle and the Late Albian. The maximum of differentiation in the radiolarian assemblage is observed within the Vraconian deposits (Rotalipora ticinensis-Planomalina buxtorfi, Planomalina buxtorfi-Rotalipora appenninica foraminiferal zones; K. Bąk 1998). Starting from the upper part of the P. buxtorfi-R. appenninica foraminiferal Zone, a relative decrease in the number of species has been observed. It illustrates the transition of radiolarians toward the Albian/Cenomanian boundary. During this period the radiolarian faunas in the Czorsztyn, Branisko and Niedzica successions show great similarities between them. The same characteristic taxa representing the suborder Nassellaria as cryptothoracic and cryptocephalic forms from the genera *Holocryptocanium, Hemicryptocapsa, Squinabollum* and *Cryptamphorella* are most abundant, together with other common genera such as *Dictyomitra, Pseudodictyomitra, Thanarla, Stichomitra, Torculum,* and *Xitus.*

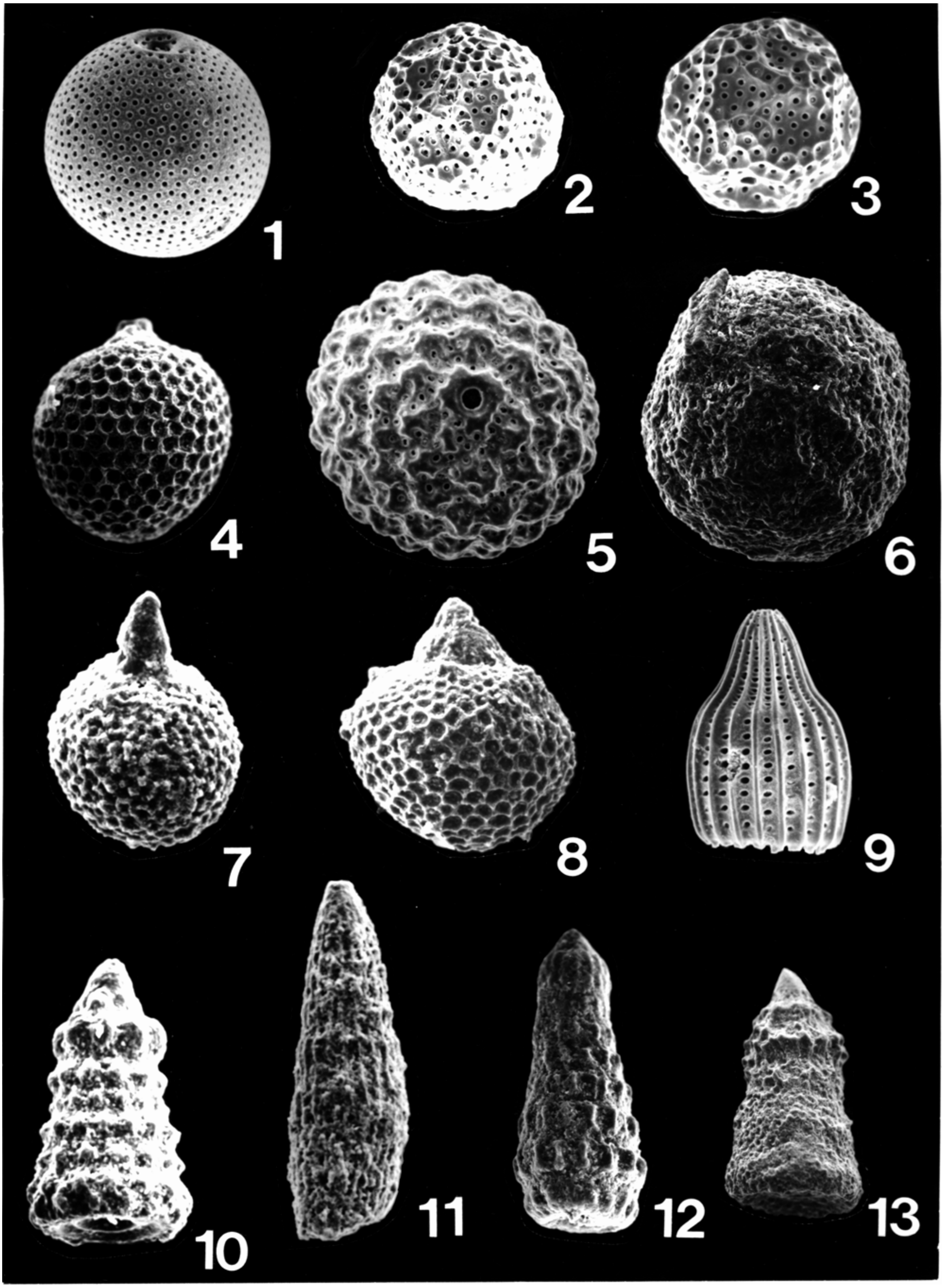
The next radiolarian changes took place around the Cenomanian/Turonian boundary. They started in the Late Cenomanian (Rotalipora cushmani foraminiferal Zone; K. Bąk 1998). In this period, the radiolarian assemblage in the Pieniny Succession is similar to those from the Czorsztyn, Niedzica and Branisko successions but it also contains forms described only from the Silesian and the Skole units of the Outer Flysch Carpathians (*Praeconocaryomma lipmanae, Godia* sp., *Diacanthocapsa* sp.; M. Bąk 1994; Górka 1996).

