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Organic-walled dinoflagellate cysts as a tool to recognize carbonate concretions: an example from Oligocene flysch deposits of the Western Carpathians

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Abstract: Carbonate concretions found within the Krosno shales (Polish Outer Carpathians) have formerly been interpreted as limestone exotics. Both the concretions and the host shales yield well preserved organic-walled dinoflagellate cysts. The dinoflagellate cyst assemblages provide valuable age-diagnostic information: they indicate a mid-Oligocene age and prove the concretionary origin of the carbonates. Detailed analysis of relative abundance, biodiversity and paleoecology of the dinoflagellates from concretions provides additional information on the sedimentary environment and the model of concretion formation.

Key words: Oligocene, Western Carpathians, biostratigraphy, concretions, organic-walled dinoflagellate cysts.

Introduction

The shaly Krosno Formation of the Outer Carpathians is abundant in carbonate rocks of various origins. Most of them undoubtedly represent exotics (e.g. Dżułyński & Ślączka 1958; Ślączka 1961; Ślączka & Wieser 1962; Mochnacka & Tokarski 1972; Burtan et al. 1984), especially those which contain fauna stratigraphically different from the host rock. Besides exotics, pelagic coccolith limestones (e.g. Haczewski 1989) and concretions (e.g. Narębski 1956; Bojanowski 2001) have been noted; these in turn should contain biostratigraphic assemblages of the same age as the host rocks. Carbonate concretions are usually rounded bodies, which may resemble reworked limestone blocks. These two genetically distant rocks types, carbonate concretions and limestone exotics, may be easily mixed up if clear diagnostic sedimentological features are absent.

This was the case of carbonate rocks from the Krosno shales from the Świątkowa Wielka tectonic window (Polish Outer Carpathians) (Fig. 1). These carbonates have been reported by many authors (Kozikowski 1956; Jurkiewicz & Karnkowski 1959; Koszarski 1985; Kopciowski et al. 1997) and regarded as limestone exotics or tectonically detached blocks. Kopciowski et al. (1997) determined the age of the host shales (latest Early Oligocene) on the basis of nannoplankton assemblages, but did not analyse the age of the carbonates themselves. Recently, the carbonates have been thoroughly examined by Bojanowski (2001), who showed that they are authigenic rocks formed by intensive methane-induced calcite precipitation.

This paper shows that intergrated biostratigraphic and petrographic analysis is an appropriate tool for distinguishing carbonate concretions formerly regarded as limestone exotics. This approach was applied to authigenic carbonates from the Krosno Formation from Świątkowa Wielka and the results are presented here.

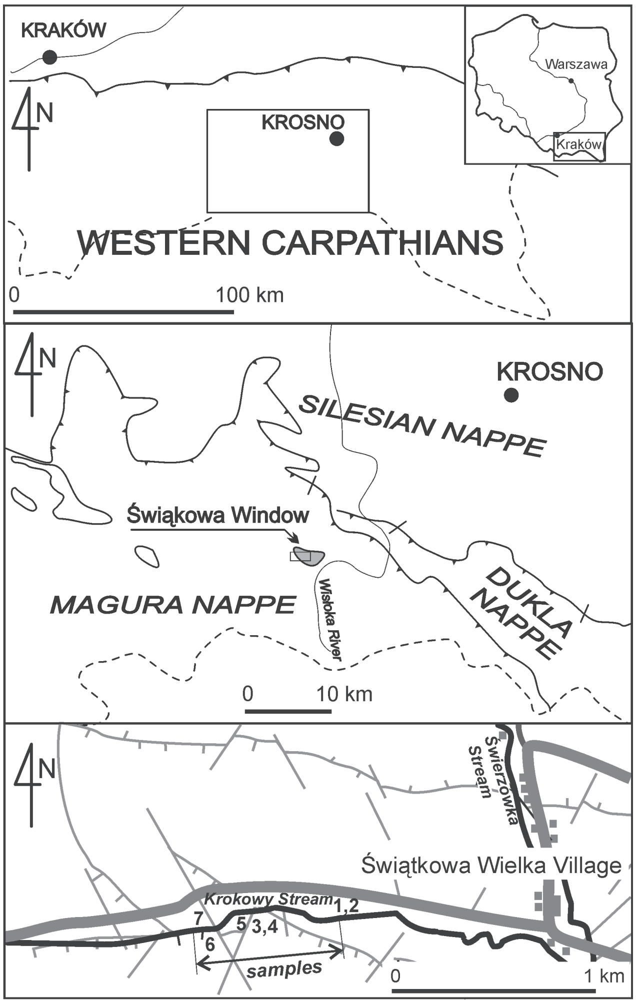


Fig. 1. Location of the study area (after Mastella & Rubinkiewicz 1998).

The microfossil assemblages examined are dominated by organic-walled dinoflagellate cysts. Previous palynological studies in the Outer Carpathians (Van Couvering et al. 1981; Gedl 1999) showed a significant impoverishment of the Oligocene dinoflagellate assemblages in the region. This is especially the case in the Menilite Formation, which is the facies-isochronic equivalent of the Krosno Formation. The few records of organic-walled dinoflagellate cysts from the Krosno Formation (Gedl 1999) show poorly diversified assemblages, dominated by *Deflandrea* sp. Therefore, this work was also focused on contributing to the record of organic-walled dinoflagellate cyst assemblages from the Paleogene rocks and on the verification of their applicability for biostratigraphic dating in the Outer Carpathians. Well-preserved assemblages were expected to be found within the concretions. The results of the detailed analysis of the organic-walled dinoflagellate cyst assemblages allowed not only the age determination of the succession, but also showed the characteristics of the diagenetic conditions of concretion formation.

