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New data on the age and stratigraphic relationships of the Czajakowa Radiolarite Formation in the Pieniny Klippen Belt (Carpathians) based on the radiolarian biostratigraphy in the stratotype section

MARTA BĄK[1], SYLWIA CHODACKA[2], KRZYSZTOF BĄK[3] and SZYMON OKOŃSKI[3]

[1] *Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Al. Mickiewicza 30, PL-30-059 Kraków, Poland. E-mail: martabak@agh.edu.pl*
[2] *Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, PL-30-063 Kraków, Poland*
[3] *Institute of Geography, Pedagogical University of Cracow, Podchorążych 2, PL-30-084 Kraków, Poland. E-mail: sgbak@cyf-kr.edu.pl; sokonski@up.krakow.pl*

ABSTRACT:

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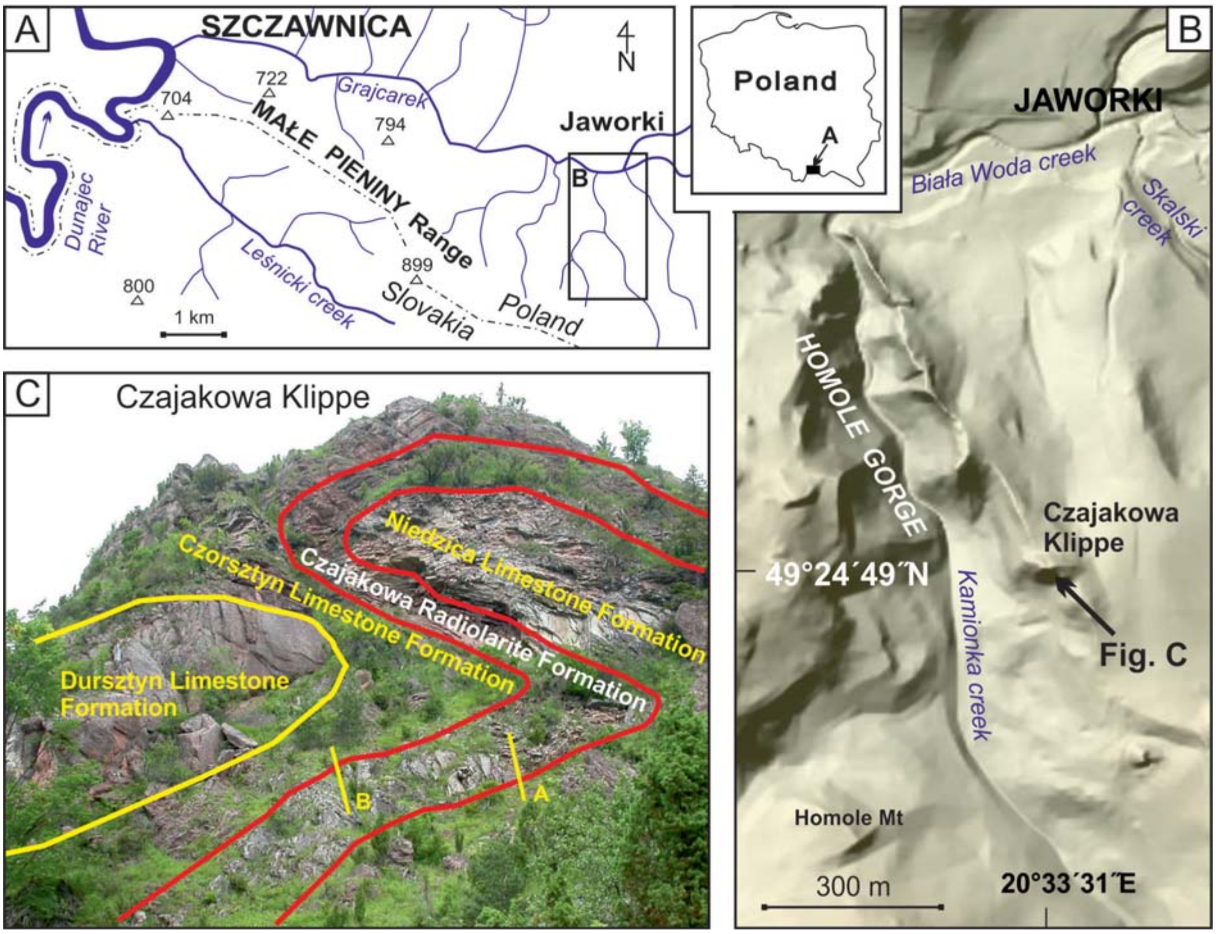
The radiolarian biostratigraphy of the Middle–Upper Jurassic pelagic siliceous sediments (Czajakowa Radiolarite Formation) in the Niedzica succession of the Pieniny Klippen Belt (Carpathians) is interpreted in terms of their age in a stratotype section, and facies equivalents in other tectonic-facies units of this region. The siliceous sediments are represented by radiolarian cherts and silicified limestones which are underlain and overlain by red nodular limestones, equivalents of the Rosso Ammonitico facies. The radiolarian association includes thirty-seven taxa belonging to twenty one genera which represent the Northern Tethyan Palaeogeographic Province. Key radiolarians recorded provide a means of correlation with zonation schemes based on Unitary Associations defined for the Jurassic Tethyan sediments. The age of the Czajakowa Radiolarite Formation in the stratotype section is determined as U.A.Z.9 to U.A.Z.11 corresponding to middle Oxfordian up to Kimmeridgian. Comparison of radiolarian biozones from the stratotype section with other facial equivalent sections in the Pieniny Klippen Belt reveals a significant diachronism for both the lower and the upper limits of the Jurassic pelagic siliceous facies.

Key words: Middle–Late Jurassic; Radiolaria; taxonomy; biostratigraphy; Czajakowa Radiolarite Formation; pelagic siliceous facies; Pieniny Klippen Belt; Carpathians.

INTRODUCTION

The Middle–Late Jurassic pelagic plateaus are good examples of palaeogeographic domains in the Tethyan Realm with pelagic siliceous deposition. Most of the plateaus formed on deeply submerged continental margins of the Tethys (e.g., Winterer and Bosellini 1981; Jenkyns and Winterer 1982; Birkenmajer 1986; Baumgartner 1987; De Wever 1989, 1996). The siliceous successions including radiolarian cherts, siliceous limestones and radiolarites occurring in such stratigraphic sequences represent rifted marginal basins and pelagic highs resting mostly on thinned continental crust. The accumulation of carbonate sediments known as the Rosso Ammonitico facies, which are traditionally defined as condensed, pelagic, red,



Text-fig. 1. A, B – Map of the Małe Pieniny Range in the Pieniny Klippen Belt, Western Carpathians, about 100 km south of Kraków, showing the location of the Czajakowa Klippe section in the Homole Gorge; C – Photograph of the southern wall of the Czajakowa Klippe with the boundaries of the pelagic siliceous sediments (Czajakowa Radiolarite Formation) and surrounding units, related to the Rosso Ammonitico facies (Niedzica Limestone Formation and Czorsztyn Limestone Formation); yellow straight lines (A, B) indicate the position of sampled material

nodular limestone rich in ammonites (e.g., Martire 1996) precluded siliceous deposition on pelagic highs. An example of an environment with such a facies pattern is the Pieniny Basin, the most northern part of the Tethys during that time (e.g., Birkenmajer 1986; Golonka and Krobicki 2004).

In this contribution, we present new biostratigraphic data based on radiolarian assemblages, related to pelagic siliceous succession in the Pieniny Klippen Belt (Poland), deposited on a pelagic high. The radiolarians from these sediments, known as the Czajakowa Radiolarite Formation (Birkenmajer 1977) have been studied in the stratotype section, which has never been investigated in detail, probably because of problems of accessibility to the almost vertical rock wall. Only its lowermost more accessible part was the subject of initial research by Widz (1991). The second goal of this contribution is to determine the stratigraphic relationship between all known sections of the Middle–Late Jurassic pelagic siliceous sediments deposited in the Pieniny Basin on the pelagic highs, directly above the Rosso Ammonitico facies, and followed by the same type of carbonate sediments.

GEOLOGICAL SETTING

The Pieniny Klippen Belt (PKB) in its present form is one of the most complex structural zones in the Carpathian Foldbelt, which contains strongly deformed Mesozoic and Paleogene sedimentary rocks. As a result of its tectonic complexity, the PKB is divided into three tectono-sedimentary sequences. These are the klippen successions, previously deposited in the Pieniny Basin (Triassic to Cretaceous) and their sedimentary cover (Upper Cretaceous to Paleogene); Inner Carpathian

Text-fig. 2. Examples of lithologies of the Czajakowa Radiolarite Formation (Kamionka Radiolarite Member) from the Czajakowa Klippe section, dominated by siliceous limestone with chert; black/white rectangles mark 1 cm

tectonic units (Jurassic–Lower Cretaceous) and their sedimentary cover (Upper Cretaceous to Paleogene); and deposits of the Magura Basin and its Paleogene sedimentary cover (e.g., Birkenmajer 1953, 1977, 1985, 1986; Birkenmajer *et al.* 1985).