Radiolarian biostratigraphy

The radiolarian zonation has been established on the basis of analysis of the vertical distribution of the taxa which were recognized in the studied sections. Though the purpose of this zonation does not pretend to be applicable to the whole Carpathian paleobiogeographic realm, it can be regarded as a calibration-tool to which local zonations from other regions could be compared.

Procedures

It is known that radiolarian abundance and preservation, especially in land sections, which underwent a deep burial diagenesis, is largely dissolution-controlled. That is why the absence of a species from a certain interval of a section does not necessarily have a chronological significance. For the same reason, the first and the last occurrences of a taxon may differ from one section to another, making these events, usually used in the biostratigraphic zonation, worthless. In order to know whether the absence from a certain interval is consistent or not it is necessary to systematically analyse the occurrences of species in all available sections and establish which species are mutually exclusive and represent consistent absences from certain stratigraphic intervals, and which species really co-occur. The stratigraphically successive sets of maximum number of co-occurring or potentially co-occurring species represent Unitary Associations (U.A.) (Guex & Davaud 1984). The resulting Unitary Associations differ from each other by containing unique and mutually exclusive assemblages of species or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species pairs. These procedures were thoroughly discussed by Baumgartner (1984a,b), who applied the U.A. method for Middle Jurassic-Early Cretaceous radiolarians.

A database records the distribution of 53 species in 17 horizons selected carefully from 210 samples containing the radiolarian fauna, collected from 18 sections. The samples chosen for the analysis contain abundant and well preserved Radiolaria. These data were processed with the BioGraph 2.02 computer program (Savary & Guex 1991) based on the Unitary Associations method. The program produced a sequence of 11 U.A. (Fig. 3).

The resulting range charts (Figs. 4, 5) are used to construct chronologically meaningful zones and subzones, in which each of these Unitary Associations is defined by the totality of its characteristic species pairs. Because only samples with the most abundant radiolarians have been chosen for the analysis, the Unitary Association method has been combined with the method based on the first and the last appearance of taxa in the profiles investigated (Fig. 6).

Proposed zonation

The combination of empirical and deterministic methods enabled us to establish the zonation proposed herein. The analysis has allowed the definition of three radiolarian zones and five subzones for the Lower Albian–Upper Turonian interval. The zonal units presented here have typical characteristics of the concurrent range zones.

Holocryptocanium barbui Zone (Schaaf 1985)
Index taxon: *Holocryptocanium barbui* Dumitrică

Definition: The base of this zone is defined as the first appearance of *Holocryptocanium barbui*. The upper limit of the zone is defined as the first appearance of *Hemicryptocapsa prepolyhedra*.

Faunal character: In this zone *H. barbui* has its maximum abundance within the Pieniny Klippen Belt deposits. The radiolarian fauna is the most diverse in this unit; over 40 species make their first appearance in this zone (e.g. *Torculum coronatum, Dictyomitra gracilis, Pseudodictyomitra pseudomacrocephala*). The zone represents an important period of the faunal renewal.

Plate I: Radiolarian microfauna in the Albian through Turonian deposits from the Pieniny Klippen Belt. **Fig. 1.** *Holocryptocanium barbui* Dumitrică, Ki-140057, ×170. **Figs. 2, 3.** *Hemicryptocapsa prepolyhedra* Dumitrică, 1 — Ki-140017, 2 — Ki-140018, ×200. **Fig. 4.** *Cryptamphorella macropora* Dumitrică, Cz-60038, ×330. **Fig. 5.** *Holocryptocanium tuberculatum* Dumitrică, Ki-140040, ×400. **Fig. 6.** *Hemicryptocapsa polyhedra* Dumitrică, Mag-305022, ×400. **Fig. 7.** *Squinabollum fossile* (Squinabol), Sb-160345, ×200. **Fig. 8.** *Trisyringium echitonicum* (Aliev), Cz-60112, ×200. **Fig. 9.** *Thanarla pulchra* (Squinabol), Ki-140048, ×170. **Fig. 10.** *Xitus mclaughlini* (Pessagno), Fl-310351, ×200. **Fig. 11.** *Dictyomitra montisserei* (Squinabol), Fl-310380, ×200. **Fig. 12.** *Pseudodictyomitra pseudomacrocephala* (Squinabol), Fl-292038, ×200. **Fig. 13.** *Torculum coronatum* (Squinabol), Sb-70351, ×200.

Remarks: This zone has been created by Schaaf (1985) for a different time interval (only for Lower Albian).

Age: This zone corresponds to the Ticinella roberti to Rotalipora reicheli foraminiferal zones (K. Bąk 1998) (Lower Albian to Middle Cenomanian) in the deposits investigated in the Polish part of the Pieniny Klippen Belt. However, according to the investigation carried out on the Slovak territory in the Manín units (Ožvoldová & Peterčáková 1992) the *H. barbui* first appears within the Hauterivian.

Stichomitra tosaensis new subzone
Index taxon: *Stichomitra tosaensis* Nakaseko & Nishimura

Definition: The lower boundary of this subzone is defined by the first appearance of the index species.

Faunal character: This zone is characterized by co-occurrence of *Holocryptocanium barbui, Pseudodictyomitra pentacolaensis, Stichomitra mediocris, Thanarla brouweri* and *Stichomitra communis. Cryptamphorella macropora, Holocryptocanium geysersensis* and *Holocryptocanium tuberculatum* make their first appearance in the upper part of the subzone.

