S T U D I A   G E O L O G I C A   P O L O N I C A

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*Geology of the Pieniny Klippen Belt and the Tatra Mts, Carpathians*
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*Part XVIII*

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# Lower Cretaceous dinocyst stratigraphy and palynofacies of the Grajcarek Unit, Pieniny Klippen Belt, West Carpathians, Poland[2]

(Figs 1–9; Tabs 1–3)

**Abstract.** Dinocyst assemblages (150 taxa) were recognised in the Lower Cretaceous deposits of the Grajcarek Unit, Pieniny Klippen Belt (West Carpathians). The following dinocyst based ages were established: a Hauterivian–Barremian boundary level age in the Sztolnia section (Pieniny Limestone Formation); a Late Barremian age of the top part of the Pieniny Limestone Formation (Rzeźnia section); a Late Barremian –Early Aptian age of the Kapuśnica Formation, Brodno Member (Rzeźnia section); latest Barremian–Early Aptian and Late Albian–Cenomanian ages of the Wronine Formation (Rzeźnia section); Late Albian–Cenomanian (Hulina section) and the latest Albian–Cenomanian (Sztolnia section) ages of the Hulina Formation. Palynofacies assemblages were described and differentiated into five types, PT1 to PT5, reflecting various palaeoenvironments. Presence of anoxic events, as based on amorphous-organic-matter-dominated palynofacies, was recognized.

**Key words:** Dinocysts, palynofacies, Early Cretaceous, Grajcarek Unit, Pieniny Klippen Belt, West Carpathians.

## INTRODUCTION

The aim of this study was dinocyst biostratigraphy of the Lower Cretaceous deposits of the Grajcarek Unit, Pieniny Klippen Belt of Poland (West Carpathians) – Fig.1. It included the Pieniny Limestone Formation (Sztolnia Creek section; Rzeźnia section), the Kapuśnica Formation (Rzeźnia section), the Wronine Formation (Rzeźnia section; Hulina section) and the Hulina Formation (Hulina section; Sztolnia Creek section).

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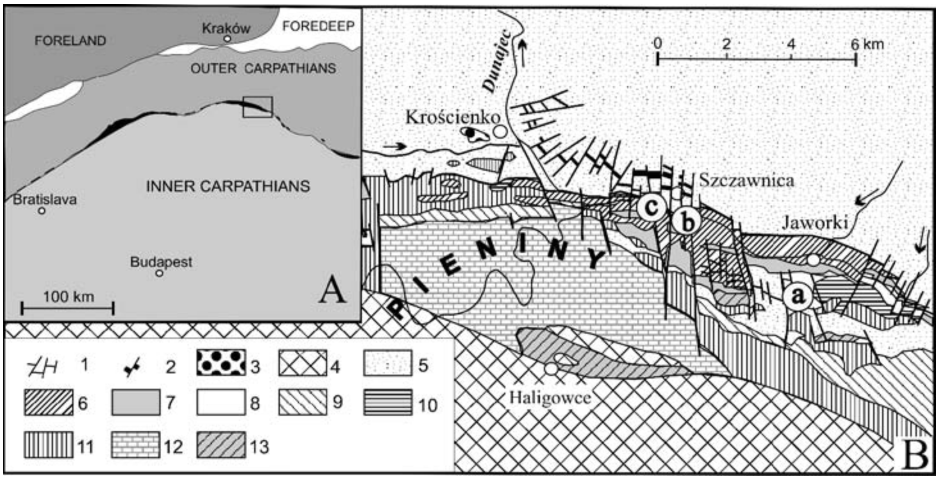


**Fig. 1.** **A.** Position of the Pieniny Klippen Belt (in black) in the West Carpathians (after Birkenmajer & Gedl, 2007); **B.** Geological sketch of the Pieniny Klippen Belt, central section (*op. cit.*, modified), with position of the studied sections in the Pieniny Klippen Belt: a – Sztolnia section; b – Rzeźnia section; c – Hulina section. *1*– Miocene faults; *2* – Miocene andesite intrusions; *3* – Neogene fresh-water deposits; *4* – Podhale Palaeogene (autochthonous); *5* – Magura Palaeogene (Magura Nappe and autochthonous Palaeogene in the Pieniny Klippen Belt); *6* – Jarmuta Formation (Maastrichtian): Grajcarek Unit and autochthonous molasse; *7* – Jurassic–Campanian of the Grajcarek Unit; *8–13* – Klippen successions (*8* – Czorsztyn; *9* – Czertezik; *10* – Niedzica; *11* – Branisko; *12* – Pieniny; *13* – Haligovce)

Dinoflagellate cysts are proved to be a tool of great potential for biostratigraphy and palaeoecological interpretations from the Late Triassic up to now (e.g., MacRae *et al.*, 1996; Nøhr-Hansen, 1993; Leereveld, 1995; Torricelli, 2000). Their importance as sensitive palaeoenvironmental indicators was recently widely discussed and summarized by Sluijs *et al.* (2005). Palynofacies analyses are successfully used as palaeoenvironment indicators (cf. Tyson, 1995; Batten, 1996), being a powerful tool also for sequence stratigraphic interpretations (e. g., Götz *et al.*, 2005).

The first data on occurrence of dinocysts in the Albian–Cenomanian strata of the Pieniny Klippen Belt (Kapuśnica Formation and Pomiedznik Formation, Czorsztyn Unit) was noted by Jaminski (1990). He described well preserved dinocyst assemblages diagnostic for Upper Albian–Cenomanian. Preliminary results of Cretaceous dinocyst stratigraphy of the Grajcarek Unit (Pieniny Klippen Belt) were presented by E. Gedl (2000), E. Gedl and P. Gedl (2001), an P. Gedl and E. Gedl (2001).

## METHODS

The samples were processed according to the following procedure: 20 G of cleaned and crushed rock was treated with 38% chloric acid (HCl) to remove car-

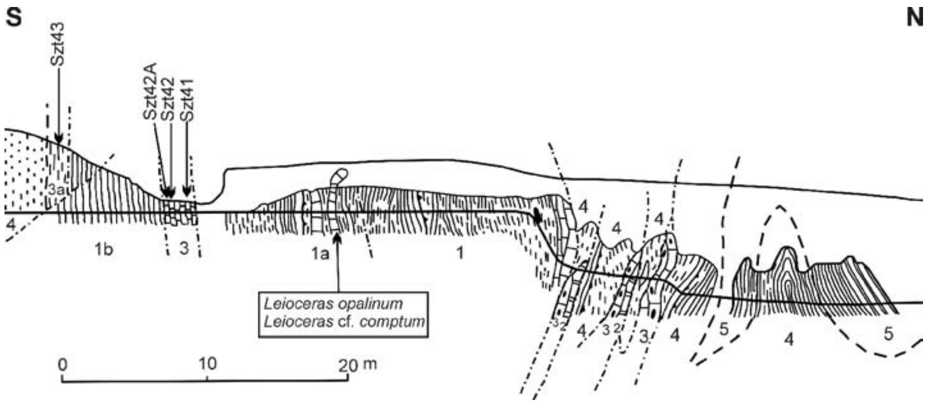


**Fig. 2.** Geology and location of studied samples at Sztolnia Creek, Grajcarek Unit (after Birkenmajer & P. Gedl, 2004; modified), with location of macrofauna (after Birkenmajer & Myczyński, 1977): 1, 1a – Szlachtowa Formation (Toarcian–Aalenian); 1b – Opaleniec Formation (lower part – Birkenmajer & Myczyński, 1977; Bajocian); 2 – Czajakowa Radiolarite Formation (Oxfordian); 3 – Pieniny Limestone Formation (Tithonian–Barremian); 3a – Hulina Formation (Albian–Cenomanian); 4 – Malinowa Shale Formation (Cenomanian–Campanian); 5 – Hałuszowa Formation (Campanian)

bonates, sieved on 15 μm sieve, treated with 40% hydrofluoric acid (HF) to remove silicates, neutralized and sieved again on 15 μm sieve. The organic matter was separated from other particles in heavy liquid ($ZnCl_2$+HCl; s. g. = 2.0 G/cm$^3$), sieved on 15 μm nylon sieve and transferred into glycerine for storage. Gelatine was used as a mounting medium. Two to five slides were made from each sample. Organic matter was examined under transmitted light microscope. The studied slides are stored in the collection of the Institute of Geological Sciences, Jagiellonian University, Cracow.

## PALYNOMORPH SAMPLE CHARACTERISTICS

Samples for study were collected from three localities (Figs. 1–4) and included into following lithostratigraphic units as distinguished by Birkenmajer (1977, 1979): the Pieniny Limestone Formation, the Kapuśnica Formation (Brodno Member), the Wronine Formation and the Hulina Formation. Palynofacies analysis is based on methods and divisions described by Tyson (1995) and Batten (1996).

### Pieniny Limestone Formation

#### Lithology

(a) **Sztolnia section** (Birkenmajer & Pazdro, 1968; Birkenmajer & Gedl, 2004; fig. 2): a 3-m thick limestone bed is exposed at the bottom of the Sztolnia Creek at the place where a forest road crosses the creek. Two samples, Szt41 and Szt42 (greyish and blackish limestone, respectively) were taken, 90 and 145 cm from the

