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Terreneuvian acritarch assemblages of the Holy Cross Mountains – a new approach

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Rock samples from four boreholes and three exposures located in the southern peripheries of the Holy Cross Mountains in Poland, from strata representing the lower Cambrian Czarna Shale Formation have been studied palynologically. A relatively numerous and well-preserved lowermost Cambrian microfloral assemblage corresponds to coeval associations known from different palaeocontinents. Our new data enables reinterpretation of the biostratigraphy of the Czarna Formation, a thick rock unit basically devoid of macrofossils. The rocks analysed represent the Terreneuvian and comparison with other lower Cambrian successions indicates the middle and upper part of this oldest Cambrian series. The discovery of *Variosphaeridium* gen. nov. supplements information about the diversity of lowermost Cambrian microfloral assemblages. The *Fimbriaglomerella membranacea–Globosphaeridium cerinum* Assemblage Zone is introduced; it has a transitional character between the *Asteridium tornatum–Comasphaeridium velvetum* and *Skiagia ornata–Fimbriaglomerella membranacea* assemblage zones distinguished by Moczydłowska (1991) and identified on most Cambrian palaeocontinents.

Key words: Cambrian, Terreneuvian, Holy Cross Mountains, Kotuszów, Acritarcha, biostratigraphy.

INTRODUCTION

The age of the oldest rocks in the Paleozoic succession of the Holy Cross Mountains has attracted interest for over a century, with stratigraphic positions inferred ranging from the Riphean to the *Holmia*-bearing strata of the Cambrian (Szczepanik and Żylińska, 2016 with a review and references therein). This rock succession, assigned by Orłowski (1975) to the Czarna Shale Formation, generally yields very few macrofossils, with none of them being age-diagnostic; therefore, microfossil assemblages are used to determine the stratigraphy of this succession. Recent age evaluation based on studies of acritarch assemblages in the Czarna Formation exposed around Kotuszów pointed to a middle to late Terreneuvian age of the strata (Szczepanik and Żylińska, 2016). This study supplements and further develops the previously published data by analysing acritarch evidence from the southern peripheries of the area, and addresses controversies related to the chronostratigraphic position of the acritarch assemblage zones in a global context.

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GEOLOGICAL SETTING

The Holy Cross Mountains (Fig. 1), comprising low, WNW–ESE-oriented hills in south-central Poland, are composed of an almost complete succession of non-metamorphosed Paleozoic rocks. They were formed in the direct vicinity of the Teisseyre-Tornquist Zone that marks the southwestern margin of the East European Craton (EEC), which in the Cambrian composed the Baltica palaeocontinent. The Paleozoic rocks are surrounded by strata of the Permian-Mesozoic margin to the north, west and south-west, and by Neogene (Miocene) strata of the Carpathian Foredeep Basin to the south and south-east. The study area is located to the south of the main Paleozoic outcrop of the Holy Cross Mountains, with Cambrian rocks exposed or encountered in shallow boreholes and exposures in the vicinity of Zbrza, Strazsniów and Kotuszów (Figs. 1 and 2). In this part of the Holy Cross Mountains, the Cambrian succession is represented by the Czarna Shale Formation, which comprises mostly claystones and siltstones with rare sandstone interbeds, of thickness estimated at 600–700 m or even 800 m (Orłowski, 1975; Kowalczewski et al., 2006). This unit constitutes the basement in most of the southern peripheries of the Holy Cross Mountains. It may be accessed by shallow boreholes or in small exposures within minor inliers of Paleozoic strata surrounded by Mesozoic or Neogene deposits (Figs. 1 and 2). Lack of index macrofossils coupled with the lack of trilobite remains resulted in assigning the Czarna Formation to an

