

The *Apectodinium* spp. acme as an evidence for the Paleocene-Eocene thermal maximum from the Polish Outer Carpathians

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Cybulska, D., Rubinkiewicz, J., 2020. The *Apectodinium* spp. acme as an evidence for the Paleocene-Eocene thermal maximum from the Polish Outer Carpathians. *Geological Quarterly*, **64** (2): 241–251, doi: 10.7306/gq.1521

Associate Editor: Stanisław Wołkowicz

Numerous *Apectodinium* taxa, with *A. augustum*, and the presence of *Florentinia reichartii* were found in the Bystre slice (Polish Outer Carpathians). Such abundance of *Apectodinium* is described for the first time in the Outer Carpathians. The occurrence of thermophilic *Apectodinium* taxa, with co-occurrence of *Florentinia reichartii*, are interpreted to be strongly related to the Paleocene-Eocene thermal maximum (PETM). The PETM is characterized by a notable global warming and changes in marine and terrestrial biota, such as a global dispersion of thermophilic dinoflagellates. We are also reporting a new, unrecorded section of the Hieroglyphic beds from the Jablonka Stream.

Key words: *Apectodinium*, PETM, dinoflagellate cysts, Polish Outer Carpathians, Hieroglyphic Beds.

INTRODUCTION

The Paleocene-Eocene thermal maximum was a global hyperthermal event which took place ~56 million years ago (e.g., Westerhold et al., 2009; Zachos et al., 2010; Carmichael et al., 2017).

In the geological record, the PETM is characterized by a negative carbon isotope ($\delta^{13}\text{C}$) excursion (CIE) that indicates the release of ^{13}C -depleted carbon into the ocean-atmosphere system (Kennett and Stott, 1991; Thomas et al., 2002; Pagani et al., 2006; Schouten et al., 2007).

This event was associated with the rise of deep-sea temperature by ~5–6°C and the warming of sea surface temperatures (SST) by 5 to 8°C at low and high latitudes, respectively (e.g., Kennett and Stott, 1991; Thomas and Shackleton, 1996; Zachos et al., 2003; Tripathi and Elderfield, 2005). The PETM is associated with significant changes in marine and terrestrial realms. Warming of the oceans caused the migration of thermophilic taxa (e.g., dinoflagellates *Apectodinium* and planktic foraminifera *Acarinina*) to the northern latitudes, the worldwide turnover of calcareous nannoplankton, and the extinction of benthic foraminifera due to anoxia (Kennett and Stott,

1991; Thomas and Shackleton, 1996; Galeotti et al., 2004; Arreguín-Rodríguez et al., 2013).

One of the most significant changes associated with the PETM within marine plankton was the dispersion of the motile stage of tropical dinoflagellates of the *Apectodinium* genus (Bujak and Brinkhuis, 1998; Crouch et al., 2001, 2003a; Egger et al., 2003). *Apectodinium* evolved at low latitudes during the Danian-Selandian transition (Brinkhuis et al., 1994; Bujak and Brinkhuis, 1998). *Apectodinium* spp. dinoflagellates are interpreted as heterotrophic and thermophilic organisms linked to relative high SST and high nutrient availability (Powell et al., 1996; Bujak and Brinkhuis, 1998; Crouch et al., 2001, 2003b; Crouch and Brinkhuis, 2005; Shcherbinina et al., 2016), which occupied waters with temperatures exceeding 20°C (Frieling, 2016). High sea surface temperatures and nutrient availability related to the onset of PETM allowed *Apectodinium* to spread towards high latitudes (Bujak and Brinkhuis, 1998; Crouch et al., 2003b). Therefore, the high abundance of *Apectodinium* taxa in the fossil record is interpreted as an evidence for the PETM. Especially important is *A. augustum*, which is related to CIE (e.g., Bujak and Brinkhuis, 1998; Crouch et al., 2001, 2003b; Steurbaut et al., 2003; Sluijs et al., 2007).

The PETM-related acme of *Apectodinium* taxa is known from many locations around the globe, e.g.: in the North Sea (Bujak and Brinkhuis, 1998; Sluijs et al., 2008), Greenland (Nøhr-Hansen, 2003), Belgium (Steurbaut et al., 2003), Austria (Heilmann-Clausen and Egger, 2000; Crouch et al., 2001), the Caucasus (Shcherbinina et al., 2016), Kazakhstan (Iakovleva et al., 2001), Uzbekistan (Crouch et al., 2003b), North America (e.g., Sluijs et al., 2008; Sluijs and Brinkhuis, 2009), New Zea-

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Received: July 30, 2019; accepted: September 19, 2019; first published online: March 12, 2020

land (Crouch et al., 2001, 2003a; Crouch and Brinkhuis, 2005; Sluijs et al., 2008), Antarctica (Bijl et al., 2013b) and Africa (Crouch et al., 2003b; Awad and Oboh-Ikuenobe, 2016; Oboh-Ikuenobe et al., 2017).

In the Polish Outer Carpathians, *Apectodinium* taxa have been observed only sparsely (Gedl, 1995, 2005, 2013; Barski and Bojanowski, 2010; Jurewicz and Segit, 2018) and are often interpreted as reworked (Gedl, 1995, 2005; Barski and Bojanowski, 2010). In nearby areas, *in situ* *Apectodinium* spp. were reported from the Rhenodanubian Flysch Zone (Mohamed and Wagreich, 2013).

This paper presents field-based studies and palynological analysis focused on the *Apectodinium* taxa, supported by stable carbon isotope ($\delta^{13}\text{C}$) analysis.