The sequences of the Jurassic radiolarites are best developed in the tectonic-facies units (successions) interpreted as the deepest marine environment in the Pieniny Basin and in the southern part of the Magura Basin, the Grajcarek Succession (Birkenmajer 1985, 1986; Birkenmajer *et al*. 1985; Birkenmajer and Widz 1995). Radiolarites are not present in the Czorsztyn Succession, which was deposited on a submarine ridge. In the lithostratigraphical scheme proposed by Birkenmajer (1977), the Jurassic radiolarites belong to the Homole Group and have been formally classified into two formations, the Sokolica Radiolarite Formation and the Czajakowa Radiolarite Formation. Both formations have been distinguished on the basis of their lithology. The Sokolica Radiolarite Formation is represented by thin-bedded, spotty, grey-green to black radiolarites, often enriched in manganese oxides (e.g., Myczyński 1973; Birkenmajer 1977). Its late Bajocian to early Oxfordian age has been assigned based on its stratigraphic position (Birkenmajer 1977).

Herein, we discuss the Czajakowa Radiolarite Formation (Birkenmajer 1977), which contains red and green radiolarian cherts and radiolarian-bearing siliceous limestones. Based on the aptychi, found directly in the Czajakowa Radiolarite Formation, the age of the formation has been previously estimated to be late Oxfordian (in the Branisko, Haligovce and Grajcarek successions), early to late Oxfordian (in the Niedzica and Czertezik successions), and late Oxfordian up to the early Kimmeridgian (in the Pieniny Succession; Birkenmajer and Gąsiorowski 1960, 1961; Gąsiorowski 1962, 1963; Birkenmajer 1977).

THE CZAJAKOWA KLIPPE SECTION

The Middle–Late Jurassic radiolarians which are the subject of the present study are from a stratotype section of the Czajakowa Radiolarite Formation exposed in the Małe Pieniny Range that is a part of the Carpathians (Southern Poland). The section is situated in the upper, eastern part of a narrow valley, called the Homole Gorge on the southern flank of the Czajakowa Klippe, at an altitude of approximately 700 m, close to the Polish/Slovak border (Text-fig. 1A, B). The near-complete section exposes a folded sequence of Aalenian to Albian calcareous and siliceous rocks, ca. 60 m thick, representing the Niedzica Succession of the PKB (Birkenmajer 1970, 1977; with detailed description and references). These strata have been divided into several lithostratigraphic units. The highest part of the Czajakowa Klippe with a steep southern rock wall (Text-fig. 1C) is built of the Niedzica Limestone Formation (NLF), the Czajakowa Radiolarite Formation (CRF), the Czorsztyn Limestone Formation (CLF), and the Dursztyn Limestone Formation (Birkenmajer 1977); the NLF and CLF represent the Rosso Amonitico facies.

The Czajakowa Radiolarite Formation at the stratotype section

The CRF is 8 m thick at the Czajakowa Klippe and contains three formally distinguished members, starting from bottom to top: the Kamionka Radiolarite Member (KRM), the Podmajerz Radiolarite Member (PRM), and the Buwałd Radiolarite Member (BRM). The CRF is represented by thin to moderately bedded non-calcareous to calcareous radiolarian cherts and siliceous limestones intercalated with clayey to marly shales (Text-fig. 2). The thickness of the chert beds ranges from one to thirty cm, whereas the marly shales between the chert beds are up to five cm thick. Parallel lamination is observed in some thin-bedded calcareous cherts. The red colour of the sequence dominates in its lowermost (KRM) and uppermost (BRM) parts, whereas in the middle part, the sequence is predominately greenish (PRM). On the micro-scale, these deposits are packstone, wackstone and mudstone, with calcified radiolarian skeletons prevailing among the bioclasts. In addition to radiolarians, this formation also yields pithonellids, aptychi, rhynchollitids and belemnites, especially in its lower part (KRM).

The upper and lower boundaries of this formation are easily recognized in the stratotype section. The lower part of the CRF is transitional to the underlying red nodular limestone of the NLF. The boundary is located at the bottom of the first red radiolarian chert, as stated by Birkenmajer (1977) (Text-fig. 3). The upper boundary of the CRF is transitional to the CLF. It is placed at the bottom of the first layer of the red nodular limestone (Birkenmajer 1977).

Text-fig. 3. The boundary between red pelagic nodular limestone of the Niedzica Limestone Formation (Rosso Ammonitico facies) and the Czajakowa Radiolarite Formation in the Czajakowa Klippe section

MATERIAL AND METHODS

Twenty nine samples have been taken from the stratotype section at the Czajakowa Klippe. The sampling was carried out using climbing equipment along two sections (A and B – Text-fig. 1C) positioned on the steep outcrop to cover an upper part (0.8 m thick) of the NLF and the whole CRF. Radiolarians were extracted from chert and siliceous limestone using hydrochloric and hydrofluoric acids respectively, according to the procedure described by Sanfilippo *et al*. (1985). Twenty five samples yielded identifiable radiolarians among all investigated samples. The microfaunal slides with Radiolaria and sampled material are housed in the AGH University of Science and Technology (collection No. CzJ/2004).

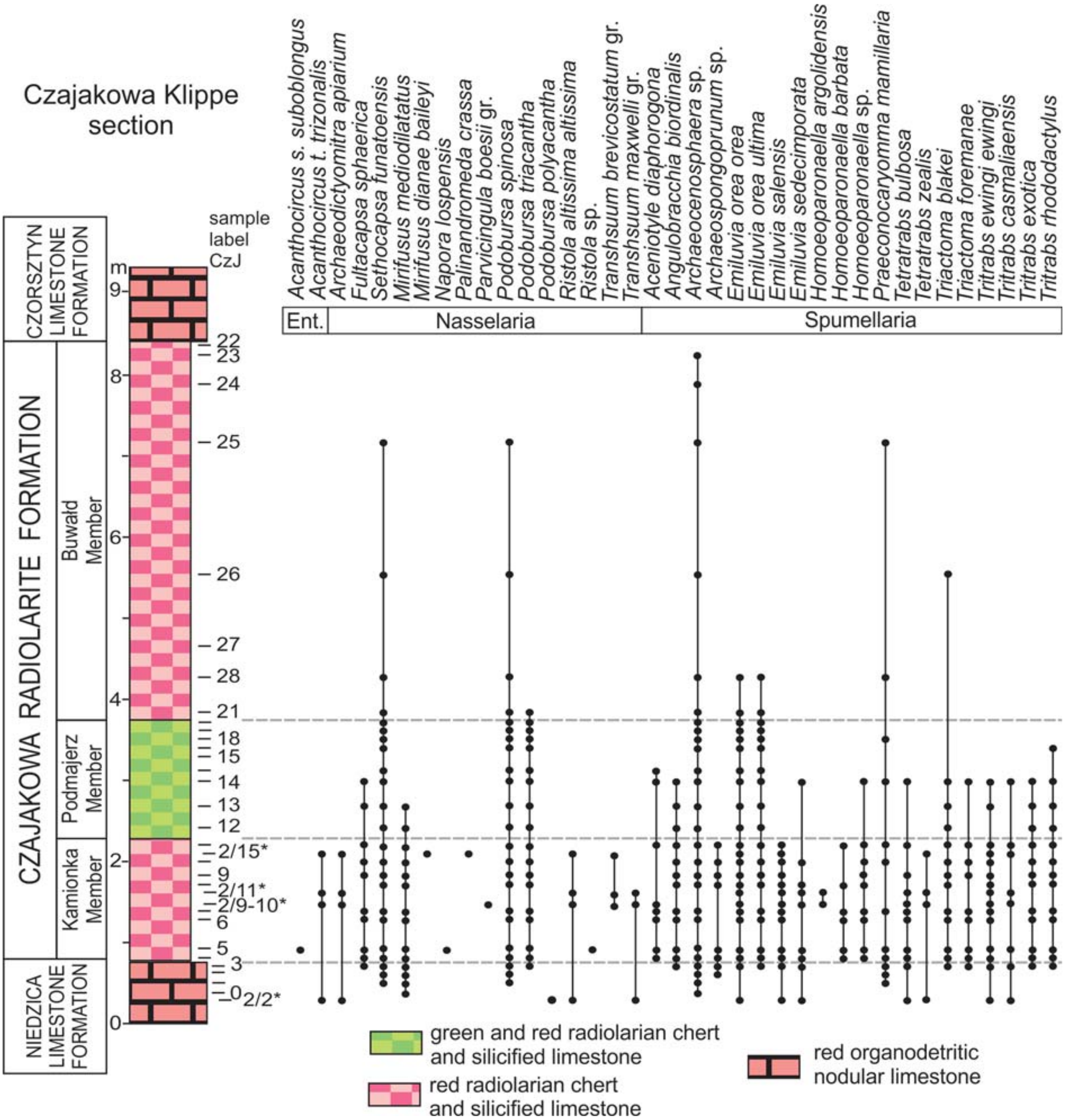
RADIOLARIAN ASSEMBLAGES

In the Czajakowa Klippe section, the samples yielded a relatively well-preserved radiolarian assemblage consist of 37 species including 4 taxa with open nomenclature (Text-fig. 4), assembled in 15 radiolarian families and 21 genera. Increased radiolarian frequency was observed in the uppermost part of the NLF, the whole sequence of the KRM and the lower part of the PRM.