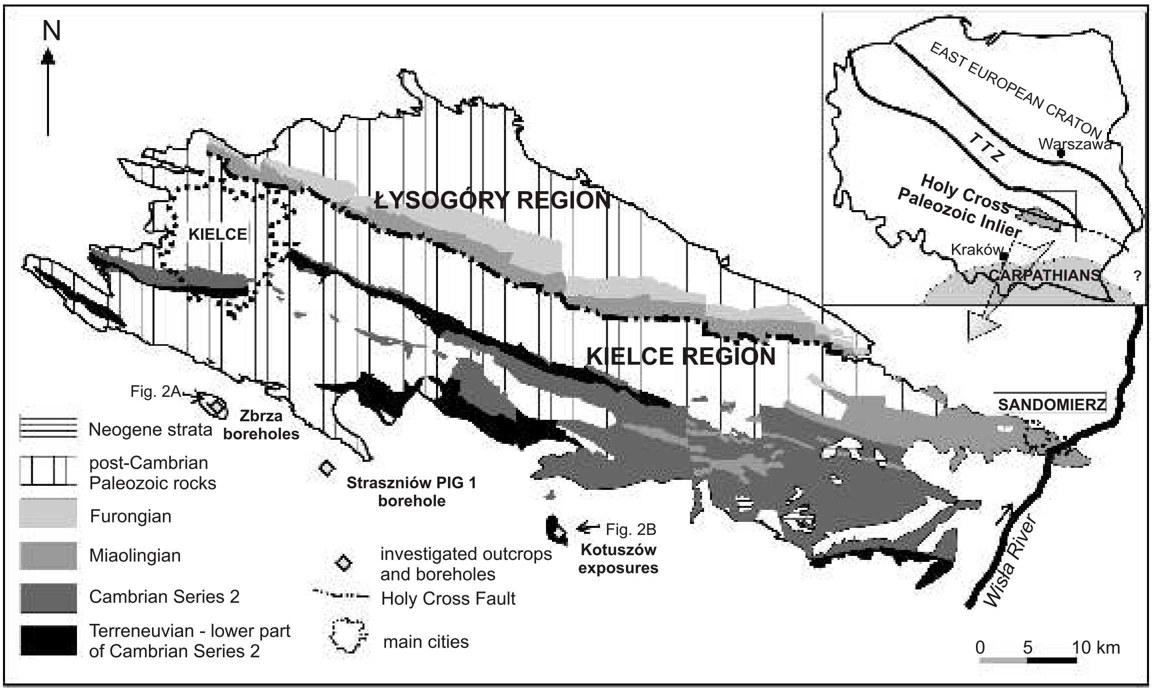

Fig. 1. Geological sketch-map of the Paleozoic of the Holy Cross Mountains with location of the boreholes and exposures studied (after Orłowski, 1975, 1992, modified)

interval preceding the first occurrence of trilobites in most regional stratigraphic interpretations; a precise age indicating the middle and upper Terreneuvian based on the analysis of acritarch assemblages was recently suggested for strata exposed around Kotuszów (Szczepanik and Żylińska, 2016).

MATERIAL

A total of 61 rock core samples, from three shallow boreholes located in the Zbrza inlier, i.e. Zbrza PIG 1, Zbrza PIG 2, and Zbrza PIG 3, the Straszniów PIG 1 borehole, and from three exposures (A, B and C) located in the Kotuszów inlier (Figs. 1 and 2) were subject to palynological analysis. Acritarchs were recorded in 32 samples, though diverse assemblages which could be used for biostratigraphic analysis were observed in only 25 of them. Microfloral associations observed in individual slides were of generally low abundance, with the number of observed acritarchs (determinable at least to genus level) varying from several to ~50 in one slide. In some slides from Zbrza PIG 2, the assemblage was abundant but dominated by forms representing only one taxon, i.e. *Leiosphaeridia* sp. (Table 1 and Appendix 1*). The degree of thermal maturity of the acritarchs analysed is high, corresponding to stages 5+ to 6 of the AMOCO thermal scale. The acritarch wall colour is generally brown though with variation depending on the wall thickness, the thicker elements being darker. In some cases, very thin-walled specimens are yellow-orange in colour (e.g., Fig. 3D, L, M, Y). Acritarch preservation is moderately good; generally the outline of individual specimens is well-preserved, whereas the fine elements of the sculpture are often effaced, which hampers precise determination, especially in the case of smaller forms (e.g., *Asteridium*) or of those in which the diagnosis is based on the presence or character of very fine morphological elements (e.g., *Comasphaeridium*). In some acritarchs (e.g., Figs. 3Y and 4H), growth of pyrite crystals has destroyed the palynomorph walls. A characteristic feature of the material analysed is large variability in palynomorph abundance. Samples collected from rocks representing the same lithology and situated close to one another may differ greatly with regard to microflora abundance. This seems to be the result of a variable primary abundance of the microphytoplankton, because there are no differences in lithology, fossilization process, or methodology of laboratory analysis.