GEOLOGICAL SETTING

The study area is located in the eastern part of the Polish Outer Carpathians in the Bystre slice that is a tectonic element of the Silesian Nappe in the Bieszczady Mountains, south of Baligród (Iczka, 1959; Cieszkowski et al., 1985; Mastella, 1995; Jankowski and Iczka, 2014; Fig. 1). In this area, the Silesian Nappe is subdivided into two tectonic subunits: the Central Synclinorium (the Central Carpathian Depression) (Tołwiński, 1933; Widziński, 1953; Oszczypko et al., 2008) and the Fore-Dukla thrust-sheets (Widziński, 1958; Oszczypko et al., 2008). The Bystre slice is a part of the Fore-Dukla thrust-sheets (Cieszkowski et al., 1985; Mastella, 1995) and it is strongly tectonically deformed. The layers have undergone tectonic reduction. They are cut by thrusts, and secondary slices are present (Mastella, 1995). Therefore, the stratigraphic sections are generally discontinuous. The most detailed tectonic map of the Bystre slice along with the Fore-Dukla thrust-sheet was prepared by Mastella (1995).

Turbiditic sediments of the Bystre slice are dated to the Lower Cretaceous to Eocene (Iczka, 1959; Jankowski and Iczka, 2014). During the Cretaceous to Early Eocene, the study area was a northern part of the Tethys Ocean, referred to as the Silesian Basin. The sedimentary system was controlled by tectonic processes and was dominated by turbidity currents (Golonka et al., 2000, 2006; Oszczypko, 2004).

MATERIALS

The Bystre slice is composed of seven lithostratigraphic units: the Cieszyn, Grodziszczce, Lgota, Godula, Istebna, and the Hieroglyphic Beds with the Ciłkowie Sandstones at the bottom (Iczka, 1959; Jankowski and Iczka, 2014). The section investigated in our study is described by Iczka (1959) as the Lower Istebna Shales, assigned to the Paleocene.

In the present study we investigated a 21 m long outcrop section located south of the village of Bystre (49°17'46.13"N, 22°16'11.56"E) along the Jabłonka Stream. Field investigation reveals an unrecorded section of the Eocene Hieroglyphic Beds. It is represented here by the typical green marly shale with few intercalations of variegated (red) shales and a thin to medium bedded, fine-grained sandstones with silica cementation (Fig. 2A, B). Sandstones are green and grey-green in colour. At the base of the sandstones, organic hieroglyphs are present, which is typical for the Hieroglyphic Beds (Fig. 2C). Additionally, greenish sandstones and conglomerates occur

at the bottom of Hieroglyphic Beds, which are probably a part of the Ciłkowie Sandstones (Beds). At the top of the section, a breccia zone is present (Fig. 2D). Above the section (upstream), there is a typical profile of the Istebna Beds. The section indicates the existence of an unrecorded thrust of the Istebna Beds resting on the Eocene Hieroglyphic Beds, and thus the tectonic repetition (Fig. 3).

A similar but thicker (~100 m) section of the Hieroglyphic Beds with Ciłkowie Sandstones at the bottom, is revealed in the same stream a few hundred metres upstream.

Samples for microplaeontological analysis were taken from shale intervals. We collected 20 sediment samples, labelled from 1 to 18.87, and the number for each sample corresponds to the position in the section (Fig. 4). In this study, we are focused on organic-walled dinoflagellate cysts, mostly on the *Apectodinium* group.

METHODS

Samples have been subjected to the standard palynological preparation technique proposed by Poulsen et al. (1990). Twenty grams of sediment were treated with 38% hydrochloric (HCl) and 40% hydrofluoric (HF) acids to dissolve carbonates and silica, respectively. The residuum was sieved through a 15 μm nylon mesh. A heavy liquid separation (ZnCl_2 density = 2 g/cm^3) was applied. Palynological slides were prepared using glycerin jelly as a mounting medium. Due to the insufficient material, two palynological slides from each sample were examined. Wherever possible, 300 dinoflagellate cysts taxa were counted. Samples with a high amount of *Apectodinium* taxa were also examined with fluorescent microscopy to estimate the ratio of reworking causing abnormal concentration. The palynological analyses were conducted at the Faculty of Geology, University of Warsaw, where all slides are stored.

To examine the content of $\delta^{13}\text{C}$ in the studied material, which could be correlated with PETM, samples for bulk organic carbon isotopes have been analysed.

Bulk organic carbon isotopes ($\delta^{13}\text{C}_{\text{org}}$) were measured on 11 samples which were taken from intervals of increased *Apectodinium* taxa abundance. For this purpose, we collected ~0.3 g of residue which was demineralized, neutralized, and finally dried. Carbon isotopes are reported relative to Vienna Pee Dee Belemnite (VPDB). The analytical error is $\pm 0.4\%$. The analysis was made at the Institute of Geological Sciences, Polish Academy of Sciences, using an isotope ratio mass spectrometer (IRMS) *Thermo Delta V Advantage* coupled in a continuous flow system with a *Thermo Flash EA 1112HT* elemental analyser.

RESULTS

DINOFLAGELLATE CYSTS

Palynological slides from all depths yield both dinoflagellate cysts and rich terrestrial phytoclasts. Only four samples are barren of dinoflagellate cyst (samples 1; 12; 15,6 and 18,87). In six samples (4,5; 7,5; 9; 12,75; 14; 16), dinocysts were rare, below 60 specimens per sample, and we did not include those samples in our final consideration. Only 10 samples yield abundant