Age: This subzone corresponds to the Ticinella roberti to Ticinella primula foraminiferal zones (K. Bąk 1998) (Lower to Upper Albian).

Squinabollum fossile new subzone
Index taxon: *Squinabollum fossile* (Squinabol)

Definition: The base of this subzone is defined by the first occurrence of *Squinabollum fossile*.

Faunal character: *Dictyomitra formosa, Dictyomitra montisserei* and *Torculum coronatum* make their first occurrence within this subzone. Simultaneously, the last occurrence of *Pseudodictyomitra carpatica* takes place here.

Age: This subzone corresponds to the Biticinella breggiensis foraminiferal Zone (K. Bąk 1998) (Upper Albian).

Thanarla pulchra new subzone
Index taxon: *Thanarla pulchra* (Squinabol)

Definition: The first appearance of *Thanarla pulchra* defines the lower boundary of this subzone.

Faunal character: This unit is characterized by co-occurrence of many characteristic pairs of species (U.A.3–U.A.4; Figs. 5, 6). The first appearances of *Holocryptocanium geysersensis, Dictyomitra montisserei, Xitus mclaughlini, Pseudoaulophacus sculptus, Thanarla veneta* and *Pseudodictyomitra pseudomacrocephala* take place within the unit. The last occurrence of *Crucella aster* is also observed.

Age: This subzone corresponds to the Rotalipora subticinensis-Rotalipora ticinensis foraminiferal Zone and lower part of the Rotalipora ticinensis-Planomalina praebuxtorfi foraminiferal Zone (Gasiński 1988; K. Bąk 1998) (Upper to uppermost Albian (Vraconian)).

Torculum dengoi new subzone
Index taxon: *Torculum dengoi* (Schmidt-Effing)

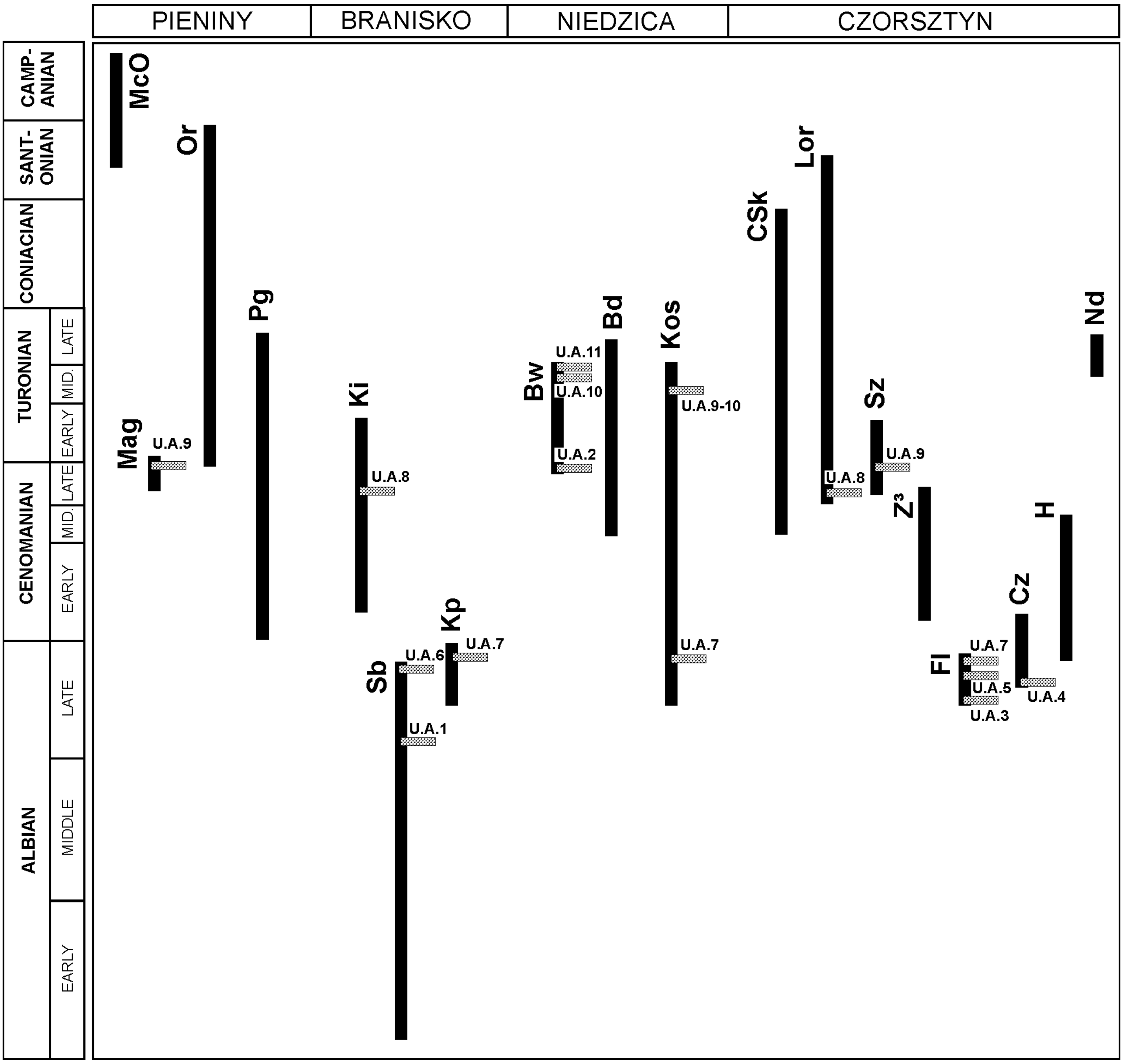


Fig. 3. Stratigraphic correlation of all profiles investigated. The samples with abundant radiolarian fauna taken for the Unitary Associations analysis with identified U.A. are indicated as grey rectangle. The calibration is based on the planktonic foraminiferal zonation after Caron (1985) modified in the Pieniny Klippen Belt area by Birkenmajer & Jednorowska (1987), Gasiński (1988) and K. Bąk (1992, 1993, 1998). For explanation of shortened profiles names see text.

Definition: The lower boundary of this subzone is marked by the first occurrence of *Torculum dengoi*, the total range of which is included within this unit.

Faunal character: The events which characterize this unit are the final appearances of many species including *Stichomitra mediocris, Thanarla brouweri, Hexapyramis pantanelli, Pseudoaulophacus sculptus, Thanarla veneta, Dictyomitra gracilis, Crolanium pulchrum, Torculum coronatum, Godia unica* and *Pseudodictyomitra paronai*. Only two radiolarian species: *Dactyliosphaera acutispina* and *Dictyomitra pulchra* make their first appearance within this unit.

Age: This subzone corresponds to the upper part of the Rotalipora ticinensis-Planomalina praebuxtorfi foraminiferal Zone trough the Rotalipora appenninica foraminiferal Zone (Gasiński 1988; K. Bąk 1998) (uppermost Albian (Vraconian)).

Obeliscoites maximus new subzone

Index taxon: *Obeliscoites maximus* (Squinabol)

Definition: The lower boundary of this subzone is defined as the first appearance of *Obeliscoites maximus*.

Faunal character: The co-occurrence *of Holocryptocanium barbui, Holocryptocanium tuberculatum, Pseudodictyomitra pseudomacrocephala, Squinabollum fossile, Stichomitra communis, Thanarla pulchra* and *Xitus mclaughlini* is observed within this unit.

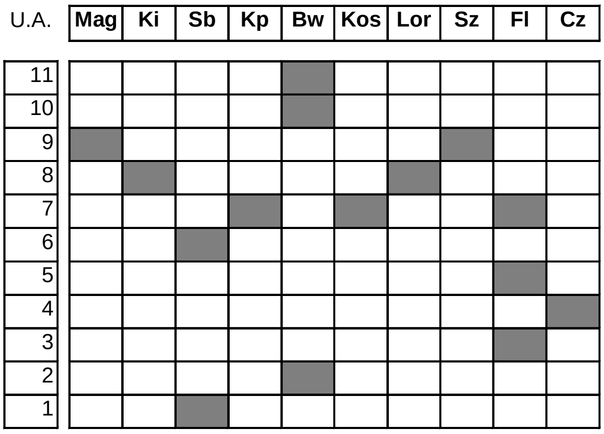


Fig. 4. Reproducibility table. Grey rectangles represent these Unitary Associations, which were strictly identified in the sections studied. For explanation of shortened profiles names see text.

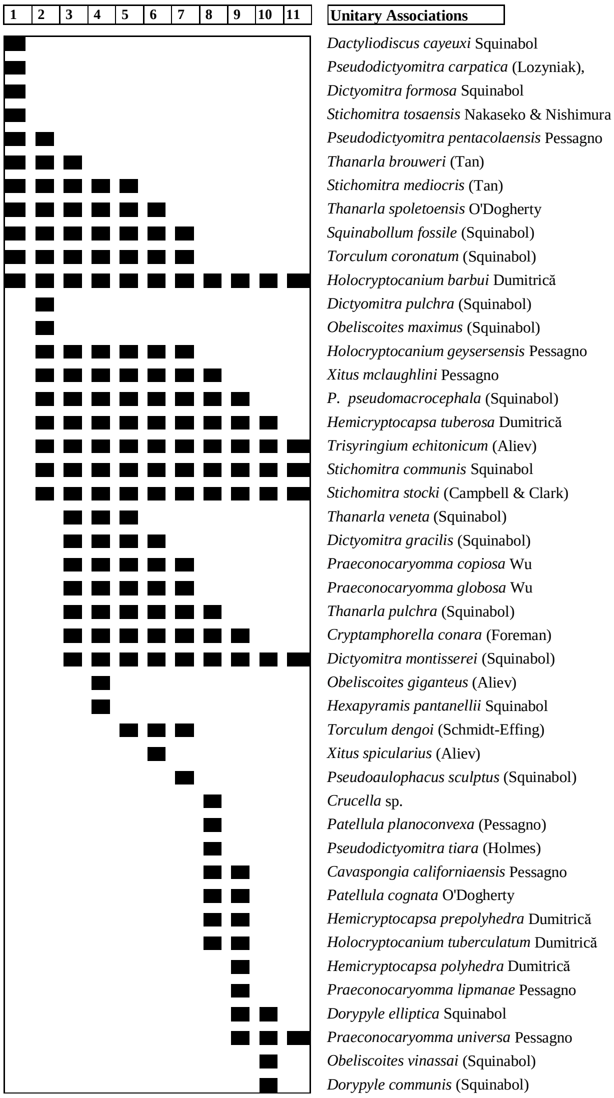


Fig. 5. Mid-Cretaceous range chart for suborders Nassellaria and Spumellaria based on the Unitary Associations.

Age: This subzone corresponds to the Rotalipora globotruncanoides and the lower part of the Rotalipora reicheli foraminiferal zones (K. Bąk 1998) (Lower to Middle Cenomanian).

Hemicryptocapsa prepolyhedra new zone
Index taxon: *Hemicryptocapsa prepolyhedra* Dumitrică

Definition: The lower boundary of this zone is marked by the first appearance of the index species.

Faunal character: The first appearances of *Hemicryptocapsa tuberosa, Pseudodictyomitra tiara, Patellula planoconvexa* and *Cavaspongia californiaensis* take place within the zone. The last occurrence of *Thanarla pulchra* is observed in the upper part of this zone. This unit is characterized by co-occurrence of characteristic pairs of species (U.A.8; Figs. 5, 6).

Age: This zone extends from the upper part of the foraminiferal Rotalipora reicheli to the lower part of the Rotalipora cushmani zones (K. Bąk 1998) (Middle to Upper Cenomanian).

Hemicryptocapsa polyhedra new zone
Index taxon: *Hemicryptocapsa polyhedra* Dumitrică

Definition: The lower boundary of this zone is defined at the first appearance of *Hemicryptocapsa polyhedra*.

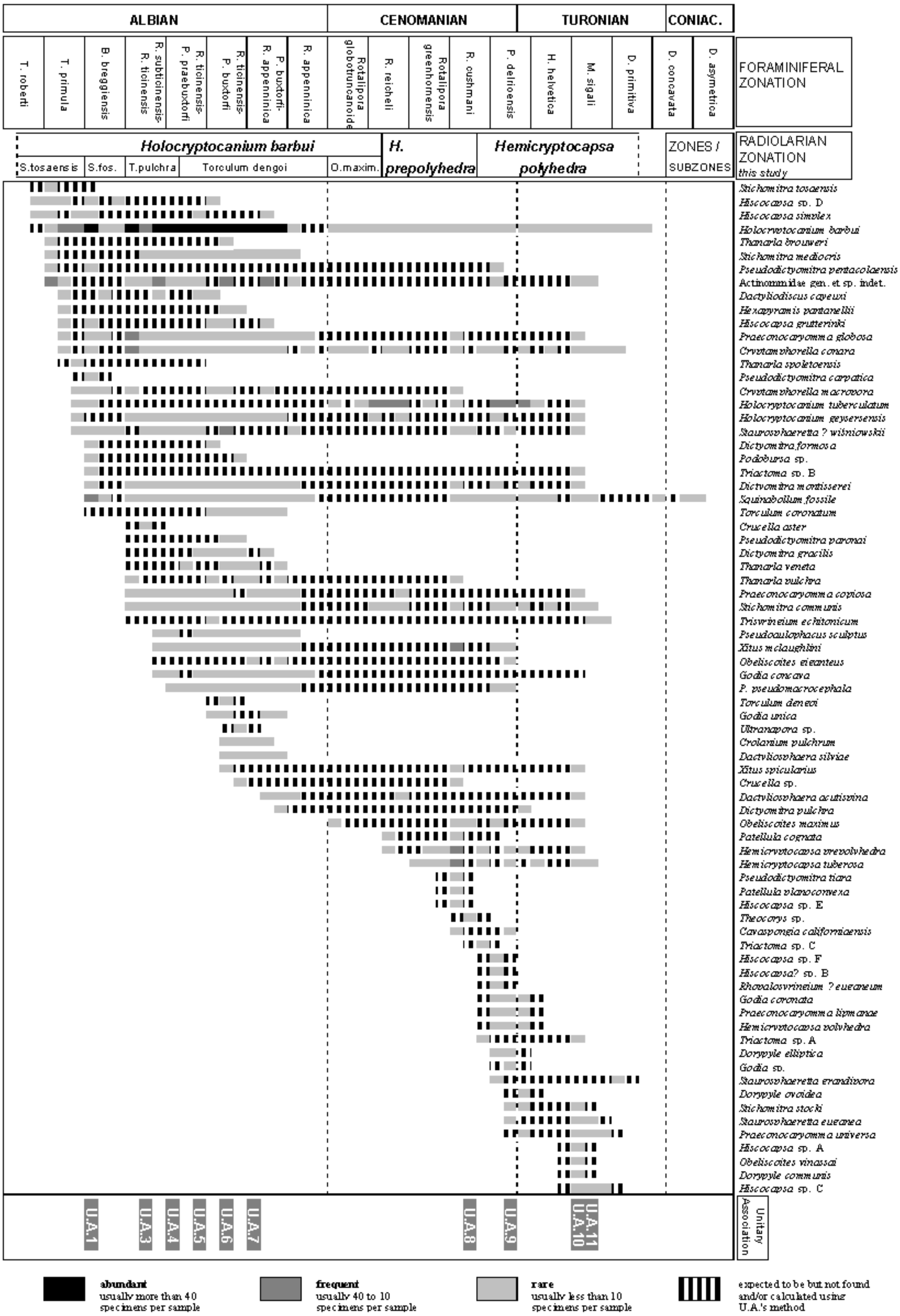
Faunal character: This unit is characterized by the co-occurrence of characteristic pairs of species (U.A.9–U.A.11; Figs. 5, 6). The zone is characterized by relative decrease in the number of species, which is characteristic of the transition of radiolarians from the Cenomanian to Turonian.

Age: This zone extends from the upper part of the foraminiferal Rotalipora cushmani to approximately the lower part of Dicarinella primitiva zones (K. Bąk 1998) (Upper Cenomanian to Upper Turonian).