METHODOLOGY

The samples were subject to classical palynologic maceration. Samples weighing ~100 g were macerated first in cold hydrofluoric acid, next in hot hydrochloric acid, filtered on 15 µm mesh membranes, and macerated once again in cold hydrofluoric acid. The residuum obtained was next centrifuged in heavy liquid. Later, glycerine-gelatine preparations were made, which were analysed in bright-field microscopy (*Olympus BX51* microscope) at magnifications between 300 and 1200. The acritarch specimens recognized were documented as graphic files with the help of a microcamera attached to a computer.

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* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1601

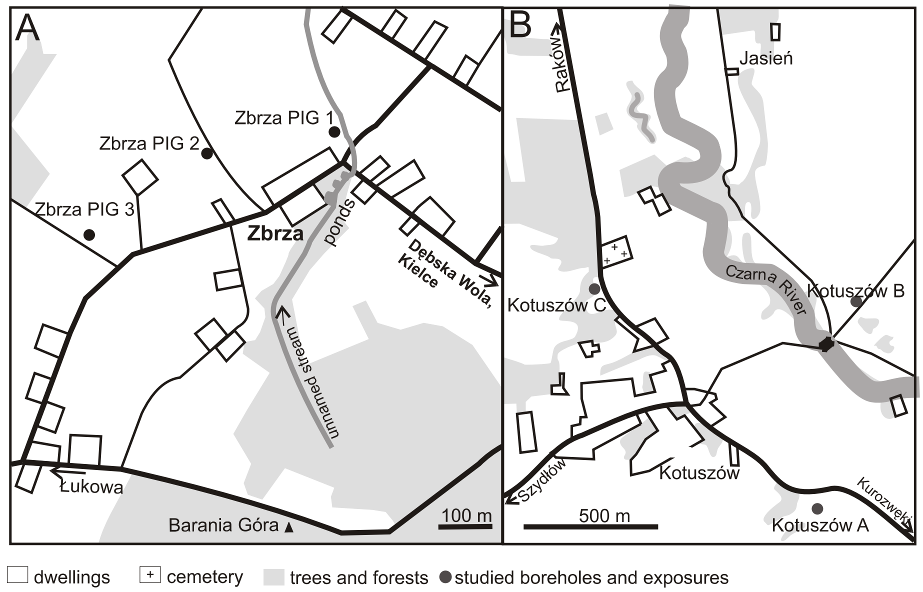

Fig. 2A – sketch map of the Zbrza area showing the location of the Zbrza PIG 1, PIG 2 and PIG 3 boreholes; B – sketch-map of the vicinity of Kotuszów, to show the exposures studied (after Szczepanik and Żylińska, 2016, slightly modified)

SAMPLING AND LITHOLOGICAL DATA

ZBRZA PIG 1

This borehole was drilled in the centre of Zbrza Village (Fig. 2A). Below Ordovician strata there is a 43.3 m thick succession of grey mudstones, becoming greenish-grey towards the top. Clayey shales dominate in the succession, with numerous beds of grey siltstone up to 2 cm thick and occasional thin beds (3–6 cm) of quartzitic sandstone. The sandstones display boudinage structures and are strongly fractured, whereas the siltstones and clayey shales are strongly folded and include numerous slickensides. Dips vary from 10 to 70°, with steep dips being prevalent. The entire succession shows intense tectonic deformation. Ten samples were collected from the core; determinable acritarchs were found in five of them, at depth levels 109.9, 115.0, 124.0, 128.0 and 133 m (Table 1 and Appendix 1).

ZBRZA PIG 2

This borehole was drilled ~200 m to the west of the Zbrza PIG 1 borehole (Fig. 2A). A 71 m thick succession of green and dark grey mudstones with rare thin beds of siltstone and sandstone was encountered at the bottom of the borehole. Some heterolithic siltstone-sandstone intervals are present. The succession is intensely deformed. Dips vary from 30° to almost vertical, most commonly 60–70°. Out of seven samples collected from this core, acritarchs were recognized in six; in the case of two samples, however, the acritarchs were very few and without stratigraphic significance. A relatively rich and moderately preserved palynomorph assemblage was collected from five samples, at depth levels 20.2, 51.2, 57.0, 63.0 and 69.0 m (Table 1 and Appendix 1).