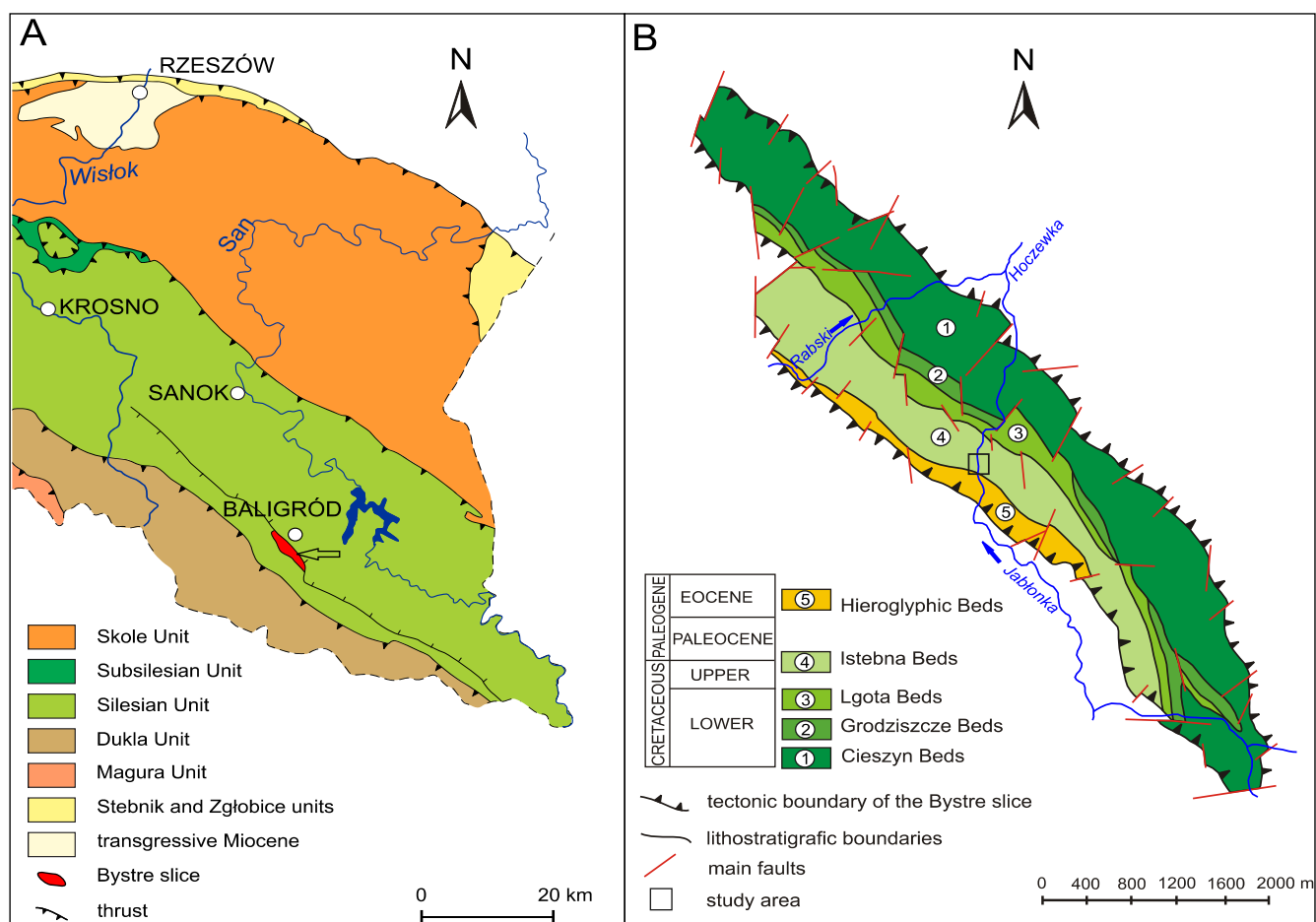


Fig. 1A – location of the study area on the map of the Polish Outer Carpathians (modified from [ytko et al., 1989](#)); **B** – lithostratigraphical map of the Bystre slice (modified from [Mastella, 1995](#))

and highly diversified dinoflagellate cyst assemblages ([Appendix 1*](#)).

The richness of dinoflagellate cyst assemblages differs between the samples. In total, 69 genera and 65 species have been recognized ([Appendices 1 and 2](#)), including reworked taxa. The material is dominated by *Apectodinium*, *Glaphrocysta*, *Adnatosphaeridium*, *Cleistosphaeridium*, *Spiniferites* and *Areoligera* ([Figs. 5–7](#)).

The dinoflagellate assemblages abound in the genus *Apectodinium* that predominates in eight samples, accounting for ~25–37% of the total dinoflagellate cyst assemblage ([Figs. 5 and 6](#)). In samples 5,4 and 6,5 *Apectodinium* are common but do not exceed 15%. In samples 3,5 and 7, *Apectodinium* specimens are scarce and do not exceed 6%.

Apectodinium appears in two abundance intervals of 5.4–7.0 m and 9.5–11.1 m. In the former, *Apectodinium* attains almost 28% of total dinocysts, whereas in the latter, it is even more abundant (25–37% of the total dinocyst assemblage) ([Fig. 5](#)).

All samples containing *Apectodinium* sp. are dominated by *A. homomorphum* – 29% of the dinoflagellate cyst assemblage. *A. augustum* dinoflagellate cysts are present, but they are rela-

tively rare, up to 3.5% of the dinoflagellate cyst assemblage ([Fig. 6A–D](#)). *Apectodinium augustum* was recently transferred to a new genus, *Axioidinium* ([Williams et al., 2015](#)), however, we follow the suggestion of [Bijl et al. \(2016\)](#) and retain the former name of the taxon.

Between 7.0 and 9.5 m, we observe the disappearance of *Apectodinium* with numerous inceptions of *Adnatosphaeridium* (17 and 41%) and *Glaphrocysta* (~33, 32 and 31%) ([Fig. 7B, G, H, M](#)). *Areoligera* sp. is characterized by a similar distribution pattern. *Spiniferites* sp. and *Cleistosphaeridium* sp. are abundant and their distribution is similar to the *Apectodinium* ([Fig. 5](#)).

We find a thin interval of common *Florentinia reichartii* (~9%) ([Figs. 5 and 6C, D](#)) co-occurring with the first peak of *Apectodinium* spp. in sample 5,9. A single specimen of *F. reichartii* is also noted in samples 7 and 9,5.

Samples examined in fluorescent microscopy show differences in colour only in the case of recycled Cretaceous dinoflagellate cysts ([Fig. 7R, S](#)). All specimens of *Apectodinium* revealed similar autofluorescence. This allows us to treat all *Apectodinium* taxa and other Paleogene dinoflagellate taxa *in situ* ([Figs. 6 and 7B–H, J–P](#)).

* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1521



Fig. 2. Photographs from the section studied

A, B – shales and sandstones of the Hieroglyphic beds; **C** – organic hieroglyphs at the base of sandstone; **D** – tectonic breccia at the top of the section (phot. Maciej Łoziński)

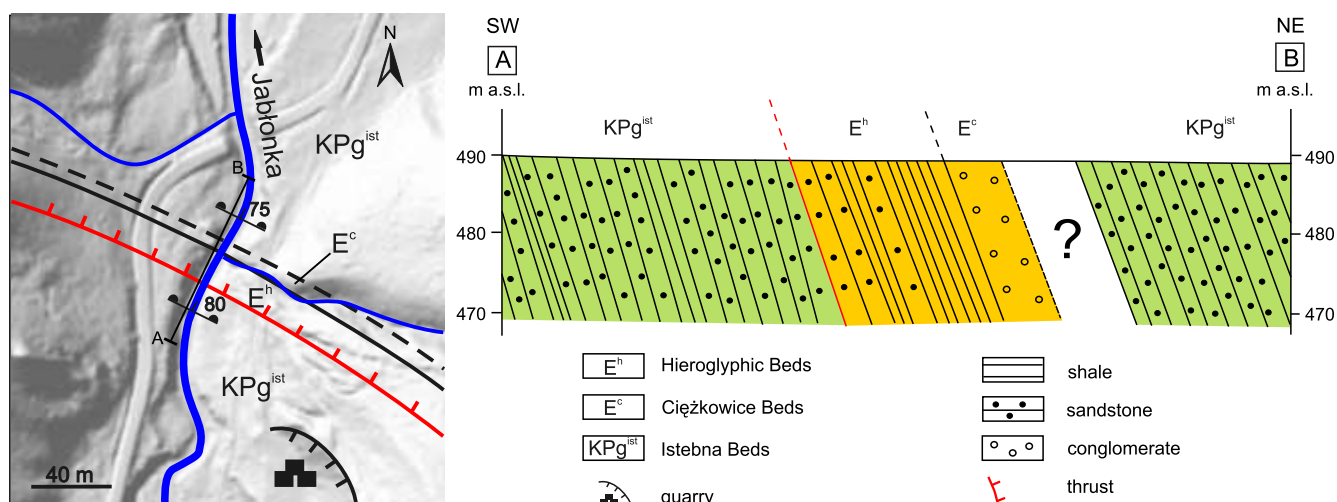


Fig. 3. Simplified map and the cross-section of the study area

Digital Terrain Model source: www.geoportal.gov.pl

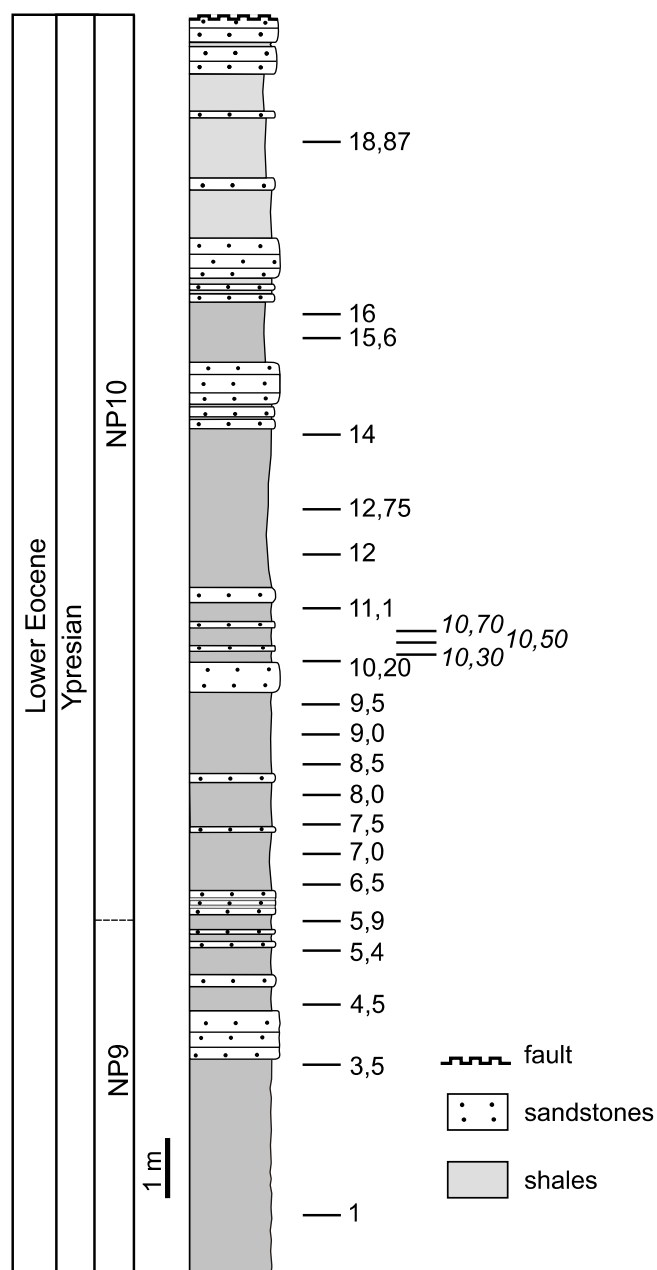


Fig. 4. Simplified lithological profile of the outcrop section along the Jablonka Stream

Numbers to the right correspond to the sample numbers; numbers in italics correspond to additional isotopic samples

STABLE CARBON ISOTOPES

We focused on intervals where the occurrence of *Apectodinium* sp. is palynologically proved, from sample 3,5 to 7,0 and from 9,5 to 11,1. In the studied interval, the carbon isotope $\delta^{13}\text{C}_{\text{org}}$ values range from -23 to -27.7‰ (Fig. 5). We observe isotope values with a signature of -27.2‰ at sample 3,5 and an increase in values in the upper part of the interval. In sample 6,5, the $\delta^{13}\text{C}_{\text{org}}$ reaches a value of -23.7 and -24.4‰ in

sample 7,0. We noticed the reappearance of *Apectodinium* sp. in sample 9,5 where the $\delta^{13}\text{C}_{\text{org}}$ is -23.3‰ . From this level isotope, the values evince a tendency to decline, with a distinctly negative trend towards sample 10,3 with a minimal signature of -27.7‰ (Fig. 5). The next three samples (10,5; 10,7; 11,1) indicate a gradual increase. The topmost sample 11,1 reach the $\delta^{13}\text{C}_{\text{org}}$ value of -23.0‰ . In the samples below 3,5 and above 11,1 the bulk organic isotope analysis is non-substantive due to organic content dominated by terrestrial tissues and significant absence of marine microplankton.