Radiolarian correlation

The radiolarian assemblage, including all Radiolaria recovered in the Pieniny, Branisko, Niedzica, and Czorsztyn successions, has been used for comparison with radiolarian biozonations from different regions.

The only zonal scheme for the Carpathians has been proposed by Dumitrică (1975). This author recognized two assemblages*: Holocryptocanium barbui-Holocryptocanium tuberculatum* and *Holocryptocanium nanum-Excentropyloma cenomana* for the Late Cenomanian–earliest Turonian interval. These radiolarian assemblages show great similarities with the association presented in this work based on the co-occurrence of *H. barbui, H. tuberculatum, Squinabollum fossile* and another cryptocephalic and cryptothoracic Nassellaria. Moreover, the associated occurrence of some multi-segmented Nassellaria from the genera as *Dictyomitra, Pseudodictyomitra, Stichomitra, Thanarla* and *Xitus* are abundant in the Pieniny Klippen Belt radiolarian associations. There is no evidence for distinguishing the upper assemblage in the


ALBIAN
CENOMANIAN
TURONIAN
CONIAC.
T. roberti
T. primula
B. breggiensis
R. subticinensis-R. ticinensis
R. ticinensis-P. praebuxtorfi
R. ticinensis-P. buxtorfi
P. buxtorfi-R. appenninica
R. appenninica
Rotalipora globotruncanoides
R. reicheli
Rotalipora greenhornensis
R. cushmani
P. deltioensis
H. helvetica
M. sigali
D. primitiva
D. concavata
D. asymetrica
FORAMINIFERAL ZONATION
Holocryptocanium barbui
H. prepolyhedra
Hemicryptocapsa polyhedra
ZONES / SUBZONES
S.tosaensis
S.fos.
T.pulchra
Torculum dengoi
O.maxim.
RADIOLARIAN ZONATION this study
Stichomitra tosaensis
Hiscocapsa sp. D
Hiscocapsa simplex
Holocryptocanium barbui
Thanarla brouweri
Stichomitra mediocris
Pseudodictyomitra pentacolaensis
Actinommidae gen. et sp. indet.
Dactyliodiscus cayeuxi
Hexapyramis pantanellii
Hiscocapsa grutterinki
Praeconocaryomma globosa
Cryptamphorella conara
Thanarla spoletoensis
Pseudodictyomitra carpatica
Cryptamphorella macropora
Holocryptocanium tuberculatum
Holocryptocanium geysersensis
Staurosphaeretta ? wisniowskii
Dictyomitra formosa
Podobursa sp.
Triactoma sp. B
Dictyomitra montisserei
Squinabollum fossile
Torculum coronatum
Crucella aster
Pseudodictyomitra paronai
Dictyomitra gracilis
Thanarla veneta
Thanarla pulchra
Praeconocaryomma copiosa
Stichomitra communis
Trisyringium echitonicum
Pseudoaulophacus sculptus
Xitus mclaughlini
Obeliscoites eleganteus
Godia concava
P. pseudomacrocephala
Torculum dengoi
Godia unica
Ultranapora sp.
Crolanium pulchrum
Dactyliosphaera silviae
Xitus spicularius
Crucella sp.
Dactyliosphaera acutispina
Dictyomitra pulchra
Obeliscoites maximus
Patellula cognata
Hemicryptocapsa prepolyhedra
Hemicryptocapsa tuberosa
Pseudodictyomitra tiara
Patellula planoconvexa
Hiscocapsa sp. E
Theocorys sp.
Cavaspongia californiaensis
Triactoma sp. C
Hiscocapsa sp. F
Hiscocapsa? sp. B
Rhopalosyringium ? euganeum
Godia coronata
Praeconocaryomma lipmanae
Hemicryptocapsa polyhedra
Triactoma sp. A
Dorypyle elliptica
Godia sp.
Staurosphaeretta grandipora
Dorypyle ovoidea
Stichomitra stocki
Staurosphaeretta euganea
Praeconocaryomma universa
Hiscocapsa sp. A
Obeliscoites vinassai
Dorypyle communis
Hiscocapsa sp. C
U.A.1
U.A.3
U.A.4
U.A.5
U.A.6
U.A.7
U.A.8
U.A.9
U.A.10
U.A.11
Unitary Association
abundant usually more than 40 specimens per sample
frequent usually 40 to 10 specimens per sample
rare usually less than 10 specimens per sample
expected to be but not found and/or calculated using U.A.'s method

presented material. Although the above mentioned species co-existing in both assemblages were distinguished by Dumitrică, and they also appeared in the Upper Turonian deposits of the Pieniny Klippen Belt, the index taxa of the upper assemblage and also *Alievium superbum* the first occurrence of which delineates the base of the *H. nanum-E. cenomana* assemblage, has not been found.

The first radiolarian biozonation of the Early to mid-Cretaceous for the Mediterranean region was proposed by O'Dogherty (1994). This author recognized five radiolarian zones and seven subzones for the Barremian–Early Turonian interval. The studied radiolarian assemblage shows great similarities with this zonation for the Middle Albian to uppermost Cenomanian (Romanus, Missilis and Anisa subzones of Spoletoensis Zone, and Spica and Biacuta subzones of Silviae Zone), based on co-occurrence of numerous Nassellaria and Spumellaria species, although the range occurrence of some of them differs in both regions. There was no evidence for distinguishing the lower Asseni and Turbocapsula zones as well as the uppermost Superbum Zone in the association investigated.