ZBRZA PIG 3

This borehole was drilled ~200 m to the south-west of the Zbrza PIG 2 borehole (Fig. 2A). Below Ordovician rocks there are 38.7 m of greenish-grey and grey mudstones, in some cases represented by siltstone-claystone heterolithic strata. The succession contains rare beds of siltstone and sandstone, 2–20 cm thick. The entire succession is intensely deformed. Dips vary from 20 to 85°. Eight samples were collected, out of which only one (at depth level 99.2 m) contained moderately preserved acritarchs (Table 1 and Appendix 1).

STRASZNIÓW PIG 1

This borehole was drilled in the northwestern part of Gumienice Village, close to the road leading to Pierzchnica, within a site referred to the no longer existing Straszniów Village. The locality is situated directly to the south-west of Słońce Hill, considered by Kowalczewski (1990) to be built of *Holmia*-age rocks. A 189 m thick succession represented by intensely deformed mudstones occurs below an 11 m thick cover of Neogene(?) mottled clays. The succession is dominated by greenish-grey claystones with numerous thin interbeds of siltstone and rare interbeds of grey quartzitic sandstone with abundant calcite veins. Dips are usually very steep. The rocks show numerous slickensides and include shear zones several metres thick. The rocks analysed seem to be most intensely deformed among the sections studied. A total of twenty samples was collected; only seven contained acritarchs, and only one, at depth level 36.0 m, yielded recognisable acritarch assemblages. Compared to the other successions analysed, the assemblage from Straszniów PIG 1 is characterized by a higher degree of thermal alteration (dark brown colour); most probably this is related to the very intense deformation of rocks in this borehole. This conclusion is consistent with the observation that, compared to the other

Table 1

Distribution of acritarch taxa recognized in particular boreholes and exposures, arranged from the west to the east of the study area

TAXON	Zbrza PIG 1	Zbrza PIG 2	Zbrza PIG 3	Straszniów PIG 1	Kotuszów A	Kotuszów B	Kotuszów C
Leiosphaeridia sp.	+	+	+	+	+	+	+
Cyanophyta	+	+			+	+	+
Comasphaeridium molliculum Moczydłowska and Vidal, 1988	+	+			+		+
?*Comasphaeridium* sp.	+		+			+	
Comasphaeridium sp.	+	+	+	+	+		
Granomarginata squamacea Volkova, 1968	+	+	+	+	+		
Lophosphaeridium sp.	+	+	+	+	+		
Pterospermella sp.	+	+	+		+		
Comasphaeridium velvetum Moczydłowska, 1991	+	+			+		
?*Globosphaeridium* sp.	+		+	+			
Globus gossipinus Vidal, 1988	+	+					
Globus sp.	+	+					
Comasphaeridium brachyspinosum (Kiryanov) Moczydłowska and Vidal, 1988	+	+					
Pterospermella velata Moczydłowska, 1988	+	+					
Asteridium sp.		+		+			+
Synsphaeridium sp.		+		+	+		+
Pterospermella solida (Volkova) Volkova in Volkova et al., 1979		+					+
Pterospermella vitalis Jankauskas in Volkova et al., 1979		+			+		+
Pterospermella cf. *inordinata* Jachowicz-Zdanowska, 2013		+					+
Gen. nov. A		+				+	
Granomarginata prima Naumova, 1960		+		+	+	+	
Lophosphaeridium tentativum Volkova, 1968		+			+	+	
Comasphaeridium strigosum (Jankauskas) Downie, 1982		+	+		cf.		
Pulvinosphaeridium sp.		+		+	+		
?*Fimbriaglomerella* sp.		+			+		
Lechistania magna Jachowicz-Zdanowska, 2013		+			+		
Asteridium tornatum (Volkova) Moczydłowska, 1991		cf.			+		
?*Ichnosphaera* sp.		+		+			
Leiomarginata simplex Naumova, 1960		+		+			
Pterospermopsimorpha sp.		+		+			
?*Pterospermopsimorpha* sp.		+		+			
Pulvinosphaeridium antiquum Paškevičiene, 1979		+					
Variosphaeridium sanctacrucensis gen. et sp. nov.		+					
Comasphaeridium agglutinatum Moczydłowska, 1988		+					
?*Dictyotidium* sp.		+					
Fimbriaglomerella cf. *minuta* (Jankauskas) Moczydłowska and Vidal, 1988		+					
Granomarginata sp.		+					
Leiovalia sp.		+					
Lophosphaeridium truncatum Volkova, 1969			+	+	+	+	+
Fimbriaglomerella membranacea (Kiryanov) Moczydłowska and Vidal, 1988			+		+	+	+
Lophosphaeridium dubium (Volkova) Moczydłowska, 1991			cf.		cf.		+
Asteridium lanatum (Volkova) Moczydłowska, 1991				cf.		+	
Ichnosphaera cf. *delicata* Jachowicz-Zdanowska, 2013				+			
Heliosphaeridium cf. *dissimilare* (Volkova) Moczydłowska, 1991				+			
?*Pulvinosphaeridium* sp.				+			
?*Liepaina* sp.					+		
Cymatiosphaera sp.						+	+
Heliosphaeridium longum (Moczydłowska) Moczydłowska, 1991						+	+
Globosphaeridium cerinum (Volkova) Moczydłowska, 1991						+	
Tasmanites sp.						+	
Gen. nov. B						+	
?*Leiosphaeridia* sp.						+	
Aliumella baltica Vanderflit in Umnova and Vanderflit, 1971						+	
Ichnosphaera sp.							+
Heliosphaeridium sp.							+
?*Heliosphaeridium* sp.							+