AGE

Biostratigraphic analysis based on dinoflagellate cysts reveals Early Eocene-lowest Ypresian age, nannoplankton zones NP9 and NP10 of Martini (1971).

The presence of *Apectodinium* spp. indicates Late Paleocene to Early Eocene age (Costa and Downie, 1976; Powell, 1992). Williams and Bujak (1985) documented that *A. homomorphum* ranges from the Upper Paleocene to the Middle Eocene. The presence of *Apectodinium homomorphum* and *A. quinquelatum* (Fig. 6H) indicates the *A. hyperacanthum* Zone of Costa and Downie (1976), suggesting a Late Paleocene to Early Eocene age. The presence of *A. augustum*, which is recorded only from the CIE (Bujak and Brinkhuis, 1998; Steurbaut et al., 2003; Sluijs et al., 2007), suggests the Late Paleocene to Early Eocene, Zone NP9 of Martini (1971; Powell, 1992; Williams et al., 2004). *Phelodinium magnificum* (Fig. 7O) indicates the Early Eocene, Zone NP10 of Martini (1971; Powell, 1996). *Florentinia reichartii* is a very important species. Its stratigraphic occurrence is very narrow, spanning the latest Paleocene and earliest Eocene (Sluijs and Brinkhuis, 2009). The ranges of *Homotryblium tenuispinosum* and *Adnatosphaeridium vittatum* are problematic. According to Powell (1992) the first appearance of *H. tenuispinosum* is in the mid-Ypresian NP11 of Martini (1971), but according to Williams et al. (2004) the first occurrence of this species in the northern Hemisphere (mid-latitudes) is in the Thanetian, before *Apectodinium augustum*. Similarly *Adnatosphaeridium vittatum* (as *Adnatosphaeridium multispinosum*) on global charts is limited to the Eocene, and according to Powell (1992) and Stover et al. (1996) it appeared for the first time in the mid-Ypresian. However, Eaton (1976) gives its first occurrence in the latest Paleocene. Moreover, *Adnatosphaeridium multispinosum* was recognized in the Late Paleocene of Nigeria (Jan du Chêne and Adediran, 1984) and Tunisia (Kocsis et al., 2014). Sánchez-Pellicer et al. (2017) report the first appearance of this species in the Selandian in the Gulf of Guinea.

DISCUSSION

DINOFLAGELLATE CYSTS

Apectodinium taxa are present in a majority of samples containing dinoflagellate cysts; in a few of them they are dominant, ranging from ~ 25 to $\sim 37\%$ of the dinoflagellate cyst assemblage. This high number of *Apectodinium* taxa from the Polish Outer Carpathians has been noted for the first time.

In the Bystre slice the maximum occurrence reaches $\sim 37\%$, whereas, for example, it exceeds 60% at the Anthering section in Austria (Heilmann-Clausen and Egger, 2000; Crouch et al.,