Spumellarians are the main components of the radiolarian assemblages, reaching their maximum in the lower part of the KRM. The content of nassellarians displays the same tendency, however, they are less common. The order Entactinaria is represented by one genus (*Acanthocircus*).

Spumellarians, classified as *Archaeocenosphaera* sp., are dominant in the whole section (Text-fig. 4). Their relative abundance attains its maximum in the NLF and in the interval from the upper part of the PRM up to the uppermost part of the BRM. Next in terms of relative abundance is *Podobursa spinosa*. Common species in the assemblages are *Hiscocapsa funatoensis*, *Podobursa triacantha*, *Angulobracchia biordinalis*, *Emiluvia orea*, *Triactoma blakei*, *Triactoma foremanae*, *Tritrabs ewingi ewingi*, *T. exotica* and *T. rhododactylus*. The majority of radiolarians species (13 taxa) in the whole assemblage belong to rare species, which do not exceed 5% in relative abundance.

The radiolarian fauna exhibits features characteristic of Tethyan assemblages with common representatives of the families Sethocapsidae, Syringocapsidae, Angulobracchiidae, Emiluviidae and Patulibracchiidae (e.g., Baumgartner *et al*. 1995). The assemblage is characterized by the total absence



Text-fig. 4. Stratigraphic log and stratigraphic distribution of radiolarians for the Niedzica Limestone Formation and Czajakowa Radiolarite Formation exposed in the Czajakowa Klippe section; the position of samples with radiolarian data published by Birkenmajer and Widz (1995) are marked next to the sample label as asterisk; Ent. – Entactinaria

of orbiculiformids, characteristic of higher palaeolatitudes (Northern Boreal Radiolarian Province; Pessagno and Blome 1986; Kiessling 1999), commonly present in the epicontinental seas which bordered the Carpathian basins to the north (e.g., Górka and Bąk 2000). However, the studied assemblages represent rather the Northern Tethyan province (according to the palaeogeographic model of Pessagno *et al*. 1984) based on a lack of pantanellids and scarcity of "Ristola-type" parvicingulids. The scarcity of forms belonging to genera *Ristola* and *Mirifusus*, interpreted so far as deep-dwelling forms (Steiger 1992) is also characteristic. The material recovered also yields species such as *Praeconocaryomma mamillaria* and *Homoeoparonaella barbata* which are known predominately from the California Coast Range (Jurassic Panthalassa region: Pessagno 1977a; Hull 1997). This might be an effect of oceanic circulation and mixing of currents flowing from Panthalassa and Tethyan regions during that time.

SYSTEMATIC PALAEONTOLOGY

Species are arranged in alphabetical order of family names. The classification presented herein has been adopted from that proposed by Baumgartner *et al.* (1995), Hull (1997), O'Dogherty (1994), De Wever *et al.* (2001) and Bąk (2011). The scheme after De Wever *et al.* (2001) summarized the discussion on radiolarian taxonomic concepts. The occurrences of the taxa studied herein represent formations and members in the stratotype section.

Class Actinopoda Calkins, 1902
Subclass Radiolaria Müller, 1858
Superorder Polycystina Ehrenberg, 1838
emend. Riedel, 1967
Order Entactinaria Kozur and Mostler, 1982
Family Saturnalidae Deflandre, 1953
Genus *Acanthocircus* Squinabol, 1903

TYPE SPECIES: *Acanthocircus irregularis* Squinabol, 1903.

Acanthocircus suboblongus suboblongus (Yao, 1972)
(Text-fig. 5A)

1972. *Spongosaturnalis* (?) *suboblongus* Yao, p. 29, pl. 3, figs 1–6; pl. 10, figs 3a–c.
1987. *Acanthocircus suboblongus* (Yao); Goričan, p. 180, pl. 3, figs 2–3.
1995. *Acanthocircus suboblongus suboblongus* (Yao); Baumgartner *et al*., p. 68, pl. 3088, figs 1–4.

REMARKS: Among pieces of rings found in the material investigated one possesses features which allow to be assigned it to the subspecies *Acanthocircus suboblongus suboblongus* (Yao). This form is sub-oblong and has two spines at the narrow end of the ring.

OCCURRENCE: KRM.

Order Nassellaria Ehrenberg, 1875
Family Dorypylidae O'Dogherty, 1994
Genus *Hiscocapsa* O'Dogherty, 1994
emend. Hull, 1997

TYPE SPECIES: *Cyrtocapsa grutterinki* Tan, 1927.

REMARKS: According to the classification proposed by Hull (1997), this genus has been included as a member of the Williriedellidae. It consists of four-chambered skeletons, with a large and inflated last, postabdominal chamber.

Hiscocapsa funatoensis (Aita, 1987)
(Text-fig. 5D, E)

1987. *Sethocapsa funatoensis* Aita, p. 73. pl. 2, figs 6a–7b; pl. 9, figs 14, 15.
2011. *Hiscocapsa funatoensis* (Aita); Yeh, p. 16, pl. 7, figs 19, 20, 23, 26.

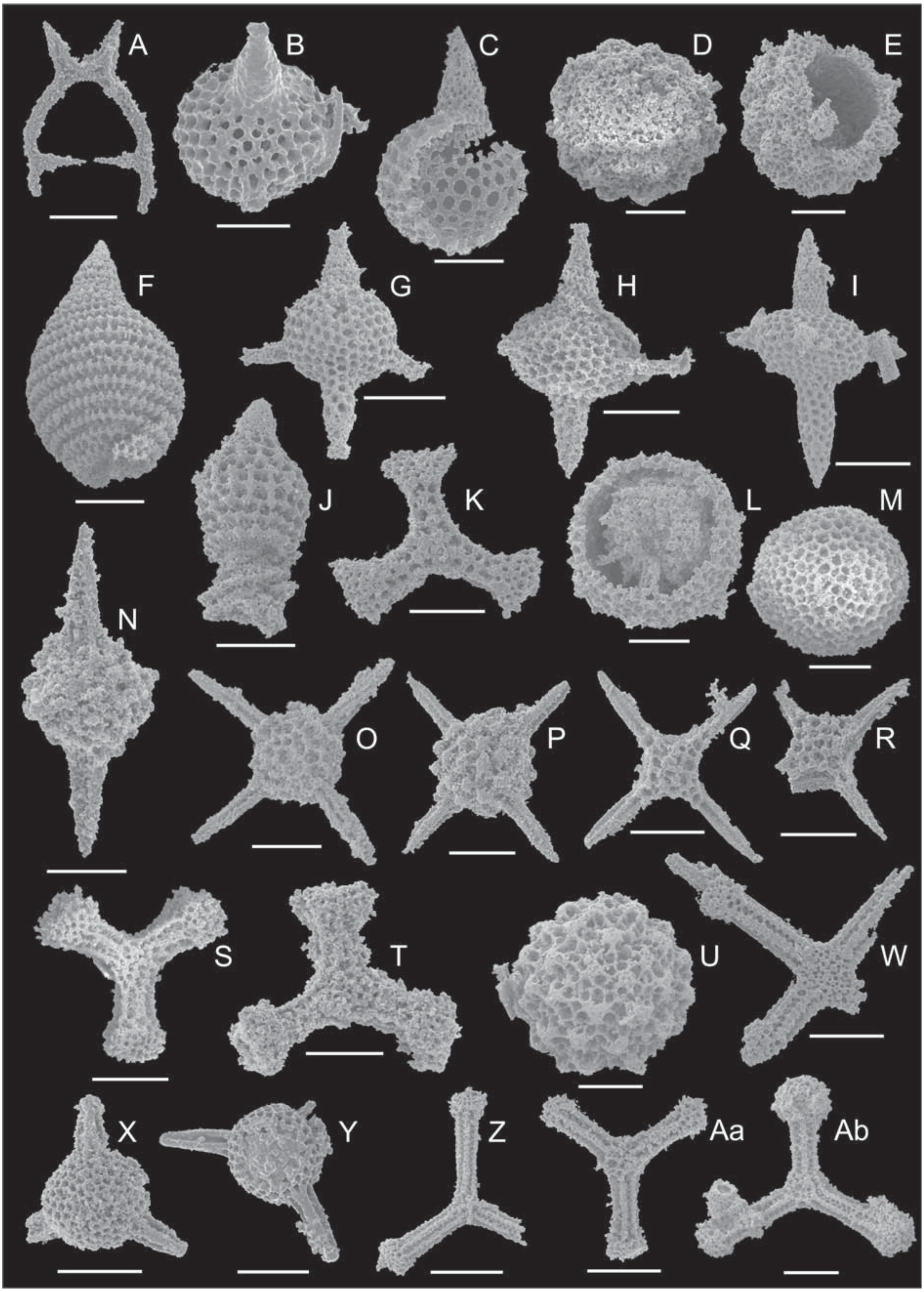
REMARKS: This species is characterized by a nodose meshwork on the last chamber. Nodes are terminated by short spines, circular in cross section.