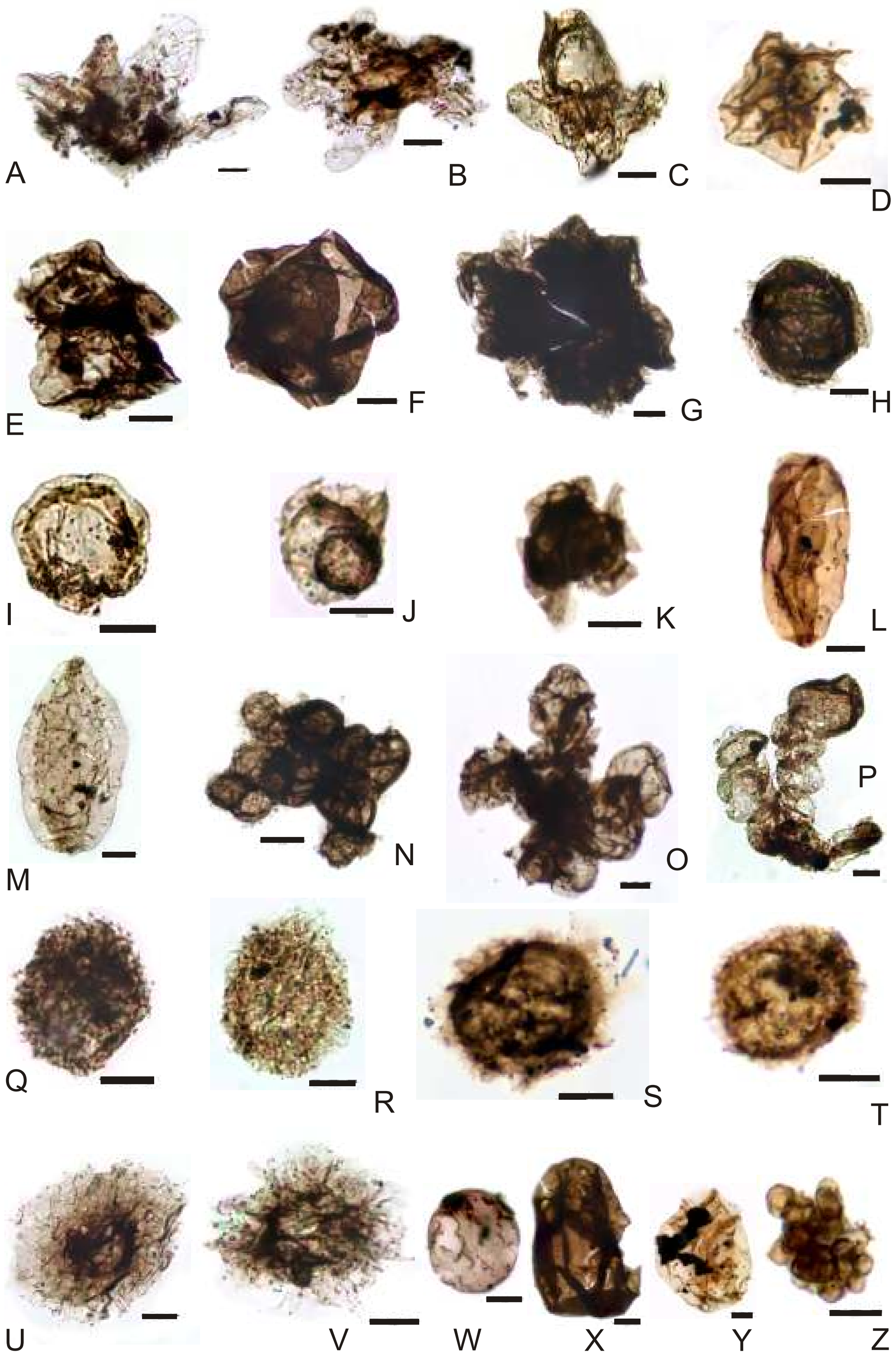

Fig. 3. Acritarchs from the Czarna Formation in the Holy Cross Mountains

A–C – *Pulvinosphaeridium antiquum* Paškevičiene, 1979, Zbrza PIG 2 (A – 20.2 m, slide 6327; B – 51.2 m, slide 6628; C – 63.0 m, slide 6630); **D–G** – *Pulvinosphaeridium* sp. (D, E – Zbrza PIG 2, 20.2 m, slide 6327; F – Kotuszów A, slide 4992; G – Strasznìów PIG 1, 36.0 m, slide 6597); **H, I** – *Leiomarginata simplex* Naumova, 1960 (H – Strasznìów PIG 1, 36.0 m, slide 6597; I – Zbrza PIG 2, 51.2 m, slide 6628); **J, K** – *Pterospermopsimorpha* sp. Strasznìów PIG 1, 36.0 m, slide 6597; **L, M** – *Leiovalia* sp., Zbrza PIG 2 (L – 69.0 m, slide 6631; M – 57.0 m, slide 6629); **N** – *Asteridium* cf. *lanatum* (Volkova) Moczydłowska, 1991, Strasznìów PIG 1, 36.0, slide 6597; **O, W–Y** – *Leiosphaeridia* sp., Zbrza PIG 2 (O – 51.2 m, slide 6628; W–Y – 69.0 m, slide 6631A); **P** – *Asteridium* cf. *tornatum* (Volkova) Moczydłowska, 1991, Zbrza PIG 2, 20.2 m, slide 6327; **Q, R** – *Globus gossipinus* Vidal, 1988 (Q – Zbrza PIG 2, 57.0 m, slide 6629; R – Zbrza PIG 1, 124.0 m, slide 6362); **S, T** – *Granomarginata prima* Naumova, 1960, Zbrza PIG 2, S – 69.0 m, slide 6631; T – 57.0 m, slide 6629; **U, V** – *Granomarginata squamacea* Volkova, 1968 (U – Zbrza PIG 1, 128.0 m, slide 6363; V – Zbrza PIG 3, 99.0 m, slide 6295); **Z** – *Synsphaeridium* sp., Strasznìów PIG 1, 36.0 m, slide 6597; scale bars equal 10 mm

