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APPLICATIONS μ

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High resolution microfossil, microfacies and palynofacies studies as the only method in recognition of the Jurassic and Cretaceous “black shales” in a strongly tectonised section of the Czorsztyn Succession, Pieniny Klippen Belt, Poland

(Figs 1–9; Tables 1–5)

Abstract. Combined stratigraphic studies based on foraminifers, radiolarians and palynomorphs together with microfacies and palynofacies characteristics allowed us to separate the Lower Turonian sediments corresponding to the Cenomanian/Turonian boundary event from the Lower–Middle Jurassic black facies in a strongly tectonised section of the Czorsztyn Succession in the Pieniny Klippen Belt, Poland. The studied section, located at Trawne creek, includes tectonised incompetent series of black marly facies and pink, cherry-red marls and marly limestones.

The Cenomanian/Turonian boundary event deposits (ca. 0.5 m thick) belong to the upper part of the Altana Shale Bed of the Jaworki Formation with uncertain transition to the pelagic pink and cherry-red marly limestones and marls. Both facies represent the *Helvetoglobotruncana helvetica* planktonic foraminiferal Zone (Lower–Middle Turonian).

The other black facies in the studied section include dark-grey marly shales with dark-grey calcareous mudstone (ca. 1.5 m of total thickness). These sediments most likely belong to the Skrzypny Shale Formation. This is documented by the filament-radiolarian microfacies, dinocyst and radiolarian stratigraphic data. An Early Bajocian age was determined only for one thin package of dark-grey shale. Other packages of black facies include long-ranging dinocyst taxa of Late Pliensbachian–Early Bathonian age. Following the earlier stratigraphic data for the Skrzypny Shale Formation (Middle Aalenian–Lower Bajocian), based on ammonite fauna, it may be suggested that a

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part of these black facies might represent the underlying lithostratigraphic unit, the Krempachy Marl Formation, or its transition to the Skrzypny Shale Formation.

Pelagic cherry-red marls and marly limestones which in most cases are in tectonic contact with the black facies are here also strongly tectonised. They represent different, non-continuous stratigraphic horizons of the Lower–Middle Turonian and the Lower Campanian.

Key words: Foraminifera, Radiolaria, dinocyst, microfacies, palynofacies, Lower–Middle Jurassic, Cenomanian–Turonian boundary event, biostratigraphy

INTRODUCTION

A number of horizons representing anoxic events are known worldwide in Jurassic and Cretaceous deposits both in oceanic and platform successions. One of them is the organic-rich facies of the Cenomanian/Turonian boundary event (CTBE; Kuhnt *et al*., 1986). The black sediments corresponding to this event are developed also in the Pieniny Klippen Belt (Birkenmajer, 1952, 1977; Alexandrowicz, 1966; K. Bąk & M. Bąk, 1994; K. Bąk, 1995, 1998, 2000; M. Bąk, 1996), the latter representing an intra-oceanic basin during the Jurassic–Cretaceous times, with pelagic sedimentation on restrictive ridges and pelagic, hemipelagic and partly turbiditic sedimentation on the slopes and in the central furrow (Birkenmajer, 1986). The black facies of the Cenomanian/Turonian boundary event occur among others in the Czorsztyn Succession, formalized there as the Altana Shale Bed within the Jaworki Formation (Birkenmajer, 1977). These are underlain by the Cenomanian variegated (mostly red) pelagic marls and covered by Turonian–Maastrichtian pink and cherry-red, pelagic marls and marly limestones. These facies characterize the submarine Czorsztyn Ridge (Birkenmajer, 1963; Alexandrowicz *et al*., 1968).

The sediments of Cenomanian/Turonian boundary event are not the only black facies in the Czorsztyn Succession (Fig. 1). Other black sediments known to occur here include: Upper Pliensbachian–Lower Aalenian dark-grey marly shales and marls (Krempachy Marl Member), Middle Aalenian–Lower Bajocian black marly shales with spherosiderite concretions, and Middle–Upper Albian grey, black and green marls and marly limestones (Pomiedznik Formation) (Birkenmajer 1977, and earlier papers cited therein; Gasiński, 1988).

Due to the Late Tertiary strong tectonic deformations of the Pieniny Klippen Belt (Birkenmajer, 1986), the Lower–Middle Jurassic and the Upper Cretaceous deposits of the Czorsztyn Succession, display complex tectonic structures. Their development was related to the prevailing share of competent, massive Middle–Upper Jurassic limestones (Smolegowa, Krupianka, and Dursztyn formations) over thin series of bedded and incompetent shales, marls, and marly limestones. Due to folding and thrusting of the latter incompetent sediments, numerous thin (even a few centimeters thick) tectonic slices were formed. They may include different lithostratigraphic units. In such cases, the recognition of the Cenomanian/Turonian boundary event from other Cretaceous and Lower–Middle Jurassic black series is quite difficult.

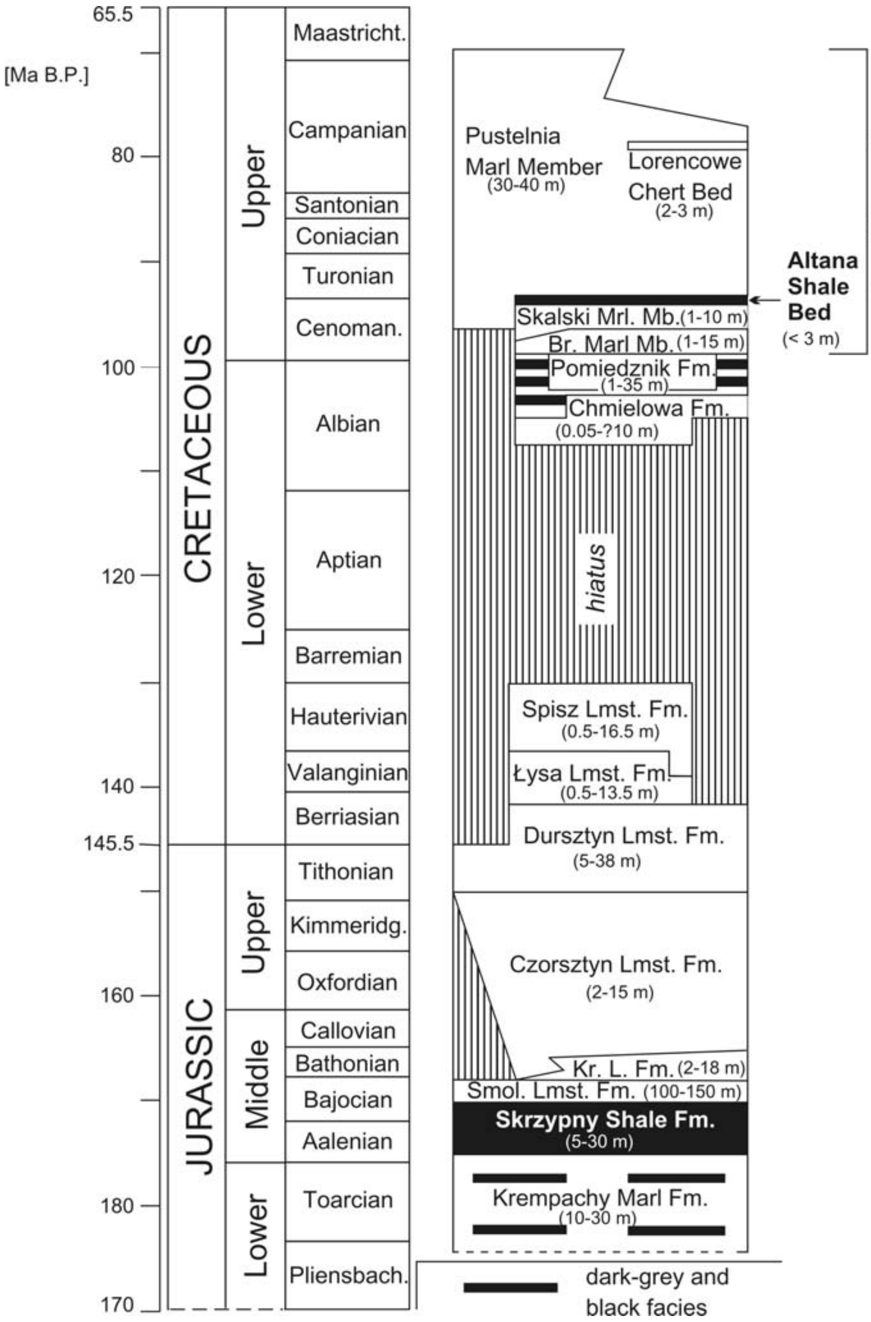


Fig. 1. Lithostratigraphy of the Jurassic–Cretaceous deposits in the Czorsztyn Succession, Polish part of the Pieniny Klippen Belt (after Birkenmajer, 1977; supplemented by Birkenmajer & Jednorowska, 1986; Bąk, 1998; Krobicki & Wierzbowski, 1996; Wierzbowski *et al.*, 1999). Black colour is indicative of "black facies". Smol. Lmst. Fm. – Smolegowa Limestone Formation, Kr. L. Fm. – Krupianka Limestone Formation, Br. Marl Mb. – Brynczkowa Marl Member. Geological Time scale – after ICS (2004)

In the present paper, we discuss the stratigraphy of a strongly tectonised incompetent series of the Czorsztyn Succession exposed at Trawne creek, in order to distinguish the black sediments accumulated during the Cenomanian/Turonian boundary event from other black sediments.

DESCRIPTION OF SECTION

The studied section is located in the central part of the Pieniny Klippen Belt, in its Polish segment, where the Czorsztyn Succession contacts with the Branisko Succession and the Grajcarek Unit (Fig. 2B, C). The section lies within the Trawne creek, approximately 50 m west of the Rogoźnik quarry ("west quarry"). Here, white and pink crinoidal limestones (Smolegowa and Krupianka formations) and the red shelly limestones (Rogoźnik Coquina Member of the Dursztyn Limestone Formation) are in tectonic contact with cherry-red (partly variegated) marls of the Pustelnia Marl Member (Fig. 2E). In the right bank of the creek, the latter lithostratigraphic unit is strongly tectonised forming several thin tectonic slices (2–60 cm thick) together with black, dark-grey, dark-green marly shales, dark-grey and dark-green mudstones (Fig. 3). The majority of the contacts between "black" sediments with cherry-red marls are tectonic, confirmed by the occurrence of tectonic striae and calcite veins.

A dozen meters north of this outcrop, black marly shales including spherosiderite concretions (Skrzypny Shale Formation, Middle Aalenian–Lower Bajocian ages) occur in both banks of the Trawne creek (Fig. 2E). South of this outcrop, the tectonised sediments tectonically contact with dark-red marls and marly shales. The latter series display lithological features similar to these of the Macelowa Marl Member, another Upper Cretaceous red-coloured, hemipelagic sediments in the Pieniny Klippen Belt (Fig. 2E). The latter sediments may belong to the Branisko Succession, cropping out at the Trawne creek, approximately 100 m south of the studied section.

The "black" sediments in the studied outcrop could at least partially represent the Skrzypny Shale Formation. However, there are some lithological differences between the studied sediments (occuring in packages, 2–40 cm thick) and the sediments cropping out in the channel of Trawne creek, some dozen meters north of the studied outcrop. In the latter outcrop, the shales are exclusively black and include spherosiderite concretions, whereas in the studied exposure, the shales consist of dark-grey, black and dark-green marly shales, with a few layers of calcareous mudstone without concretions.

On the other hand, occurrence of dark-grey, grey-green and black marly shales, including thin green shale levels, resembles another lithostratigraphic unit, namely the Altana Shale Bed of the Jaworki Formation. Type section of the latter unit occurs close to the studied outcrop, at the Szaflary quarry (Birkenmajer, 1952, 1963, 1977).

Therefore, the question remains open: are the thin black shales within the Upper Cretaceous brick-red marls of Early–Middle Jurassic or Late Cretaceous age?

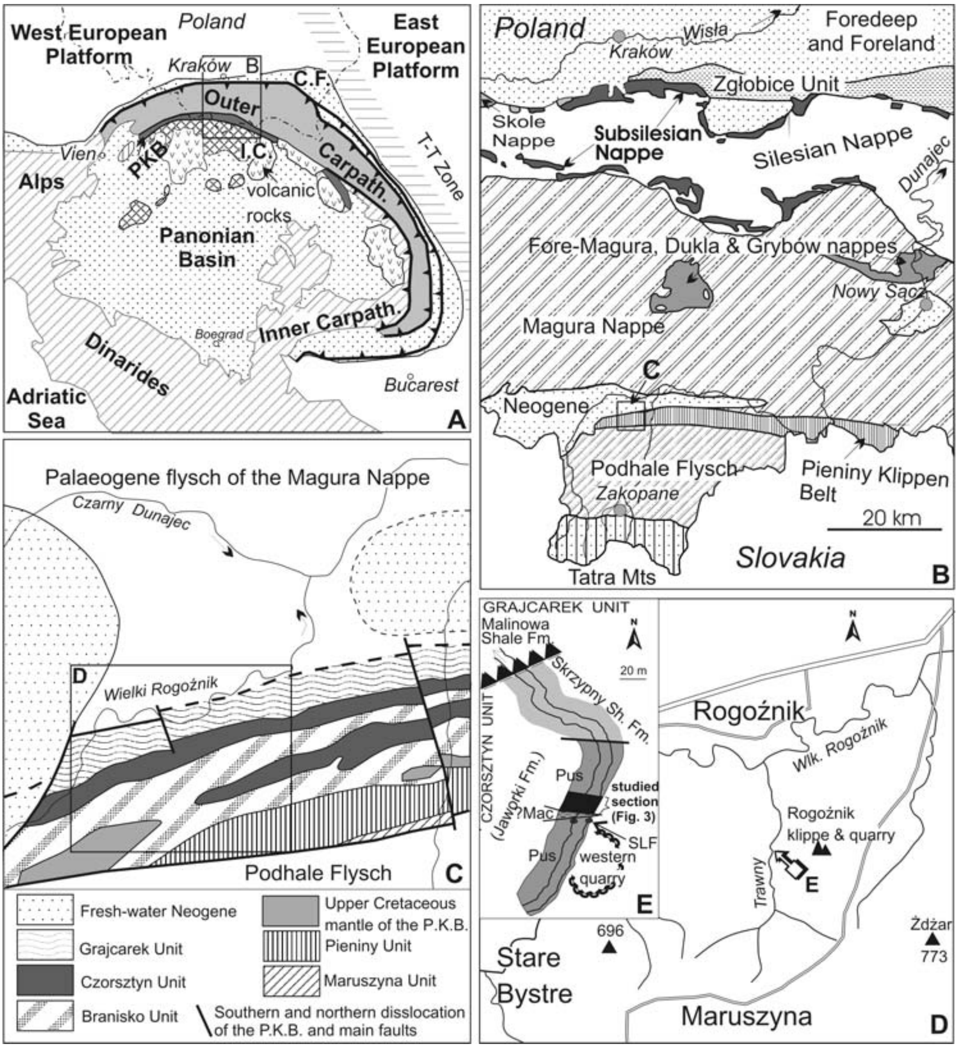


Fig. 2. Location maps of the study area in the Pieniny Klippen Belt in relation to the main geological units. **A** – Outer Carpathians against the background of simplified geological map of the Alpine orogens and their foreland; I.C. – Inner Carpathians, C.F. – Carpathian Foredeep, PKB – Pieniny Klippen Belt. **B** – Pieniny Klippen Belt against the background of the Polish Carpathians. **C** – Tectonic map of the western part of the Pieniny Klippen Belt in Poland (after Birkenmajer, 1979). **D** – Topographic map of the Rogoźnik vicinity with position of the studied section. **E** – Geologic map of the Trawne creek, west of the Rogoźnik quarry: Pus – Pustelnia Marl Member, Mac – Macelowa Marl Member (?Branisko Succession), Skrzypny Sh. Fm. – Skrzypny Shale Formation, SLF – Smolegowa Limestone Formation

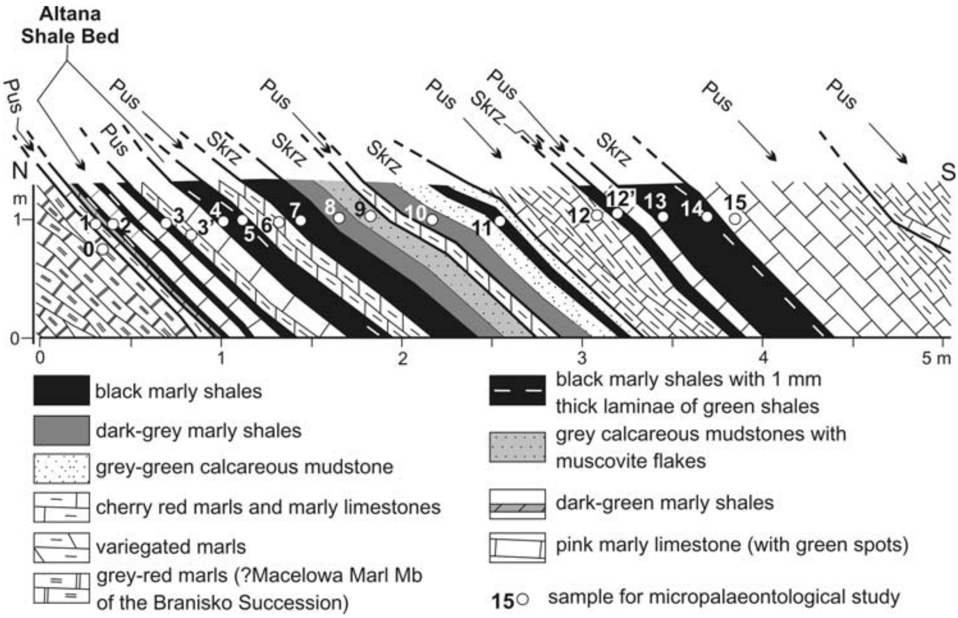


Fig. 3. Strongly tectonised black and red facies of the Czorsztyn Succession, exposed at the right bank of the Trawne creek, west of Rogoźnik quarry, in 1999. Recognition of the units – due to microfacies and biostratigraphical studies. Pus – Pustelnia Marl Member, Skrz – Skrzypny Shale Formation

METHODS

The lithology of the studied deposits was determined during field-work, carried out by the first author, and supported by the study of microfacies in thin-section (K. & M. Bąk). The palaeontological studies have been carried out in three steps: (1) by analyses of foraminiferal assemblages (K. Bąk), (2) followed by the radiolarian analyses (M. Bąk), and finally (3) by dinocyst and palynofacies analyses (M. Barski).

Samples of approximately 300 grams each have been taken carefully from most lithological types following a centimetrical sampling step (Fig. 3). Due to observed tectonic disturbances, the samples have been cleaned in labolatory in order to rid them of contaminants.

For foraminiferal and radiolarian studies, the samples were dried and disintegrated in a solution of sodium carbonate. Then the material was washed through sieves with mesh diameters of 63 µm. The microfauna were picked from the 0.063–1.5 mm fraction and mounted on cardboard slides for microscopic examination. At least 300 foraminiferal and radiolarian tests were picked, except for those samples where microfossils were extremely rare.

Eleven samples, collected mostly from dark and black horizons were studied palynologically. The rock material underwent a standard palynological preparation (Evitt, 1984; Poulsen *et al.*, 1990), using 37% HCL, 40% HF, 78% HNO_3 and 5%

KOH. The residuum for analysis was obtained using a 15 μm diameter sieve. The quantity of rock used for processing was 20 g. Ten additional thin plates from brick-red marls and more consolidated mudstones have been made.

RESULTS

Microfacies

Microfacies have been analysed in ten thin sections of the studied rocks. Three microfacies were recognized in the **dark-grey and black marly shales**.

(1) Samples Tr-13, Tr-11, Tr-9 and Tr-8 are composed of 5 to 40% of biogenic grains, and 5 to 10% of silt-sized, mostly calcareous grains (Fig. 4A–C). Quartz and muscovite as sharp-edged grains are rare and dispersed within the sediments (sample Tr-11). Bioclasts are usually recrystalized or secondary replaced by blocky calcite. There are thin filaments and radiolarian casts predominantly, with single-specimen occurrences of thick-walled mollusc shell fragments, benthic calcareous foraminifers and ostracods. The matrix consists of microcrystalline calcite, partly recrystalized in sparry calcite, and of aggregates of organic matter and clay minerals, which result in a hardly visible wavy lamination. Unrecognisable black mineral grains, and rare, small pyrite crystals occur in thin laminae (sample Tr-11). Fragments of brown wood, 1–2 mm long have been also observed (Tr-11).

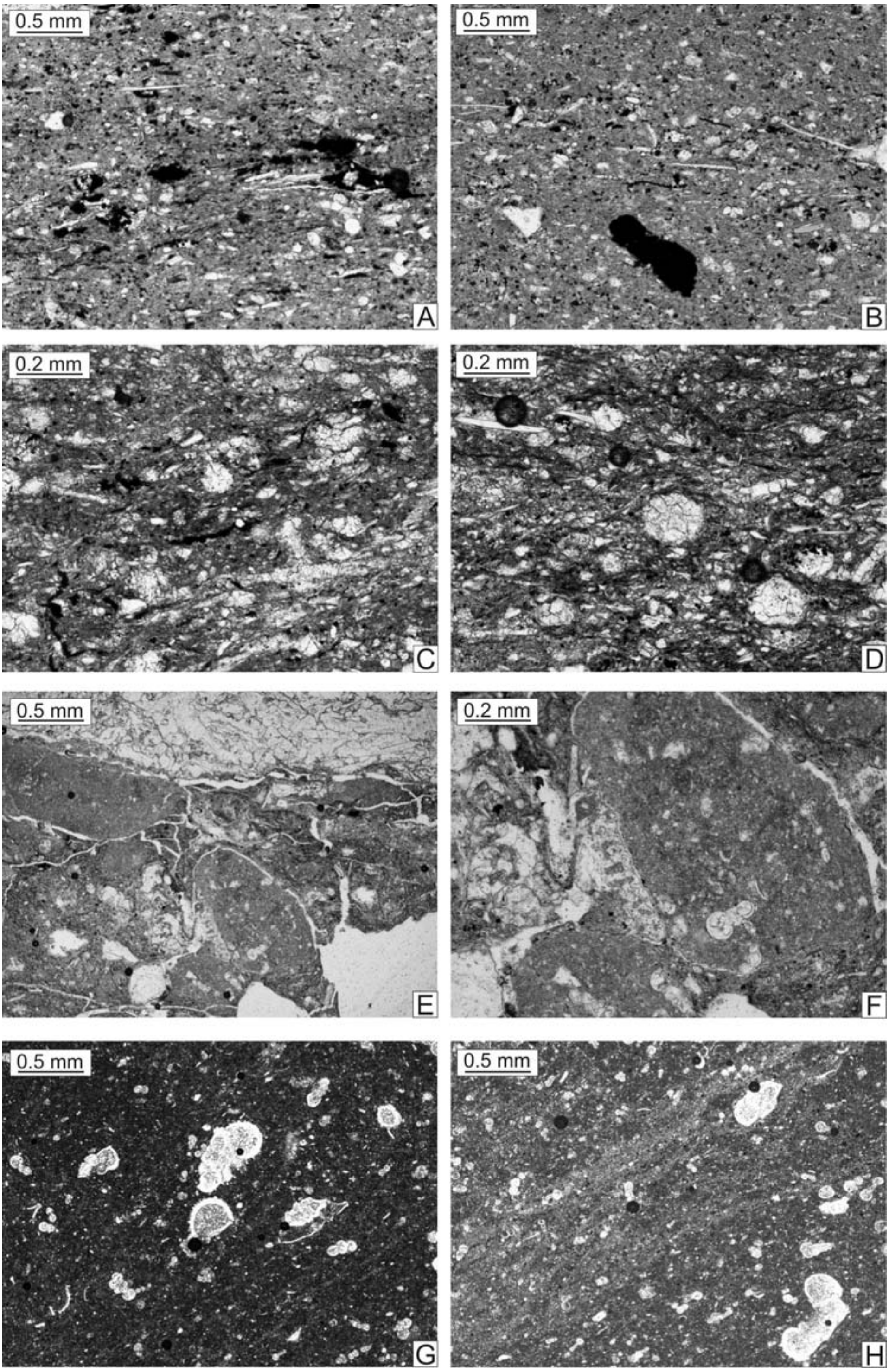
(2) Sample Tr-2 represents radiolarian microfacies (Fig. 4D). Radiolaria are mostly represented by large-sized forms; their tests are calcified and the molds are unfilled by large calcite crystals.

(3) Sample Tr-4 comes from a black, sparite marl layer. It is in contact with black marl including rounded grains of pelagic shale, approximately 1 mm thick in diameter (Fig. 4E, F). These grains include small-sized planktonic foraminifers, such as hedbergellids, *Heterohelix* and uncertain rotaliporids. These foraminifers may suggest that clasts derive from the Albian, or most probably, from Middle–Upper Cenomanian redeposited sediments. The matrix of the sparite marl layer also includes rare planktonic foraminifers from the genus *Hedbergella* and a single specimen of the benthic foraminifer *Tritaxia*.

Pink and cherry-red marls are represented by two types of microfacies.

(1) Samples Tr-15, Tr-12 and Tr-3' are characterised by planktonic foraminiferal microfacies, dominated by small hedbergellids and associated with large-sized specimens belonging to the genera such as: *Praeglobotruncana*, *Helvetoglobotruncana*, *Whiteinella*, *Dicarinella*, *Marginotruncana* and *Globotruncana*. Calcareous benthic foraminifers and calcified radiolarian tests represent the other components in these sediments. The encountered microfacies are typical of the Turonian and Campanian marls of the Pustelnia Marl Member (e.g., Alexandrowicz *et al.*, 1962; Alexandrowicz, 1975).

(2) Sample Tr-0 showed a detrital microfacies with small-sized, sharp-edged quartz grains concentrated in small, discrete laminae and burrow-fillings. Quartz laminae and burrows occur within brown clay-micritic matrix including smaller, dispersed quartz grains. Only one specimen of a small, keeled, planktonic foramini-


0.5 mm
A
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fer was found there. The microfacies apparently confirm that the studied layer succession belongs to the Macelowa Marl Member, most probably of the Branisko Succession.

Foraminifera

Foraminifers practically do not occur in the **black deposits, rich in filament-radiolarian microfacies** (Tr-14, 13, 11, 10, 9, 8, 7). The only forms are represented by very small specimens of agglutinated taxa, such as *Ammodiscus* sp., *Trochammina* sp. and *Haplophragmoides* sp., as well as single, poorly-preserved calcareous benthic taxa, *Lenticulina* and *Laevidentalina*. Besides them, rare fragments of large, pyritized tubular-shaped forms (?*Rhabdammina* sp.) were found.

Foraminiferal assemblages from the **black marly shales, rich in radiolarians** (Tr-5, 4, 3, 2) include numerous and diverse planktonic forms and rare, less-diverse benthics, both calcareous and agglutinated. Planktonic foraminifers include Early–Middle Turonian taxa (Table 1, Fig. 5), such as *Helvetoglobotruncana helvetica*, *H. praehelvetica*, frequent hedbergellids, praeglobotruncanids, marginotruncanids and less frequent whiteinellids. Besides them, samples Tr-5 and Tr-4 include rare reworked rotaliporid tests with the late Cenomanian species, *Rotalipora cushmani* (Fig. 5K, L). Tests of rotaliporids and some praeglobotruncanids and hedbergellids differ from tests of the Turonian taxa in their darker colour. A thin section from this black shale (Tr-4) shows that rotaliporids and part of praeglobotruncanids and hedbergellids derive from the intraclasts.

Benthic foraminiferal assemblages from the Lower–Middle Turonian black shales consist mainly of opportunistic taxa belonging to either, ammodiscids and glomospirids, or to infaunal, organic- and calcareous-cemented species (Table 1). The latter group of benthics is represented by single specimens of agglutinated forms belonging to the genera *Tritaxia*, *Gaudryina* and *Marsonella*, and *Lenticulina* among the calcareous benthics.

Foraminifers from the **pink and cherry-red pelagic marls and marly limestones** show that these deposits are strongly tectonised. Three samples represent the *Helvetoglobotruncana helvetica* Zone, corresponding to the Lower–Middle Turonian. However, it is imposible to set their mutual stratigraphic position. Planktonic foraminifers comprise nearly 99% of the whole foraminiferal assemblage; small-

◄

Fig. 4. Microfacies of the “black deposits” from the Lower–Middle Jurassic (A–C), the Upper Cenomanian–Lower Turonian transition (D–F) and the Turonian pink, pelagic marls (G, H) in the Czorsztyn Succession (Pieniny Klippen Belt): **A, B** – Filament microfacies of black marly shales (Tr-11), Skrzypny Shale Formation; **C** – Radiolarian-filament microfacies of dark-grey calcareous mudstone (Tr-9), Skrzypny Shale Formation; **D** – Radiolarian microfacies of black marly shale (Tr-2), Altana Shale Bed; **E, F** – Rounded clasts of dark-grey shale including planktonic forami- nifers within black marly shale (Tr-4), Altana Shale Bed; **G, H** – Planktonic foraminiferal microfacies of pink marl (Tr-15), Pustelnia Marl Member

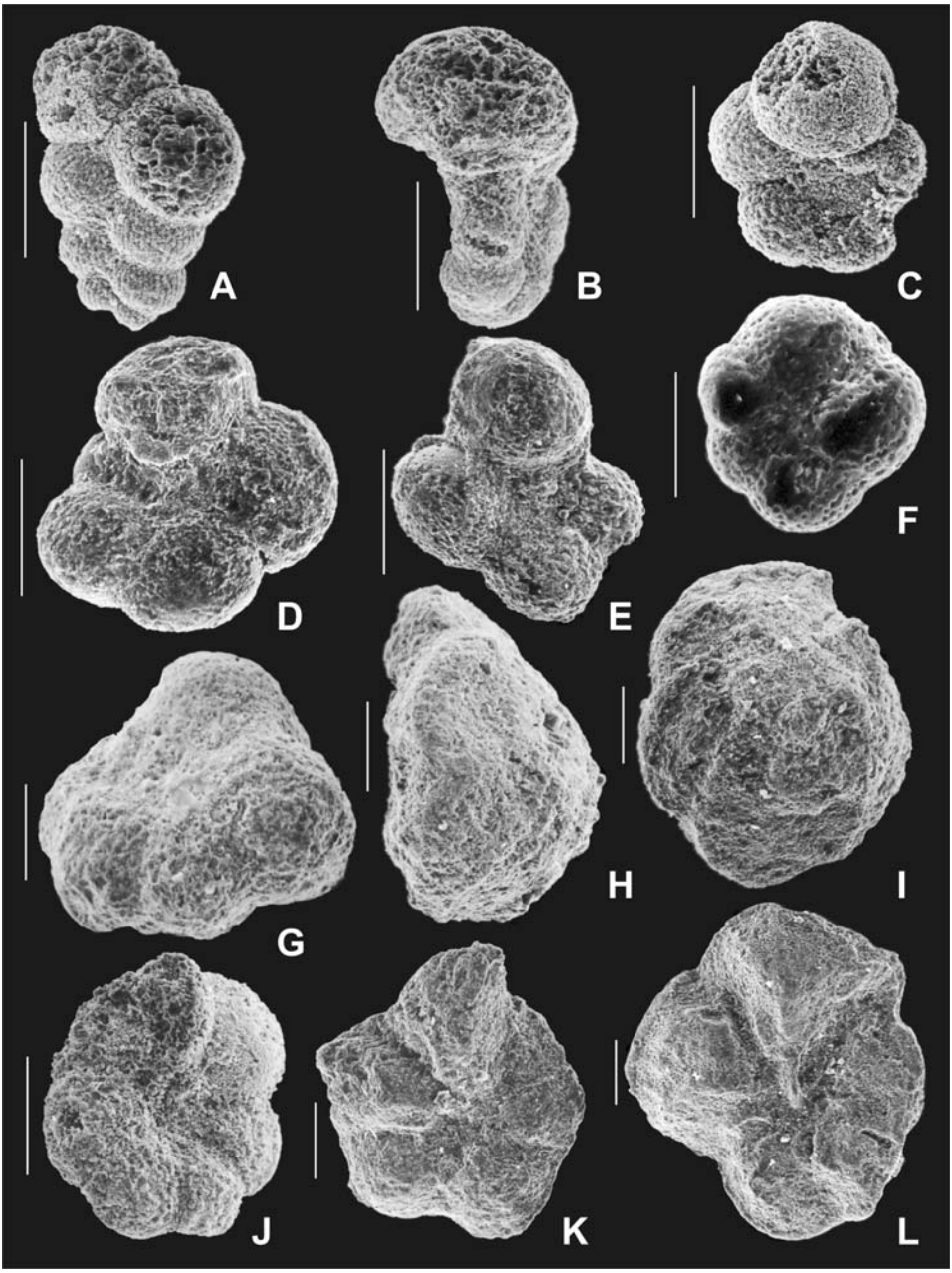


Fig. 5. Photographs of planktonic Foraminifera from the Upper Cenomanian–Lower Turonian deposits of the Czorsztyn Succession (Pieniny Klippen Belt). **A** – *Heterohelix moremani* (Cushman), Tr-2/99. **B, C**, *Globigerinelloides ultramicra* (Subbotina), Tr-2/99. **D** – *Hedbergella delrioensis* (Carsey), Tr-5/99. **E** – *Hedbergella simplex* (Morrow), Tr-4/99. **F**, *Whiteinella* cf. *archaeocretacea* Pessagno, Tr-4/99. **G**–**I** – *Praeglobotruncana gibba* (Klaus), Tr-2/99. **J**, *Praeglobotruncana stephani* (Gandolfi), Tr-5/99. **K, L** – *Rotalipora cushmani* (Morrow), K – Tr-5/99, L – Tr-4/99. Scale bar – 100 µm

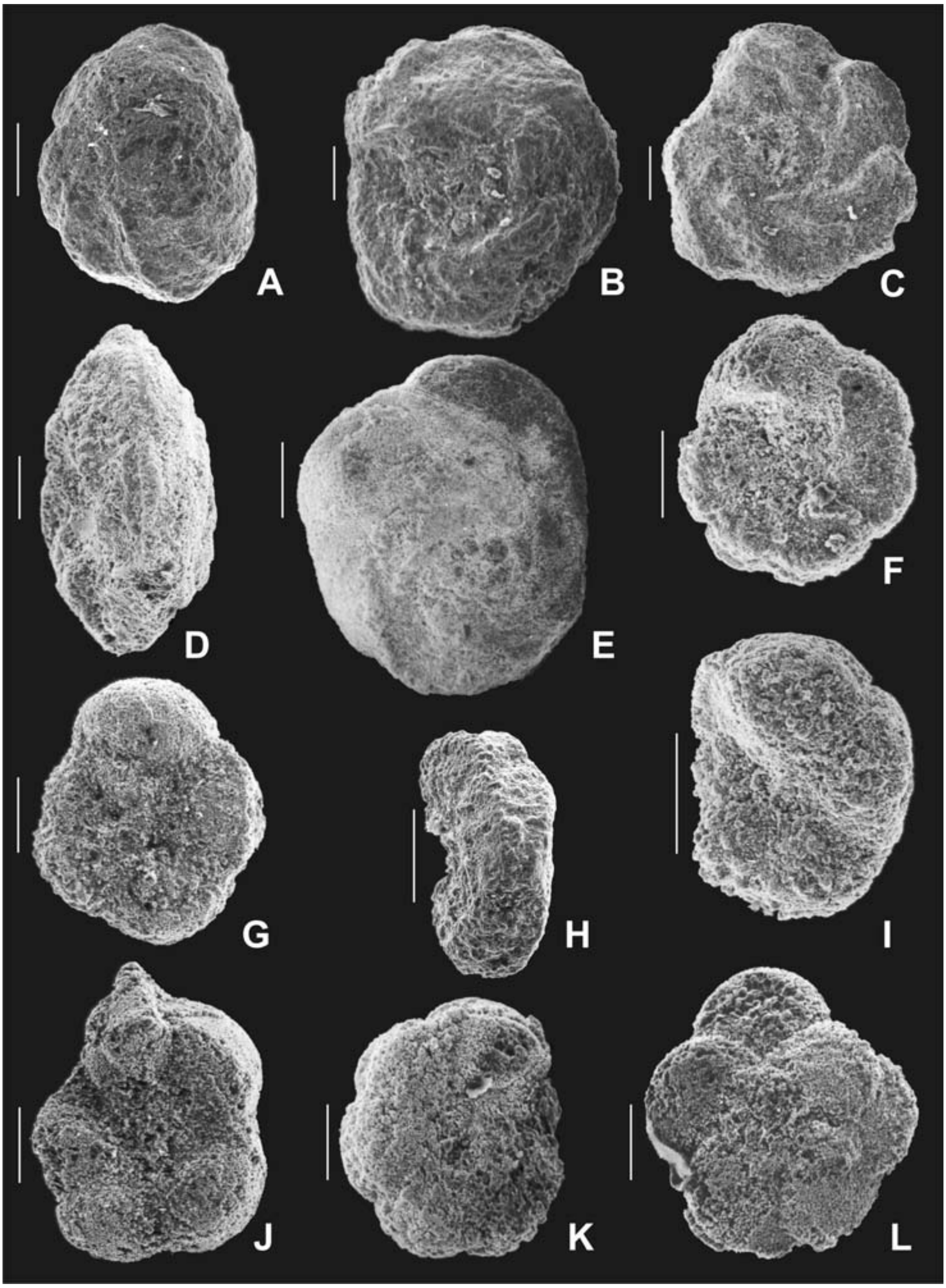


Fig. 6. Photographs of planktonic Foraminifera from the Upper Cenomanian–Lower Turonian deposits of the Czorsztyn Succession (Pieniny Klippen Belt). **A, B** – *Marginotruncana sigali* (Reichel), Tr-5/99. **C, D** – *Marginotruncana renzi* (Gandolfi), Tr-2/99. **E** – *Marginotruncana pseudolinneiana* Pessagno, Tr-3'/99. **F** – *Marginotruncana marginata* (Reuss), Tr-3'/99. **G–I** – *Dicarinella canaliculata* (Reuss), G, H – Tr-3'/99, I (with broken first chamber) – Tr-5/99. **J** – *Dicarinella* cf. *hagni* (Scheibne- rová), Tr – 3/99. **K, L** – *Dicarinella imbricata* (Mornod), K – Tr-5/99, L – Tr-3/99. Scale bar – 100 μm

Table 1

Distribution of Upper Cretaceous planktonic Foraminifera at Trawne creek, Czorsztyn Succession, Pieniny Klippen Belt

Sample	Tr-5/99	Tr-4/99	Tr-2/99	Tr-3/99	Tr-3'/99	Tr-6/99	Tr-15/99	Tr-12/99	Tr-1/99
Colour of sediments	Black				Pink and cherry-red				
Age of sediments	E.-M. Turonian	E.-M. Turonian	E.-M. Turonian	E.-M. Turonian	E.-M. Turonian	Turonian	E.-M. Turonian	Early Campanian	Early Campanian
Dicarinella canaliculata			vr		f			vr	
Dicarinella concavata								r	
Dicarinella hagni				vr					
Globigerinelloides ultramicra	vr	r		vr	a			a	
Globotruncana arca								c	vr
Globotruncana lapparenti								c	
Globotruncana linneiana								a	vr
Hedbergella delrioensis	c	a		f	a	r		a	
Hedbergella planispira	r	r			r				
Hedbergella simplex		vr			r			r	
Helvetoglobotruncana helvetica	r	vr	r						
Helvetoglobotrun. praehelvetica	r		vr	vr					
Heterohelix moremani	r	r	r	r	r	f	r		
Marginotruncana marginata	r	vr	vr	vr					
Marginotruncana peudolinneiana	f	r	f	f	c	f			
Marginotruncana renzi	c	f	c	c	c	f			
Marginotruncana schneegansi				vr		vr			
Marginotruncana sigali		r	f	f		f			
Praeglobotruncana delrioensis	a	a	vr	f					
Praeglobotruncana gibba		f							
Praeglobotruncana stephani	a	a	f	r					
Rotalipora appenninica	r*								
Rotalipora cushmani	r*	r*							
Rotalipora montsalvensis	vr*								
Whiteinella baltica	r	f							
Whiteinella archeocretacea		r							
Whiteinella paradubia	r			r		r			

* – reworked specimens

sized hedbergellids, *Globigerinelloides* and *Heterohelix* dominate (Table 1, Fig. 6). Marginotruncanids, dicarinellids and whiteinellids are less frequent, including typical Turonian taxa. These deposits also yielded rare, well-preserved agglutinated foraminifera, with forms characteristic of *Uvigerinammina jankoi* assemblage described from other Turonian–Santonian pelagic and hemipelagic facies in the Pieniny Klippen Belt (Bąk, 2000). Another foraminiferal assemblage occurs in samples Tr-12 and Tr-1: it includes Early Campanian globotruncanids and various benthic forms including *Uvigerinammina jankoi* and *Goesella rugosa*. Their co-occurrence well defines the Early Campanian age of these sediments (Bąk, 2000).

Radiolaria

Radiolarians have been analysed both in thin sections and in the residual fractions. They are frequent only in the black and dark-grey marly shales, and in the dark-grey mudstone layers. In thin sections of these rocks, radiolarians are common to abundant, preserved predominantly as moldic porosity, partly or completely reduced by blocky calcite. In residuum after rock dissolution, radiolarian specimens are also common but, in general, calcite pseudomorphs after radiolarian skeletons dominate, showing in some cases relatively intense process of secondary recrystalisation. Nevertheless, enough specimens are sufficiently preserved for biostratigraphic studies.

Two assemblages have been recognised (Table 2). The first of them, identified in the residual fraction of sample Tr-7 includes species such as *Pseudocrucella sanfilippoae* (Fig. 7A, B), *Paronaella kotura* (Fig. 7D, E) and *Parahsuum officerense* (Fig. 7H). Their co-occurrence suggests an Early Bajocian age for this sample (taxon ranges after Carter *et al*., 1988 and Baumgartner *et al*., 1995). Sample Tr-10 includes a single identifiable specimen of *Acaeniotyle* sp., which also may be indicative of a Middle Jurassic assemblage, however, the stratigraphic range of the genus *Acaeniotyle* reaches the Lower/Upper Cretaceous boundary. Radiolarian molds are abundant (up to 50%) in the sample Tr-9 and common (up to 10%) in samples Tr-13, Tr-11 and Tr-8; unfortunately, their identification is impossible. However, in thin section, they co-occur with filaments, ostracods and rare calcareous benthic foraminifers, which may suggest their Middle Jurassic age.

Different assemblages are present in samples Tr-5, Tr-4 and Tr-2 from black shales, and cherry-red pelagic marls (sample Tr-6). Abundant radiolarians occur in sample Tr-2. They consist up to 50% of the whole thin slide view. In residuum, radiolarians are common but occur as calcite pseudomorphs. Only a few species have been identified here including *Staurosphaeretta euganea*, *Quadrigastrum lapideum*, *Holocryptocanium tuberculatum*, *Pseudoeucyrtis spinosa* (Fig. 7L, M), *Rhopalosyringium radiosum* (Fig. 7P, R), *Praeconocaryomma lipmanae* (Fig. 7O), *Acaeniotyle* sp. aff. *A. vitalis* (Fig. 7K) and ?*Hemicryptocapsa tuberosa* (Fig. J). The first three species occurring in a sample Tr-2 indicate a stratigraphical range from the Middle Albian to Lower Turonian. The last five species coming from sam-

Table 2

Distribution of Radiolaria at Trawne creek, Czorsztyn Succession, Pieniny Klippen Belt

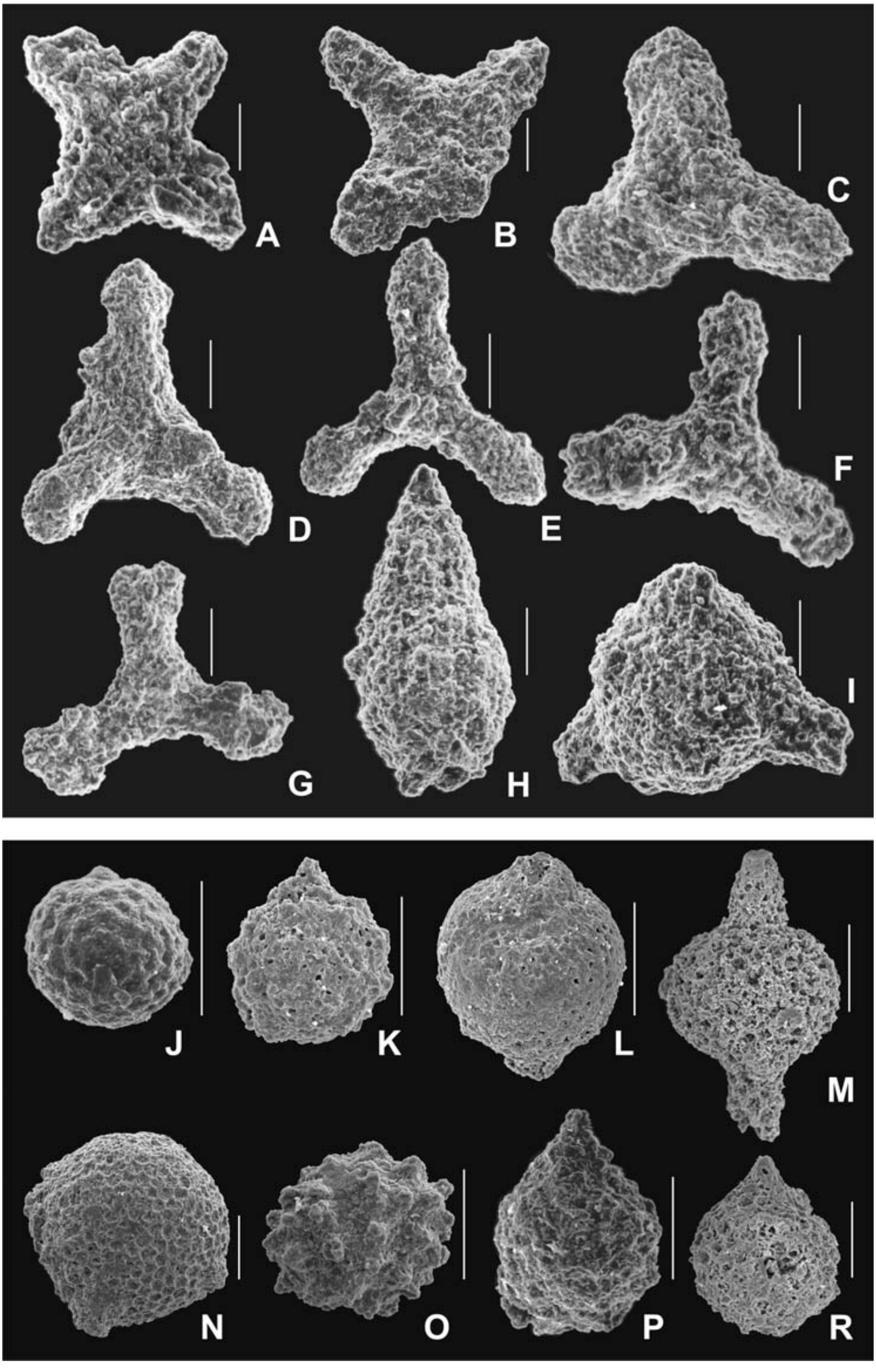
	Sample	Tr-10/99	Tr-7/99	Tr-5/99	Tr-4/99	Tr-2/99	Tr-6/99
	Age of sediments	Middle Jurassic-Cretaceous	E. Bajocian	L. Cenomanian -E. Turonian	L. Cenomanian -E. Turonian	M. Albian -E. Turonian	L. Cenomanian -E. Turonian
Late Creta-sceous	*Acaeniotyle* sp. aff. *A. vitalis*				x		
	Hemicryptocapsa tuberosa				?		
	Holocryptocanium tuberculatum			x	x	x	
	Praeconocaryomma lipmanae			x			
	Pseudoeucyrtis spinosa				x		x
	Quadrigastrum lapideum					x	
	Rhopalosyringium radiosum				x		x
	Squinabollum fossile			x			x
	Staurosphaeretta euganea			x		x	
Middle Jurassic	*Acaeniotyle* sp.	x					
	Parahsuum officerense		x				
	Paronaella sp. aff. *P. corpulenta*		x				
	Paronaella kotura		x				
	Paronaella spp.		x				
	Pseudocrucella sanfilippoae		x				
	Triactoma sp.		x				

L – Lower, M – Middle

ples Tr-5, Tr-4 and Tr-6 indicate the Late Cenomanian–Early Turonian age (the ranges after O'Dogherty, 1994).

The poor preservation of the studied radiolarian skeletons does not allow any statistical comparison of the Jurassic and the Cretaceous assemblages because their

Fig. 7. Photographs of Radiolaria from the Aalenian–Bajocian (A–I) and the Upper Cenomanian – Lower Turonian deposits (J–R) of the Czorsztyn Succession, Pieniny Klippen Belt. **A, B** – *Pseudocrucella sanfilippoae* (Pessagno), Tr-7/99; **C** – *Paronaella* sp. aff. *P. corpulenta* sensu Baumgartner *et al.*, Tr-7/99; **D, E** – *Paronaella kotura* Baumgartner, Tr-7/99; **F** – *Paronaella* sp., Tr-7/99; **G**, *Paronaella* sp., Tr-7/99; **H** – *Parahsuum officerense* (Pessagno & Whalen), Tr-7/99; **I** – *Triactoma* sp., Tr-7/99; **J** – Specimen of the family Williriedellidae, strongly eroded, most probably *Hemicryptocapsa tuberosa*, Tr-4/99; **K** – *Acaeniotyle* sp. aff. *A. vitalis* O'Dogherty, Tr-4/99; **L, M** – *Pseudoeucyrtis spinosa* (Squinabol), L – Tr-4/99, M – Tr-6/99; **N** – *Staurosphaeretta euganea* (Squinabol), Tr-2/99; **O** – *Praeconocaryomma lipmanae* Pessagno, Tr-5/99; **P, R** – *Rhopalosyringium radiosum* O'Dogherty, P – Tr-6/99 R – Tr-4/99. Scale bar – 100 μm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composition and differences reflect the state of preservation rather than primary faunal composition.

Dinocysts

All of the analyzed samples yielded poorly preserved palynological material. Dinoflagellate cysts were recovered only from seven samples (Tr-14, 12, 11, 10, 9, 8 and 7; Table 3). The assemblages consist mainly of Jurassic Dinoflagellate species as *Nannoceratopsis gracilis* (Fig. 8A, F), *Nannoceratopsis dictyambonis*, *Dissiliodinium* sp. (Fig. 8B), *Parvocysta* cf. *nasuta* (Fig. 8E) and the acritarch *Limbicysta bjaerkei* (Fig. 8C).

Generally, the assemblages show low diversity and richness. The species *Nannoceratopsis gracilis* dominates in all positive samples (2–10 specimens per slide). Most of its specimens are complete, lacking any mechanical damages. Both parts: the epicyst and hypocyst are usually attached and well preserved. The characteristic feature for this species is the presence of a spongy, delicate outer layer (ectophragme). This fragile element is undamaged in most preserved specimens.

All other taxa are found sporadically. They are physically damaged, incomplete and flattened, probably due to thermal maturation, oxidation and bio-degradation. Samples Tr-11, Tr-9 and Tr-8 additionally consist of several unidentified morphotypes of palynomorphs (Fig. 8G–I). They show some features of Dinoflagellate cysts, such as general shape, presence of horns or archeopyle. They occur as a single specimen per slide and they are too obscure to diagnose.

Table 3

Distribution of palynomorphs at Trawne creek, Czorsztyn Succession, Pieniny Klippen Belt

Sample	Tr-14/99	Tr-12'/99	Tr-11/99	Tr-10/99	Tr-9/99	Tr-8/99	Tr-7/99	Tr-4/99	Tr-2/99
Age of sediments	Late Pliensbachian-Late Bathonian	Late Pliensbachian-Late Bathonian	Early Toarcian-Early Aalenian	Late Pliensbachian-Late Bathonian	Late Pliensbachian-Early Bathonian	Late Pliensbachian-Late Bathonian	Late Pliensbachian-Early Bajocian	?	?
Dissiliodinium sp.					x				
Nannoceratopsis gracilis	x	x	x	x	x	x	x		
Nannoceratopsis cf. *dicyambonis*							x		
Parvocysta cf. *nasuta*			x						
Limbicysta bjaerkei			x		x				
Foraminiferal test-linings	x		x		x		x	x	x

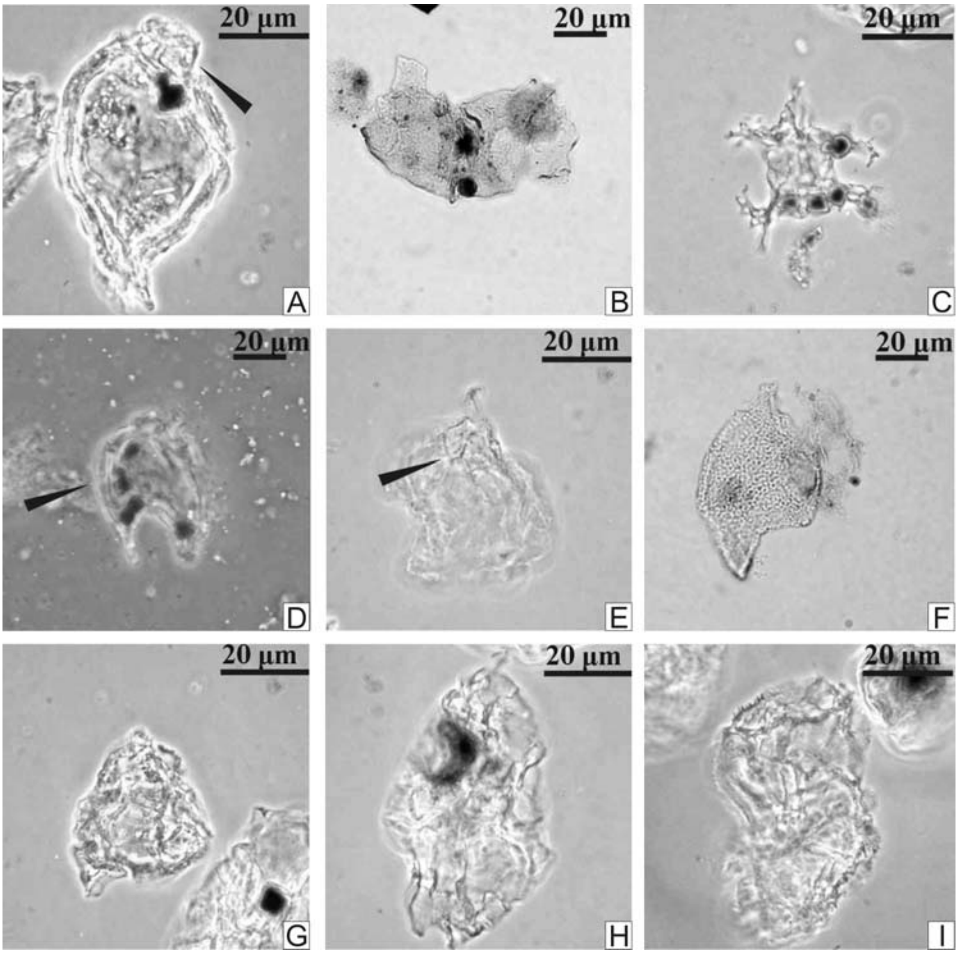

Fig. 8. Photographs of palynomorphs from the Middle Jurassic deposits of the Czorsztyn Ridge (Pieniny Klippen Belt). **A** – *Nannoceratopsis gracilis* (Alberti 1961) Evitt 1962 (complete specimen with well preserved epi- and hypocyst; arrow points well preserved epicyst), Tr-11/99; **B** – *Dissiliodinium* sp., Tr-9/99; **C** – *Limbicysta bjaerkei* (Smerlor 1987) MacRae, Hills et McIntyre 1996 – acritarch, Tr-11/99; **D** – *Nannoceratopsis dictyambonis* Riding 1984 (arrow points characteristic ridges in lateral edges of the cyst), Tr-7/99; **E** – *Parvocysta* cf. *nasuta* Bjaerke 1980 (arrow points well expressed tabulation pattern within intercalary series), Tr-12/99; **F** – *Nannoceratopsis gracilis* (Alberti 1961) Evitt 1962 (note well developed and preserved ectophragme), Tr-12/99; **G–I** – undeterminable specimens of ?Dinoflagellata cysts, G – Tr-8/99, H – Tr-9/99, I – Tr-11/99

Stratigraphically, the studied material from samples Tr-14 – Tr-7 revealed an Early–Middle Jurassic dinocyst assemblage (Table 3). The most frequent species, *Nannoceratopsis gracilis* has the widest stratigraphical range, from the Late Pliensbachian to the Late Bathonian. This species is considered to be euryhaline (Riding, 1983) and thus has wide palaeogeographical distribution and frequently occurs in monogeneric associations.

Stratigraphic ranges of other dinocysts allow a more precisely definition of the age of the studied deposits. The genus *Nannoceratopsis dictyambonis* appeared from the Late Pliensbachian to Early Bathonian (Powell, 1992) and *Parvocysta nasuta* – from the Early Toarcian to Early Aalenian (Powell, 1992). Although, the specimen of the latter species is difficult for unequivocal determination (*P.* cf. *nasuta*; Fig. 8E), it undoubtedly represents the genus *Parvocysta*, and thus is indicative of above-mentioned stratigraphical range. The acritarch *Limbicysta bjaerkei* is also an Early–Middle Jurassic species: its stratigraphic range is from the Late Pliensbachian to the Early Bathonian (Bailey & Hogg, 1995). The latter two taxa were first described from the Toarcian deposits of Spitsbergen (Bjaerke, 1980).

Dinoflagellate cysts have not been found in samples Tr-13, Tr-5, Tr-4 and Tr-2 (Table 3). The composition of palynofacies (see chapter below) suggests advanced chemical or bacterial decay of organic matter in these sediments.

Apart from Dinoflagellate cysts and an acritarch, noteworthy is a relatively high abundance of foraminiferal test-linings in practically all of the studied black sediments (Table 3). They have been recovered even from samples in which are other microfossils are absent.

Palynofacies

More than a hundred particles per slide have been counted in eleven studied samples (Table 4). Palynofacies analysis reveals three types of assemblages. The

Table 4

Percentage of palynofacies in black facies from Trawne creek, Czorsztyn Succession, Pieniny Klippen Belt; p – present (<1%)

Age of sediments	Sample	Black wood	Brown wood	Cortex	Cuticule, membranes	Pollen, spores	Dinocysts and other marine palyno-morphs	Amorphic organic matter
Late Cenom.- E. Turon	Tr-2/99	66	8	2	-	2	-	22
	Tr-4/99	65	14	-	-	5	-	16
	Tr-5/99	51	10	-	-	1	-	38
Early-Middle Jurassic	Tr-7/99	24	21	-	-	2	p	53
	Tr-8/99	22	26	2	-	4	p	46
	Tr-9/99	38	49	2	3	7	p	1
	Tr-10/99	35	41	-	-	7	p	17
	Tr-11/99	12	37	7	18	18	7	1
	Tr-12'/99	76	22	1	-	1	p	-
	Tr-13/99	10	1	-	-	-	-	89
	Tr-14/99	7	3	-	-	-	p	90

first one is recorded in Lower–Middle Jurassic black shales and is dominated (ca. 90%) by amorphous organic matter (Tr-13 and 14). It suggests a high degree of degradation by chemical, physical and bacterial processes in anoxic environment (Hart, 1986). The second one recorded both in the Lower–Middle Jurassic and the Upper Cenomanian–Lower Turonian black facies is dominated by black/brown wood and amorphous organic matter (Tr-2, 4, 5, 7, 8 and 10). This may suggest a lower degree of degradation, which affected only more delicate tissues (Tyson, 1995). The third type (Tr-9 and Tr-11) consists of varied organic particles including brown/black wood, spores, cuticles, pollen, cortex, and marine palynomorphes. The particles of this assemblage are only mechanically damaged by a high energy environment and the compaction processes.

DISCUSSION

Black facies in the Czorsztyn Succession: correlation horizons or Pandora boxes?

Due to strong tectonic deformations of the incompetent shales and marls, the recognition of black facies from various stratigraphic horizons in the Czorsztyn Succession during field investigations is very difficult, and in some cases, impossible. This fact is obvious in the studied section, where combined stratigraphic studies based on three groups of microfossils, and additionally, microfacies and palynofacies data contribute to a precise differentiation of Upper Cretaceous from Lower–Middle Jurassic black facies (Table 5, Fig. 8). By using a single microfossil group (foraminifers, radiolarians, or dinocysts) one may obtain incomplete or erroneous stratigraphic results in such strongly tectonised sections.

For instance, **planktonic foraminifers** do not occur in any Jurassic deposits of the studied section. Their absence in black sediments is not unusual because of the dissolution effect in corrosive bottom water and during diagenesis. However, in the studied section it is caused by stratigraphic reasons. The common occurrence of the earliest protoglobigerinids is reported in the Upper Callovian (also from the Pieniny Klippen Belt; Wierzbowski *et al.*, 1999), whereas the Jurassic facies in our section represent much older horizons.

The **benthic foraminifera** are used in most cases to recognize the Jurassic from Cretaceous black sediments in the Pieniny Klippen Belt (cf. Birkenmajer & Pazdro, 1963, 1968; Pazdro, 1969, 1979; Tyszka, 1994; Tyszka & Kaminski, 1995; Birkenmajer & Tyszka, 1996 – for the Early-Middle Jurassic benthic assemblages, and Bąk, 1998, 2000 – for the Cenomanian–Turonian transition). However, the benthos in the studied section is very scarce or absent. Long-ranging forms of the genera *Ammodiscus*, *Glomospira*, *Trochammina*, and poorly-preserved (due to dissolution) calcareous ones, also long-ranging forms of the genera *Lenticulina* and *Laevidentalina* do not allow the discrimination of the Lower–Middle Jurassic from the Upper Cretaceous black facies. The benthic assemblage from this section resembles from one hand the benthics in samples of the uppermost Cenomanian *Praeglobotruncana delrioensis* Zone from the Altana Shale Bed (cf. Szaflary section: Bąk,

Table 5

Summarised stratigraphic data based on various group of microfossils, microfacies and palynofacies from the Skrzypny Shale Formation and the Altana Shale Bed of the Jaworki Formation; Trawne creek, Czorsztyn Succession, Pieniny Klippen Belt

			Age of sample based on:			Microfacies		Age of samples based on composite data
		Sample	Planktonic Foraminifera	Radiolaria	Palyno-morphs	Intraclasts	Filament-radiolarian microfacies	
Jaworki Formation	Pustelnia Marl Member	Tr-1/99	Early Campan.	?				Early Campanian
		Tr-12/99	Early Campan.	?				
		Tr-15/99	E.-M. Turonian	?				Early-Middle Turonian
		Tr-6/99	Turonian	Late Cenom.-E. Turonian				
		Tr-3'/99	E.-M. Turonian	?				
	Altana Shale Bed	Tr-2/99	E.-M. Turonian	Middle Albian- E. Turon.				
		Tr-4/99	L. Cenom -E-M. Turonian	Late Cenom.-E. Turonian	?	Upper Cenomanian		
		Tr-5/99	E.-M. Turonian	L. Cenoman.-E. Turonian	?			
Skrzypny Shale Formation (partly ?Krempachy Marl Formation)		Tr-7/99		E. Bajocian	Late Pliensb.-Early Bajoc.			E. Bajocian
		Tr-8/99		?	Late Pliensb.-Late Bathon.		x	Late Pliensbach.-Late Bathon.
		Tr-9/99		?	Late Pliensb.-Early Bathon.		x	Late Pliensbach.-Early Bathon.
		Tr-10/99		Mid-Jurassic-Cretaceous	Late Pliensb.-Late Bathon.			Late Pliensbach.-Late Bathon.
		Tr-11/99		?	Early Toarc.-Early Aalen.		x	Early Toarc.-Early Aalenian
		Tr-12'/99		?	Late Pliensb.-Late Bathon.			Late Pliensbach.-Late Bathonian
		Tr-13/99		?	-		x	
		Tr-14/99		?	Late Pliensb.-Late Bathon.			

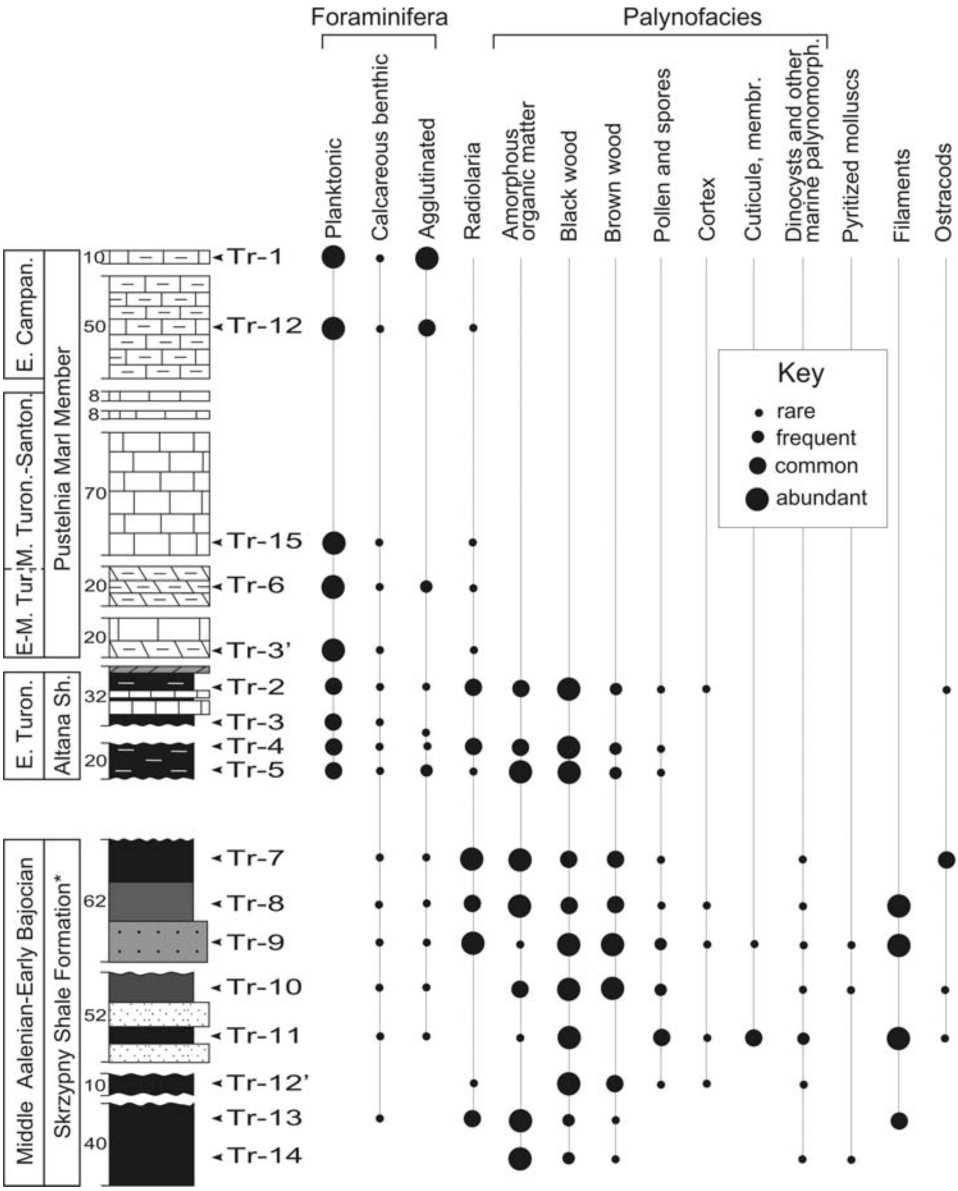

Fig. 9. Reconstructed lithostratigraphic column of the Skrzypny Shale Formation, Altana Shale Bed and Pustelnia Marl Member in the Trawne creek section exposed in 1999, with percentage distribution of microfossils, microfacies and palynofacies. For explanation of lithologies – see Fig. 3
* Note that a part of the Skrzypny Shale Formation can represent the transition to the underlying Krempachy Marl Member. Thickness in centimetres

1998), and on the other hand – Aalenian *Trochammina* aff. *eoparva* Assemblage from the lower part of the Skrzypny Shale Formation (cf. Krupianka section: Tyszka & Kaminski, 1995). It seems that the occurrence of the same taxa in both horizons corresponds rather to dysoxic conditions on the basin floor than to stratigraphic horizons.