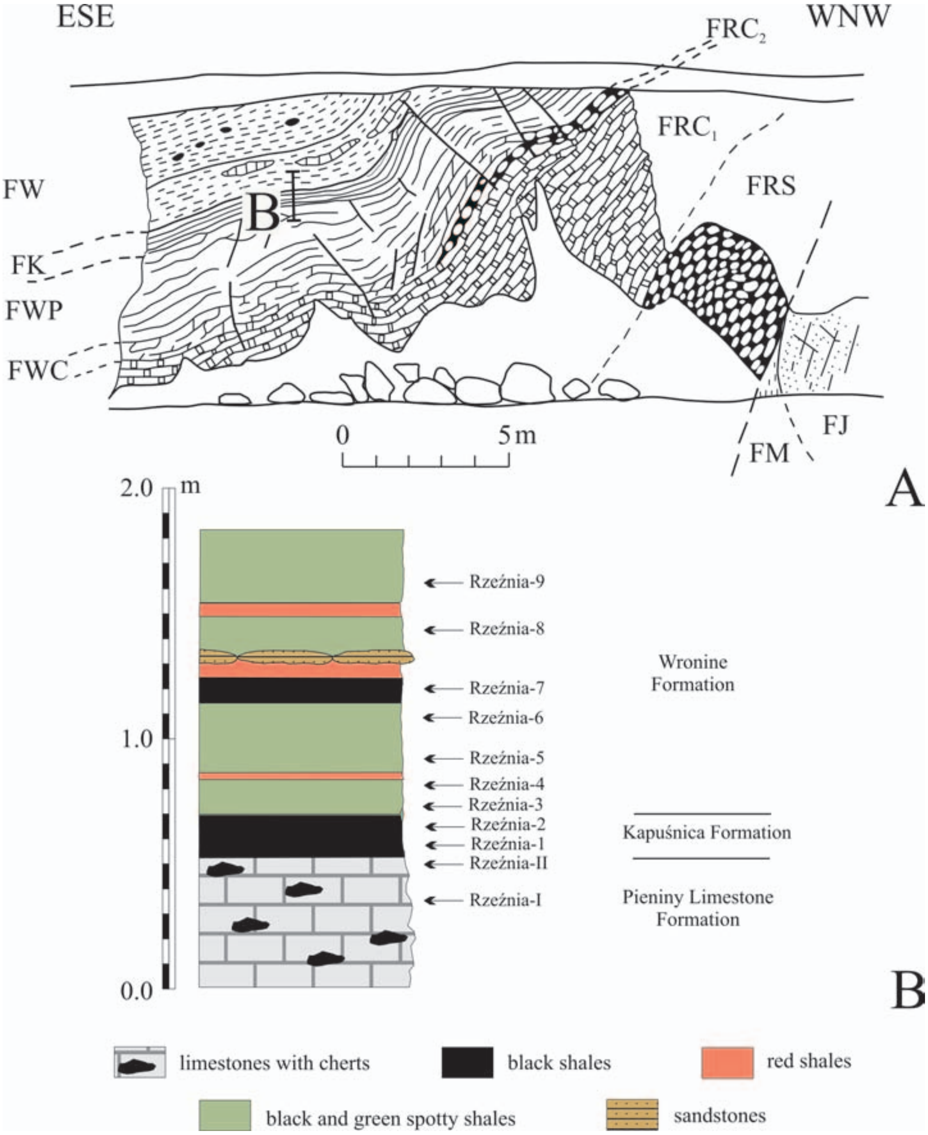


**Fig. 3.** Location of samples at Rzeźnia section, Szczawnica-Zabaniszcze: **A.** Geological section from Birkenmajer, 1979, and Birkenmajer & Dudziak, 1987a: FJ – Jarmuta Formation (Maastrichtian); FM – Malinowa Shale Formation (Cenomanian–Campanian); FRS – Sokolica Radiolarite Formation (?Bajocian–?Oxfordian); $FRC_1$ – Czajakowa Radiolarite Formation, Podmajerz Radiolarite Member (Oxfordian); $FRC_2$ – Czajakowa Radiolarite Formation, Buwałd Radiolarite Member (Oxfordian); FWC – Czorsztyn Limestone Formation, Palenica Marlstone Member (Kimmeridgian–Tithonian); FWP – Pieniny Limestone Formation (Tithonian–Barremian); FK – Kapuśnica Formation (Aptian–Albian); FW – Wronine Formation (Albian)

base of the limestone exposure; a third sample, Szt42A, was taken from the topmost part of the limestone layer – fig. 2.

(b) **Rzeźnia section** (Birkenmajer, 1979; Birkenmajer & Dudziak, 1987a; Gedl, 2000; fig. 3): sample Rzeźnia-I was taken from very hard, dark-grey limestone with black chert intercalation, 15 cm below the top of the highest limestone bed. Sample Rzeźnia-II represent topmost part of this bed – fig. 3.

### Palynomorphs

(a) Samples from the **Sztolnia section** contain palynomorphs (see Fig. 5A, B), however, in sample Szt41, dinocysts are infrequent (ca. 5%) and rather poorly preserved. Land-derived palynomorphs (pollen and spores) predominate. In sample Szt42A, dinocysts dominate over sporomorphs (3:1) and are better preserved, representing 29% of the palynofacies. The dinocyst assemblage is moderately diversified, with domination of gonyaulacoids.

(b) Palynofacies present in sample Rzeźnia-I, **Rzeźnia section**, is characterised by a high percentage of palynomorphs (44%), among which dinocysts represent 21%, fungi 1.3%, and the rest are sporomorphs. Black woody particles constitute only 34%, brown phytoclasts are quite frequent (15%). Amorphous organic matter is present (7%). Black woody particles are more common in sample from the topmost part of the limestone (Rzeźnia-II) where they represent 69% of the palynofacies components: dinocysts (12%) and sporomorphs (9%) are less frequent, amorphous organic matter disappear and brown woody particles constitute the rest of the assemblage (10 %).

The dinocyst assemblages in both samples are rich and diversified, but they are poorly preserved. Oceanic (cf. Leereveld, 1995) dinocyst group is rich (24%, at Rzeźnia-I), increasing in the Rzeźnia-II sample (35%). In the topmost part of the limestone (Rzeźnia-II), littoral species are less frequent (9%) than in the previous sample (Rzeźnia-I – 26%). The sporomorph content decreases accordingly. This may suggest a transgressive trend from the Rzeźnia-I to the Rzeźnia-II samples.

## Kapuśnica Formation (Brodno Member)

### Lithology

Two samples were collected at Rzeźnia section (Fig. 3): sample Rzeźnia-1 was taken from calcareous black shales overlying the limestones; sample Rzeźnia-2 – from very hard, silicified black shales a few cm above.

### Palynomorphs

Palynofacies of the Rzeźnia-1 sample is characterised by the presence of amorphous organic matter (16%). Dinocysts are infrequent (5%), whereas sporomorphs are frequent (nearly 37%). Well preserved scolecodonts (1%) and foraminifera linnings (1%; see Fig. 6A) are present. Black and brown woody particles represent 40%, including cuticles (3%).

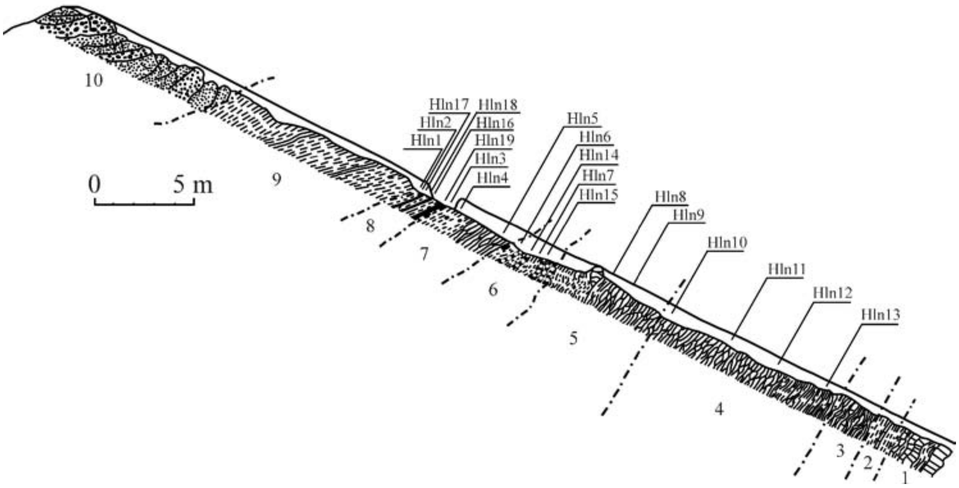


**Fig. 4.** Location of samples at Hulina section (see Birkenmajer & Gedl, 2007, Fig. 3). 1, 10 – Jarmuta Formation (Maastrichtian); 2, 9 – FM – Malinowa Shale Formation (Cenomanian–Campanian); 3 – Szlachtowa Formation (?Toarcian – Aalenian); 4 – Wronine Formation (Albian); 5, 7 – Opaleniec Formation (Bajocian); 6 – Sokolica Radiolarite Fm (?Bajocian–?Oxfordian); 8 – Hulina Formation, Ubocz Shale Member (Albian–Cenomanian)

Rzeźnia-2 sample is dominated by amorphous organic matter (55%). Palynomorphs are represent only by dinocysts (4%) and sporomorphs (4%). Phytoclast assemblage consists of black (30%) and brown (7%) woody particles.

## Wronine Formation

### Lithology

(a) **Rzeźnia section** (Fig. 3). Samples Rzeźnia-3 to Rzeźnia-9 were taken from deposits above black shales of the Kapuśnica Formation. They are hard, green, mostly non-calcareous, often dark-spotted shales (exclusively of Rzeźnia-9 sample which consists of relatively soft, green marly shales), except of the Rzeźnia-7 sample which consists of hard black shales.

(b) **Hulina section** (Fig. 4). Samples were taken from deposits exposed at the south-western slope of Mt Hulina at Szczawnica Niżna. Samples Hln8–Hln13 are represented mostly by greenish-grey soft claystones with black spots.

### Palynomorphs

(a) **Rzeźnia section.** Palynofacies of samples Rzeźnia-3, Rzeźnia-4 and Rzeźnia-6 are dominated by black woody particles (91%). Dinocysts and other palynomorphs are absent. The rest of the palynofacies assemblage consists of brown particles (8%) and amorphous organic matter (ca 1%). In samples Rzeźnia-5, Rzeźnia-8 and Rzeźnia-9 black woody particles dominate (ca 85%), however palynomorphs, although uncommon, are also present (dinocysts 0.3–2%; sporomorphs 0.5–4%). The dinocyst assemblage in sample Rzeźnia-9 is dominated by *Odontochitina operculata* and *Pseudoceratium* sp. A different palynofacies assemblage is present in sample Rzeźnia-7, where amorphous organic matter represents 72%, and black woody particles c. 10% only. Sporomorphs predominate over dinocysts (4:1). Among dinocysts, *Kiokansium polypes* is predominant.

(b) **Hulina section.** Cretaceous dinocysts were found in samples Hln10, Hln11 and Hln13. They are not numerous (0.5–6%) and poorly preserved. *Odontochitina* sp., *Spiniferites* sp. and *Pterodinium* sp. are the most common taxa. Palynofacies are dominated by black woody particles, except for sample Hln12 which is characterized by frequent occurrence of plant tissue remains (27%); black and dark brown phytoclasts represent 69%. Among rare and poorly preserved dinocysts, only a few specimens may be determined. The samples Hln8 and Hln9 reveal a Jurassic dinocyst assemblage (see Birkenmajer & Gedl, 2007).

## Hulina Formation

### Lithology

(a) **Hulina section** (Fig. 4). Samples Hln1–2 were taken from grey and greenish mudstones and claystones, just below red shales of the Malinowa Formation; samples Hln16, Hln17 and Hln19 represent black, finely laminated bentonitic shales *sensu* Birkenmajer (1973, 1976). Samples Hln3–7 and Hln14–15 were taken from deposits below the bentonitic shales. They represent greenish, often dark-spotted shales, except of samples Hln14 and Hln15 which represent dark greenish silicified limestone.

(b) **Sztolnia section** (Fig. 2). Sample Szt43 was taken from black mudstones (7.30 m above base of the Pieniny Limestone Formation. This limestone is followed by the Malinowa Shale Formation).

### Palynomorphs

(a) **Hulina section**. Dinocysts, present in the majority of samples, are poorly preserved. Sample Hln1 contained a very small amount of organic matter, mainly small, black, opaque woody particles. *Odontochitina costata* was the only species determined. Very small amount of organic matter was also characteristic for sample Hln2. The most common elements of the palynofacies were black (52%) and dark brown (39%) woody particles. No dinocysts were found in this sample. Amorphic organic matter constituted the rest (9%) of the palynofacies components.

A distinctively different palynofacies was found in samples from black bentonitic layers (Hln16, Hln17 and Hln19) exposed slightly below. It was composed of predominating amorphic organic matter constituting from 42% (Hln16) to 77% (Hln17). Black woody particles (10–40%), sporomorphs (3–5%), and brown woody particles were subordinate. Presence of Prasinophyte algae (*Pterospermella* and *Tasmanites*), although infrequent, was another outstanding feature; they do not appear in any other samples from the studied section.

Greenish shales between the bentonitic layers (Hln18) yielded a different palynofacies, resembling palynofacies of sample Hln1; it was dominated by black woody particles (84%). Dinocysts, rather poorly preserved, in samples Hln16–Hln19 constituted 1.8–5%.

Samples Hln3–Hln7, Hln14 and Hln15 yielded only Jurassic dinocyst assemblages (see Birkenmajer & Gedl, 2007).

(b) **Sztolnia section**. Dinocyst assemblage from sample Szt43 is rather poorly preserved. Only a few species were recognised, among which *Paleohystrichophora infusorioides*, *Litosphaeridium siphoniphorum* and *Odontochitina costata* are the most stratigraphically important.

## AGE

### Pieniny Limestone Formation

(a) **Sztolnia section** (Tab. 1). Co-occurrence of *Muderongia staurota* (FO in lower Early Hauterivian, Leereveld, 1995), *Cymososphaeridium validum* (LO in the uppermost Hauterivian, Torricelli, 2000) and *Bourkidinium granulatum* (LO in the uppermost Hauterivian according to Torricelli, 2000; *Bourkidinium* spp. LO in the uppermost Hauterivian according to Leereveld, 1995) suggest an age of sample Szt41as not younger than Hauterivian.

Sample Szt42 is characterized by the presence of *Pseudoceratium anaphrissum* which appears for the first time in Early Barremian and is typical only for Lower Barremian strata (see Nøhr-Hansen, 1993). Co-occurrence of this species with *Gonyaulacysta perforobusta* and *Cribroperidinium sepimentum* (LOs in Early Barremian; Heilmann-Clausen, 1987) confirms the Barremian age of the sample. *Rhynchodiniopsis aptiana* is a typically Barremian species in the Tethyan realm (Torricelli, 2000).

The same Early Barremian age has been accepted for sample Szt42A, where *Muderongia staurota*, *Cribroperidinium sepimentum* and *Rhynchodiniopsis aptiana* are also present. Co-occurrence of *Florentinia interrupta* (FO in the lowermost Upper Hauterivian, Leereveld, 1995) and *Nexosispinum vetusculum* (LO close to the L/U Barremian boundary; Leereveld, 1995) suggests a Late Hauterivian to Early Barremian interval (*Pseudoceratium anaphrissum* is absent), but Early Barremian age may be concluded based on the lack of *Cymososphaeridium validum* and *Bourkidinium granulatum*. These taxa appear for the last time in the uppermost Hauterivian, and are present in sample Szt41. This suggests that a boundary between Hauterivian and Barremian stages lies somewhere between samples Szt41 and Szt42.

(b) **Rzeźnia section** (Tab. 2). Dinocyst assemblages in samples Rzeźnia-I and Rzeźnia-II are different, however both suggest a similar age. Co-occurrence, in sample Rzeźnia-I, of: *Cauca parva* (FO in mid-Barremian strata, Heilmann-Clausen, 1987), *Cerbia tabulata* (FO in the latest Early Barremian in the Tethian realm, Leereveld, 1995), *Pseudoceratium solocispinum* (occurence only in Upper Barremian strata, Nøhr-Hansen, 1993; Costa & Davey, 1992), *Hystrichosphae-*

**Table 1**

Cretaceous dinocysts in the Sztolnia section

| Lithostratigraphy | Pieniny Limestone Formation | | | Hulina Formation |
|---|---|---|---|---|
| Taxon Sample | Szt41 | Szt42 | Szt42A | Szt43 |
| *Achomosphaera* sp. | | | + | |
| *Aprobolocysta neistosa* | | + | | |
| *Batioladinium jaegeri* | | + | | |
| *Bourkidinium granulatum* | + | | | |
| *Bourkidinium* sp. 1 of Leereveld, 1995 | + | | | |
| *Bourkidinium* sp. 2 of Leereveld, 1995 | + | | | |
| *Bourkidinium* sp. | + | | | |
| *Callaiosphaeridium assymetricum* | | | | + |
| *Cerbia* cf. *tabulata* | + | | | |
| *Circulodinium* sp. | | | + | |
| *Cleistosphaeridium* sp. | + | | | |
| *Coronifera alberti* | + | | | |
| *Coronifera* sp. | | | | + |
| *Cribroperidinium sepimentum* | | + | + | |
| *Cymososphaeridium validum* | + | | | |
| *Dapsilidinium multispinosum* | + | | | |
| *Dapsilidinium warreni* | | | + | |
| *Dingodinium coerviculum* | + | + | | |
| *Florentinia interrupta* | | | + | |
| *Florentinia* sp. | | | | + |
| *Gardodinium trabeculosum* | | | + | |
| *Gonuaulacysta diutina* | + | | + | |
| *Gonyaulacysta perforobusta* | | + | | |
| *Gonyaulacysta* sp. | + | | | |
| *Kleithriasphaeridium corrugatum* | + | | | |
| *Kleithriasphaeridium eoinodes* | | | + | |
| *Kleithriasphaeridium fasciatum* | + | | | |
| *Lithodinia stoveri* | + | + | + | |
| *Litosphaeridium siphoniphorum* | | | | + |
| *Muderonga neocomica* | + | | | |
| *Muderongia staurota* | + | | + | |
| *Muderongia tabulata* | | + | | |
| *Nexosispinum vetusculum* | + | | + | |
| *Occisucysta* sp. | + | | | |
| *Occisucysta tentoria* | | + | | |
| *Odontochitina costata* | | | | + |

**Table 1 continued**

Cretaceous dinocysts in the Sztolnia section

| Lithostratigraphy | Pieniny Limestone Formation | | | Hulina Formation |
|---|---|---|---|---|
| Taxon / Sample | Szt41 | Szt42 | Szt42A | Szt43 |
| *Odontochitina imparilis* | + | | | |
| *Odontochitina* sp. | | | | + |
| *Oligosphaeridium albertense* | | + | | |
| *Oligosphaeridium asterigerum* | + | + | + | |
| *Oligosphaeridium complex* | | | + | |
| *Oligosphaeridium irregulare* | | + | | |
| *Oligosphaeridium* sp. | + | + | + | |
| *Ovoidinium/Deflandrea* group | | | | + |
| *Paleohystrichophora infusorioides* | | | | + |
| *Pseudoceratium anaphrissa* | | + | | |
| *Pterodinium* sp. | | | | + |
| *Rhynchodiniopsis aptiana* | | + | + | |
| *Spiniferites* sp. | + | + | | + |
| *Systematophora* sp. | + | | | |
| *Tanyosphaeridium boletum* | | + | + | |
| *Tanyosphaeridium* sp. | + | | | |
| *Valensiella reticulata* | + | + | + | |
| *Wallodinium krutzschi* | | + | + | |
| *Wallodinium* sp. | | | | + |

*ridium ramoides* (LO in the uppermost Barremian, Nøhr-Hansen, 1993), *Pseudoceratium pelliferum* (LO in the uppermost Barremian in Tethian realm, cf. Leereveld, 1995; Wilpshaar, 1995) and *Muderongia staurota* (LO in the uppermost Barremian of Tethian realm, Wilpshaar, 1995) suggest a Late Barremian age of the sample. Specimens of *Bourkidinium* (LO in the uppermost Hautherivian, Leereveld, 1995) are probably recycled.

The dinocyst assemblage in Rzeźnia-II sample is less diversified: *Cerbia tabulata* co-occurs with *Aprobolocysta neistosa* (LO at Upper Barremian; Costa & Davey, 1992), *Odontochitina operculata* and *Prolixosphaeridium parvispinum* (both FOs in the lowermost Upper Barremian strata in the Tethian realm, Leereveld, 1995; Wilpshaar, 1995). This assemblage also suggests a Late Barremian age of the sample.

In both samples (Rzeźnia-I and Rzeźnia-II), *Membranosphaera* sp. A is present. This species was described by Davey (1979) from Lower Aptian. Acme-zone of this species correlates with Early Aptian anoxic event (pers. inf., Dr Lenny Kouvenberg).

Age of the topmost part of the Pieniny Limestone Formation in the Pieniny Klippen Belt was interpreted as Barremian/Aptian boundary (Birkenmajer, 1977; Obermajer, 1986, 1987), Albian (Golonka & Sikora, 1981), or Upper Aptian (Birkenmajer & Dudziak, 1987b). In the presented study, as based on dinocysts, the age of the top part of the Pieniny Limestone Formation in the Grajcarek Unit is interpreted as Late Barremian.

### Kapuśnica Formation

**Rzeźnia section** (Tab. 2). Co-occurrence of *Odontochitina operculata* and *Cerbia tabulata* (FOs of both species – see above) and occurrence of *Rhynchodiniopsis aptiana* – a typical Barremian species in the Tethyan realm (Torricelli, 2000), in Rzeźnia-1 sample, suggests a Late Barremian age. However, Heilmann-Clausen (1987) cites presence of *R. aptiana* also from Aptian. In Rzeźnia-2 sample, *O. operculata* nad *Ctenidodinium elegantulum* (LO in Early Aptian; *op.cit.*) co-occur, so the age of this sample is Late Barremian to Early Aptian. Considering the presence of palynofacies type PT5 (described below) induced by anoxia, the age of this sample is probably Early Aptian. A high frequency of *Valensiella reticulata*, morphologically very similar to *Membranosphaera* sp., is remarkable.

Previous data based on uncommon amonites, belemnites and bivalvia, foraminiferes and calcareous nannnofossils, suggested an Aptian–Albian (see Birkenmajer, 1970, 1973, 1977) or a Late Aptian–latest Albian (Birkenmajer & Dudziak, 1987b) age of the Brodno Member of the Kapuśnica Formation. Dinocyst assemblage from Rzeźnia section is barren of typical Aptian dinocysts such as *Pseudoceratium polymorphum* or *P. eisenackii*, also no *Ovoidinium* specimens have been found.

### Wronine Formation

(a) **Rzeźnia section** (Tab. 2). Samples Rzeźnia-3, Rzeźnia-4 and Rzeźnia-6 are barren of dinocysts. Presence of *Litosphaeridium siphoniphorum* in Rzeźnia-5 sample suggests a Late Albian–Cenomanian age (cf. Leereveld, 1995; Marshall & Batten, 1988; Prössl, 1990). Co-occurrence of *Cepadinium ventriosum* and *Cribroperidinium sepimentum* in Rzeźnia-7 sample is characteristic for the uppermost Barremian to Lower Aptian deposits (see Lister & Batten, 1988; Duxbury, 1980; Nøhr-Hansen, 1993), however the presence of *E. rugulosum* suggests an age not older than Albian (see Heilmann-Clausen, 1987; Prössl, 1990). The age of the Rzeźnia-8 sample corresponds to the Late Barremian to the latest Albian interval, based on co-occurrence of *Prolixosphaeridium parvispinum*, *Odontochitina operculata* and *Cerbia tabulata* (see Leereveld, 1995; Wilpshaar, 1995). Presence of *P. securigerum* and *P. polymorphum* in Rzeźnia-9 sample implies an Early Aptian age (cf. Davey & Verdier, 1974; Duxbury, 1983).

Age determination of the samples Rzeźnia-5 to Rzeźnia-9 indicate a tectonic repetition of strata. Data obtained from calcarous nannoplankton study of the same deposits (Birkenmajer & Dudziak, 1987a) show that in the lower part of the section (beds belonging to the Wronine Formation), a long-ranging taxon *Eiffellithus*

**Table 2**

Cretaceous dinocysts in the Rzeźnia section

| Lithostratigraphy | Pieniny Limestone Formation | | Kapuśnica Formation | | Wronine Formation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Taxon Sample | Rz-I | Rz-II | Rz-1 | Rz-2 | Rz-3, Rz-4 | Rz-5 | Rz-7 | Rz-8 | Rz-9 |
| *Achomosphaera verdieri* | | | | | | | | | + |
| *Aprobolocysta neistosa* | | + | | | | | | | |
| *Apteodinium granulatum* | + | | | | | | | | |
| *Apteodinium* sp. | | | | | | | | + | |
| *Batiacasphaera* sp. | | | | | | + | | | |
| *Bourkidinium* sp. 2 of Leereveld, 1995 | + | | | | | | | | |
| *Bourkidinium* sp.1 of Leereveld, 1995 | + | | | | | | | | |
| *Canningia* sp. | | | + | + | | + | | | |
| *Carpodinium granulatum* | | | | | | | | | |
| *Cauca parva* | + | | | | | | | | |
| *Cepadinium ventriosum* | | | | | | | + | | |
| *Cerbia tabulata* | + | + | + | | | | | + | |
| *Chlamydophorella nyei* | | | | | | + | | | |
| *Chlamydophorella* sp. | | | | + | | | | | |
| *Chytroeisphaeridia scabrata* | + | | + | | | + | | | |
| *Circulodinium asperum* | | | | | | + | | | |
| *Circulodinium brevispiosum* | | + | + | | | | | | |
| *Circulodinium distinctum* | + | | | | | | | | |
| *Circulodinium* sp. | + | + | + | + | | + | | + | + |
| *Cleistosphaeridium* spp. | | + | + | | | + | | | + |
| *Cometodinium? comatum* | | + | + | | | | | | |
| *Cometodinium* sp. | | | | | | | | | + |
| *Cribroperidinium muderongense* | | | | | | + | | | |
| *Cribroperidinium sepimentum* | | | | | | | + | | |
| *Cribroperidinium* sp. | + | | | + | | + | + | + | |
| *Ctenidodinium eleganthulum* | + | | | + | | | | | |
| *Cymososphaeridium validum* | + | | | | | | | | |
| *Dapsilidinium* sp. | | | | | | + | | | |
| *Dapsilidinium warrenii* | + | | + | + | | + | | | |
| *Dingodinium albertii* | + | | + | | | | | | |
| *Dingodinium* spp. | + | | | | | | | | |
| *Dissiliodinium globulum* | + | + | | | | | | | |
| *Ellipsodinium rugulosum* | | | | | | | + | | |
| *Ellipsoidictium imperfectum* | + | | + | | | | | | |
| *Eppelidosphaeridia spinosa* | | | | | | | | | |

**Table 2 continued**

Cretaceous dinocysts in the Rzeźnia section

| Lithostratigraphy | Pieniny Limestone Formation | | Kapuśnica Formation | | Wronine Formation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Taxon Sample | Rz-I | Rz-II | Rz-1 | Rz-2 | Rz-3, Rz-4 | Rz-5 | Rz-7 | Rz-8 | Rz-9 |
| *Exochosphaeridium phragmites* | + | | + | + | | | | | |
| *Fromea amphora* | | | | | | + | | | |
| *Gardodinium trabeculosum* | | | | + | | | | | |
| *Gonyaulacysta diutina* | | | + | | | | | | |
| *Gonyaulacysta fastigiata* | | + | | | | | | | |
| *Gonyaulacysta helicoidea* | + | | | | | | | | |
| *Gonyaulacysta* sp. | + | + | | + | | | | | |
| *Heslertonia heslertonensis* | | | | | | + | | | |
| *Hystrichodinium pulchrum* | + | | | | | + | | | |
| *Hystrichodinium ramoides* | + | | | | | | | | |
| *Hystrichodinium* sp. | | | | | | + | | | |
| *Hystrichodinium voighti* | + | | | | | | | | |
| *Kiokansium polypes* | | | | | | | + | | |
| *Kiokansium* sp. | | | | + | | | | | + |
| *Kiokansium unituberculatum* | | | | | | | | | + |
| *Kleithriasphaeridium simplicispinum* | | | | + | | | | | |
| *Lithodinia pertusa* | + | | | | | | | | |
| *Lithodinia stoveri* | + | + | | | | | | | |
| *Litosphaeridium siphoniphorum* | | | | | | + | | | |
| *Membranosphaera* sp. A sensu Davey, 1974 | + | + | | | | | | | |
| *Membranosphaera* sp. | | + | | | | | | | |
| *Mendicodinium* sp. | | | | + | | | | | + |
| *Muderongia imparilis* | | + | | + | | | | | |
| *Muderongia neocomica* | + | | | | | | | | |
| *Muderongia* sp. | + | | | | | | | | |
| *Muderongia staurota* | + | | | | | | | | |
| *Nexosispinium hesperum* | + | | | | | | | | |
| *Occisucysta tentoria* | | | + | | | | | | |
| *Occisucysta* sp. | + | | | | | + | | | |
| *Odontochitina costata* | | | | | | | | | |
| *Odontochitina operculata* | | + | + | + | | + | + | + | + |
| *Odontochitina rhakodes* | | | + | | | | | | |
| *Odontochitina* sp. | | | | + | | + | | + | + |
| *Oligosphaeridium albertense* | | | | | | + | | | |

**Table 2 continued**

Cretaceous dinocysts in the Rzeźnia section

| Lithostratigraphy | Pieniny Limestone Formation | | Kapuśnica Formation | | Wronine Formation | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Taxon Sample | Rz-I | Rz-II | Rz-1 | Rz-2 | Rz-3, Rz-4 | Rz-5 | Rz-7 | Rz-8 | Rz-9 |
| *Oligosphaeridium complex* | | + | + | | | + | + | | + |
| *Oligosphaeridium irregulare* | + | + | | | | | | | |
| *Oligosphaeridium pulcherrimum* | | | + | | | | | | |
| *Oligosphaeridium* sp. | + | + | + | + | | + | | + | + |
| *Oligosphaeridium totum* subsp. *minus* | + | | | | | | | | |
| *Pervosphaeridium* sp. | | + | + | | | | | | |
| *Prolixosphaeridium deirense* | | + | | | | + | | | |
| *Prolixosphaeridium parvispinum* | | + | + | | | | | + | + |
| *Protoellipsodinium* sp. | | | | + | | | | | |
| *Pseudoceratium pelliferum* | + | | | | | | | | |
| *Pseudoceratium polymorphum* | | | | | | | | | + |
| *Pseudoceratium securigerum* | | | | | | | | | + |
| *Pseudoceratium solocispinum* | + | + | | | | | | | |
| *Pseudoceratium* sp. | | | | | | | | | + |
| *Pterodinium cingulatum* | | | | | | + | | + | + |
| *Pterodinium premnos* | | + | | | | | | | |
| *Pterodinium* sp. | + | + | + | | | + | + | + | + |
| *Rhynchodiniopsis aptiana* | | + | + | | | | | | |
| *Sentusidinium* sp. | + | | | | | | | | |
| *Spinidinium* sp | | | | | | | | | |
| *Spiniferites* sp. | + | + | + | + | | + | + | | + |
| *Stephanelytron cretaceum* | + | | | | | | | | |
| *Subtilisphaera* sp. | | | | | | | + | | |
| *Surculosphaeridium* sp. | | | | | | | | | + |
| *Systematophora syliba* | | | | | | | | | + |
| *Systematophora* sp. | | | | | | | | | |
| *Taleisphaera hydra* | | + | | | | | | | |
| *Tanyosphaeridium boletus* | + | | | | | | | | |
| *Tanyosphaeridium regulare* | | + | + | | | | | + | + |
| *Tanyosphaeridium* sp. | + | | | + | | | | | |
| *Tehamadinium sousense* | | | | + | | | | | |
| *Trichodinium* sp. | | | | | | + | | | + |
| *Valensiella reticulata* | + | + | + | | | | | | |
| *Wallodinium krutzschii* | + | + | + | | | + | | | |

*turriseiffeli* (FO in Late Albian) is present, but is missing in its upper part. Dudziak (1979) cited this species as very common in the Pieniny Klippen Belt deposits.

(b) **Hulina section** (Tab. 3). Dinocyst assemblage from the Wronine Formation, present in samples Hln10 and Hln11, contains: *Odontochitina costata*, *Cribroperidinium* sp., *Epelidosphaeridia spinosa* (in sample Hln10 only), *Hapsocysta peridictia*, *Spinidinium* sp. and, common, *Spiniferites* sp. and *Pterodinium* sp. The last occurrence of *Epelidosphaeridia spinosa* (FO in Late Albian *inflatum* Ammonite Zone, according to Leereveld, 1995), is noted from the Middle/Upper Cenomanian boundary (Davey, 1979), Middle Cenomanian (Foucher, 1981), lower Upper Cenomanian (Prössl, 1990), and upper Middle Cenomanian (Costa & Davey, 1992). *Hapsocysta peridictya* (re-appearence of this species is noted just below the Aptian/Albian boundary – Davey, 1979; Masure, 1984) has the last occurrence in Upper Cenomanian (Davey, 1979). Co-occurrence of these species with *Odontochitina costata* might suggest an uppermost Albian–Middle Cenomanian age of sample Hln10.

Palynofacies of these samples represents a well oxidised environment. In sample Hln12, dinocysts are very uncommon, representing long-ranging taxa. Uncommon dinocyst *Ovoidinium scabrosum* is present in sample Hln13. The first occurrence of this species is noted from middle Late Aptian (Heilmann-Clausen, 1987; Davey & Verdier, 1974), the last occurrence – from the uppermost Albian (Davey & Verdier, 1973, 1974; Verdier, 1974; Davey & Verdier, 1974; Heilmann-Clausen, 1987; Costa & Davey, 1992), just above the Albian/Cenomanian boundary (Foucher, 1981), or from Upper Cenomanian (Prössl, 1990). Age of the sample Hln13, based on the presence of *Ovoidinium scabrosum*, is Late Aptian–Albian (Cenomanian?). Absence of *Lithosphaeridium siphoniphorum* and *Palaeohystrichophora infusorioides* in the uppermost Albian strata is untypical, but the presence of *Epelidosphaeridia spinosa* and *Odontochitina costata* suggest an age not older than the uppermost Albian age of the samples Hln10–Hln13.

The age of Wronine Formation, as based on dinocysts, spans the time from Early Aptian to Cenomanian. Previous studies suggested an Early-Middle Albian age (Birkenmajer, 1965, 1973; Birkenmajer & Dudziak, 1987a; Birkenmajer & Pazdro, 1968).

### Hulina Formation

(a) **Hulina section** (Tab. 3). Cretaceous dinocysts are present in samples Hln1 and Hln16–Hln19, taken from the Ubocz Shale Member. *Odontochitina costata*, present in Hln1 sample, occurs from Vraconian (Clarke & Verdier, 1967; Davey & Verdier, 1973) to Maastrichtian inclusively (Costa & Davey, 1992). Sample Hln2 is barren of dinocysts.

Dinocyst assemblages in samples Hln17, Hln16 and Hln19 (“bentonitic” layers) contain the following taxa which are usually present in mid-Cretaceous rocks: *Paleohystrichophora infusorioides*, *Odontochotina costata*, *Chlamydophorella ambigua*, *Dinopterygium* sp., *Eurydinium* sp., *Exochosphaeridium* sp., *Litosphaeridium siphoniphorum* and *Pervosphaeridium* sp.

**Table 3**

Cretaceous dinocysts in the Hulina section

| Lithostratigraphy | Hulina Formation, Ubocz Shale Member | | | | | | Wronine Formation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Taxon Sample | Hln1 | Hln2 | Hln17 | Hln18 | Hln16 | Hln19 | Hln10 | Hln11 | Hln12 | Hln13 |
| *Achomosphaera* sp. | | | | | + | | | | | |
| *Chlamydophorella* sp. | | | | | | + | | | | |
| *Circulodinium distinctum* | | | | | | + | | | | |
| *Circulodinium* spp. | | | | + | + | | + | | | |
| *Cribroperidinium* sp. | | | | | | | + | + | | |
| *Dapsilidinium ambiguum* | | | + | | | | | | | |
| *Dinopterygium* sp. | | | | | | + | | | | |
| *Ellipsodinium rugulosum* | | | | | | + | | | | |
| *Endoscrinium campanula* | | | | | | + | | | | |
| *Epelidosphaeridia spinosa* | | | | | | | + | | | |
| *Eurydinium* sp. | | | + | | + | | | | | |
| *Exochosphaeridium* sp. | | | | | + | + | | | | |
| *Florentinia laciniata* | | | | | | | | + | | |
| *Florentinia mantellil* | | | | | | | + | | | |
| *Florentinia* sp. | | | | | | + | | | | |
| *Gonyaulacysta extensa* | | | + | | | + | | | | |
| *Gonyaulacysta* spp. | | | | | | | + | + | + | |
| *Hapsocysta peridyctya* | | | | | | | + | + | | |
| *Kiokansium polypes* | | | + | | | | | | | |
| *Kleithriasphaeridium loffrense* | | | | + | | | | | | |
| *Leberidocysta chlamydata* | | | | | | + | | | | |
| *Litosphaeridium siphoniphorum* | | | + | + | + | + | | | | |
| *Microdinium ornatum* | | | | | | + | | | | |
| *Odonthochidinia castata* | + | | + | | | + | + | + | | + |
| *Odonthochidinia operculata* | | | | | | | + | + | | + |
| *Odonthochidinia* sp. | | | + | | | | + | + | | + |
| *Ovoidinium scabrosum* | | | | | | | | | | + |
| *Ovoidinium* spp. | | | + | | | | | | | |
| *Paleohystrichophora infusorioides* | | | + | | + | + | | | | |
| *Pervosphaeridium pseudohystrichodinium* | | | | | | + | | | | |
| *Pervospaeridium* sp. | | | + | | + | | | | | |
| *Pesudoceratium?* sp. | | | | | | | | | | + |
| *Pterodinium aliferum* | | | | | | | + | + | | |
| *Pterodinium cingulatum* | | | | | | + | + | | | |
| *Pterodinium cingulatum* var. *reticulatum* | | | | | | + | | | | |

**Table 3 continued**

Cretaceous dinocysts in the Hulina section

| Lithostratigraphy | Hulina Formation, Ubocz Shale Member | | | | | | Wronine Formation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Taxon Sample | Hln1 | Hln2 | Hln17 | Hln18 | Hln16 | Hln19 | Hln10 | Hln11 | Hln12 | Hln13 |
| *Pterodinium? reticulatum* | | | | | | + | | | | |
| *Pterodinium* sp. | | | + | | + | | + | + | | |
| *Spinidinium* sp. | | | | | | | | + | | |
| *Spiniferites* sp. | | | + | + | + | + | + | + | + | + |
| *Wallodinium* sp. | | | | | | + | | | | |

FOs in the uppermost Albian of: *Paleohystrichophora infusorioides* (Leereveld, 1995; Davey & Verdier, 1973), *Pervosphaeridium pseudohystrichodinium* (Davey & Verdier, 1973; Prössl, 1990) and *Odontochotina costata*, and LO of *Litosphaeridium siphoniphorum* close to the Cenomanian/Turonian boundary, suggest the uppermost Albian–Cenomanian age of the studied deposits. LO data of *Litosphaeridium siphoniforum*, which appears since the Late Albian *inflatum* Amonite Zone (Leereveld, 1995), is generally used as a Cenomania/Turonian boundary marker. Data from Canada (Lucas-Clark, 1984) suggests the LO of *Litosphaeridium siphoniphorum* subsp. *glabrum* at the Cenomanian/Turonian boundary, and subsp. *siphoniphorum* – at the Turonian/Coniacian boundary. Data from Great Britain (Costa & Davey, 1992) restricts LO of *Litosphaeridium siphoniphorum* (without subspecies differentiations) to lower Early Turonian (*coloradoense*, Western European Ammonite Zonation). The last occurrence of this species is in the uppermost Cenomanian (Marshall & Batten, 1988; Prössl, 1990).

Marshall and Batten (1988) described dinocyst assemblages with *Eurydinium* sp. from Cenomanian/Turonian boundary interval of Northern Europe. This species was associated with palynofacies enriched with amorphous organic matter, characteristic for anoxic layers. The same relationship is observed in the studied material. *Eurydinium* species, a high amount of amorphous organic matter, and the presence of representatives of Prasinophytae (*Pterospermella*, *Tasmanites*) associated with euxynic conditions (Batten, 1996), are characteristic of samples from "bentonitic" layers. Sporomorphs predominate over dinocysts there. Occurrence of numerous peridinioid-type dinocysts reflect increase of eutrophysation, probably influenced by both terrestrial input and ?volcanic activity. Blooms of primary producers could have caused oxygen depletion.

Sample Hln18, taken from greenish soft claystone between "bentonitic" layers, represents a different environment: palynofacies assemblage is poor, dominated by black woody phytoclasts, dinocysts are uncommon. *Litosphaeridium siphoniphorum* (Upper Albian–Cenomanian) was found in this sample.

(b) **Sztolnia section.** Sample Szt43 (Tab. 1) represents the uppermost Albian (Vraconian)–Cenomanian on the basis of co-occurrence of *Paleohystrichophora infusorioides*, *Odontochitina costata* and *Litosphaeridium siphoniforum*. FOs of *Palaeohystrichophora infusorioides* (Leereveld, 1995; Davey & Verdier, 1973) and *Odontochitina costata* (Clarke & Verdier, 1967; Davey & Verdier, 1973) are known from the uppermost Albian. According to data from France and Germany (Marshall & Batten, 1988; and Prössl, 1990), LO of *Litosphaeridium siphoniforum* fits the Cenomanian/Turonian boundary.

As based on dinocysts, the latest Albian–Cenomanian age of the Ubocz Shale Member of the Hulina Formation, confirms the previous age estimation (see Birkenmajer & Pazdro, 1968).

A discovery of Jurassic dinocysts (E. Gedl, 1999) in the deposits belonging, on the basis of lithostratigraphic features only, to the Groń Radiolarite Member of the Hulina Formation caused new interpretation of the Hulina section stratigraphy (see Birkenmajer & Gedl, 2007).

## PALAEOENVIRONMENT

Palynofacies of the studied samples differ in state of preservation of palynomorphs and their diversity. They are described as several types, each of them representing different palaeoenvironment, however, interpretation of sedimentary trends in a larger scale was not possible.

Five main palynofacies types were distinguished: PT1 – dominated by black woody particles (80–100%); PT2 – with palynomorph assemblage dominated by dinocysts (Fig. 5A); PT3 – enriched with dinocysts, sporomorphs and brown woody particles, occurring in similar percentages (Fig. 5B); PT4 – with rich palynomorph assemblage dominated by sporomorphs, with presence of cuticles (Fig. 5C); PT5 – dominated by amorphous organic matter (AOM 50–70%; Fig. 5 D–F).

**PT1 palynofacies** is the most common in the studied deposits (samples Hln1, Hln2, Hln10–Hln13, Rzeźnia-3 to Rzeźnia-6, Rzeźnia-8 and Rzeźnia-9). Apart from black particles, a small amount of other palynoclasts may be found: brown phytoclasts, amorphous organic matter, sporomorphs, and very few dinocysts. Interpretation of such an assemblage (see Batten, 1996) can be variable: a low primary production in the oligotrophic surface water may be the cause. Lack of palynomorphs, or its very low frequency, may be influenced by palaeobathymetry: in deep ocean most of particles may be oxidised before burial. Thermal history of the rock is also highly important: increased pressure and temperature may cause destruction of organic matter in the rock.

**PT2 palynofacies** (Szt42A, Rzeźnia-I): dinocysts predominate over sporomorphs, representing together 20–30% of the palynofacies. Dinocyst assemblage is moderately diversified. Black woody particles constitute approximately 40–50 %. Other components are similar as in PT4.

**PT3 palynofacies** (Szt42, Rzeźnia-II) is characterised by the presence of

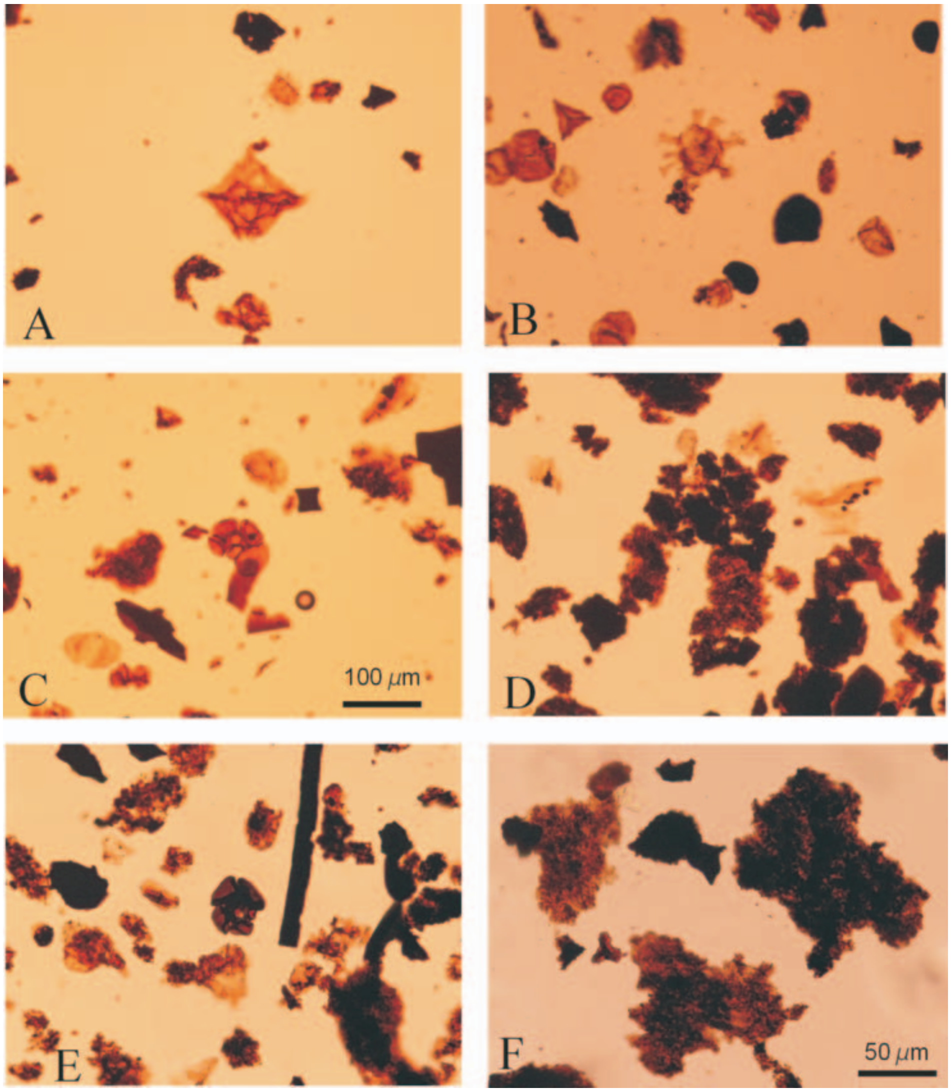


**Fig. 5.** Palynofacies types: **A** – PT2 (Szt42A); **B** – PT3 (Szt42); **C** – PT4 (Rzeźnia-1); **D** – PT5 (Rzeźnia-2); **E** – PT5 (Rzeźnia-7); **F** – amorphous organic matter from sample Hln16 (PT5). Scale bar in C referes to A–E figures

dinocysts, sporomorphs and brown woody particles, each about 10% in frequency. Black particles are remarkably less frequent. Amorphous organic matter, fungi and oval-shaped pellets, usually produced by benthic organisms like Polychaetes (cf. Robbins & Cuomo, 1991), are present. This may reflect eutrophic conditions and high palaeoproductivity.

**PT4 palynofacies** is characterised by very diversified palynomorph assemblage consisting of dinocysts, foraminifers, scolecodonts, faecal pellets (Fig. 6B)

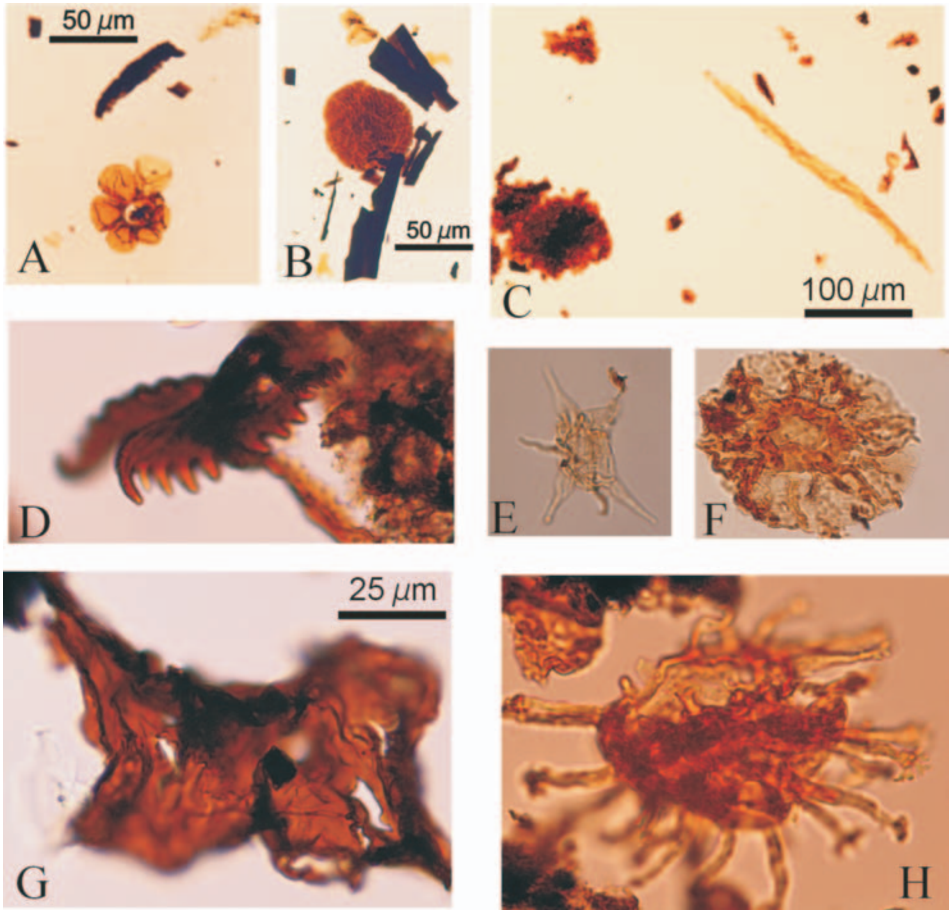


**Fig. 6.** Palynomorphs: **A** – foraminifera test linning (Rzeźnia-1); **B** – coprolite (Rzeźnia-1); **C** – flute-shaped algae(?) present in palynofacies type PT5 (Hln16); **D** – scolecodont (Rzeźnia-7); **E** – acritarch (Hln17); **F** – *Pterospermella* (Hln17); **G** – zooclast (Rzeźnia-7); **H** – thick walled variation of dinocyst *Kiokansium polypes*, characteristic for PT5 (Rzeźnia-7). Scale bar in G referes to D–H figures

and sporomorphs which dominate over other components. Cuticles are present. Black woody particles represent only about 30% of the whole palynofacies assemblage. Amorphous organic matter (c. 16%) is present. This type of palynofacies is probably a result of influx of land-derived matterial. A similar palaeoenvironmental regime reigned during deposition of the foraminiferal B2 association in the Pieniny Klippen Belt (Gasiński, 1991; Birkenmajer & Gasiński, 1992; Pióro, 2005). Increase of nutrients, as confirmed by the presence of foraminifera linnings, induced high palaeoproductivity and, as the consequence, oxygen depletion (see palynofacies PT5). The PT4-palynofacies was recognised in the Rzeźnia-1 sample (Kapuśnica Formation).

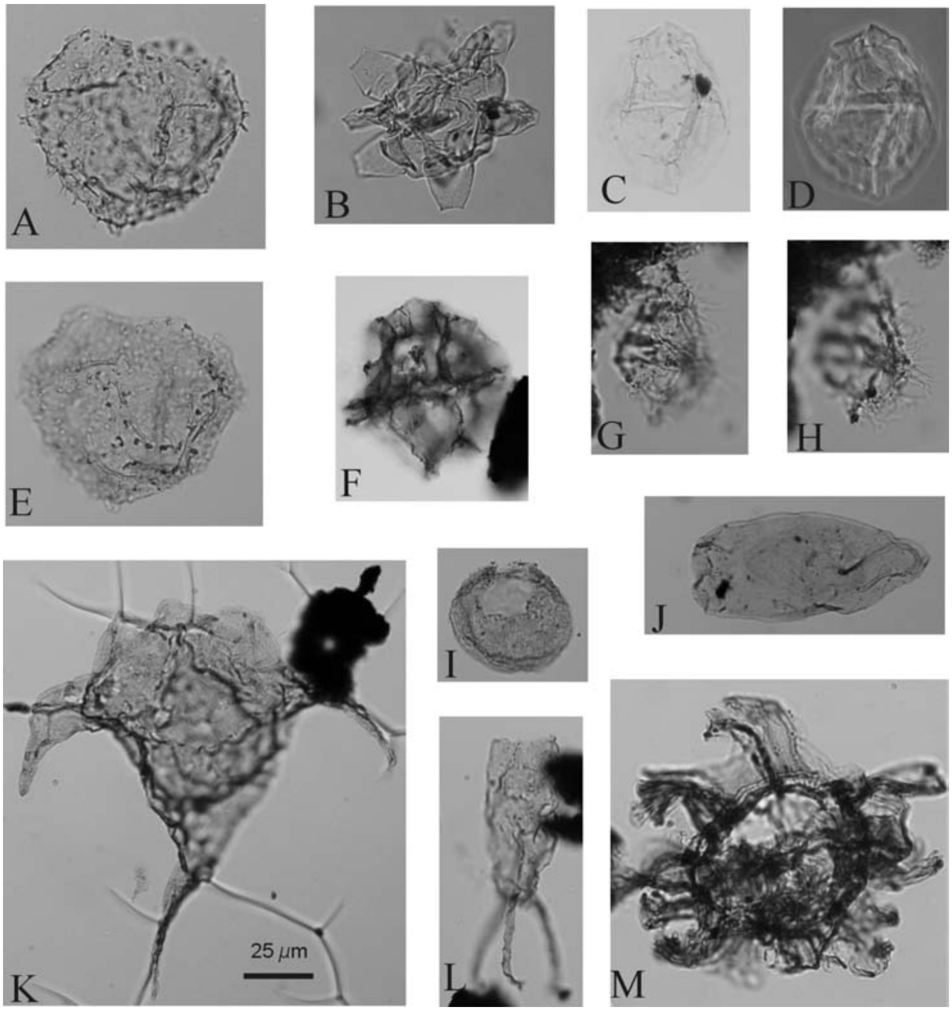


**Fig. 7.** Selected dinocysts: **A**, **E** – *Cerbia tabulata* (Rzeźnia-II); **B** – *Lithosphaeridium siphoniphorum* (Hln18); **C**, **D** – *Eurydinium* sp. (Hln16); **F** – *Pterodinium premnos* (Szt41); **G**, **H** – *Palaeohystrichophora infusorioides* (Hln17); **I** – *Membranosphaera* sp. A (Rzeźnia-II); **J** – *Wallodinium krutzschii* (Szt42A); **K** – *Muderongia staurota* (Szt41); **L** – *Bourkidinium* sp. 2 of Leereveld, 1995 (Szt41); **M** – *Kleithriasphaeridium fasciatum* (Szt41). Scale bar referes to all figures

**PT5 palynofacies.** This palynofacies is strongly dominated by amorphous organic matter (50–70%). Palynomorphs are infrequent (less than 10%) but diversified (Fig. 6C–H). Scolecodonts may be present (Fig. 6D). A high amount of amorphous organic matter indicates anoxic event conditions. The PT5- palynofacies was recognised in samples Rzeźnia-2, Rzeźnia-7, and Hln16, Hln17. The dinocyst assemblage from Rzeźnia-7 sample is dominated by *Kiokansium polypes* (Fig. 6H). Considering the age of the Rzeźnia-2 sample, its palynofacies assemblage would

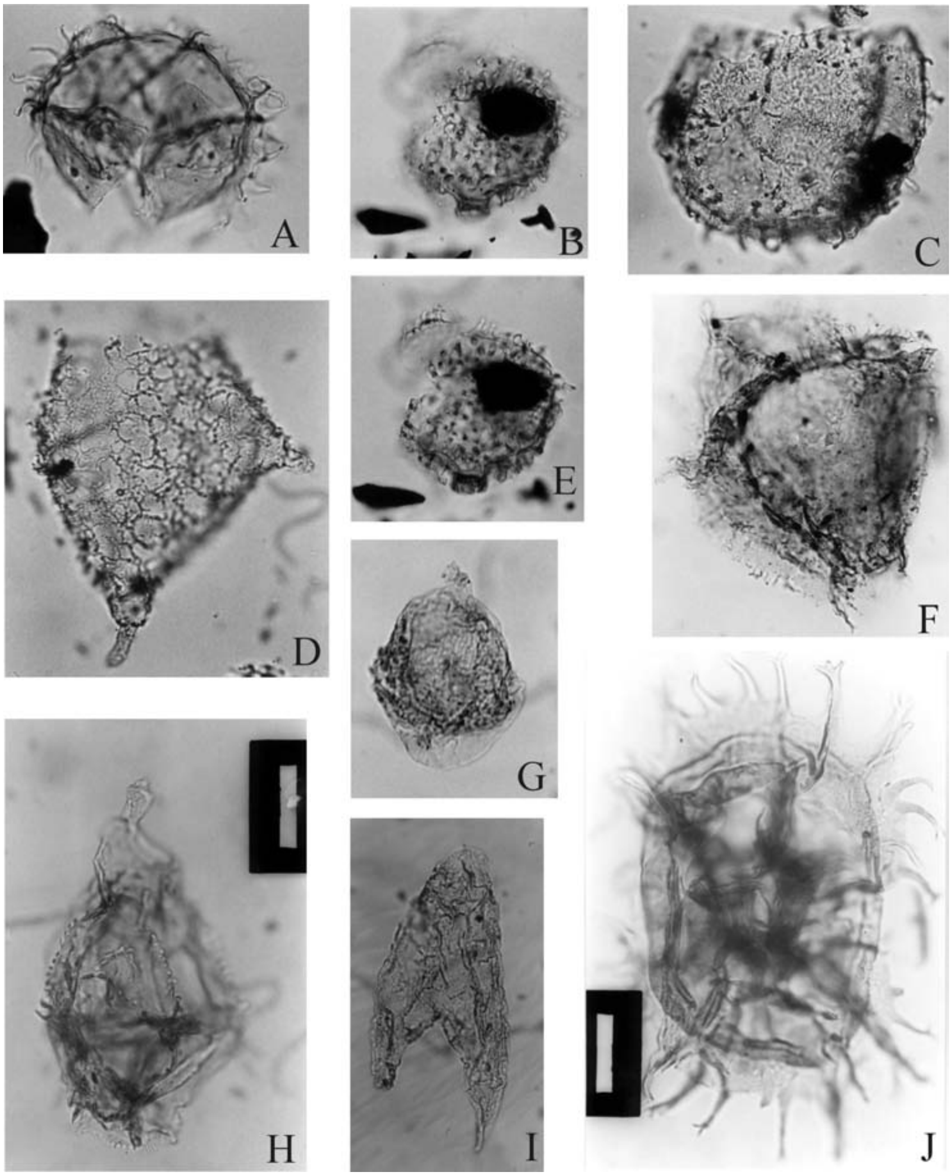


**Fig. 8.** Selected dinocysts: **A** – *Ctenidinium elegantulum* (Rzeźnia-II); **B**, **E** – *Stephanelytron cretaceum* (Rzeźnia-II); **C** – *Cerbia tabulata* (Rzeźnia-II); **D** – *Pseudoceratium solocispinum* (Rzeźnia-II); **F** – *Rhynchodiniopsis aptiana* (Rzeźnia-1); G – *Dingodinium albertii* (Rzeźnia-1); **H–J** – selected Jurassic dinocysts from the Hulina section: **H** – *Gonyaulacysta* sp. (Hln7); **I** – *Nannoceratiopsis* sp. (Hln7); **J** – *Ctenidodinium* sp. (Hln8). Scale bar (20 µm) referes to all figures

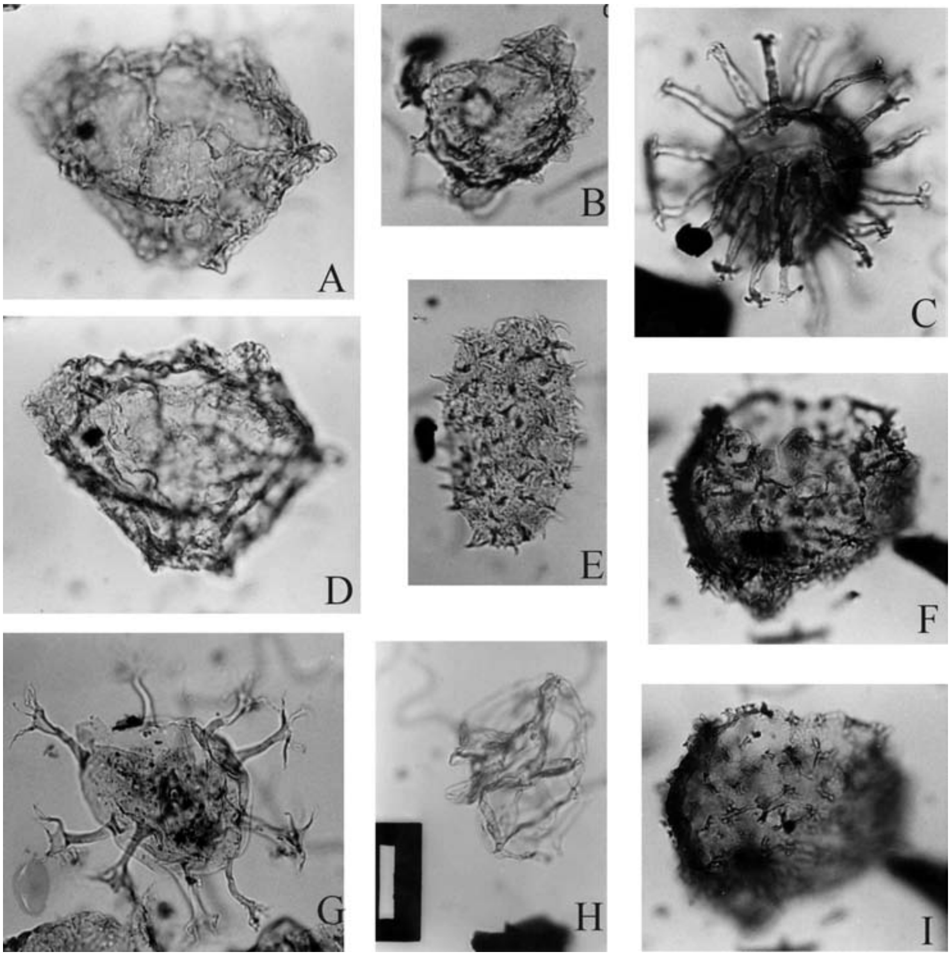

**Fig. 9.** Selected dinocysts: **A**, **D** – *Ellipsoidictyum imperfectum* (Rzeźnia-1); **B** – *Litosphaeridium siphoniphorum* (Rzeźnia-5); **C** – *Kiokansium polypes* (Rzeźnia-7); **E** – *Prolixosphaeridium parvispinum* (Rzeźnia-1); **F**, **I** – *Pseudoceratium securigerum* (Rzeźnia-9); **G** – *Oligosphaeridium complex* (Rzeźnia-1); **H** – *Hapsocysta peridictya* (Hln11). Scale bar (20 µm) referes to all figures

reflect the Early Aptian anoxic event known as Selli level (Coccioni *et al.*, 1989), recognised also in the Koňhora Formation in the Slovak part of the Pieniny Klippen belt (Michalík *et al.*, 1999). An uppermost Abian–Cenomanian age of the samples Hln16 and Hln17 indicates that their palynofacies (PT5) reflects one of the anoxic events of this age. The Cenomanian–Turonian OAE 2 anoxic event (Arthur & Schlanger, 1979) was recognised in the Pieniny Klippen Belt by Birkenmajer and Jednorowska (1984). Presence of numerous anoxic events in the Czorsztyn and Branisko successions in the Pieniny Klippen Belt was recognized by Gasiński (1988).

## CONCLUSIONS

(1) Dinocyst assemblages (150 taxa) were recognised in 22 samples of four different lithostratigraphic units, i.e.: Pieniny Limestone Formation, Kapuśnica Formation (Brodno Member), Wronine Formation and Hulina Formation, from three sections (Sztolnia s., Rzeźnia s. and Hulina s.) of the Grajcarek Unit.

(2) The following dinocyst-based ages were established in the investigated formations:

– Hauterivian–Barremian boundary level in the Sztolnia section;

– Late Barremian age of the top part of the Pieniny Limestone Formation in the Rzeźnia section;

– Late Barremian–Early Aptian age of the Kapuśnica Formation (Rzeźnia section);

– Latest Barremian–Early Aptian and Late Albian–Cenomanian ages of the Wronine Formation (Rzeźnia section);

– Late Albian–Cenomanian age of the Hulina Formation in the Hulina section, and the latest Albian–Cenomanian age in the Sztolnia section.

(3) On the basis of preliminary results, five palynofacies assemblages, PT1-PT5, reflecting various palaeoenvironmens, were distinguished. Passages from PT1 to PT5 may, accordingly, correlate with trends: from oligotrophy to eutrophy; from decreasing oxidation to anoxia; from distal to more proxy facies; and/or to climate changes from dry to humid or cold to warm.