OCCURRENCE: Very common in the upper part of the NLF, the KRM, and the lower part of the PRM; rare in the BRM.

Family *Parvicingulidae* Pessagno, 1977b
Genus *Mirifusus* Pessagno, 1977b
emend. Baumgartner, 1984

TYPE SPECIES: *Mirifusus guadalupensis* Pessagno, 1977b.

Text-fig. 5. The middle Oxfordian–late Kimmeridgian radiolarians from the Czajakowa Radiolarite Formation and surrounding units in the Niedzica Succession of the Pieniny Klippen Belt, Western Carpathians: A – *Acanthocircus suboblongus suboblongus* (Yao), CzJ-4; B, C – *Fulthacapsa sphaerica* (Ožvoldová), CzJ-5, CzJ-7; D, E – *Hiscocapsa funatoensis* (Aita), CzJ-4, CzJ-5; F – *Mirifusus mediodilatatus* (Karrer), CzJ-5; G, H – *Podobursa spinosa* (Ožvoldová), CzJ-7, CzJ-11; I – *Podobursa triacantha* (Fischli), CzJ-5; J – *Ristola* sp., CzJ-5; K – *Angulobracchia biordinalis* Ožvoldová, CzJ-5; L, M – *Archaeocenosphaera* sp., CzJ-5; N – *Archaeospongoprunum* sp., CzJ-3; O – *Emiluvia orea orea* Baumgartner, CzJ-5; P – *Emiluvia orea ultima* Baumgartner and Dumitriča; CzJ-4; Q – *Emiluvia salensis* Pessagno, CzJ-5; R – *Emiluvia sedecimporata* (Rüst), CzJ-5; S – *Homoeoparonaella barbata* Hull, CzJ-5; T – *Homoeoparonaella* sp., CzJ-3; U – *Praeconocaryomma mamillaria* (Rüst) *sensu* Pessagno, CzJ-5; W – *Tetratrabs bulbosa* Baumgartner, CzJ-5; X – *Triactoma blakei* (Pessagno), CzJ-4; Y – *Triactoma foremanae* Muzavor, CzJ-5; Z – *Tritrabs ewingi ewingi* (Pessagno), CzJ-4; Aa – *Tritrabs exotica* (Pessagno), CzJ-5; Ab – *Tritrabs rhododactylus* Baumgartner, CzJ-5. Scale bars – 100 µm →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Mirifusus mediodilatatus (Karrer, 1867)
(Text-fig. 5F)

1867. *Lagena dianae* Karrer, p. 365, pl. 3, figs 8a, b.
1885. *Lihocampe mediodilatata* Rüst, p. 316, pl. 40, fig. 9.
1977a. *Mirifusus* (?) *mediodilatata* (Rüst); Pessagno, p. 84, pl. 11, figs 1, 2.
1980. *Mirifusus mediodilatatus* (Rüst); Baumgartner, p. 56, pl. 5, figs 9, 10.
1995. *Mirifusus dianae dianae* (Karrer); Baumgartner *et al.*, pp. 312–313, pl. 3274, figs 1–4.

REMARKS: This species is characterized by the globose-shape of the skeleton which consists of sixteen to eighteen segments. The outer layer on each segment possesses two rows of pores, which are rounded, triangular to circular.

OCCURRENCE: Upper part of the NLF, lower part of the KRM, and the lower part of the PRM.

Genus *Ristola* Pessagno and Whalen, 1982
sensu Baumgartner, 1984

TYPE SPECIES: *Parvicingula* (?) *procera* Pesagno, 1977b.

REMARKS: The genus *Ristola* is characterized by a multicyrtid, very long skeleton without a horn. The outer shape of the skeleton is conical to cylindrical. Some species may possess up to 33 postabdominal chambers. The outer mesh on postabdominal chambers is arranged with three rows of symmetrical pore frames between two adjacent circumferential ridges. Final postabdominal chambers, when preserved, possesses tubular extensions.

Ristola sp.
(Text-fig. 5J)

REMARKS: Three incomplete skeletons have been found in the material investigated. Each skeleton shows a proximal part of the test with cephalis, thorax, abdomen and one to three postabdominal segments.

OCCURRENCE: KRM (only in one sample – CzJ-5).

Family Sethocapsidae Haeckel, 1881
Genus *Fultacapsa* Ožvoldová in Ožvoldová and Frantova, 1997

TYPE SPECIES: *Acotripus sphericus* Ožvoldová, 1988.

REMARKS: The genus *Fultacapsa* has been newly defined by Ožvoldová and Frantova, (1997) to incorporate a group of species, different from those belonging to the genera *Podocyrtis* Ehrenberg, *Acotripus* Haeckel, *Hiscocapsa* O'Dogherty, *Sethocapsa* Haeckel and *Birkenmajeria* Widz. The species of the genus *Fulacapsa* are nassellarian possessing three or four postabdominal chambers. The cephalis is sub-globose or conical, and usually bears an apical horn. The last postabdominal chamber is large, inflated and without an aperture. Spines occur only on the terminal segment.

Fultacapsa sphaerica (Ožvoldová, 1988)
(Text-figs 5B, C, 6A, B)

1988. *Acotripus sphericus* Ožvoldová, p. 376, pl. 5, figs 1–5, 7; pl. 8, fig. 7.
1993. *Birkenmajeria sphaerica* (Ožvoldová); Widz and De Wever, p. 82, pl. 1, figs 3, 4.
1995. *Sethocapsa* (?) *sphaerica* (Ožvoldová); Baumgartner *et al.*, p. 500, pl. 3168, figs 1–4.
1997. *Fultacapsa sphaerica* (Ožvoldová); Ožvoldová and Frantová, p. 59, pl. 5, figs 1, 2.

OCCURRENCE: A common species in the uppermost part of the NLF, the KRM, and the lower part of the PRM.

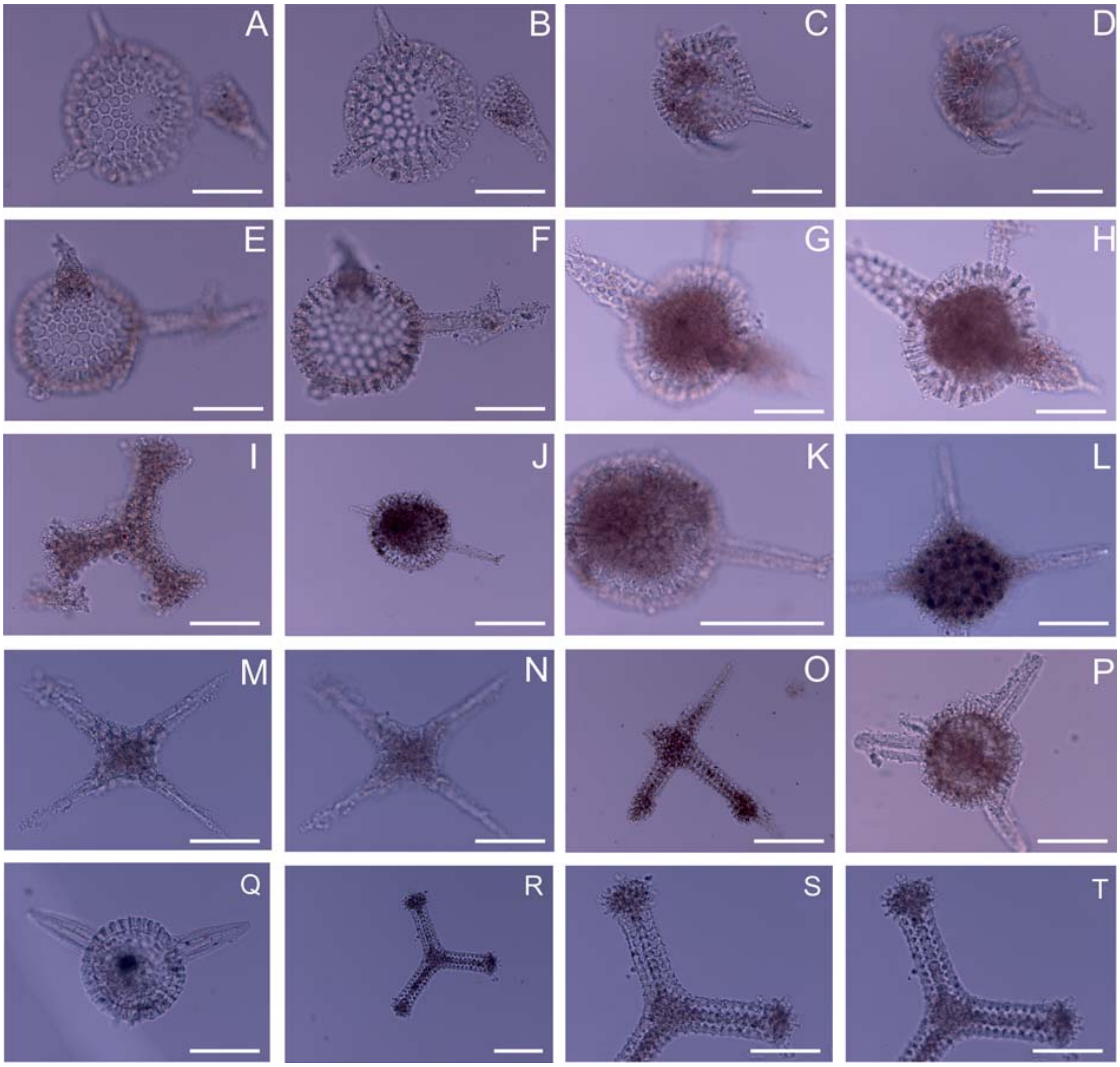
Family Syringocapsidae Foreman, 1873
Genus *Podobursa* Wiśniowski, 1889
emend. Foreman, 1973

TYPE SPECIES: *Podobursa dunikowskii* Wiśniowski, 1889.

REMARKS: Species belong to the genus are characterized by a skeleton consisting of cephalis, thorax, abdomen and one postabdominal chamber. The proximal part is small and conical. The distalmost segment is large, globose, bears three or more outward-directed spines and a porous terminal tube.

Podobursa spinosa (Ožvoldová, 1979)
(Text-figs 5G, H, 6E–H)

1975. *Heitzerina spinosa* Ožvoldová, p. 78, pl. 101, fig. 2.



Text-fig. 6. The middle Oxfordian–late Kimmeridgian radiolarians from the Czajakowa Radiolarite Formation and surrounding units in the Niedzica Succession of the Pieniny Klippen Belt, Western Carpathians: A, B – *Fulthacapsa sphaerica* (Ožvoldová), CzJ-5; C, D – *Napora lospensis*, CzJ-5; E–H – *Podobursa spinosa* (Ožvoldová), CzJ-5; I – *Homoeoparonaella* sp., CzJ-3; J, K – *Archaeospongoprunum* sp., CzJ-5; L – *Emiluvia orea orea* Baumgartner, CzJ-5; M, N – *Emiluvia salensis* Pessagno, CzJ-5; O – *Tetratrabs bulbosa* Baumgartner, CzJ-5; P – *Triactoma blakei* (Pessagno), CzJ-4; Q – *Triactoma foremanae* Muzavor, CzJ-5; R–T – *Tritrabs ewingi minima* Steiger, CzJ-5. Scale bars – 100 µm

1979. *Podobursa spinosa* (Ožvoldová); Ožvoldová, p. 256, pl. 2, fig. 4.

REMARKS: The proximal part of the skeleton is conical and narrow. It contains a non-porous cephalis with an apical horn, which splits into three to four lateral spines. The abdomen is wide, oval to slightly compressed in the vertical direction, terminated by a narrow, conical terminal tube. Three massive and three-bladed spines protrude radially from the abdomen wall. Each spine splits into three to four small, laterally diverging spines at their distal part. The terminal tube is closed by a similar spine. The meshwork of the test is hexagonal, with slightly protruding nodes.

OCCURRENCE: Very common species in the upper part of the NLF, the KRM, and the lower part of the PRM; rare in the BRM.

Podobursa triacantha (Fischli, 1916)
(Text-fig. 5I)

1916. *Theosyringium acanthophorum* Rüst var. *triacanthus* Fischli, p. 47, figs 38, 39.
1973. *Podobursa triacantha* (Fischli); Foreman, p. 226, pl. 13, figs 1–7.

REMARKS: This species is characterized by three to six outward-directed, slender spines protruding from the abdomen.

OCCURRENCE: Uppermost part of the NLF, the KRM, lower part of the PRM; rare in the BRM.

Family Ultranaporidae Pessagno, 1977a
Genus *Napora* Pessagno, 1977a

TYPE SPECIES: *Napora bukryi* Pessagno, 1977a.

Napora lospensis Pessagno, 1977a
(Text-fig. 6C, D)

1977a. *Napora lospensis* Pessagno, p. 96, pl. 12, figs 9, 10.

REMARKS: This species may co-occur with *N. deweveri* which differs from *N. lospensis* by its generally more massive skeleton and much thicker apical horn. This species is also characterized by its rounded triangular basal aperture, and three feet which are strongly curved inwards, usually longer than the height of the thorax.

OCCURRENCE: KRM (only one specimen in sample CzJ5).

Order Spumellaria Ehrenberg, 1875
Family Angulobracchiidae Baumgartner, 1980
Genus *Angulobracchia* Baumgartner, 1980

TYPE SPECIES: *Paronaella* (?) *purisimaensis* Pessagno, 1977b.

REMARKS: Skeleton with three rays and without bracchiopyle. Lateral external beams of the top and bottom sides parallel or distally diverging to form broadening or thickening rays. Ray tips expanded and bulbous with tubular bracchiopyle-like extensions, or porous spines on all three rays. Central area of equal thickness of ray tips.

Angulobracchia biordinalis Ožvoldová, 1984
(Text-fig. 5K)

1984. *Angulobracchia biordinale* Ožvoldová and Sykora, p. 262, pl. 2, figs 1–7; pl. 16, figs 1, 2.

REMARKS: Well preserved skeletons consist of three short rays, bulbous at their ends, arising from a small central area. The meshwork along the rays consists of two longitudinal rows of large pores with prominent nodes.

OCCURRENCE: Uppermost part of the NLF, the KRM, and the lower part of the PRM.

Family Archaeospongoprunidae Pessagno, 1973
Genus *Archaeospongoprunum* Pessagno, 1973

TYPE SPECIES: *Archaeospongoprunum venadoensis* Pessagno, 1973.

Archaeospongoprunum sp.
(Text-figs 5N, 6J, K)

REMARKS: All skeletons including in this taxa are sub-globular in outer shape, with two polar spines, which are slender and sharp. Surfaces of the tests formed by meshwork of pore frames. The shape of the pores is not well seen because of the poor state of preservation.

OCCURRENCE: Uppermost part of the NRF and whole KRM.

Family Conocaryommidae Lipman, 1969
emend. De Wever *et al*., 2001
Genus *Praeconocaryomma* Pessagno, 1976

TYPE SPECIES: *Praeconocaryomma universa* Pessagno, 1976.

Praeconocaryomma mamillaria (Rüst, 1898)
sensu Pessagno, 1977a
(Text-fig. 5U)

1898. ?*Heliosphaera mamillaria* Rüst, p. 12, pl. 4, fig. 2.
1977a. *Praeconocaryomma mamillaria* (Rüst); Pessagno, p. 77, pl. 6, fig. 2.

REMARKS: The species is characterized by its cortical shell, with distinct poreless mammae. Each mamma is surrounded by eight subcircular to elliptical pores. The area between the mammae possesses the same shaped pores.

OCCURRENCE: Upper part of the NLF, the KRM; rare in the PRM and lower part the BRM.

Family Emiluviidae Dumitrică, 1995
Genus *Emiluvia* Foreman, 1973
emend. Foreman, 1975
emend. Pessagno, 1977a

TYPE SPECIES: *Emiluvia chica* Foreman, 1973.

Emiluvia orea orea Baumgartner, 1980
(Text-figs 5O, 6L)

1980. *Emiluvia orea* Baumgartner, p. 52, pl. 1, figs 1–7.

REMARKS: This subspecies is characterized by its large test with four three-bladed spines. The meshwork is formed by large circular pores.

OCCURRENCE: Uppermost part of NLF, KRM, and lower part of PRM.

Emiluvia orea ultima Baumgartner and Dumitrica, 1995
(Text-fig. 5P)

1995. *Emiluvia orea ultima* Baumgartner and Dumitrica in Baumgartner *et al*., p. 204, pl. 4070.

REMARKS: *Emiluvia orea ultima* differs from *E. orea orea* Baumgartner in having a smaller number of nodes, which are very big and arranged concentrically, in two circles around a central node. The outer shape of the test is rather cylindrical, with concave lateral sides.

OCCURRENCE: Uppermost part of the NLF, the KRM, and lower part of PRM.

Emiluvia salensis Pessagno, 1977a
(Text-fig. 5Q)

1977a. *Emiluvia salensis* Pessagno, p. 77, pl. 5, figs 9–11.