The **radiolarian** data also may not be unequivocal in terms of the stratigraphy of this particularly tectonised section. Radiolaria-rich horizons, which are commonly used as stratigraphic markers in the Cretaceous oceanic anoxic events may be also frequent within the Lower–Middle Jurassic black facies, as shown by the microfacies in the studied section (cf. sample Tr-9). A certain problem with the stratigraphy is the preservation state of the radiolarian tests. In black calcareous deposits, radiolarian skeletons occur as calcified or pyritized skeletons or molds; in most cases they are indeterminable.

In the studied section, radiolarians from only one sample (Tr-7) unambiguously indicated the Middle Jurassic (Early Bajocian) age of the black facies. They also show that at least a part of these black sediments represent the Skrzypny Shale Formation. Radiolarian taxa also confirmed that a part of the black facies belong to the mid-Cretaceous Altana Shale Bed (Tr-5, 4, and 2).

Similarly as the radiolarians, the **dinocysts** do not allow distinguishing the Lower–Middle Jurassic from the Upper Cretaceous black facies in the studied section. They have not been recorded from the Upper Cretaceous strata, probably due to very strong degradation by chemical, physical and bacterial processes. The lithology together with long stratigraphic ranges of the determined taxa may suggest that the Lower–Middle Jurassic black facies belong to the Skrzypny Shale Formation. However, it is also possible that at least a 0.5 m-thick package of dark-grey marly shale, black shale and grey-green calcareous mudstone with dispersed quartz and muscovite grains (samples Tr-10 and 11) might represent the Krempachy Marl Formation or its transition to the Skrzypny Shale Formation.

The dinocyst assemblage from the studied section is taxonomically similar to those from another Lower–Middle Jurassic facies in the Pieniny Klippen Belt, the Szlachtowa Formation (its lower part), described lately by Birkenmajer & Gedl (2004). However, the assemblage from the studied section has lower abundance and diversity, and specimens are poorly preserved.

The **microfacies** might be very useful as an additional stratigraphic tool, particularly when they include fragments of thin-shelled bivalves and planktonic foraminifers. An example of this are samples Tr-13, Tr-11, Tr-9, and Tr-8 which are rich in thin-shelled bivalves of the genus *Bositra* (filaments). Single pyritized specimens, attributed to larval forms of the latter genus have been also found in the residual fraction in these samples. Such bivalves are known mostly from fine-grained, black facies of Early–Middle Jurassic ages (e.g., *Posidonia* shales: Jefferies & Minton, 1965) including also deposits of the Pieniny Klippen Belt. They were reported in this region from the Szlachtowa Formation (Birkenmajer, 1977; Krawczyk & Słomka, 1986), Krzonowe Formation (Birkenmajer & Tyszka, 1996), Stembrow Formation (Birkenmajer, 1977), Opaleniec Formation (Birkenmajer *et* *al*., 1975); Harcygrund Shale Formation (Birkenmajer, 1958; Myczyński, 1973), Skrzypny Shale Formation (Tyszka & Kaminski, 1995), Krupianka Limestone, Niedzica Limestone and Czorsztyn Limestone formations (Wierzbowski *et al*, 1999).

Another example of the microfacies stratigraphic approach is sample Tr-4, where residuum from dissolved rock includes both Middle–Late Cenomanian and Early–Middle Turonian planktonic assemblages. Two working hypothesis may be suggested here to explain this fact, when microfacies of these sediments are not analysed: (1) tectonic mélange of different units, and (2) redeposition of the Upper Cenomanian black marly shale. The latter appears to be true as the Lower–Middle Turonian deposits include intraclasts of older pelagic marly shales (as shown in thin sections; Fig. 4).

The **palynofacies** has also been used as a stratigraphic tool. An example of this is shown by sample Tr-13, which lacks any of the microfossil debris. The similar composition of palynofacies in samples Tr-13 and Tr-14, and also their position in the outcrop suggest the same age of these deposits. On the other hand, it should be stressed that it is impossible to separate the Lower–Middle Jurassic black facies in the studied section from the Upper Cretaceous ones on the basis of composition of palynofacies only.

Cenomanian/Turonian boundary event

A compilation of biostratigraphic data, together with microfacies and palynofacies study, enabled us to clearly separate the Lower Turonian black and red facies in the studied section. It seems that these facies, corresponding to the Cenomanian/Turonian boundary event, represent here the uppermost part of the Altana Shale Bed with its transition to the overlying Pustelnia Marl Member.

The black facies (Tr-5, 4 and 2) comprise four thin black marly shale horizons (35 cm of total thickness) that belong to the *Helvetoglobotruncana helvetica* Zone (Early-Middle Turonian; Caron, 1985). The black marly shales are intercalated by two thin (8 cm thick, each) pink, marly limestones. Due to tectonic contacts between competent red limestones and incompetent black marly shales, it is not possible to resolve their stratigraphic relationships.

The tectonised packages of pink marly limestones and cherry-red marls (Tr-3’, 6 and 15) also belong to the *H. helvetica* Zone. Their mutual relationships are here also indefinite; they may represent tectonic repetition of the same lithological horizon or they may be fragments of a thicker Lower–Middle Turonian pelagic complex.

CONCLUSIONS

The strongly tectonised section at the Trawne creek includes among others a thin horizon of black facies (the Altana Shale Bed of the Jaworki Formation) corresponding to the Cenomanian/Turonian boundary event. The exposed layer represents the uppermost part of this horizon with uncertain transition to the pelagic pink and cherry-red marly limestones and marls. Both facies are strongly tectonised and belong to the *H. helvetica* Zone (Lower–Middle Turonian).

Combined biostratigraphic data, based on a study of foraminifers, radiolarians, and palynomorphs together with analyses of microfacies and palynofacies, allowed us to separate this Upper Cretaceous unit from another one, also consisting of strongly tectonised black deposits of Early–Middle Jurassic age. The latter facies most probably belongs to the Skrzypny Shale Formation and consists of dark-grey and black marly shales, and dark-green and dark-grey calcareous mudstone layers. This unit occurs in a thicker series some dozen meters north of the studied section. This is suggested on the of microfacies, dinocyst, and radiolarian stratigraphic data. Its Early Bajocian age was determined only for one thin package of dark-grey shale. Other packages of black facies include long-ranging dinocyst taxa, showing for them a late Pliensbachian–early Bathonian age. Following the earlier stratigraphic data for the Skrzypny Shale Formation, based on ammonite fauna (Late Aalenian–Middle Bajocian: Birkenmajer, 1963; Myczyński, 1973, 2004), it may be suggested that a part of the Lower–Middle Jurassic black facies might represent the underlying lithostratigraphic unit, the Krempachy Marl Formation, or its transition to the Skrzypny Shale Formation.

Pelagic cherry-red marls and marly limestones which, in most cases, are in tectonic contact with black facies are here also strongly tectonised. They represent different, non-continuous stratigraphic horizons of Early–Middle Turonian and Early Campanian ages.

The last, a more general conclusion is related to the methodology of biostratigraphic studies in strongly tectonised rock complexes of the Pieniny Klippen Belt. It should be stressed that only high-resolution and combined biostratigraphic data, supplemented by microfacies and palynofacies studies may help determinate the age and stratigraphic position of lithologically similar rock units.

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Appendix

List of microfossils determined in the Trawne creek

Planktonic Foraminifera

Dicarinella canaliculata (Reuss)
Dicarinella concavata (Brotzen)
Dicarinella hagni (Scheibnerova)
Globigerinelloides ultramicra (Subbotina)
Globotruncana arca (Cuchman)
Globotruncana lapparenti Brotzen
Globotruncana linneiana (d'Orbigny)
Hedbergella delrioensis (Carscy)
Hedbergella planispira (Tappan)
Hedbergella simplex (Morrow)
Helvetoglobotruncana helvetica (Bolli)
Helvetoglobotruncana praehelvetica (Trujillo)
Heterohelix moremani (Cushman)
Heterohelix reussi (Cushman)
Marginotruncana marginata (Reuss)
Marginotruncana peudolinneiana Pessagno
Marginotruncana renzi (Gandolfi)
Marginotruncana schneegansi (Sigal)
Marginotruncana sigali (Reichel)
Praeglobotruncana delrioensis (Plummer)
Praeglobotruncana gibba Klaus
Praeglobotruncana stephani (Gandolfi)
Rotalipora appenninica (Renz)
Rotalipora cushmani (Morrow)
Rotalipora montsalvensis Mornod
Whiteinella baltica Douglas & Rankin
Whiteinella archeocretacea Pessagno

Radiolaria

Acaeniotyle sp. aff. *A. vitalis* O'Dogherty
Acaeniotyle sp.
Hemicryptocapsa tuberosa Dumitrica
Holocryptocanium tuberculatum Dumitrica
Paronaella sp. aff. *P. corpulenta* De Wever
Paronaella kotura Baumgartner
Paronaella spp.
Parahsuum officerense (Pessagno & Whalen)
Praeconocaryomma lipmanae Pessagno
Pseudocrucella sanfilippoae (Pessagno)
Pseudoeucyrtis spinosa (Squinabol)
Quadrigastrum lapideum O'Dogherty

Rhopalosyringium radiosum O'Dogherty
Squinabollum fossile (Squinabol)
Staurosphaeretta euganea (Squinabol)
Triactoma sp.

Dinocysts

Nannoceratopsis gracilis (Alberti) Evitt
Parvocysta cf. *nasuta* Bjaerke
Dissiliodinium sp.
Nannoceratopsis dictyambonis Riding

Acritarch

Limbicysta bjaerkei (Smerlor) MacRae, Hills et McIntyre