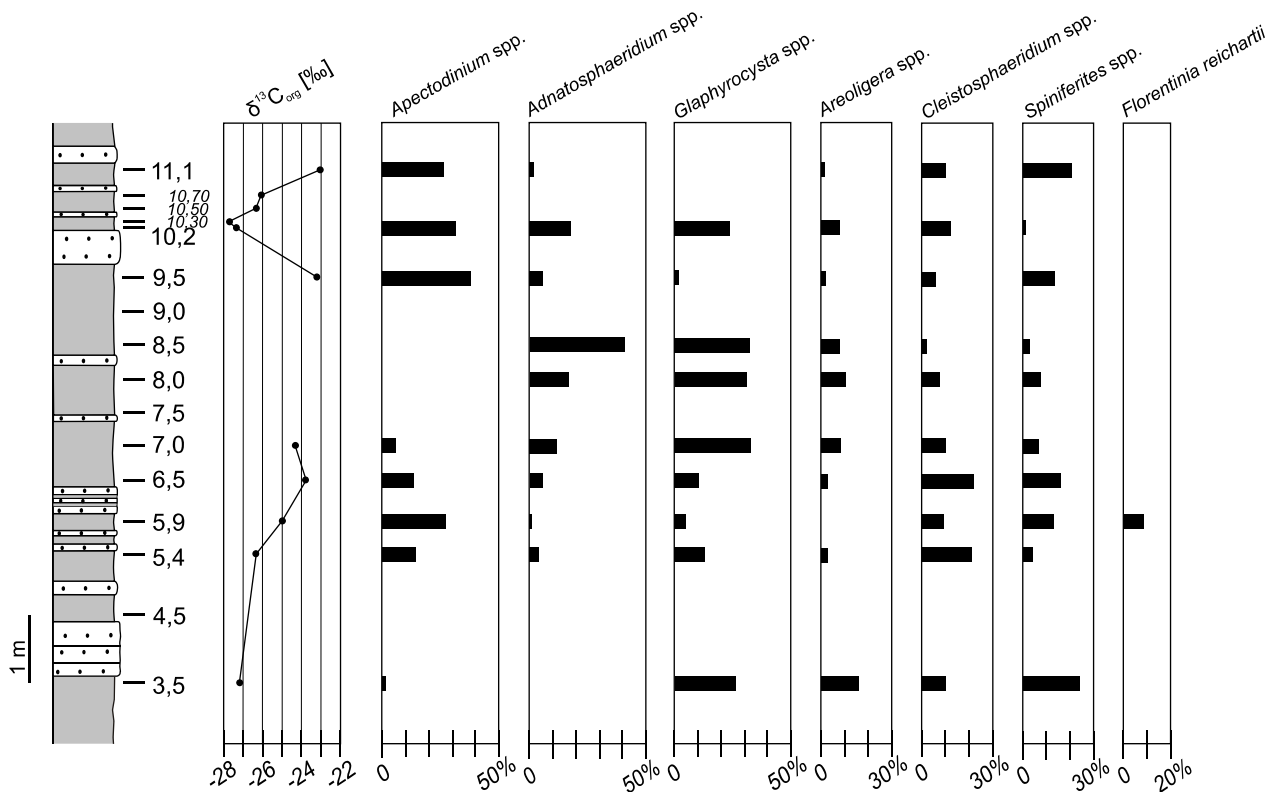


Fig. 5. Part of the study section showing the $\delta^{13}\text{C}_{\text{org}}$ isotope records and the percentage distribution of main groups of dinoflagellate cysts

2001), 70% at the Kheu section, Caucasus (Shcherbinina et al., 2016), >90% at the Tienen Formation, Belgium (Steurbaut et al., 2003), and ~60% at the Tawanui section, New Zealand (Crouch et al., 2001, 2003a). However, at the Aktumsuk section, Uzbekistan, Crouch et al. (2003b) reported the occurrence of *Apectodinium* up to ~35% of the assemblage. It should be mentioned that both the Bystre and Aktumsuk sections were within the northern Tethys realm in the Late Paleocene/Lower Eocene (Bolte et al., 2000; Oszczypko, 2004; Golonka, 2006). In the studied material, *Apectodinium augustum* is actually uncommon, reaching 3.5% of the assemblage. Previous studies show that *A. augustum* is sometimes not even recorded in the PETM sections (Crouch et al., 2003b; Frieling et al., 2018b).

One of the interesting features of our study is the two peaks of *Apectodinium* abundance with values ~28 and ~37%. Similar features of abundance peaks are recorded in other locations with the PETM, e.g. at the Tienen Formation (Steurbaut et al., 2003) and the Elles section (three peaks) (Crouch et al., 2003b). They are referred to other Late Paleocene and Early Eocene *Apectodinium* occurrences in the Northern Hemisphere (Powell et al., 1996; Bujak and Brinkhuis, 1998; Crouch et al., 2003b; Steurbaut et al., 2003).

Dinoflagellate cysts from Bystre indicate an Early Eocene age. It could be coeval with other Early Eocene sections, e.g. Jebel Boudabous (Bujak and Brinkhuis, 1998) and Aktumsuk (Crouch et al., 2003b).

In the part of the section where *Apectodinium* disappears or is scarce, a significant increase of the *Areoligera* complex (*Areoligera* sp., *Adnatosphaeridium* sp., *Glaphyrocysta* sp.) is noted. Motile *Apectodinium* dinoflagellates probably fed on organic detritus and other plankton (Bujak and Brinkhuis, 1998). They are typical of neritic and coastal (lagoonal, estuarine or

brackish) settings with low salinities (Stover et al., 1996). In contrast, the *Areoligera* complex is interpreted as autotrophic dinoflagellates, linked mostly with inner neritic settings (Brinkhuis, 1994; Powell et al., 1996) and also found in high-energy marginal marine environments (Stover et al., 1996; Shcherbinina et al., 2016). Within secondary dinoflagellate assemblages, *Spiniferites* and *Cleistosphaeridium* spp. are common. *Spiniferites* sp. appears in both ocean and neritic settings (Brinkhuis, 1994); *Cleistosphaeridium* sp. is linked to normal marine, shallow water (Köthe, 1990).

The disappearance of heterotrophic *Apectodinium* and the significant increase of the autotrophic *Areoligera* complex probably indicate changes in nutrient delivery. There must have been a factor controlling the supply of nutrients, for instance, sea level changes. The Silesian Basin, like other Carpathian basins, was controlled by tectonic processes (Oszczypko, 2004; Golonka, 2006) and this could have had a significant impact on sea level changes and thus the nutrient supply. Consequently, *Apectodinium* is associated with a coastal environment, so an increase in sea level could have an impact on their distribution.

Along with the acme of *Apectodinium* spp. the occurrence of *Florentinia reichartii* has been noted herein for the first time in the Outer Carpathians. This species is described from the New Jersey Shelf (Sluijs and Brinkhuis, 2009), East Tasman Plateau (Sluijs et al., 2011), South Pacific Ocean (Bijl et al., 2013a) and the Otway Basin, Australia – where it was treated as a marker species for the PETM (Frieling et al., 2018a). *F. reichartii* also was thermophilic, but the temperature range for this species was >30°C (Frieling, 2016). The presence of *F. reichartii* may indicate warming of sea surface waters more than is assumed with the occurrence of *Apectodinium*.

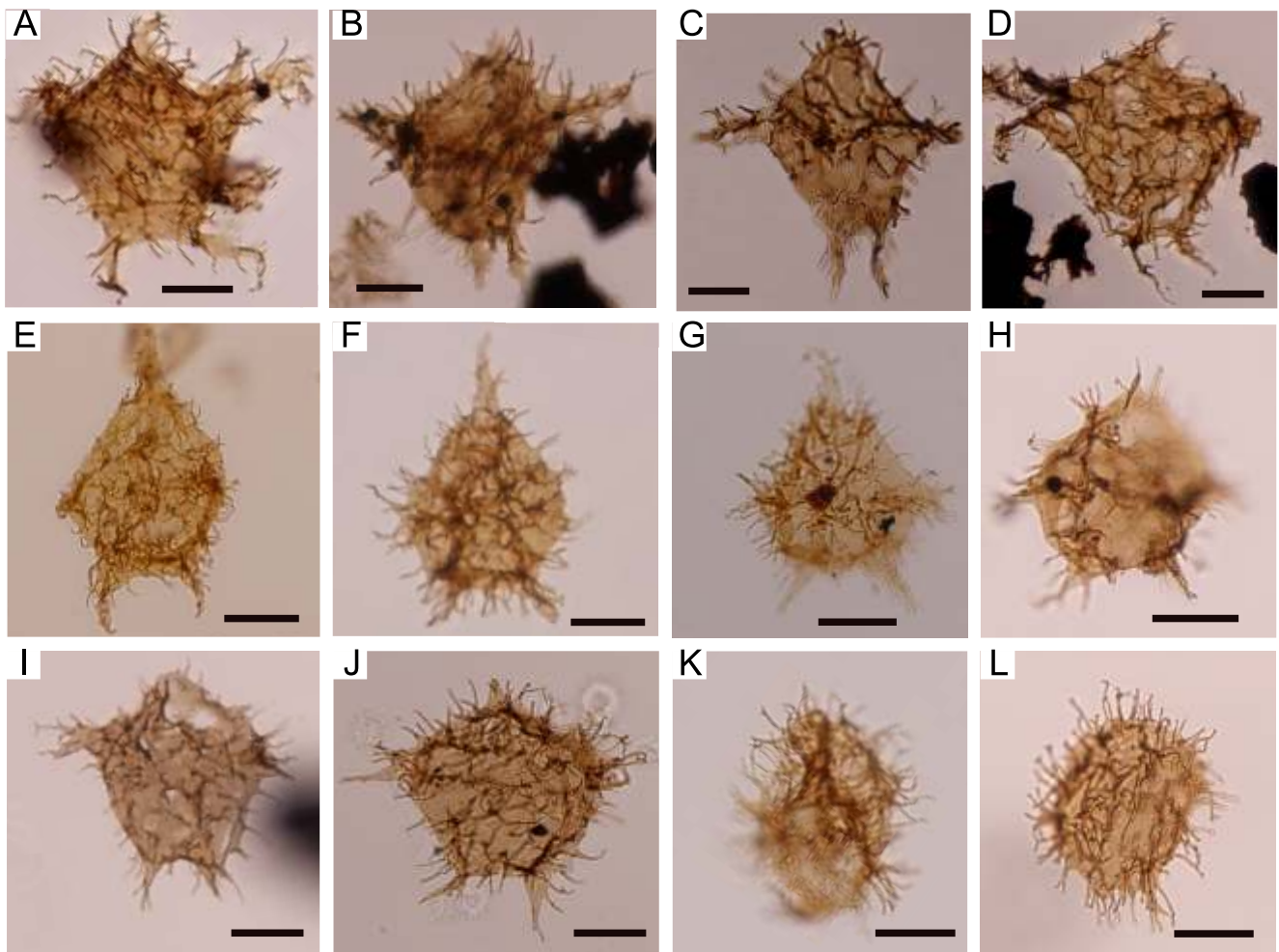


Fig. 6. Light microscope images for the *Apectodinium* group

A–D – *Apectodinium augustum* (sample 10,20); **E** – *Apectodinium longispinosum* (sample 5,9); **F, G** – *Apectodinium parvum* (samples 10,20; 5,9); **H** – *Apectodinium quinquelatum* (sample 10,20); **I, J** – *Apectodinium hyperacanthum* (samples 7; 3,5); **K, L** – *Apectodinium homomorphum* (samples 10,20; 11.1); scale bar = 25 μ m

CARBON ISOTOPE

Stable carbon isotope analysis is a standard method for determining the source of organic matter in modern and ancient environments, especially to trace proportions of phytoplankton and terrestrial organic matter. The source of suspended or buried organic matter is determined from bulk isotopic data; therefore, evaluation of the proportion of the pure marine and pure terrestrial elements is an important question (Calder and Parker, 1968; Newman et al., 1973). There are also other factors influencing the organic matter distribution pattern, including: e.g. regional and local terrestrial and marine floras variations, seasonal and spatial variability, degradative processing, and various external and internal transport pathways in/to sedimentary basins (Stiller, 1977). Recycling of particulate, especially terrestrial organic matter, which is resistant to mechanical and chemical damage, is a common geological process within flysch-type deposits. Moreover, omnipresent in clastic environments, submarine erosion is also capable of reworking ancient marine particles including dinoflagellate cysts, acritarcha, and foraminifera test linings

potentially influencing the isotopic signal. Therefore, all kinds of anomalies should not be underestimated.

In our material, we have noticed several evidences of reworking of Cretaceous and Jurassic dinoflagellate (Fig. 7A, I, R, S); therefore, recycling of other older organic particles must be considered. According to Tyson (1993) the recycled terrestrial material of Mesozoic age tends to shift isotopic signatures to be heavier.

Our $\delta^{13}\text{C}_{\text{org}}$ values served only as reference points to previous PETM values occurring around this global phenomenon. The analysis shows $\delta^{13}\text{C}_{\text{org}}$ values between -23 and -27.7% and seems to be similar to other $\delta^{13}\text{C}_{\text{org}}$ analysis from the PETM in Europe (Steurbaut et al., 2003; Thiry et al., 2006; Collinson et al., 2009). However, due to the high ratio of recycling we are aware that the method can yield only poor or ambiguous results in our case. This is the main reason we believe rather in a palaeontological signal reflected by increased number of *Apectodinium* genera. To ensure that our palaeontological results are reliable we excluded the reworking process of *Apectodinium* specimens by means of autofluorescence excited by ultraviolet light. After microscopic examination, all specimens of *Apectodinium* occurring in the samples around the PETM re-