REMARKS: This species is characterized by the totally flat surface of the central area. It differs from another species of the genus by its square-shaped test with nodes interconnected by bars forming square-shaped pores.

OCCURRENCE: Uppermost part of the NLF and whole KRM.

Emiluvia sedecimporata (Rüst, 1885)
(Text-fig. 5R)

1885. *Staurosphaera sedecimporata* Rüst, p. 288, pl. 28(3), fig. 1.
1984. *Emiluvia sedecimporata* (Rüst); Ožvoldová and Sykora, pl. 3, figs 5, 7.

REMARKS: The described material belonging to this species is characterized by concave lateral sides and a square pore pattern with sixteen similar pores. Nodes on quadruple junctions are moderately developed. A pair of nodes is located at the base of each spine.

OCCURRENCE: Uppermost part of the NLF, the KRM, and lower part of the PRM.

Family Hagiastridae Riedel, 1971
Genus *Tetratrabs* Baumgartner, 1980

TYPE SPECIES: *Tetratrabs gratiosa* Baumgartner, 1984.

Tetratrabs bulbosa Baumgartner, 1980
(Text-figs 5W, 6O)

1980. *Tetratrabs bulbosa* Baumgartner, p. 295, pl. 5, fig. 1; pl. 6, figs 1–3, 8.

REMARKS: Specimens included into this species possess an skeleton composed of four rays of equal length at nearly right angles. The central area and external beams are strongly nodose. Pores on upper and lower sides are small, situated in narrow depressions between external beams. Ray tips are inflated bulbous, often with two spongy protrusions extending in the axial direction with a surface of irregularly distributed small pores between broad nodes.

OCCURRENCE: Uppermost part of the NLF, the KRM; rare in the PRM.

Family Patulibracchiidae Pessagno, 1971
Genus *Homoeoparonaella* Baumgartner, 1980

TYPE SPECIES: *Paronaella elegans* Pessagno, 1977b.

Homoeoparonaella barbata Hull, 1997
(Text-fig. 5S)

1997. *Homoeoparonaella barbata* Hull, p. 40, pl. 13, figs 3, 6, 9, 11, 14, 17, 20.

REMARKS: The test of the species is characterized by three short rays extending from a small central area. On best-preserved specimens, rays are terminated by spongy, bulbous tips, with a slender, centrally placed spine. This element is not preserved in the specimens studied. Pore frames are more irregular in the central area, became hexagonal on spongy ray tips. External beams of rays are joined by perpendicular transverse bars, forming tetragonal pore frames. Moderate to well-developed nodes are present at pore frames.

OCCURRENCE: KRM.

Homoeoparonaella sp.
(Text-figs 5T, 6I)

REMARKS: specimens assembled into *Homoeoparonaella* sp. possess skeletons with three short rays terminating in spongy, bulbous tips. The shape and arrangement of the pores is not visible because of poor state of preservation.

OCCURRENCE: KRM and lower part of the PRM.

Family Tritrabidae Baumgartner, 1980
Genus *Tritrabs* Baumgartner, 1980

TYPE SPECIES: *Paronaella* (?) *casmaliaensis* Pessagno, 1977b.

Tritrabs ewingi ewingi (Pessagno, 1971)
(Text-fig. 5Z)

1971. *Paronaella* (?) *ewingi* Pessagno, p. 47, pl. 19, figs 2–5.
1980. *Tritrabs ewingi* (Pessagno); Baumgartner, p. 293, pl. 4, figs 5, 7, 17.
1992. *Tritrabs ewingi ewingi* (Pessagno) Steiger, p. 38, pl. 7, figs 3, 4.

REMARKS: Forms including into this subspecies have their tests with three elongated, slender rays of nearly equal length, ending by ellipsoidal tips, terminating in prominent central spines. The central area of the cortical shell possesses irregularly arranged small pores. Meshwork present on rays comprised of square to rectangular frames arranged in two markedly linear rows.

OCCURRENCE: Uppermost part of the NLF, the KRM, and lower part of the PRM.

Tritrabs casmaliaensis (Pessagno, 1977b)
(Text-fig. 6R–T)

1977b. *Paronaella* (?) *casmaliaensis* Pessagno, 1977b, p. 69, pl. 1, figs 6–8.
1980. *Tritrabs casmaliaensis* (Pessagno); Baumgartner, p. 293, pl. 1, fig. 10; pl. 4, fig. 11; pl. 11, fig. 10.

REMARKS: *Tritrabs casmaliaensis* differs from *T. ewingi ewingi* (Pessagno) by having a smaller test and possessing three massive rays protruding from the distal part of each arm.

OCCURRENCE: Uppermost part of NLF, KRM, and lower part of PRM.

Tritrabs exotica (Pessagno, 1977a)
(Text-fig. 5A)

1977a. *Paronaella* (?) *exotica* Pessagno, p. 70, pl. 1, figs 12–13.
1980. *Tritrabs exotica* (Pessagno); Baumgartner, p. 294, pl. 4, fig. 16.

REMARKS: This species differs from other forms belonging to genus *Tritrabs* by having three nearly equal-sized rays with three parallel longitudinal ridges along each of them. Rays end in broad tips, subcircular in outline. Each tip possesses five to seven smaller spines.

OCCURRENCE: Uppermost part of the NLF, the KRM, and lower part of the PRM.

Tritrabs rhododactylus Baumgartner, 1980
(Text-fig. 5A, B)

1980. *Tritrabs rhododactylus* Baumgartner, p. 294, pl. 4, figs 12–15.

REMARKS: This form differs from *T. exotica* by its less bulbous tips and flatter central area. Ray tips are variable in shape.

OCCURRENCE: Uppermost part of the NLF, the KLM, and lower part of the PRM.

Family Xiphostylidae Haeckel, 1881
sensu Pessagno and Yang, 1989 in Pessagno *et al*., 1989 *emend*. De Wever *et al*., 2001
Genus *Archaeocenosphaera* Pessagno and Yang in Pessagno *et al*., 1989

TYPE SPECIES: *Archaeocenosphaera ruesti* Pessagno and Yang, in Pessagno *et al*., 1989.

Archaeocenosphaera sp.
(Text-fig. 5L, M)

REMARKS: Spumellarians classified into this taxon possess a thick cortical shell without spines and without medullary shell inside. The cortical shell consisting of two fused layers with symmetrical polygonal pore frames. The open nomenclature for this species refers to the medullary shell which might not be preserved due to diagenetic processes.

OCCURRENCE: Upper part of the NLF, and all members of the CRF.

Genus *Triactoma* Rüst, 1885

TYPE SPECIES: *Triactoma tithonianum* Rüst, 1885, subsequent designation by Campbell, 1954.

Triactoma blakei (Pessagno, 1977a)
(Text-figs 5X, 6P)

1977a. *Tripocyclia blakei* Pessagno, p. 80, pl. 6, figs 15, 16.
1978. *Triactoma blakei* (Pessagno); Foreman, p. 743, pl. 1, fig. 15.

REMARKS: Species found in the material investigated possess a rounded skeleton, globular with large, uniform hexagonal pore frames with circular pores inside the frame, and three relatively short spines arranged in one plane. Spines are characterized by a complicated system of longitudinal ridges and grooves.

OCCURRENCE: Uppermost part of the NLF, the KRM, and the PRM.

Triactoma foremanae Muzavor, 1977
(Text-figs 5Y, 6Q)

1977. *Triactoma foremanae* Muzavor, p. 55, pl. 1, fig. 11.

REMARKS: *Triactoma foremanae* has often been synonymized with *T. blakei* (Pessagno). It differs from the latter by having no buttresses at the base of the spines and by more pointed spines.