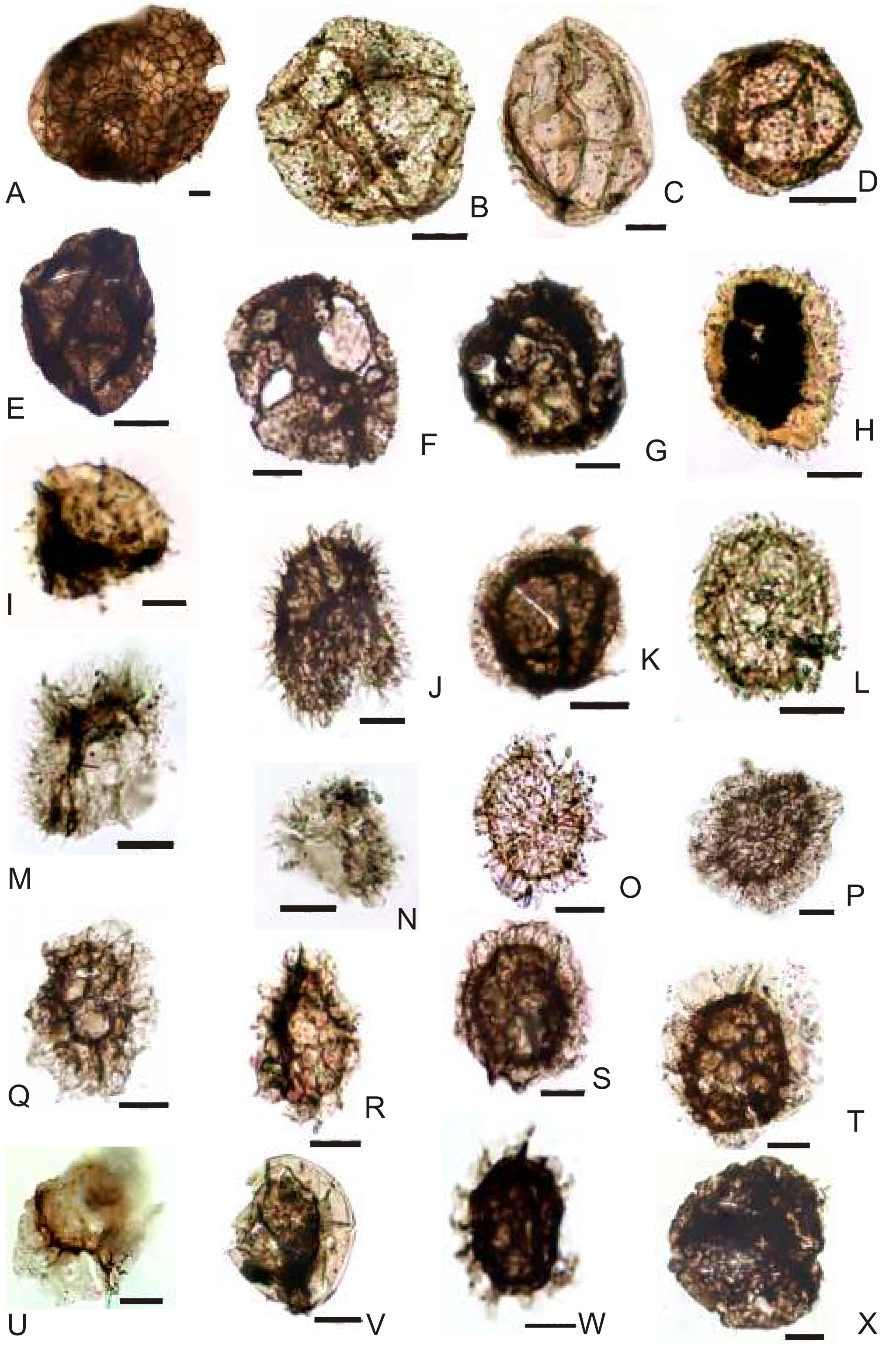

Fig. 4. Acritarchs from the Czarna Formation in the Holy Cross Mountains

A – ?*Dictyotidium* sp., Zbrza PIG 2, 69.0 m, slide 6331; **B–D** – *Lophosphaeridium tentativum* Volkova, 1968, Zbrza PIG 2, 63.0 m, slide 6330; **E** – *Lophosphaeridium truncatum* Volkova, 1969, Kotuszów C, slide 4990n; **F** – *Lophosphaeridium dubium* (Volkova) Moczydłowska, 1991, Kotuszów C, slide 4990n; **G** – *Lophosphaeridium* cf. *dubium* (Volkova) Moczydłowska, 1991, Zbrza PIG 3, 99.0 m, slide 6695; **H, I** – ?*Globosphaeridium* sp. (H – Zbrza PIG 3, 99.0 m, slide 6295; I – Zbrza PIG 1, 115.0 m, slide 6360A); **J** – *Comasphaeridium brachyspinosum* (Kiryanov) Moczydłowska and Vidal, 1988, Zbrza PIG 1, 128.0 m, slide 6363; **K, L** – *Comasphaeridium velvetum* Moczydłowska, 1991 (K – