

Lower Turonian radiolarians from the Červená skála section (Pieniny Klippen Belt, Western Carpathians)

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Abstract

The Cenomanian–Turonian deposits studied in the Červená skála section (Czorsztyn Succession of the Pieniny Klippen Belt) comprise pelagic facies belonging to the siliceous bed, in which abundant radiolarian and foraminiferal fauna was indentified. They indicate the deeper development of the Czorsztyn elevation of the Pieniny Klippen Belt. The radiolarians *Alievium superbum* (SQUINABOL), *Crucella cachensis* PESSAGNO, *Patellula ecliptica* O'DOHERTY and *Acanthocircus tympanum* O'DOHERTY have been used as marker fossils for the Cenomanian–Turonian boundary interval. On the basis of the ratio of Spumellaria and Nassellaria abundance, the siliceous bed may represent unstable environmental conditions connected with the eutrophication.

Key words: radiolarians, Púchov Marls, Cretaceous, Czorsztyn Succession, Pieniny Klippen Belt, OMZ, Western Carpathians

Introduction

The Cenomanian–Turonian stratigraphic interval of the Púchov Marls of the Czorsztyn Succession in the Pieniny Klippen Belt is characterized by a common occurrence of two planktonic microfossils – radiolarians and foraminifers. Their common occurrence in associations from the Cretaceous formations is stated in silicified rocks. Up to the present, such an interval was detected at the Vršatec locality (Sýkora et al., 1997) and in the klippe of Dolný Mlyn, near the village Stará Turá (Scheibnerová, 1969). The results of the first systematic investigation of the Upper Cretaceous radiolarian fauna from the Czorsztyn Succession in the Polish sector of the Pieniny Klippen Belt belonging to the Skalski Marl Member (the Altana Shale Bed) and to the Pustelnia Marl Member (the Lorencowe Chert Bed) of the Jaworki Formation (Birkenmajer, 1977) were published by M. Bąk (1996a). Further information about the Upper Cretaceous radiolarians of the Pieniny Klippen Belt is in publications of M. Bąk (1993a, 1993b, 1995, 1996b), M. Bąk and K. Bąk (1999) and M. Bąk and Sawłowicz (2000).

Our research was focused on the Upper Cretaceous red pelagic marls – the Púchov Marls (Štúr, 1860; Andrusov et al., 1985) which are exposed at the Červená skála locality (the English name *Red Rock* was derived after the prominent red colour of the exposed part of the klippe) near the village Nižná in the Orava region (Fig. 1). In Poland, these rocks form a part of the **Jaworki Formation** (after Jaworki village) in the lithostratigraphic division of the Pieniny Klippen Belt after Birkenmajer

(1977). This paper brings the new taxonomical results concerning radiolarians selected from the Púchov Marls studied in the locality mentioned above. The qualitative and quantitative evaluations of these associations were used for a paleoecological interpretation.

Geological settings

The sequence of the Červená skála section comprises rocks typical of the deeper development of the Czorsztyn elevation of the Pieniny Klippen Belt (former margin of the Mesozoic Paleoeuropean shelf; Fig. 1). It can be subdivided into three lithological units: Czorsztyn Limestone Formation, Pieniny Limestone Formation and Púchov Marls. Red Upper Cretaceous pelagic marls, claystones and marl shales were described by Štúr (1860) for the first time from four localities – Hrabovka, Vieska-Bezdedov, Brezie and Ihrište and they were named as the **Ihrište Marls** (after Ihrište village, N from Púchov). Later, they were re-named to the **Púchov Marls** (Štúr, 1860; Andrusov et al., 1985) after the town of Púchov. The variegated marls of the Lower Campanian were called as the **Gbelany Marls** (after Gbelany village near Varín) by Kantorová and Andrusov (1958). Their equivalents are represented by the “Couches Rouges” in the Alps and the “Scaglia Rosa” in Apennines.

Despite the **Jaworki Formation** according to Birkenmajer and Jednorowska (1987) is divided into a greater number of lithostratigraphic members, the specification of the **Jaworki Formation** is used in this paper. The formation consists mainly of marls and limestones (pelagic foraminifers facies). The Jaworki Formation is subdivided into eight

lithostratigraphic units (Birkenmajer and Jednorowska, 1987). The silicified parts with radiolarian fauna occur in the following members (Fig. 2):

The **Skalski Marl Member** (Uppermost Lower Cenomanian–Lower Turonian) is characterized by the variegated marls, marl shales and limestones, interbedded in several places with the black radiolarian shales, which were produced by an anoxic event (the Altana Shale Bed).

The **Magierowa Marl Member** (Middle Cenomanian–Upper Turonian) also contains the Altana Shale Bed in greyish green to black marls and limestones.

The **Pustelnia Marl Member** (Upper Cenomanian–Lower Maastrichtian, after Birkenmajer and Jednorowska, 1987, Middle Cenomanian–Upper Campanian, after Bağ, 1998) consists of rustbrown coloured marls. Other colours, like white or green are infrequent. Layers of silicified limestones with chert interbeds (Lorencowe Chert Bed)

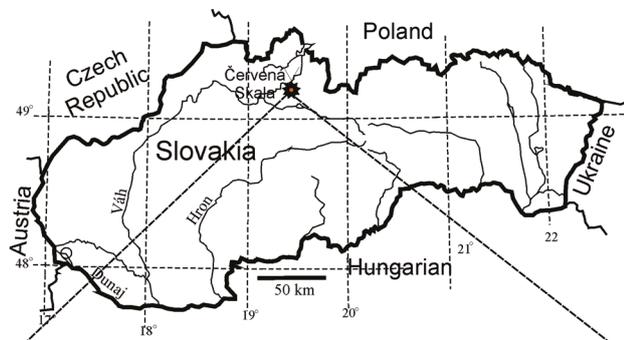


Fig. 1. Location of the studied section.

are common. These strata were first integrated into the Skalski Marl Member by Birkenmajer (1977) and later, on the basis of the analysis of foraminifers microfauna, they were placed to Santonian–Campanian by Jednorowska (1979).

Correlation with the Jaworki Formation is possible outside Poland, where they were defined. Some of formations, e.g. Albian Rudina Formation, Cenomanian Lalinok Formation, Middle Turonian–Lower Coniacian Snežnica Member, Campanian–Maastrichtian Gbelany Formation or Lower Campanian Košariské Formation in the Brezovská Group represent an equivalent to some members of the Jaworki Formation (Michalík et al., 2002). In the Ukraine (Gluško, 1971) and Romania (Bombita, 1972) the Jaworki Formation is correlated with the Púchov Formation and Tisalo Formation. A partial equivalent of the Jaworki Formation is also Buntmergelserie (Klippenhüllflysch) in Austria (Prey, 1960).

Investigated silicified marlstones belong to the Skalski Marl Member (Uppermost Lower Cenomanian–Lower Turonian) of the Jaworki Formation. These are characterized

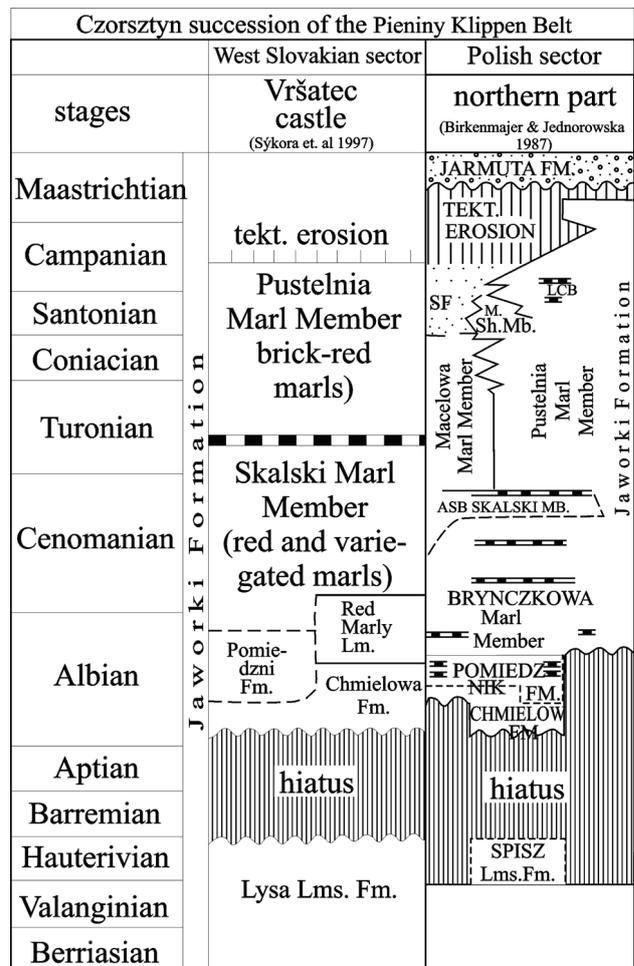


Fig. 2. Correlation of lithostratigraphic units (Hauterivian–Maastrichtian) in the Czorsztyn Succession of the Pieniny Klippen Belt in the Polish and Slovak territory (according to Sýkora et al., 1997, adapted).

by marls, marl shales and limestones with intercalations of the dark Altana Shale Bed. In the investigated profile the silicified limestones and marlstones possess characteristics of the Lorencowe Chert Bed (Birkenmajer, 1977; M. Bağ, 1996a, a.o.). Although, these beds were assigned to Santonian–Campanian on the basis of foraminiferal microfauna by Jednorowska (1979). Birkenmajer (1977) placed them to the Skalski Marl Member in the original division. However, it is possible that investigated silicified beds represent the Lorencowe Chert Bed in the frame of the Skalki Marl Member in the Jaworki Formation.

Sedimentology of Jaworki Formation at locality Červená skala

The Červená skala (Red Rock) locality is situated in the Orava region, at Nižná village, near the elevation point 707 (Fig. 1). The investigated profile is located at GPS coordinates of 49° 19' 8.0" of NW latitude and 19° 30' 26.2" of EW longitude.

The Jaworki Formation is exposed in an approximately 500 cm long section (Fig. 3). Stratigraphic range of the formation according to radiolarians and foraminifers is from

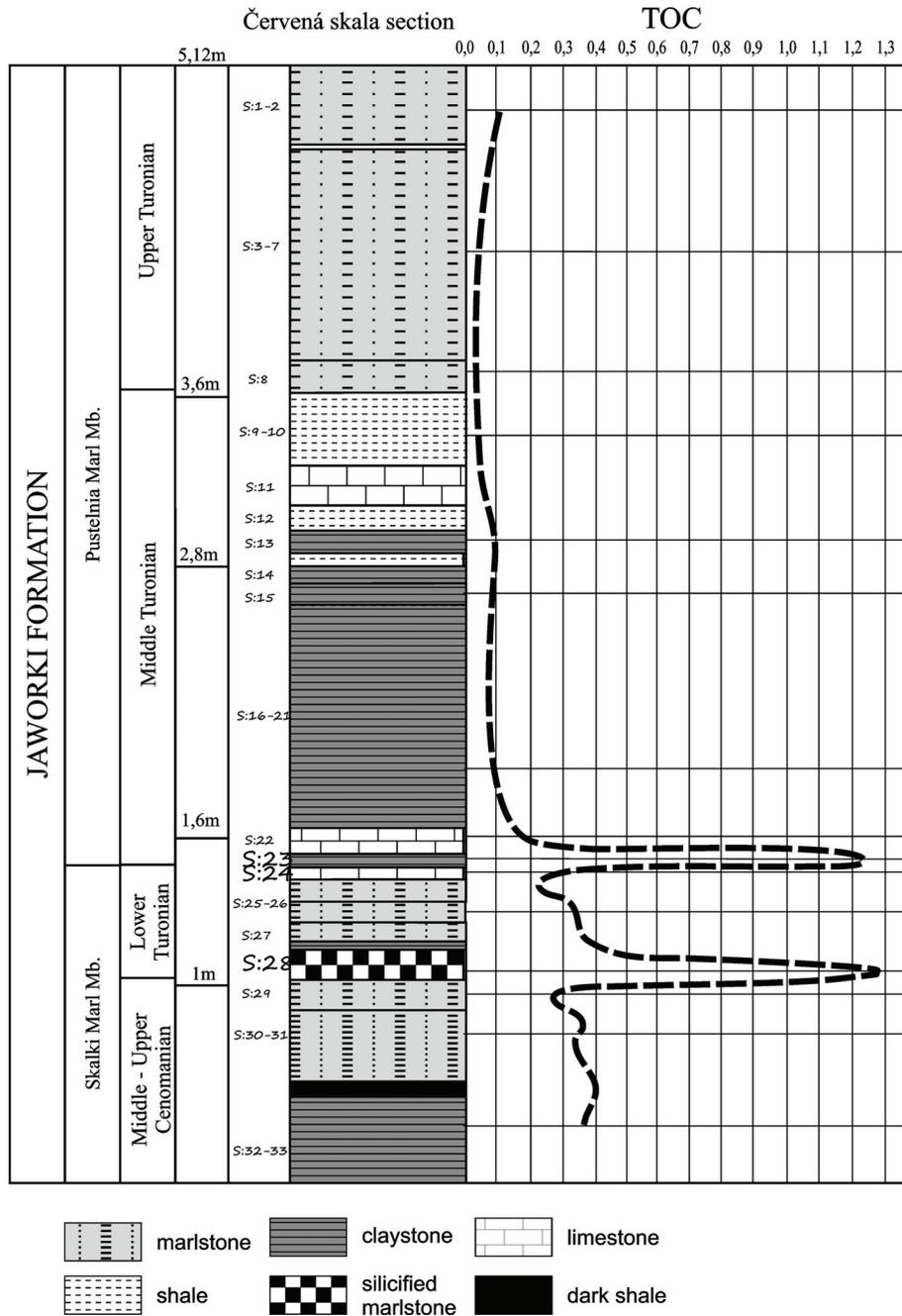
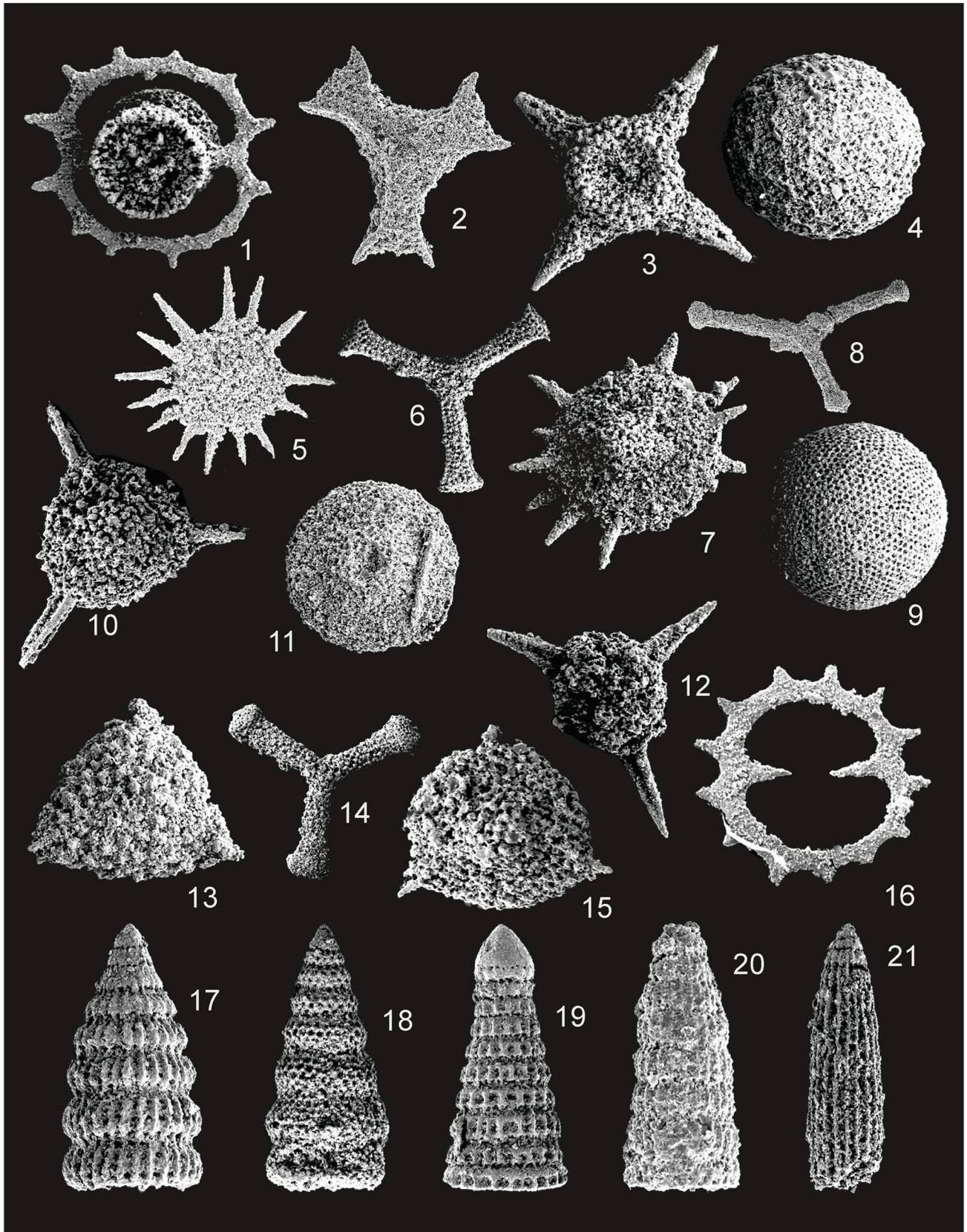


Fig. 3. Lithostratigraphic column of the studied section.



the Middle Cenomanian up to the Upper Turonian (Soták, personal communication).

Since the sequence is in the reverse position, sampling and description of profile has been done also in the reverse order. The section starts with the red and reddish brown coloured marlstones with shell-like fracturing and irregular disintegration, crumbling into small pieces in several places. This roughly 200 cm part of the section is replaced by 10 cm bed of the greenish grey to dark grey calcareous marlstones, followed by thin light grey limestone layer, 8 cm brownish grey shale and schistose purple-red limestones. The section is succeeded by an approximately 1 m thick reddish brown to red marls, which are changed

by 6 cm bed of greenish-grey to olive-yellow plastic clays with 1.3 cm of dark-grey to black organic-rich claystones at the top. The sedimentological section continues with 6 cm thick bed of thin-bedded ash-grey to light grey laminated limestones. The horizontal bands are represented by the concentrations of clay minerals, all fossils are preserved very well and they are concentrated into a lamina within the layer itself and their amount increases to the top (Richter, 2004). Then the bed of light grey limestones with the radiolaria-rich fauna appears, being followed by a thin bed of olive green marlstones, which also contain microfossils of foraminifers and radiolarians (cf. Richter, 2004). The section then follows up with the red, poorly schistose marls

Tab. 1
Distribution of radiolarians in the studied samples

Radiolarian microfauna	28	24	23	Radiolarian zonation O'Dogherty 1994
<i>Acastea rebellis</i> (O'DOGHERTY, 1994)		X		U.A. 14-21
<i>Acastea vitalis</i> (O'DOGHERTY, 1994)		X		U.A. 11-21
<i>Acastea cf. diaphorogona</i> (FOREMAN, 1973)		X		
<i>Acanthocircus tympanum</i> O'DOGHERTY, 1994	X	X		U.A. 20-21
<i>Acanthocircus venetus</i> (SQUINABOL, 1914)	X	X		U.A. 14-21
<i>Actinomma</i> sp.	X	X	X	
<i>Alievium superbum</i> (SQUINABOL, 1914)	X	X	X	U.A. 20-21
<i>Archaeocenosphaera mellifera</i> O'DOGHERTY, 1994	X	X	X	U.A. 10-21
<i>Crucella cachensis</i> PESSAGNO, 1971	X	X	X	U.A. 20-21
<i>Crucella cf. hispana</i> O'Dogherty, 1994		X		
<i>Dictyomitra formosa</i> SQUINABOL, 1904	X	X	X	U.A. 14-21
<i>Dictyomitra montisserei</i> (SQUINABOL), 1903	X	X		U.A. 10-20
<i>Dictyomitra multicostata</i> ZITTEL, 1876		X		U.A. 21
<i>Halesium amissum</i> (SQUINABOL, 1914)	X	X		U.A. 16-21
<i>Halesium triacanthum</i> (SQUINABOL, 1903)		X		U.A. 14-21
<i>Holocryptocanium barbui</i> DUMITRICA, 1970	X	X	X	
<i>Paronaella cf. californiensis</i> (PESSAGNO, 1971)		X		U.A. 20-21
<i>Patellula andrusovi</i> OŽVOLDOVÁ, 1997		X		
<i>Patellula ecliptica</i> O'DOGHERTY, 1994	X	X		U.A. 20-21
<i>Patellula helios</i> (SQUINABOL, 1903)	X	X		U.A. 17-21
<i>Pessagnobracchia fabianii</i> (SQUINABOL, 1914)	X	X		U.A. 11-21
<i>Pessagnobracchia irregularis</i> (SQUINABOL, 1903)		X		U.A. 12-17
<i>Praeconocaryomma universa</i> PESSAGNO, 1976		X	X	
<i>Pseudoaulophacus cf. polonicus</i> GÖRKA, 1989		X		
<i>Pseudoaulophacus putahensis</i> PESSAGNO, 1972	X	X		U.A. 14-21
<i>Pseudodictyomitra pseudomacrocephala</i> (SQUINABOL, 1903)	X	X	X	U.A. 10-21
<i>Quinquecapsularia grandiloqua</i> O'DOGHERTY, 1994		X		U.A. 18-21
<i>Staurosphaeretta cf. longispina</i> (SQUINABOL, 1903)		X		
<i>Stichomitra communis</i> SQUINABOL, 1903	X	X	X	U.A. 5-21

- ◀ PI. I. Radiolarian microfauna in silicified marlstones – Turonian. 1 – *Acanthocircus tympanum* O'DOGHERTY – samp. 24, 175x; 2 – *Halesium amissum* (SQUINABOL) – samp. 24, 190x; 3 – *Crucella cachensis* PESSAGNO – samp. 28, 230x; 4 – *Archaeocenosphaera mellifera* O'DOGHERTY – samp. 23, 220x; 5 – *Patellula ecliptica* O'DOGHERTY – samp. 28, 120x; 6 – *Halesium triacanthum* (SQUINABOL) – samp. 24, 150x; 7 – *Patellula helios* (SQUINABOL) – samp. 24, 340x; 8 – *Pessagnobracchia irregularis* (SQUINABOL) – samp. 24, 180x; 9 – *Holocryptocanium barbui* DUMITRICA – samp. 23, 180x; 10 – *Pseudoaulophacus putahensis* PESSAGNO – samp. 24, 140x; 11 – *Patellula andrusovi* OŽVOLDOVÁ – samp. 24, 290x; 12 – *Acastea rebellis* O'DOGHERTY – samp. 24, 210x; 13 – *Alievium superbum* (SQUINABOL) – samp. 24, 170x; 14 – *Pessagnobracchia fabianii* (SQUINABOL) – samp. 24, 190x; 15 – *Pseudoaulophacus putahensis* PESSAGNO – samp. 28, 190x; 16 – *Acanthocircus venetus* (SQUINABOL) – samp. 24, 210x; 17 – *Dictyomitra formosa* SQUINABOL – samp. 24, 230x; 18 – *Stichomitra communis* SQUINABOL – samp. 28, 310x; 19 – *Pseudodictyomitra pseudomacrocephala* (SQUINABOL) – samp. 24, 190x; 20 – *Dictyomitra multicostata* ZITTEL – samp. 24, 230x; 21 – *Dictyomitra montisserei* (SQUINABOL) – samp. 24, 230x.

and by alternating red to greenish grey marls, changed by the very thin bed of dark grey to black claystones under the next radiolarian horizon. This 14 cm thick dark grey poorly laminated radiolarian horizon is followed up with 18 cm thick bed of red solid marlstone and with 28 cm thick bed of grey to greenish grey solid marlstones. The section ends with 40 cm thick bed of brownish grey, brownish red to purple red schistose claystones.

Methods

Thirty samples have been collected from the studied section. Each sample consisted of a small pieces of rock (5–6 cm), cut parallel to bedding. Radiolarians were extracted using two methods. Calcareous samples were cleaned, crushed into smaller pieces, poured with 12 % of acetic acid (CH₃COOH) and leached out during 7 days. Calcareous samples with high content of SiO₂ were cleaned, crushed into smaller pieces, poured with hydrofluoric acid in 1 : 7 ratio during 3 days. Selected samples were studied under the scanning electron microscope (SEM).

Radiolarian assemblages

The radiolarians in the samples S-23, S-24 and S-28 were analysed from the residuum (Tab. 1). Evaluation of the samples is based on the detailed biozonation for the Mediterranean area after O'Dogherty (1994; Pl. I).

Acanthocircus tympanum O'DOGHERTY, *Acanthocircus venetus* (SQUINABOL), *Alievium superbum* (SQUINABOL), *Crucella cachensis* PESSAGNO, *Dictyomitra montisserei* SQUINABOL, *Patellula ecliptica* O'DOGHERTY, *Patellula helios* (SQUINABOL), *Pessagnobracchia fabianii* (SQUINABOL), *Pseudoaulophacus putahensis* PESSAGNO in the sample S-28 and *Acanthocircus tympanum* O'DOGHERTY, *Acanthocircus venetus* (SQUINABOL), *Alievium superbum* (SQUINABOL), *Crucella cachensis* PESSAGNO, *Dictyomitra montisserei* SQUINABOL, *Dictyomitra multicostata* ZITTEL, *Patellula andrusovi* OŽVOLDOVÁ, *Patellula ecliptica* O'DOGHERTY, *Patellula helios* (SQUINABOL), *Pessagnobracchia fabianii* (SQUINABOL), *Pseudoaulophacus putahensis* PESSAGNO in the sample S-24 indicate that the assemblages belong to the Superbum Zone which begins in the lowermost Turonian. The zone comprises the Unitary Association UA 20 and the overlying UA 21. The upper boundary of the zone was not assigned.

The index taxon of this zone is *Alievium superbum* (SQUINABOL). The species *Acanthocircus tympanum* O'DOGHERTY, *Crucella cachensis* PESSAGNO and *Patellula ecliptica* O'DOGHERTY also appear in UA 20. *Dictyomitra montisserei* (SQUINABOL) finishes in the same Unitary Association. But *Dictyomitra multicostata* ZITTEL which appears in the following UA 21 can rarely be observed in the sample S-24. It is assumed that the presented assemblage from the sample S-28 represents the Lower Turonian, while the association from the sample S-24 represents the boundary of Lower and Middle Turonian.

In the sample S-23 the presence of *Alievium superbum* (SQUINABOL) and *Crucella cachensis* PESSAGNO, which

appear for the first time on the lower boundary of the Turonian and species *Archaeocenosphaera mellifera* O'DOGHERTY, *Dictyomitra formosa* SQUINABOL and *Holocryptocanium barbui* DUMITRICA, which finish in the Turonian, indicates that the presented assemblage represents relatively wide stratigraphic range – the Turonian.

Paleoenvironmental implications

Traditionally, from the time of Haeckel (1873–1887), the Spumellaria are considered to dwell only in the surface waters and therefore most authors (Kießling, 1996, 1999, a.o.) used the proportion of Spumellaria vs. Nassellaria S/N as possible indicator of the depth of sedimentary accommodation space and/or the distance from the mainland. It was documented in the investigations of Casey (1993) in recent oceans that Spumellaria dominate in the offshore, while Nassellaria dominate in pelagic oceanic parts.

The predominance of Spumellaria in the medium-depth deposits and the abundance of Nassellaria not only in the deep-water but also in the shallow-water deposits were recorded by Empson-Morin (1984) in the Campanian. Similarly, extreme abundance of Nassellaria in the shallow-water deposits was described by Zügel et al. (1998).

In investigated associations within the samples S-24 and S-28, Nassellaria slightly prevail over Spumellaria (52–60 %), but the diversity of Spumellaria is substantially higher. More than 90 % of Nassellaria specimens belong to the genus of *Dictyomitra* and *Stichomitra*, less of them to *Pseudodictyomitra*. Genus *Patellula* from the *Sponguridae* is almost equal to the genera of *Hagiastridae*, *Pseudoaulophacidae* and *Patulibracchiidae* (*Crucella*, *Pseudoaulophacus*, *Pessagnobracchia*).

The sample S-23 revealed radiolarian association which was poor in the species and possessed remarkable indications of sorting in the size and shape. Spherical shells of mostly Spumellaria (*Actinomma*, *Praeconocaryomma* a. o.) as well as Nassellaria (*Holocryptocanium*) prevailed. The other different forms constituted minimal proportion. Since the composition of the association was affected by sorting, quantitative proportion of individual components was not detected.

After Takashi (1991, 1997) and Casey (1971, 1977), the associations in the middle part of the Bonarelli Level, in which the Nassellaria of the genus *Cryptamphorella*, *Holocryptocanium*, *Pseudodictyomitra*, *Stichomitra*, *Archaeodictyomitra*, *Dictyomitra* a.o., represent impoverished associations. They are analogous to present deep-water forms. Although, it is possible that impoverished associations resulted from a selective dissolution as well as worse conditions of the preservation of certain type of shells. In spite of this, the authors prefer the view that acquired associations represent at least a part of original association.

Kuhnt et al. (1986) recorded remarkably increased content of the spongy forms of Spumellaria around the C/T boundary in the Tethyan region in deposits representing middle depths and oxygen-depleted environment.

In our associations, deep-water forms slightly prevail over Spumellaria, in which the number of spongy forms

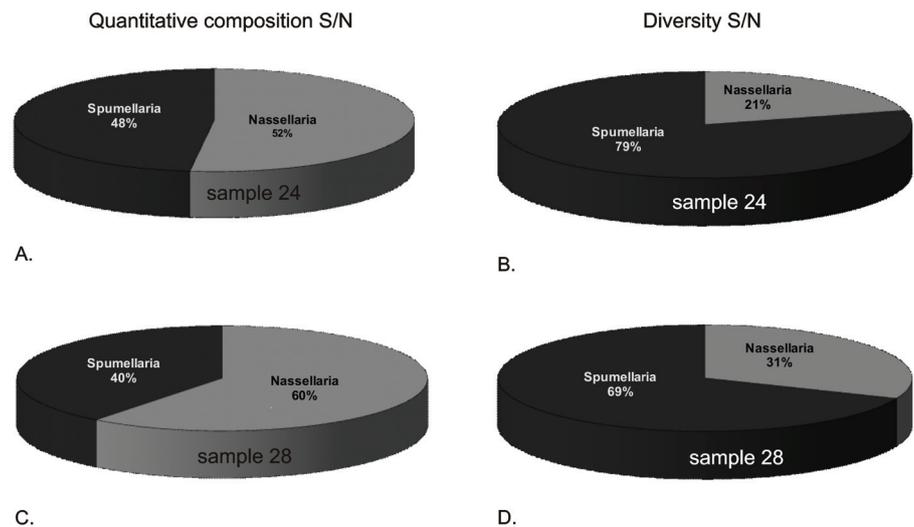


Fig. 4. Quantitative composition and diversity of Spumellaria/Nassellaria in the samples 24 and 28.

is not remarkably increased and which are in equilibrium with the other spumellarian forms of community.

According to mentioned informations resulting from the study of radiolarians, the investigated associations represent the deposits of intermediate depths, without more expressive oxygen deficit.

O'Dogherty and Guex (2002) suggested that the variations in the proportion of Spumellaria vs. Nassellaria indicate rather the conditions of ecological stress than the depth of sedimentary accommodation space. Their data (l.c.) provide the evidence that Spumellaria are more resistant to unstable ecological conditions than Nassellaria. However, Nassellaria reveal a greater rate of evolution in the periods of radiation than Spumellaria.

It is suggested that the diversity proportion of Spumellaria to Nassellaria is an acceptable indicator of aggravating climate as well as the ecological stress.

In connection with the research results of Erbacher and Thurow (1996) a.o., O'Dogherty and Guex (2002) determined a few repetitive successive phases based on the research of the rate and the model of radiolarian evolution in the Cretaceous.

The 1st phase represents the event of extinction. The 2nd phase contains the period of the lowest diversity of Radiolaria. The 3rd phase represents the event of radiation. The last, 4th phase represents the period of the highest diversity.

If we want to place the associations from the Červená skala locality to one of the phases after O'Dogherty and Guex (2002), then it would correspond with the 2nd phase, because the silicification of marls is a remarkable feature of eutrophication of under-surface waters. The diversity of Spumellaria is higher than that of Nassellaria, however Nassellaria dominate by forms which tolerate unstable environmental conditions and which, after the research at the type localities, continued since the Cenomanian until early Turonian (Fig. 4).

The Ocean Anoxic Event 2 is indicated by some geochemical proxies, such as increasing organic carbon

content in radiolarian-bearing horizons and the increase of $\delta^{13}\text{C}$ values towards the Cenomanian/Turonian boundary (Fig. 3).

Conclusions

The detailed radiolarian zonation of O'Dogherty (1994) was used for the evaluation of the radiolarian microfauna. Based on the radiolarian evaluation of the samples from the locality Červená skala, the investigated associations represent the Lower Turonian and originate from deposits formed in unstable environmental conditions connected with the eutrophication in intermediate water depth without more expressive oxygen deficit.

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