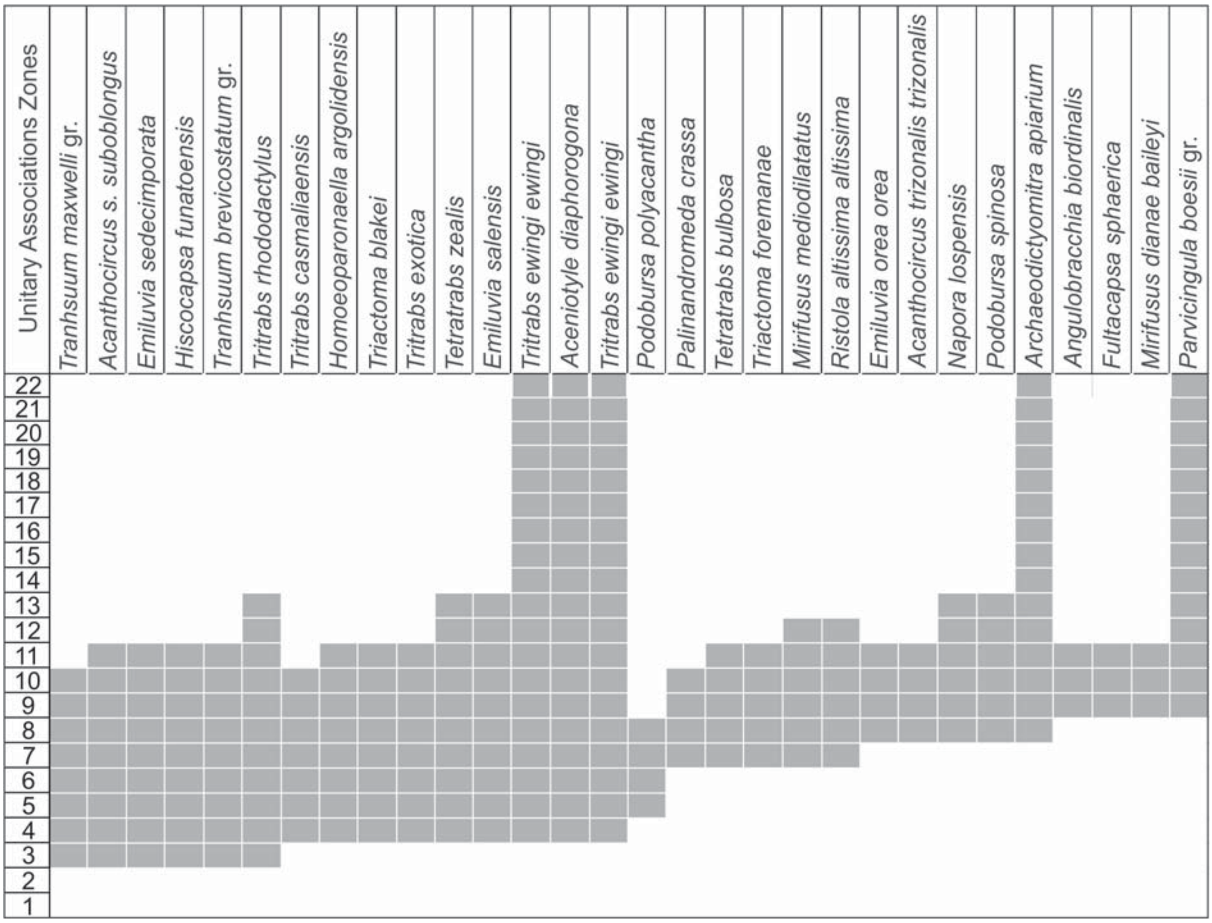
OCCURRENCE: Uppermost part of the NLF, the KRM, and the PRM.

RADIOLARIAN BIOCHRONOLOGY

The age of the radiolarian assemblages is discussed in terms of the Unitary Association Zones (U.A.Z.) defined by Baumgartner *et al*. (1995) and the findings of cephalopod remnants (shells of ammonites and aptychi) in deposits belonging to the CRF and red nodular limestones of the Rosso Ammonico facies (NLF and CLF) lying directly below and above this formation (e.g., Birkenmajer and Myczyński 1984; Wierzbowski *et al*. 1999, 2004). The ranges of age-diagnostic radiolarian species according to Baumgartner *et al*. (1995) are juxtaposed in Text-fig. 7. Previous discussion of the age of the radiolarian assemblages was provided by Widz (1991) and Birkenmajer and Widz (1995) for the Czajakowa Klippe section. However, these previous authors discriminated the age of radiolarian assemblage only for the KRM (comp. sample locations at Text-fig. 4). In this study, the radiolarian data given by Widz (1991) and Birkenmajer and Widz (1995) are considered in the context of the determination of age based on radiolarians in the whole studied section.

The first sample with an age diagnostic radiolarian assemblage is located within the NLF, 37 cm below the lower boundary of the CRF. This assemblage is correlated with U.A.Z. 8 (middle Callovian–early Oxfordian) based on the co-occurrence of *Podobursa spinosa* and *Podobursa polyacantha*.

The radiolarian species which have their first occurrence in the U.A.Z. 9 (middle to late Oxfordian) appear also in the NLF, 6 cm below the first radiolarite layer of the CRF. The radiolarian assemblage in the whole KRM is correlated with U.A.Z. 9–10 (middle Oxfordian to early Kimmeridgian) based on



Text-fig. 7. Occurrence range chart of radiolarian species recorded in the Czajakowa Klippe section based on Unitary Association Zones (U.A.Z.), defined by Baumgartner *et al.* (1995)

the co-occurrence of the radiolarian species such as *Angulobracchia biordinalis*, *Fulthacapsa sphaerica*, *Mirifusus dianae baileyi* and *Parvicingula boesii* gr, which first appeared in the U.A.Z. 9 and species that made their last appearance within U.A.Z. 10 such as *Transhsuum maxwelli* gr., *Tritrabs casmaliaensis*, and *Palinandromeda crassa*.

Twenty radiolarian species that are present in the KRM continue their ranges in the lower part of the above lying PRM. The minimum age of the interval is constrained by *Tritrabs casmaliaensis* which has its final occurrence in U.A.Z. 10 (early Kimmeridgian). This species has its last appearance in sample CzJ14, located in the lower part of the PRM. Other taxa such as *Acanthocircus suboblongus suboblongus*, *Emiluvia sedecimporata*, *Hiscocapsa funatoensis*, *Homoeoparonaella argolidensis*, *Triactoma blakei*, *Tritrabs exotica*, *Tetratrabs bulbosa*, *Triactoma foremanae*, *Emiluvia orea orea*, *Acanthocircus trizonalis trizonalis*, *Angulobracchia biordinalis*, and *Fulthacapsa sphaerica* which have their final occurrences in U.A.Z. 11 (late Kimmeridgian–Tithonian), are also present in this interval marking the highest radiolarian abundance in the Czajakowa Klippe section. Based on this coincidence, the radiolarian assemblage from the lower part of the PRM has been also assigned to the U.A.Z. 9–10 (middle Oxfordian–early Kimmeridgian).

The radiolarian frequency and diversity abruptly diminishes in the above-lying deposits belonging to the upper part of the PRM and BRM. Among eight radiolarian species present in these sediment, only *Hiscocapsa funatoensis*, *Podobursa spinosa* and *Tritrabs rhododactylus* can be recognized in the zonation of Baumgartner *et al.* (1995). The age of these deposits could be assigned to the U.A.Z. 11 interval (late Kimmeridgian–Tithonian) based on the presence of the species *Hiscocapsa funatoensis* which has its final occurrence in this U.A.Z.

The correlation of the studied radiolarian assemblage with other radiolarian zonal schemes used in regions outside the Tethys is very restricted because of differences in species occurrences, resulting from the distribution of oceanic water masses with specific chemical and physical parameters (e.g., Caulet *et al.* 1992; Kling and Boltovskoy 1995; Bąk 2011). During the Late Jurassic, the Pieniny Klippen Basin was located in tropical to subtropical regions of the Western Tethys (e.g., Lewandowski *et al.* 2005; Grabowski *et al.* 2008) therefore, the radiolarian biozonation after Baumgartner *et al.* (1995) used worldwide for Tethyan deposits is also very useful in the PKB. However, the correlation of radiolarian assemblages from corresponding regions of Panthalassa is difficult, although many species were present in both regions (Matsuoka 1996). Comparison of the radiolarian zonation defined for Japan and the western Pacific (Matsuoka 1995) with the biozones of Baumgartner *et al.* (1995) shows as large a discrepancy between radiolarian species ranges in both regions as Panthalassa and Tethys. Likewise, correlation of the U.A. Zones of Baumgartner *et al.* (1995) with the radiolarian zonal schemes defined in the Boreal region (e.g., biozonation after Pessagno *et al.* 1984) is also difficult because of a lack of many Tethyan taxons; species present in both regions have usually different first and last appearance data.

The age determination of the CRF based on the radiolarians in our study is much wider than the age previously stated based on aptychi by Gąsiorowski (1962, 1963). On the other hand, there is an agreement with the age assigned for the lower boundary of the CRF based on radiolarian U.A. Zones and the ammonite fauna found in the NLF, which directly underlies the CRF. The nodular limestones of the NLF have yielded abundant ammonites of the latest Bajocian through to Late Callovian age (Birkenmajer and Znosko 1955; Birkenmajer and Myczyński 1984). According to the newest data given by Wierzbowski *et al.* (1999), the upper part of the NLF in the Czajakowa Klippe section could be correlated with the late Callovian and/or early Oxfordian, based on representatives of the ammonite subfamily Peltoceratinae.

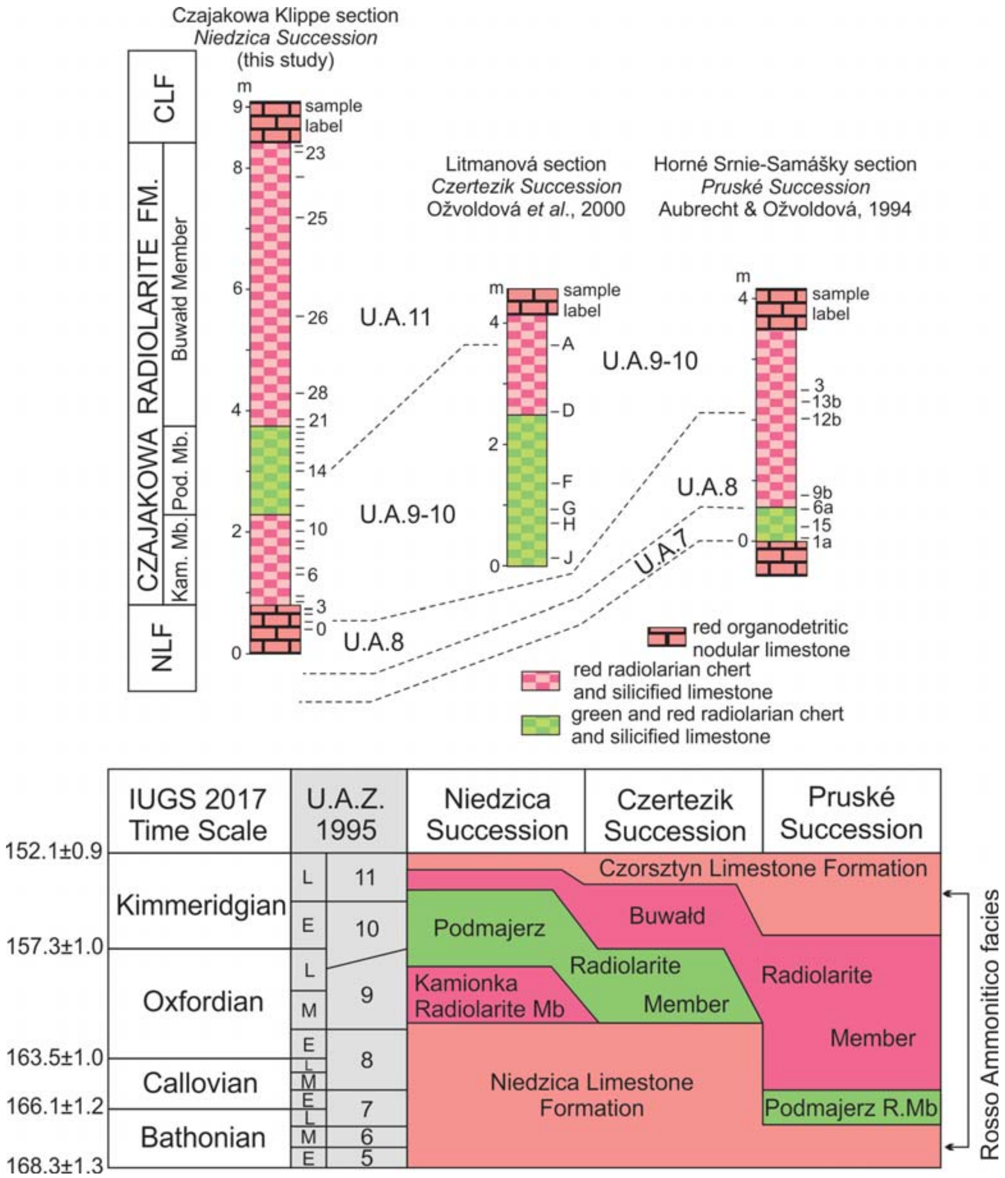
The CRF is overlain by the nodular limestone of the CLF. The age of the lower part of this formation was determined in the Niedzica Succession as Kimmeridgian (Birkenmajer 1977, and references herein). However, the age determination of the upper limit of the CRF based on radiolarians is still disputable because it is based on an ecologically and/or diagenetically reduced assemblage with scarce specimens, mostly long ranging.

STRATIGRAPHIC RELATIONSHIPS OF THE CZAJAKOWA RADIOLARITE FORMATION IN THE TRANSITIONAL FACIES OF THE PIENINY KLIPPEN BELT

The radiolarian cherts and siliceous limestones of the Czajakowa Radiolarite Formation, as observed in the stratotype section, reflect the transitional facies pattern in the Pieniny Klippen Belt between shallow shelf sediments of the Czorsztyn Ridge and deep pelagic sediments of the Pieniny Basin. Its characteristic feature is the replacement of Middle Jurassic nodular limestone by siliceous-calcareous facies in the middle Oxfordian, which in turn are replaced by nodular limestone in the early Kimmeridgian.

The Upper Jurassic radiolarian-bearing facies in the Pieniny Klippen Belt occus also in the Czertezik Succession (Birkenmajer 1959; Scheibner 1968; Wierzbowski *et al.* 2004), where the CRF consists of grey-green radiolarian limestones with radiolarian cherts (PRM), followed by red radiolarian limestones with radiolarian cherts (BRM); the KRM is here absent. The radiolarian assemblages from the CRF of the Czertezik Succession, 4.2 m thick, have been studied in the Litmanova section (Slovakia) by Ožvoldová *et al.* (2000) (Text-fig. 8). These sediments represent the U.A.Z 9–10 interval, similar to the section studied, corresponding to the middle Oxfordian–early Kimmeridgian.

The Niedzica Succession has an equivalent in the Slovak part of the Pieniny Klippen Belt, named the Pruské Succession (Andrusov 1945). However, the Middle–Late Jurassic siliceous radiolarian-bearing sediments from the Pruské Unit represent much deeper facies than those from the Niedzica Unit, interpreted on the basis of low or zero content of calcium carbonate in the CRF. These facies consist of green radiolarites at the base (PRM) which replaced nodular limestone, and they are overlain by red radiolarites (BRM); intercalations of siliceous shales characterize an upper part of the CRF. The red radiolarian cherts/radiolarites (KRM) are absent in this section. The data published by Aubrecht and Ožvoldová (1994) from the Pruské Succession are here revised in relation to radiolarian distribution in the Horné Srnie–Samášky section (Slovakia) using the zonation of Baumgartner *et al.* (1995) (Text-fig. 8). The base of the whole radiolarite succession is stratigraphically older than in the Niedzica and Czertezik Successions, representing the U.A.Z. 7 interval that corresponds to the late Bathonian–early Callovian. In turn, the accumulation of red radiolarian oozes finished in this part of the basin similarly, as in the regions represented by the



Text-fig. 8. Radiolarian biostratigraphic correlation of the Middle–Upper Jurassic pelagic siliceous facies between various successions in the Pieniny Klippen Belt (Western Carpathians) by means of radiolarian Unitary Association Zones, and revised lithostratigraphic scheme. The successions represent the Czajakowa Radiolarite Formation underlain and overlain by red nodular limestone of Rosso Ammonitico facies (Niedzica Limestone Formation and Czorsztyn Limestone Formation)

Niedzica and Czertezik Successions, being replaced by sedimentation of calcareous oozes during the U.A.Z. 9 interval corresponding to the middle–late Oxfordian.

SUMMARY

The accumulation of pelagic green and red radiolarian cherts and radiolarian-bearing siliceous limestones which created an intermediate siliceous succession in the pelagic nodular limestones of the Rosso Ammonitico facies was diachronous in the Pieniny Basin.

The age of these sediments was determined using the distribution of radiolarian taxa discussed in terms of the Unitary Association Zones (U.A.Z.) defined for the Jurassic Tethyan sediments.

(1) In the section related to the Niedzica Succession (Czajakowa Klippe section; this paper) and the Czertezik Succession (Litmanova section;

Ožvoldová *et al.* 2000), the siliceous sediments began subsequent to the mid Oxfordian (U.A.Z. 9). In the Horné Srnie–Samášky section representing the Pruské Succession (Aubrecht and Ožvoldová 1994; revised in this paper) the onset of the siliceous facies is older, *i.e.* subsequent to the late Bathonian–early Callovian interval (U.A.Z. 7).

(2) In turn, the final accumulation of siliceous sediments occurred during the early Kimmeridgian (U.A.Z. 10) in places which are represented by the Niedzica and Czertezik Successions, and earlier, *i.e.* during the ?late Oxfordian (U.A.Z. 9) in much deeper parts of the basin, corresponding to the Pruské Succession. However, the diachronism of the upper boundary between these places could be related to the incompleteness of radiolarian data from all sections due to the scarcity of radiolarian skeletons in their uppermost parts.

(3) The significant diachronism for the lower and for the upper limit of the siliceous facies in the Pieniny Klippen Belt sections is not unique in the Tethyan Realm. Similar examples have been presented based on the correlation of the siliceous successions of the Rosso Ammonitico Formation in the Southern Alps (Trento Plateau) and Western Sicily (Trapanese Domain) by Beccaro (2006). The combined occurrence of radiolarians and ammonites from that area shows that in those submerged pelagic platforms, carbonate accumulation was replaced by pelagic siliceous facies in the interval from the Bathonian through the late Kimmeridgian.

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