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## APPENDIX

Alphabetic list of dinocyst taxa from the Sztolnia, Rzeźnia and Hulina sections (for taxonomic citation see Williams *et al.*, 1998):

*Achomosphaera* sp.
*Achomosphaera verdieri* Below, 1982
*Aprobolocysta neistosa* Duxbury, 1980
*Apteodinium granulatum* Eisenack, 1958; emend. Sarjeant, 1985; emend. Lucas-Clark, 1987
*Apteodinium* sp.
*Batiacasphaera* sp.
*Batioladinium jaegeri* (Alberti, 1961) Brideaux, 1975
*Bourkidinium granulatum* Morgan, 1975, emend Nøhr-Hansen, 1993
*Bourkidinium* sp. 1 of Leereveld, 1995
*Bourkidinium* sp. 2 of Leereveld, 1995; **Fig. 7L**
*Callaiosphaeridium asymmetricum* (Deflandre et Courteville, 1939) Davey et Williams 1966
*Canningia* sp.
*Carpodinium granulatum* Cookson et Eisenack, 1962, emend. Leffingwell et Morgan, 1977
*Cauca parva* (Alberti, 1961) Davey et Verdier, 1971

*Cepadinium ventriosum* (Alberti, 1959b) Lentin et Williams, 1989
*Cerbia* cf. *tabulata* sensu Leereveld, 1995
*Cerbia tabulata* (Davey et Verdier, 1974) Below, 1981; **Fig. 7A, E; Fig. 8C**
*Chlamydophorella nyei* Cookson et Eisenack, 1958
*Chlamydophorella* sp.
*Chytroeisphaeridia scabrata* Pocock, 1972
*Circulodinium asperum* (Singh, 1971) Helby, 1987
*Circulodinium brevispiosum* (Pocock, 1972) Jansonius, 1986
*Circulodinium distinctum* (Deflandre et Cookson, 1955) Jansonius, 1986
*Circulodinium* sp.
*Cleistosphaeridium* sp.
*Cometodinium*? *comatum* Srivastava, 1984
*Cometodinium* sp.
*Coronifera alberti* Millioud, 1969
*Coronifera* sp.
*Cribroperidinium muderongense* (Cookson et Eisenack, 1958) Davey, 1969a
*Cribroperidinium sepimentum* Neale et Sarjeant, 1962
*Cribroperidinium* sp.
*Ctenidodinium eleganthulum* Millioud, 1969, emend. Below, 1981; **Fig. 8A**
*Ctenidodinium* sp.
*Cymososphaeridium validum* Davey, 1982b
*Dapsilidinium ambiguum* (Deflandre, 1937) Wheeler et Sarjeant, 1990
*Dapsilidinium multispinosum* (Davey, 1974) Bujak *et al.*, 1980
*Dapsilidinium* sp.
*Dapsilidinium warrenii* (Habib, 1976) Lentin et Williams, 1981
*Dingodinium albertii* Sarjeant, 1966
*Dingodinium coerviculum* Cookson et Eisenack, 1958, emend. Khowaja-Atteequzzaman *et al.*, 1990
*Dingodinium* spp.
*Dinopterygium* sp.
*Dissiliodinium globulum* Drugg, 1978
*Ellipsodinium reticulatum* Duxbury, 1980
*Ellipsodinium rugulosum* Clarke et Verdier, 1967
*Ellipsoidictium imperfectum* (Brideaux et McIntyre, 1975) Lentin et Williams, 1977b; **Fig. 9A, D**
*Endoscrinium campanula* (Gocht, 1959) Vozzhennikova, 1967
*Epelidosphaeridia spinosa* (Cookson et Hughes, 1964) Davey, 1969a
*Eurydinium* sp.; **Fig. 7C, D**
*Exochosphaeridium phragmites* Davey *et al.*, 1966
*Exochosphaeridium* sp.
*Florentinia interrupta* Duxbury, 1980
*Florentinia laciniata* Davey et Verdier, 1973
*Florentinia mantelli* (Davey et Williams, 1966) Davey et Verdier, 1973
*Florentinia* sp.
*Fromea amphora* Cookson et Eisenack, 1958
*Gardodinium trabeculosum* (Gocht, 1959) Alberti, 1961, emend. Harding, 1996
*Gonyaulacysta diutina* Duxbury, 1977
*Gonyaulacysta extensa* Clarke et Verdier, 1967
*Gonyaulacysta fastigiata* Duxbury, 1977
*Gonyaulacysta helicoidea* (Eisenack et Cookson 1960) Sarjeant 1966
*Gonyaulacysta perforobusta* Duxbury, 1977
*Gonyaulacysta* sp.
*Hapsocysta peridictya* (Eisenack et Cookson, 1960) Davey, 1979; **Fig. 9H**
*Heslertonia heslertonensis* (Neale et Sarjeant, 1962) Sarjeant, 1966

*Hystrichodinium pulchrum* Deflandre, 1935
*Hystrichodinium ramoides* Alberti, 1961
*Hystrichodinium* sp.
*Hystrichodinium voighti* (Alberti, 1961) Davey, 1974
*Kiokansium polypes* (Cookson et Eisenack, 1962) Below, 1982; **Fig. 6H; Fig. 9C**
*Kiokansium* sp.
*Kiokansium unituberculatum* (Tasch *in* Tasch *et al.*, 1964) Stover et Evitt, 1978
*Kleithriasphaeridium corrugatum* Davey, 1974
*Kleithriasphaeridium eoinodes* (Eisenack, 1958) Davey, 1974; emend. Sarjeant, 1985
*Kleithriasphaeridium fasciatum* (Davey et Williams, 1966b) Davey, 1974; **Fig. 7M**
*Kleithriasphaeridium loffrense* Davey et Verdier, 1974
*Kleithriasphaeridium simplicispinum* (Davey et Williams, 1966) Davey, 1974
*Leberidocysta chlamydata* (Cookson et Eisenack, 1962) Stover et Evitt, 1978, emend. Fechner, 1985, emend. Marheinecke, 1992.
*Lithodinia pertusa* Duxbury, 1977
*Lithodinia stoveri* (Millioud, 1969) Gocht, 1976
*Litosphaeridium bacar* Lucas-Clark, 1984
*Litosphaeridium conispinum* Davey et Verdier, 1973; emend. Lucas-Clark, 1984
*Litosphaeridium siphoniphorum* (Cookson et Eisenack, 1958) Davey et Williams, 1966, emend. Lucas-Clark, 1984; **Fig. 7B; Fig. 9B**
*Litosphaeridium* sp.
*Membranosphaera* sp.
*Membranosphaera*sp. A *sensu* Davey, 1974; **Fig. 7I**
*Mendicodinium* sp.
*Microdinium ornatum* Cookson et Eisenack, 1960a
*Muderongia neocomica* (Gocht, 1957) Lentin et Williams, 1993
*Muderongia* sp.
*Muderongia staurota* Sarjeant, 1966c, emend. Monteil, 1991; **Fig. 7K**
*Muderongia tabulata* (Raynaud, 1978) Monteil, 1991
*Nannoceratopsis* sp.
*Nexosispinium hesperum* Davey, 1979
*Nexosispinum vetusculum* (Davey, 1974) Davey, 1979
*Occisucysta* sp.
*Occisucysta tentoria* Duxbury, 1977, emend. Jan du Chêne *et al.*, 1986
*Odontochitina costata* Alberti, 1961, emend. Clarke et Verdier, 1967
*Odontochitina imparilis* (Duxbury, 1980) Jain et Khowaja-Ateequzzaman, 1984
*Odontochitina operculata* (O.Wetzel, 1933) Deflandre et Cookson, 1955
*Odontochitina rhakodes* Bint, 1986
*Odontochitina* sp.
*Oligosphaeridium albertense* (Pocock, 1962) Davey et Williams, 1969
*Oligosphaeridium asterigerum* (Gocht, 1959) Davey et Williams, 1969
*Oligosphaeridium complex* (White, 1842) Davey et Williams, 1969; **Fig. 9G**
*Oligosphaeridium irregulare* (Pocock, 1962) Davey et Williams, 1969
*Oligosphaeridium pulcherrimum* (Deflandre et Cookson, 1955) Davey et Williams, 1966
*Oligosphaeridium* sp.
*Oligosphaeridium totum* spp. *minus* (Brideaux, 1971) Lentin et Williams, 1973
*Ovoidinium scabrosum* (Cookson et Hughes, 1964) Davey, 1970
*Ovoidinium* sp.
*Ovoidinium/Deflandrea* group
*Paleohystrichophora infusorioides* Deflandre, 1935; **Fig. 7G, H**
*Pervosphaeridium pseudohystrichodinium* (Deflandre, 1937) Yun, 1981
*Pervosphaeridium* sp.
*Prolixosphaeridium deirense* Davey *et al.*, 1966; emend. Harding, 1990

*Prolixosphaeridium parvispinum* (Deflandre, 1937) Davey *et al.*, 1969; **Fig. 9E**
*Pseudoceratium anaphrissum* (Sarjeant 1966) Bint 1986
*Pseudoceratium pelliferum* Gocht, 1957, emend. Dörhöfer et Davies, 1980
*Pseudoceratium polymorphum* (Eisenack, 1958; emend. Dörhöfer et Davies, 1980) Bint, 1986
*Pseudoceratium securigerum* (Davey et Verdier, 1974) Bint, 1986; **Fig. 9F, I**
*Pseudoceratium solocispinum* (Davey, 1974) Harding 1990; **Fig. 8D**
*Pseudoceratium* sp.
*Pterodinium aliferum* Eisenack, 1958; emend. Sarjeant, 1985
*Pterodinium cingulatum* (O. Wetzel, 1933) Below, 1981
*Pterodinium cingulatum* var. *granulatum* (Clarke et Verdier, 1967) Lentin et Williams, 1981
*Pterodinium premnos* Duxbury, 1980; **Fig. 7F**
*Pterodinium*? *Reticulatum* Singh, 1971
*Pterodinium* sp.
*Rhynchodiniopsis aptiana* Deflandre, 1935; emend. Sarjeant, 1982; **Fig. 8F**
*Sentusidinium* sp.
*Spinidinium* sp.
*Spiniferites* sp.
*Stephanelytron cretaceum* Duxbury, 1983; **Fig. 8B, E**
*Subtilisphaera* sp.
*Surculosphaeridium* sp.
*Systematophora* sp.
*Systematophora sylibum* Davey, 1979
*Taleisphaera hydra* Duxbury, 1979; emend. Harding, 1986
*Tanyosphaeridium boletus* Davey, 1974
*Tanyosphaeridium regulare* Davey et Williams, 1966
*Tanyosphaeridium* sp.
*Tehamadinium sousense* (Below, 1981) Jan du Chêne *et al.* in Jan du Chêne *et al.*, 1986; emend. Jan du Chêne *et al.*, 1986
*Trichodinium* sp.
*Valensiella reticulata* (Davey, 1969) Courtinat, 1989
*Wallodinium krutzschii* (Alberti, 1961) Habib, 1972 emend., Poulsen 1996; **Fig. 7J**
*Wallodinium* sp.
*Xenascus* sp.

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