Aliev (1965, 1967) initiated the studies of Early and mid-Cretaceous radiolarians from the eastern part of the Greater Caucasus, but precise biostratigraphic scales were not available. Recently Vishnevskaya (1993) proposed a zonation for the Late Jurassic–Late Cretaceous interval in the Caucasus region. She proposed two radiolarian biozones for the interval investigated in that work. This radiolarian association shows great resemblance with the presented fauna. The Pseudodictyomitra pseudomacrocephala-Holocryptocanium barbui Zone of Vishnevskaya (1993) can be well correlated with the assemblage investigated, based on the co-occurrence of the index species with abundant cryptothoracic and cryptocephalic Nassellaria, and also *Stichomitra mediocris, Thanarla veneta, Thanarla elegantissima (= T. pulchra)*. But its boundaries differ in my assemblage, because of the different range of *P. pseudomacrocephala*. Some of the species included in the Alievium superbum-Thanarla veneta radiolarian Zone of Vishnevskaya as *T. veneta* and *Amphipyndax stocki (= Stichomitra stocki)* are also present in the assemblage investigated. However, the first and last appearance of *Alievium superbum* have not been observed in this zone in the assemblage investigated, and the presence of *Thanarla veneta* is observed only in the latest Albian.

Vishnevskaya (1988) also proposed a first zonal scheme for the Cretaceous of eastern Russia which has been slightly modified by her in 1993 (Vishnevskaya 1993). That zonation only distinguishes two zones for the mid-Cretaceous. The faunal assemblage recorded from the Russian Pacific Rim can be compared with the fauna investigated, on the basis the co-existence of *Xitus spicularius, Holocryptocanium barbui, Thanarla elegantissima (= Thanarla pulchra), T. veneta, Amphipyndax mediocris (= Stichomitra mediocris), Pseudodictyomitra pseudomacrocephala* in both associations. Its boundaries differ in my assemblage, because of the different range of *P. pseudomacrocephala.*

The first radiolarian zonation of the Upper Jurassic to mid-Cretaceous deposits in Japan was proposed by Nakaseko & Nishimura (1981). These authors recognized the *Holocryptocanium barbui-H. geysersensis* assemblage of Dumitrică (1975) which can be correlated with the association investigated on the basis of the coexistence of index species and also another cryptothoracic Nassellaria which are also very abundant there as in Carpathians deposits (Dumitrică 1975; M. Bąk 1994), as well as *Pseudodictyomitra pseudomacrocephala, Archeodictyomitra simplex (= Dictyomitra montisserei), A. vulgaris (= Dictyomitra montisserei), Novixitus weyli (= Xitus mclaughlini), Praeconocaryomma universa, Thanarla elegantissima (= Thanarla pulchra), T. veneta*, and *T. brouweri*. The upper assemblage can also be recognized in my material, on the basis of the presence of *Patellula planoconvexa*. Although the faunal composition is quite similar to that in the Pieniny Klippen Belt, the correlation is very difficult due to discrepancies in the first or last occurrences data. The similar discrepancies are observed during the comparison of the assemblage investigated with those of Taketani (1982) and Tumanda (1989) who have been described radiolarians from the Cretaceous deposits on Hokkaido Island.

The radiolarian zonation proposed by Pessagno (1976, 1977) for the California Coast Ranges is somewhat difficult to compare with the Pieniny Klippen Belt region due to certain discrepancies in the occurrence ranges of the species. In spite of these, the radiolarian fauna seems to be similar to that of the Pieniny Klippen Belt region on the basis of the co-occurrence of the taxa: *Orbiculiforma maxima (= Dactyliosphaera maxima), Pseudodictyomitra pseudomacrocephala, Thanarla veneta, Spongocapsula zamoraensis (= Torculum coronatum), Thanarla elegantissima (= Thanarla pulchra), Archaeodictyomitra sliteri (= Dictyomitra montisserei), Holocryptocanium barbui, H. geysersensis, Praeconocaryomma universa,* and *Cavaspongia californiaensis*.

The first attempt to establish a zonation based on radiolarians for the Cretaceous sediments from the Pacific Ocean was proposed by Moore (1973). The radiolarian assemblages studied by Moore show great similarities with those from the Pieniny Klippen Belt region especially for the zones RK 4 and RK 5 on the basis of the co-occurrence of many taxa in them.

Foreman (1973, 1975) established a zonation for the Cretaceous sediments recovered at different DSDP sites in the Pacific Ocean. She proposed two radiolarian zones for the interval investigated. The radiolarian fauna recorded in the Pieniny Klippen Belt region can be included into both zones although the index species do not appear in the assemblage investigated. Only the boundary between the zones can be recognized on

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Fig. 6. Occurrence range chart of all radiolarian species recorded in the Albian to Coniacian deposits in the Pieniny Klippen Belt successions based on their first and the last appearance within the deposits investigated and their co-occurrence based on the Unitary Associations. Abbreviations: S. tosaensis = *Stichomitra tosaensis*; S.fos. = *Squinabollum fossile*; T. pulchra = *Thanarla pulchra*; O. maxim. = *Obeliscoites maximus*; H. prepolyhedra = *Hemicryptocapsa prepolyhedra*. The planktonic foraminiferal zonation after Caron (1985) modified in the Pieniny Klippen Belt area by Birkenmajer & Jednorowska (1987), Gasiński (1988) and K. Bąk (1992, 1993, 1998).

the basis of the almost simultaneous appearance of *Thanarla veneta* and *Pseudodictyomitra pseudomacrocephala* in my assemblage.