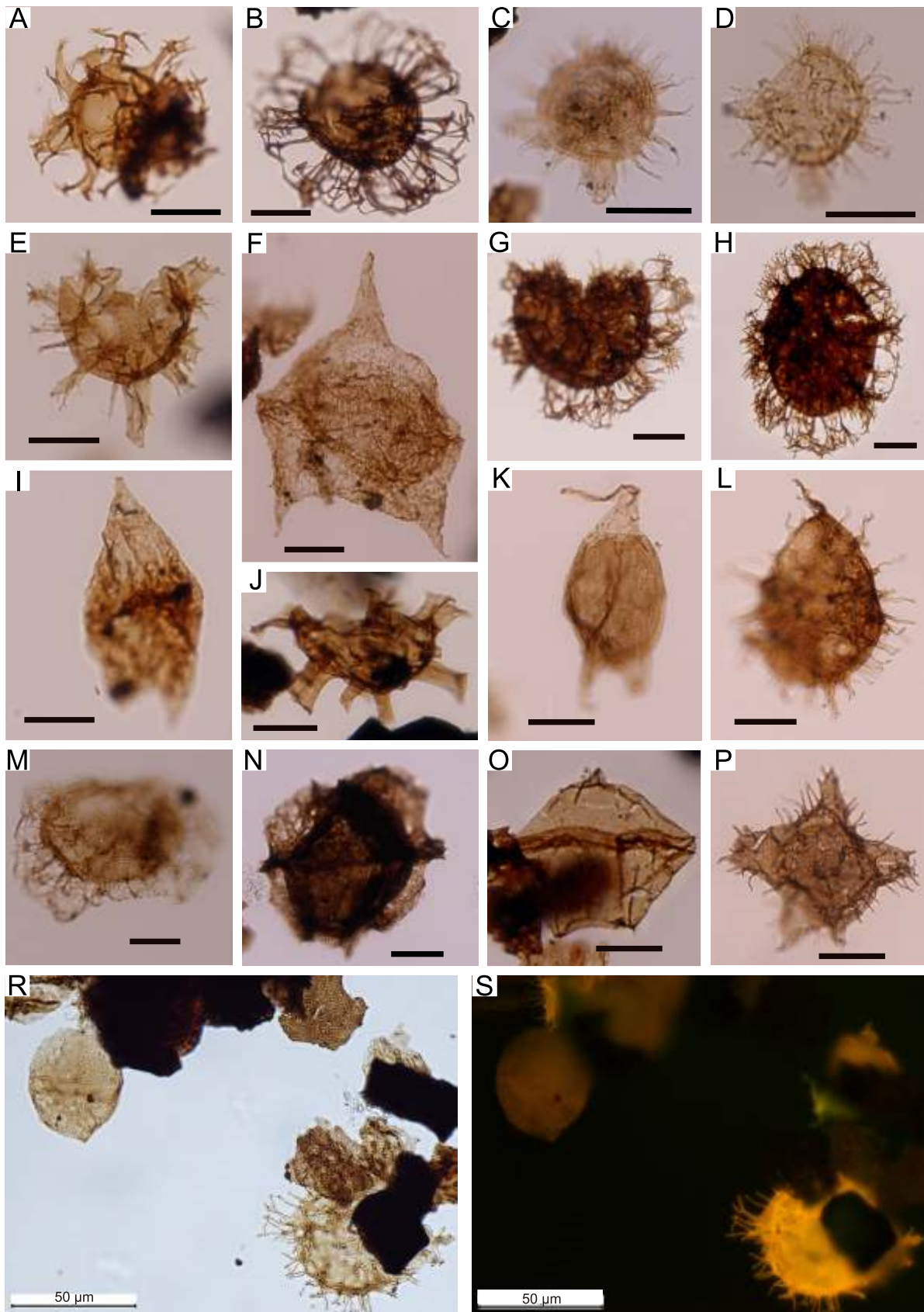


Fig. 7. Light microscope images for the selected dinoflagellate cysts

A – *Areoligera neptuni* (sample 6,5); **B** – *Adnatosphaeridium vittatum* (sample 8,5); **C, D** – *Florentinia reichtrii* (sample 5,9); **E** – *Hystrichokolpoma rigaudiae* (sample 6,5); **F** – *Deflandrea oebisfeldensis* (sample 5,9); **G, H** – *Glaphyrocysta divaricata* (samples 8,5; 7); **I** – *Isabelidinium* sp. (sample 5,9); **J** – *Homotryblium abbreviatum* (sample 11,1); **K** – *Cerodinium diebelii* (sample 5,9); **L** – *Fibrocysta bipolaris* (sample 5,4); **M** – *Glaphyrocysta microfenestrata* (sample 5,9); **N** – *Muratodinium* sp. (sample 8); **O** – *Phelodinium magnificum* (sample 5,9); **P** – *Wilsonidium* sp. (sample 7); **R, S** – *Apectodinium* sp. and reworked *Subtilisphaera* sp. in transmitted light and UV (sample 5,9); A–P: scale bar = 25 µm; R and S: scale bar = 50 µm

cord, revealed a similar autofluorescence level. On the one hand, it proves *in situ* character of this record, and on the other, reduces probability of artificial concentration of these taxa.

CONCLUSIONS

The study reveals a high number of *Apectodinium* dinoflagellate cysts in the material from the Outer Carpathians. *Apectodinium augustum* is particularly important. Being a marker taxon, it indicates the PETM record in this area. The presence of *Florentinia reichartii* has also been recorded. Likewise, the *Apectodinium* species is thermophilic and related to the PETM. Changes in the content of *Apectodinium* and their substitution by the *Areoligera* complex may indicate sea level changes and/or delivery of nutrients.

Our study reveals also an unrecorded section of the Eocene Hieroglyphic beds and the existence of the Istebna Beds thrust over the Hieroglyphic Beds, which indicates tectonic repetition.

Acknowledgements. We are grateful to Dr M. Barski for the great help and discussion. Dr M. Bojanowski and Dr W. Kozłowski are thanked for valuable remarks in interpretation of isotopic analysis. We would like to thank Dr M. Łoziński for help in field work, and E. Demianiuk and T. Plasota for critical reading of a previous version of this manuscript. P. Steele is thanked for English linguistic improvements. We would like to thank Prof. A. Konon and the second, anonymous reviewer for comments which significantly improved this paper. This study was supported by an internal grant of the Faculty of Geology, University of Warsaw.

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