Geological setting

The rocks examined consist of shales of the Krosno Formation which contain various authigenic carbonates. They occur in the Grybów Unit that crops out from beneath the Magura Nappe in the Świątkowa Wielka tectonic window of the Outer Western Carpathians (Fig. 1). The succession examined crops out along Krokowy stream (Fig. 1). The thickness of the succession is difficult to determine precisely due to tectonic deformations. It is estimated to be between 80 and 110 m.

The Krosno shales are represented by grey to black calcareous mudstones composed of two types of laminae: turbiditic and hemipelagic. The laminated limestone is a 20-cm-thick bed deposited mainly due to increased pelagic deposition of coccoliths. It is composed of a series of brown and grey thin laminae containing fish remains. The concretions are regular, rounded bodies with diverse morphologies, but never spherical (Bojanowski 2001). The carbonate fraction of the concretions constitutes 75–90 weight %, and is represented almost exclusively by concretionary cements. Detrital material enclosed within them is analogous to the mineralogical composition of the surrounding shales. Three types of carbonate concretions have been distinguished:

Dolomite concretions: beige-coloured laminated concretions that may coalesce to form nodular layers. The detrital material enclosed within them is generally silt and the scarce lamination is sometimes cut by burrows. They occur in the lower part of the section.

Calcite concretions type A: blueish-grey concretions with brown rims and hollow septarian cracks. The cemented detrital material is predominantly silty quartz, while clay minerals occur less frequently. These concretions occur in the middle part of the section.

Calcite concretions type B: laminated concretions, with brown and grey laminae. The grey laminae are similar in mineralogical composition to that of calcite concretions type A. The brown laminae contain mainly clay minerals with minor additions of clayey quartz, as well as planktonic foraminifers, coccoliths and kerogen, whereas the grey laminae contain more quartz than clay minerals and are devoid of bioclasts. The lamination is parallel and only rarely shows slight deflection in the outermost parts of the concretions. Well-preserved trace-fossils, represented by burrows filled with reworked material from both kinds of laminae, are not uncommon. Individual concretions reveal septarian cracks which may be filled with brown blocky calcite. These concretions occur in the upper part of the section.

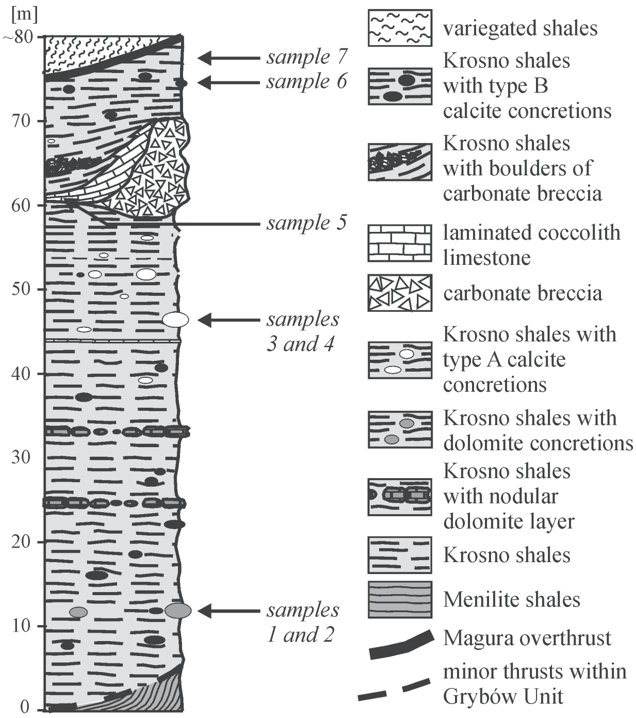


Fig. 2. Geological section with samples distribution.

Material and methods

The analysis is based on ten palynological samples because of a limited number of reliable exposures within the stream banks. Seven samples were collected directly in the outcrops and they can be ordered in the following stratigraphic sequence: 1 and 2 → 3 and 4 → 5 → 6 → 7 (Fig. 2). The three remaining samples (8, 9, 10 — calcite concretions type B) were collected from stream rubble. These three samples most probably come from the upper part of the section above calcite concretions found *in-situ* (Fig. 2) and they could represent the youngest deposits of the succession. Samples number 6, 8, 9 and 10 come from calcite concretions type B, sample 3 from a calcite concretion type A, sample 1 from a dolomite concretion, samples 2, 4 and 7 from the shales, and sample 5 from the coccolith limestone bed.

Palynological samples were prepared according to the standard techniques following Poulsen et al. (1990), involving HCl and HF treatment, sieving through a 20-μm sieve and heavy liquid separation ($ZnCl_2$). Glycerine jelly was used as a mounting medium. Microphotographs were taken using a

Zeiss Axioskop microscope with an interference-contrast facility. England Finder coordinates are provided for all the specimens illustrated.

All the samples yielded organic-walled dinoflagellate cysts. As a restricted amount of samples from different rocks types was available for palynological analysis, the dinoflagellate cyst range chart is provided for qualitative purposes only. In some cases less than 100 specimens per slide were recovered, therefore this might have led to anomalous quantitative values.

Generally the dinocysts have not been affected by thermal maturation, oxidation or biological degradation. A total of 56 taxa have been recorded in this study (Figs. 3, 4; Table 1). The earlier Paleogene species, *Adnatosphaeridium multispinosum*, and *Glaphyrocysta ordinata*, as well as the Late Cretaceous *Chatangiella* sp. and the Jurassic *Tubotuberella* sp. have been reworked. A minor quantity of other palynomorphs such as spores, pollen, acritarchs, prasinophytes and microforaminiferal linings are present in the studied slides.

A dinoflagellate cyst zonal scheme has not yet been established for the Paleogene succession of the Polish Outer Carpathians. Therefore, biostratigraphical diagnosis in the present work had to be based on published dinocyst taxa ranges (Haq et al. 1987; Kothe 1990; Powell 1992; Brinkhuis & Biffi 1993; Wilpshaar et al. 1996; Gedl 2000; Gradstein et al. 2004; Williams et al. 2004). Determination of the ages of the assemblages recovered (Fig. 5) has been based on the co-occurrences of ranges of well-known taxa, and on comparison to dinocyst zones (Powell 1992; Gradstein et al. 2004; Williams et al. 2004).

Dinocyst assemblages and age assignment

Sample 1 comes from a dolomite concretion collected from the lowermost part of the section. The dinocyst assemblage recovered consists of 18 species. The stratigraphically most significant species include *Deflandrea phosphoritica*, *Wetzeliella gochtii* and *Memhranophoridium aspinatum*.

Age: According to Williams et al. (2004) and Gradstein et al. (2004), the presence of *Wetzeliella gochtii* indicates a range from the lowermost Rupelian to the mid part of the Chattian — lower part of subzone C of Zone D15 (Gradstein et al. 2004). Following Powell (1992), the first occurrence datum (FOD) of *Wetzeliella gochtii* marks the base of dinocyst biozone Wgo (lower Rupelian), which corresponds to the base of the calcareous nannofossil biozone NP22. The upper boundary of the assemblage depends on the interpretation of the ranges of *Deflandrea phosphoritica* and *Wetzeliella gochtii*. According to Powell (1992), the top of the stratigraphical range of *Wetzeliella gochtii* correlates with the top of the Pcr Zone, which corresponds to the Rupelian/Chattian boundary. The LOD (last occurrence datum) of *Deflandrea phosphoritica* lies within the Hfl Zone, and coincides with the boundary between the NP24 and NP25 nannoplankton Zones (lower Chattian).

Sample 2 comes from the shales present in the lowermost part of the section close to sample 1. In total, 23 species were recognized in the sample. The following species are of stratigraphical importance: *Chiropteridium lobospinosum*, *Deflandrea phosphoritica*, *Chiropteridium galea*, *Wetzeliella gochtii*, *Wetzeliella symmetrica* and *Thallasiphora pelagica.*

Age: Considering the occurrence of *Chiropteridium lobospinosum*, *Wetzeliella symmetrica* and *Thallasiphora pelagica*, the stratigraphic range of the sample embraces the lower Rupelian — upper part of subzone A of Zone D14 to the lowermost Chattian — mid part of subzone B of Zone D15 (Gradstein et al. 2004).

Following Powell (1992), the stratigraphical range of this assemblage is determined by the FOD of *Chiropteridium lobospinosum* and the LOD of *Wetzeliella gochtii*, which limit the range of the assemblage to the Pcr dinoflagellate Zone, corresponding to the upper Rupelian.

Sample 3 was taken from the calcite concretion type A and yielded a very poor, low-diversity dinocyst assemblage. Only sixteen specimens, represented by *Homotriblium* sp. and *Thallasiphora pelagica*, were found.

Age: According to Gradstein et al. (2004), the LOD of the latter species is not later than the earliest Chattian within the upper part of subzone B of Zone D15.

Sample 4. The assemblage from this sample consists of 18 species. The biostratigraphically most significant species include *Wetzeliella symmetrica*, *Chiropteridium lobospinosum* and *Thallasiphora pelagica.*

Age: The FOD of *Chiropteridium lobospinosum* marks the upper part of subzone A of zone D14 within the Rupelian, whereas the two other species terminate their occurrence within the lowermost Chattian in subzone B of Zone D15 (Gradstein et al. 2004). According to Powell (1992), the FOD of *Chiropteridium lobospinosum* defines the lower boundary of the Pcr Zone and the LOD of *Wetzeliella symmetrica* correlates with the base of the Hfl Biozone, which is considered to be coeval with the top of the nannoplankton Zone NP24. This means that the age of the sample embraces a range from the upper part of the Rupelian to the lower part of the Chattian.

Sample 5 from the coccolith limestone yielded a poor, low-diversity assemblage composed of *Systematophora placacantha* (20 specimens) and *Chiropteridium lobospinosum* (5 specimens).