Some years later, Schaaf (1981) provided stratigraphic information on radiolarian faunas from the Valanginian–Early Cenomanian interval of the mid-Pacific Ocean. This author proposed a slight modification for the zonal scheme of Foreman (1975) for the Hauterivian–Aptian interval.

The first zonation for the Cretaceous sediments from the Indian Ocean was established by Renz (1974) on the basis of data from the eastern Indian Ocean. He distinguished three radiolarian assemblages in the approximately Valanginian to Lower Albian interval. The radiolarian fauna from the uppermost assemblage of Renz shows slight similarities to the association investigated, but the ranges of occurrence of the taxa are different.

Radiolarian fauna from the north Atlantic Ocean sediments was studied recently by Thurow (1988) who applied Schaaf's (1985) zonation with slight modification. Although the radiolarian fauna described by Thurow shows many similarities with the fauna studied in the presented work, his zonal scheme is difficult to recognize in the Pieniny Klippen Belt region.

In the middle 80s, two composite zonations were proposed simultaneously: Sanfilippo & Riedel's (1985) and Schaaf's (1985). Sanfilippo & Riedel (1985) based their zonation on Cretaceous radiolarians from different DSDP sites and two land sections, from Japan and Italy. This zonation is comparable to those proposed by Foreman (1975) and Schaaf (1981). Two radiolarian biozones *Acaeniotyle umbilicata* and *Obesacapsula somphedia* (Sanfilippo & Riedel 1985), among the all zones distinguished can be correlated with the assemblage investigated, on the basis of coexisting species, although both index species are lacking.

Schaaf (1985) in his radiolarian biozonation proposed eleven zones in the Lower Aptian–uppermost Turonian interval. The first appearance data of the index taxa of Spongocapsula zamoraensis (= Torculum coronatum), Holocryptocanium barbui, Mita gracilis (= Dictyomitra gracilis), Pseudodictyomitra pseudomacrocephala and Thanarla veneta zones are present in the assemblage studied, but they do not appear in the same succession as presented by Schaaf. As a consequence, the radiolarian zones defined by Schaaf should appear in my assemblage in a different order.

Conclusions

The results of the studies presented here are based on micropaleontological analysis of 210 samples from 18 profiles. The radiolarian fauna has been recorded in the deposits of the Kapuśnica, Pomiedznik, and Jaworki formations in the Czorsztyn, Niedzica, Branisko and Pieniny successions. A systematic search of all different radiolarian morphotypes in the samples investigated proved the diversity of radiolarian fauna. Twenty genera and 53 species from the suborder Nassellaria, and 11 genera and 24 species from the suborder Spumellaria have been recognized within the Lower Albian through Santonian deposits. The most abundant and diverse radiolarian assemblage has been recorded within the Middle Albian to Middle Turonian interval.

The radiolarian assemblage, in all successions investigated, is dominated by the cryptocephalic and cryptothoracic nassellarians belonging to the genera: *Holocryptocanium, Hemicryptocapsa, Cryptamphorella, Dorypyle, Hiscocapsa, Trisyringium* and *Squinabollum.* Spumellarians are less common in the studied deposits. The most abundant are the specimens belonging to the families Actinommidae, Praeconocaryommidae, Xiphostylidae (genera *Staurosphaeretta* and *Triactoma*), and Dactyliosphaeridae (*Dactyliodiscus*, *Godia* and *Dactyliosphaera*).

Two great changes in the radiolarian assemblage can be recorded in the Middle to uppermost Albian, and in the Late Cenomanian to Early Turonian intervals. Both might reflect the ecological response of the biota to global climatic and sea level changes which occurred during mid-Cretaceous times.

In order to establish a radiolarian biostratigraphy for the deposits investigated, the occurrences of 53 of the most characteristic taxa have been calculated with the computer program BioGraph 2.0. It enabled us to recognize 11 unitary associations which combined with the first appearance data of the recognized taxa. These combined methods allowed us to construct five subzones in the Holocryptocanium barbui radiolarian Zone of Schaaf (1985) (Stichomitra tosaensis, Squinabollum fossile, Thanarla pulchra, Torculum dengoi, Obeliscoites maximus) and two new radiolarian zones (Hemicryptocapsa prepolyhedra and H. polyhedra) for the Early Albian–Late Turonian interval.

The radiolarian assemblages including all Radiolaria recovered in the Pieniny Klippen Belt have been used for comparison with the radiolarian zonal scheme used by the previous authors in different areas.

Acknowledgements: I would like to express my gratitude to Dr. L. Ožvoldová (Department of Geology and Paleontology, Comenius University) for her comments and revision of the manuscript. The researches presented here are a part of my doctoral thesis. I wish to thank my supervisor Professor E. Morycowa (Institute of Geological Sciences, Jagiellonian University) for her guidance during this study. Particular thanks go to Professor K. Birkenmajer (Polish Academy of Sciences) who encouraged me to begin this study. Dr. J. Guex (University of Lausanne) introduced me to using the Biograph programme. I am very thankful to my husband Krzysztof for his help in the field and the many useful discussions. Mrs I. Chodyń helped me in the laboratory part of the work, and Mrs J. Faber kindly made the SEM photographs. This research was supported by KBN Grant No 0058/P2/93. While carrying out this study in 1995 the author was sponsored by the Foundation for Polish Science.

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