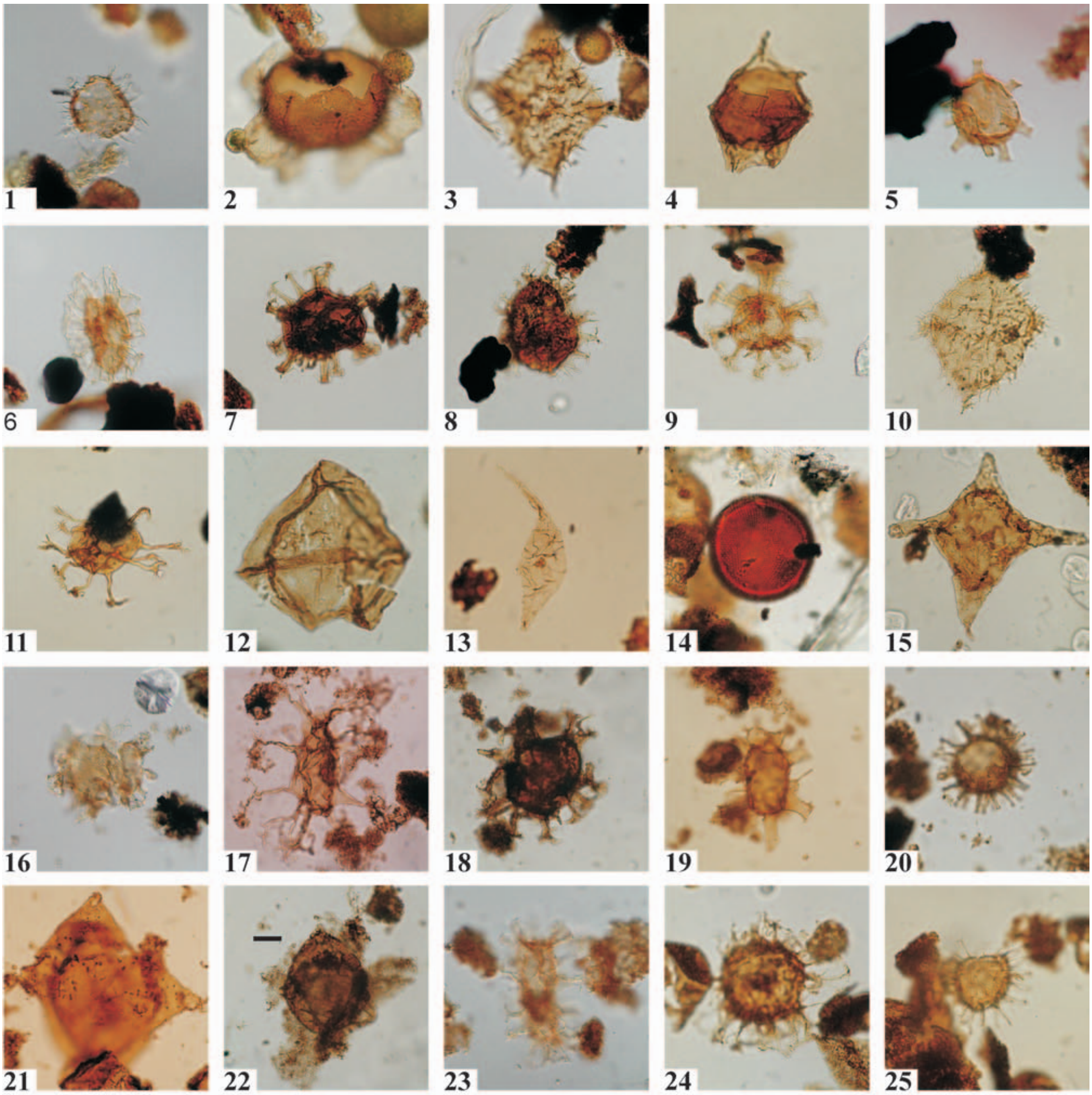
Age: The presence of the latter species limits the range of the assemblage to subzone A of Zone D14 within the Rupelian and to subzone C of Zone D15 of the Chattian (Gradstein et al. 2004). According to Powell (1992), the same species marks the Pcr, Lxa and the lower Hfl dinoflagellate biozones. In both cases the biozones correspond to the upper Rupelian up to the lower Chattian.

Sample 6. The assemblage recognized in sample 6 from calcite concretion type B is composed of 9 species (54 specimens). *Chatangiella* sp. (Late Cretaceous) is reworked.

Age: The stratigraphical range of the assemblage is determined by *Chiropteridium lobospinosum*, and is similar to the range stated for sample 5.

Sample 7 was collected from the uppermost part of the section. Only 5 taxa were recognized: *Homotryblium aculeatum*, *Homotryblium* sp., *Phelodinium* sp., *Rhombodinium draco*, and *Wetzeliella* sp. *A*.

Age: *Rhombodinium draco* marks the top of Zone D14 which corresponds to the mid part of the Rupelian (Will-



Scale bars 20 µm. — figs. — 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 19, 20, 21, 22, 23, 24, 25; — figs. — 12,17,18, 23

Fig. 3. Photographs of the selected dinoflagellate specimens from the studied samples. Sample number and English finder coordinates are given in brackets. Scale bar equivalents are presented below plates. **1** — *Lingulodinium machaerophorum* (Deflandre & Cookson, 1955) Wall 1967 (Sample 8/W55.1). **2** — *Membranophoridium aspinatum* Gerlach, 1961 (Sample 1/Y54.4). **3** — *Wetzeliella gochtii* Costa & Downie, 1976 (Sample 2/G28.0). **4** — *Deflandrea phosphoritica* Eisenack, 1938 (Sample 1/A32.4). **5** — *Homotryblium abbreviatum* Eaton, 1976 (Sample 4/U47.2). **6** — *Adnatsphaeridium multispinosum* Williams & Downie, 1966 (Sample 2/J39.4). **7** — *Spiniferites pseudofurcatus* (Klumpp, 1953) Sarjeant, 1970 (Sample 4/O21.1). **8** — *Chiropteridium galea* (Maier, 1959) Sarjeant, 1983 (Sample 2/E33.1). **9** — *Cordosphaeridium cantharellus* (Brosius, 1963) Gocht, 1969 (Sample 8/D42.2). **10** — *Wetzeliella symmetrica* Weiler, 1956 (Sample 4/H69.0). **11** — *Homotryblium aculeatum* Williams, 1978 (Sample 9/F67.0). **12** — *Lejeunecysta* sp. Artzner & Dörhöfer, 1978, (Sample 2/F18.4). **13** — *Palaeocystodinium golzowense* Alberti, 1961 (Sample 2/U41.4). **14** — *Tasmanites* sp. (Newton, 1875) Wilson & Bentall, 1944 (Sample 8/J49.0). **15** — *Rhombodinium* sp. *B* of Gedl (2000) (Sample 1/W51.4). **16** — *Areoligera senonensis* Lejeune-Carpentier, 1938 (Sample 1/V20.2). **17** — *Distatodinium paradoxum* (Brosius, 1963) Eaton, 1976 (Sample 8/C53.4). **18** — *Cordosphaeridium inodes* (10/D27.1). **19** — *Hystrichokolpoma rigaudiae* (10/B47.4). **20** — *Dapsilidinium pseudocolligerum* (Stover, 1977) Bujak et al., 1980 (Sample 4/P59.3). **21** — *Wetzeliella* sp. *B* of Gedl (2000) (10/J54.1). **22** — *Cribroperidinium* sp. Neale & Sarjeant, 1962 (Sample 8/W49.1). **23** — *Distatodinium ellipticum* (Cookson, 1965) Eaton, 1976 (Sample 10/F38.0). **24** — *Glaphyrocysta exuberans* (Deflandre & Cookson, 1955) Stover & Evitt, 1978 (Sample 1/U18.2). **25** — *Cleistosphaeridium placacanthum* (Deflandre & Cookson, 1955) Eaton et al., 2001 (Sample 2/T17.3).

Table 1: Semi-quantitative distribution of the dinoflagellate cysts in studied samples.

	SAMPLE NR									
TAXON	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Apectodinium sp.	0	6	0	0	0	0	0	0	0	0
Areoligera senonensis	6	0	0	0	0	0	0	4	0	0
Areoligera sentosa	7	0	0	0	0	5	0	0	11	0
Caligodinium sp. *A* of Gedl (2000)	0	0	0	7	0	4	0	0	5	0
Charlesdowniea sp.	0	0	0	5	0	0	0	0	0	0
Chiropteridium galea	0	20	0	0	0	0	0	15	12	26
Chiropteridium lobospinosum	0	10	0	5	5	6	0	14	14	22
Cleistosphaeridium placacanthum	0	21	0	0	20	0	0	25	23	5
Cordosphaeridium cantharellus	0	0	0	0	0	0	0	15	6	0
Cordosphaeridium inodes	5	0	0	6	0	0	0	14	0	0
Cribroperidinium sp.	0	0	0	0	0	0	0	5	0	0
Dapsilidinium pseudocolligerum	0	0	0	14	0	0	0	10	0	0
Dapsilidinium sp.	0	15	0	0	0	0	0	10	0	0
Deflandrea phosphoritica	30	21	0	20	0	0	0	5	110	19
Distatodinium ellipticum	0	0	0	0	0	0	0	5	0	0
Distatodinium paradoxum	0	6	0	0	0	5	0	41	7	5
Dracodinium laszczynskii	0	0	0	5	0	0	0	0	0	0
Enneadocysta pectiniformis	0	0	0	6	0	0	0	0	0	0
Glaphyrocysta exuberans	5	0	0	0	0	0	0	0	11	0
Glaphyrocysta pastielsi	0	5	0	0	0	0	0	0	10	0
Glaphyrocysta sp.	0	0	0	0	0	5	0	0	0	0
Homotryblium abbreviatum	0	5	0	11	0	0	0	0	6	0
Homotryblium aculeatum	0	11	0	0	0	0	5	0	36	6
Homotryblium sp.	5	11	6	5	0	0	4	0	0	0
Homotryblium tenuispinosum	12	0	0	5	0	5	0	0	21	0
Hystrichokolpoma rigaudiae	0	5	0	0	0	0	0	20	7	0
Impletosphaeridium sp.	4	25	0	10	0	3	0	14	15	15
Lejeunecysta sp.	6	24	0	0	0	0	0	0	4	0
Lejeunecysta sp. *A* of Gedl (2000)	0	0	0	0	0	0	0	0	5	0
Lingulodinium machaerophorum	5	0	0	0	0	0	0	25	11	65
Membranophoridium aspinatum	18	0	0	0	0	0	0	0	5	5
Nematosphaeropsis lativittata	0	0	0	0	0	0	0	0	5	0
Nematosphaeropsis labyrinthus	0	3	0	0	0	0	0	0	3	0
Operculodinium sp.	0	30	0	5	0	0	0	5	5	0
Operculodinium uncinispinosum	0	11	0	14	0	0	0	0	0	0
Paleocystodinium golzowense	0	5	0	0	0	0	0	0	0	4
Phelodinium sp.	0	0	0	0	0	0	6	0	0	0
Polysphaeridium sp.	0	0	0	0	0	0	0	20	0	0
Polysphaeridium subtile	3	0	0	0	0	0	0	0	5	0
Reticulatosphaera actinocoronata	0	5	0	0	0	6	0	0	4	0
Rhombodinium draco	0	0	0	0	0	0	5	0	0	0
Rhombodinium sp. *B* of Gedl (2000)	6	0	0	0	0	11	0	0	0	0
Spiniferites pseudofurcatus	0	0	0	5	0	0	0	0	0	0
Spiniferites ramosus	5	45	0	5	0	0	0	115	36	33
Systematophora sp.	5	0	0	0	0	0	0	0	0	0
Thallasiphora pelagica	0	5	10	22	0	0	0	0	11	0
Vozzhennikovia sp.	0	0	0	0	0	0	0	0	5	0
Wetzeliella gochtii	5	17	0	0	0	0	0	0	0	0
Wetzeliella sp. *A* of Gedl (2000)	0	0	0	0	0	0	7	5	0	0
Wetzeliella sp. *B* of Gedl (2000)	0	0	0	0	0	0	0	10	0	0
Wetzeliella symmetrica	0	5	0	4	0	0	0	0	0	0
Ynezidinium cf. *brevisulcatum*	6	0	0	0	0	0	0	0	0	0
Dinocyst sp. *A*	3	0	0	0	0	0	0	0	0	0
*Adnatsphaeridium multispinosum**	0	4	0	0	0	0	0	3	0	0
*Chatangiella** sp.	0	0	0	0	0	2	0	0	0	0
*Glaphyrocysta ordinata**	3	0	0	0	0	0	0	0	0	0
Tubotuberalla sp. *(J)*	0	0	0	0	0	0	0	0	5	0
Foraminiferal test linings	0	12	0	0	0	0	0	0	0	0
Tasmanites sp.	0	0	0	0	0	0	0	15	0	12
TOTAL/SPECIMEN	**139**	**327**	**16**	**154**	**25**	**52**	**27**	**395**	**398**	**217**
DIVERSITY	**17**	**23**	**2**	**18**	**2**	**9**	**5**	**20**	**27**	**11**

iams et al. 2004; Gradstein et al. 2004).

Samples 8, 9 and 10 representing calcite concretion type B were collected from stream rubble.

Sample 8 yielded a rich, high-diversity assemblage. A total of 20 species were recognized, with all but one characteristic of the Oligocene; only *Adnatsphaeridium multispinosum* is a reworked Late Eocene species.

Age: The most precise stratigraphic interval represented by the sample is based on the occurrence of two species: *Chiropteridium galea* and *Chiropteridium lobospinosum.* According to Gradstein et al. (2004), the latter species indicates a stratigraphic interval in the range between subzone A of Zone D14 within the Rupelian and subzone C of Zone D15 of the Chattian. *Chiropteridium galea* confirms this interval, although this species finally disappears within the uppermost Chattian.

Sample 9 yielded the highest diversity assemblage, with 27 species recognized. However, only a few of them have biostratigraphical importance: *Chiropteridium lobospinosum*, *Deflandrea phosphoritica*, *Chiropteridium galea*, *Thallasiphora pelagica*, and *Memhranophoridium aspinatum.*

Age: Considering the presence of *Chiropteridium lobospinosum* and *Thallasiphora pelagica*, the narrowest stratigraphic range of the sample embraces the lower Rupelian — upper part of subzone A of Zone D14 to the lowermost Chattian — mid part of subzone B of Zone D15 (Gradstein et al. 2004). Other species listed above more or less confirm this interval.

Sample 10. Among the 11 species of sample 10, only a few have stratigraphical significance. They include *Chiropteridium galea*, *Chiropteridium lobospinosum*, *Deflandrea phosphoritica*, and *Memhranophoridium aspinatum.*

Age: As in sample 9, the occurrence of *Chiropteridium lobospinosum* and *Thallasiphora pelagica* suggest a stratigraphic range between the lower Rupelian — upper part of subzone A of Zone D14 and the lowermost Chattian — mid part of subzone B of Zone D15 (Gradstein et al. 2004).

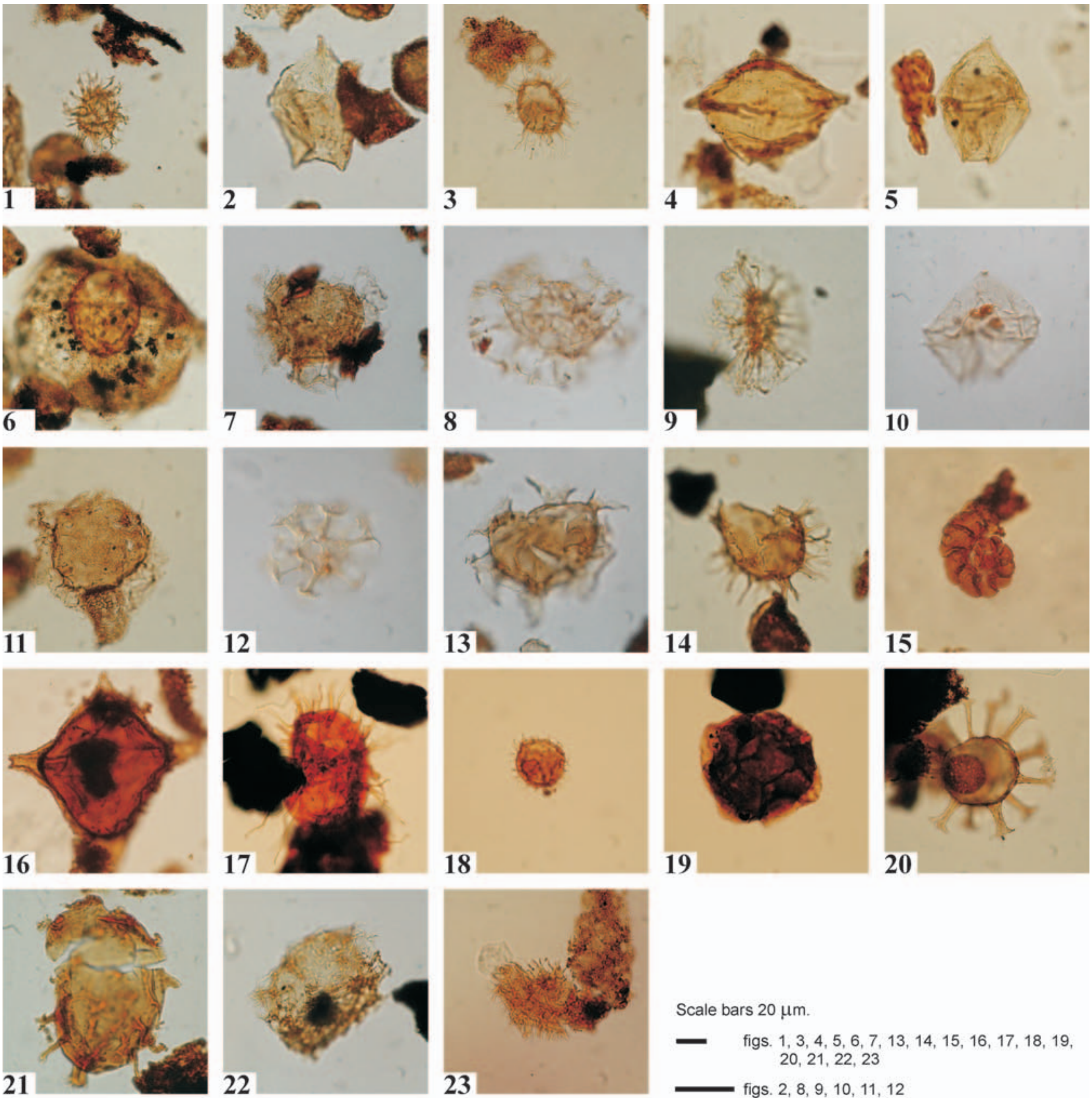


Fig. 4. Photographs of the selected dinoflagellate specimens from the studied samples. Sample number and English finder coordinates are given in brackets. Scale bar equivalents are presented below plates. **1** — *Spiniferites ramosus* (Ehrenberg, 1838) Mantell, 1854 (Sample 8/U36.0). **2** — *Lejeunecysta* sp. *A* of Gedl (2000) (Sample 9/F18.4). **3** — *Polysphaeridium subtile* (7/Y29.4). **4** — *Rhombodinium draco* Gocht, 1955 (Sample 7/G59.0). **5** — *Phelodinium* sp. (3/K26.0). **6** — *Thallasiphora pelagica* (7/O51.1). **7** — *Glaphyrocysta pastielsii* (Deflandre & Cookson, 1955) Stover & Evitt, 1978 (Sample 2/G37.2). **8** — *Nematosphaeropsis lativittata* Wrenn, 1988 (Sample 9/M15.4). **9** — *Nematosphaeropsis labyrinthus* (Ostenfeld, 1903) Reid, 1974 (Sample 2/U45.0). **10** — *Vozzhennikovia* sp. Lentin & Williams, 1976 (Sample 9/M26.0). **11** — *Caligodinium* sp. *A* of Gedl (2000) (7/M40.0). **12** — *Reticulatosphaera actinocoronata* (Benedek, 1972) Bujak & Matsuoka, 1986 (Sample 6/B50.4). **13** — *Areoligera sentosa* Eaton, 1976 (Sample 9/C47.1). **14** — *Chiropteridium lobospinosum* Gocht, 1960 (Sample 8/P26.0). **15** — Foraminiferal test linings (5/54.4). **16** — *Wetzeliella* sp. *A* of Gedl (2000) (10/K55.3). **17** — *Operculodinium uncinispinosum* (de Coninck, 1969) Islam, 1983 (Sample 4/U18.0). **18** — *Impletosphaeridium* sp. Morgenroth, 1966 (Sample 2/E46.0). **19** — *Ynezidinium* cf. *brevisulcatum* Michoux, 1985 (Sample 1/D64.0). **20** — *Homotryblium tenuispinosum* Davey & Williams, 1966 (Sample 9/N23.1). **21** — Dinocyst sp. *A* (Sample 1/U47.0). **22** — *Charlesdowniea* sp. Lentin & Vozzhennikova, 1989 (Sample 4/E51.3). **23** — *Apectodinium* sp. (Costa & Downie, 1976) Lentin & Williams, 1977 (Sample 2/T24.4).

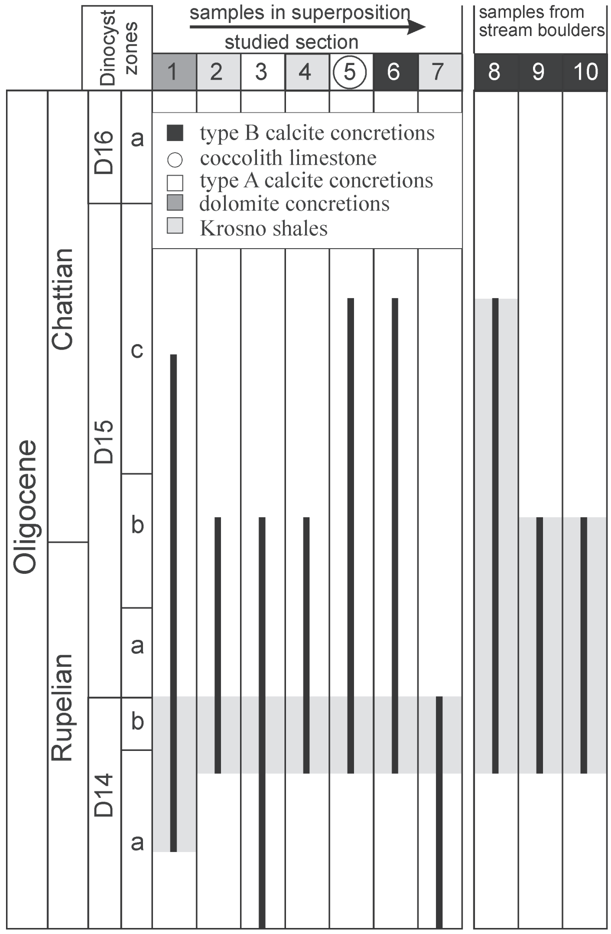


Fig. 5. Stratigraphic ranges of the samples in stratigraphic order from the lowermost (sample 1) to the uppermost in the section (sample 7). Dinoflagellate biozones from Powell (1992).

On the basis of the FOD *Chiropteridium lobospinosum* and LOD of *Deflandrea phosphoritica*, the assemblage ranges between the base of the Pcr Biozone and the lower part of the Hfl Biozone, corresponding to the top of Nannoplankton Biozone NP24 (Powell 1992).

Considering the superposition of samples 1 to 7 collected from the section, further detailed age assignment may be suggested as shown by the grey block on the range chart (Fig. 5). The stratigraphic position of the uppermost sample 7 comprising the index species *Rhombodinium draco* delimits the upper rages of all samples to the mid part of the Rupelian — top of Zone D14 (Gradstein et al. 2004). Sample 2 delimits all lower ranges of the samples to the uppermost part of subzone A of Zone D14. The stratigraphic range of the lowermost sample begins within the mid part of subzone A of Zone D14. The ages of the samples collected from stream boulders must be assigned individually (Fig. 5).

Sedimentary environment and concretion formation

All the samples contain mixed dinoflagellate cyst assemblages comprising off-shore and near-shore taxa. They contain near-shore derived genera such as *Deflandrea* and *Homotribli-um*, as well as off-shore genera represented by *Spiniferites*, *Systematophora*, *Nematosphaeropsis* and *Hystrichokolpoma* (Köthe 1990; Brinkhuis 1994; Pross & Brinkhuis 2005; Sluijs et al. 2005). The recognized mixing suggests the redepositional character of the studied deposits, probably executed by turbidity flows widely described from this area (Dżułyński & Ślączka 1958; Ślączka 1961; Ślączka & Wieser 1962; Mochnacka & Tokarski 1972). Redeposition events are also confirmed by the striking predominance of *Deflandrea phosphoritica* in sample 9 confirming an influx of proximal sediments into the deeper part of the basin as well as by the reworked dinocysts present in samples 1, 2, 6, 8 comprising Jurassic and Early Eocene taxa (Table 1).

The striking preservation of the dinoflagellate cysts in the concretions, in contrast to their significant flattening in the surrounding shales, implies that the concretions grew during early diagenesis, before significant compaction took place. Fast lithification of the concretionary carbonate cements led to the formation of a compaction-resistant framework which acted as a shelter for the microfossils.

It seems that the great impoverishment of dinoflagellate cyst assemblages and absence of other microfossils in calcite concretions of type A stems from the fact that they contain much coarser detrital material than the other carbonate concretions. This suggests that the microfossils are more abundant within the finer material, which is of hemipelagic origin, and in the upper parts of turbiditic laminae. Therefore, it is concluded that all the calcite concretions formed in a similar way, but within different intervals of the section: precipitation of authigenic calcite within turbiditic material led to the formation of “pure” concretions (type A), whereas laminated concretions (type B) originated in places where the turbiditic material was intercalated with hemipelagic laminae rich in microfossils. The brown laminae from type B calcite concretions represent the hemipelagic material cemented by authigenic calcite.

Systematic notes

Dinocyst sp. *A* (Fig. 4.21)

Material: Three specimens of this species were found in sample 1 (Table 1).

Description: Height of elongated central body is about 100 μm, and width does not exceed 60 μm. Short processes are solid, foliating towards the ends. Archeopyle type is apical with adnate operculum. Paratabulation formula is not evident besides archeopyle suture.

Occurrence in the studied material: Described species was noted from the lowermost sample (Sample 1) of the studied section. According to ranges of co-occurring species its stratigraphical distribution is from the lower Rupelian to the lower Chattian.

Conclusions

♦ Biostratigraphic analysis of the dinoflagellate cysts from the studied carbonate rocks and the Krosno shales of the Grybów Unit, which crop out from beneath the Magura Nappe in the Świątkowa Wielka tectonic window of the Outer Western Carpathians, precludes an exotic origin of the carbonate bodies. They are concretions which formed *in situ* within the sediment by authigenic precipitation of carbonate cements during early diagenesis (Bojanowski 2001, 2004). This conclusion is supported here by the preservation state and compression ratio of the organic cyst bodies.

♦ The dinoflagellate cyst assemblages from both the host shales and the concretions indicate an Oligocene age.

♦ The dinoflagellate cysts appear to be more abundant within the finer material, which is of hemipelagic origin, and in the upper parts of turbiditic laminae. This is the reason for the impoverishment of dinoflagellates and other microfossils observed in "pure" calcite concretions (type A) when compared to their great abundance in the laminated calcite concretions (type B). This suggests that type A calcite concretions were formed by cementation of turbiditic material, whereas type B calcite concretions grew within turbiditic material intercalated by hemipelagic laminae.

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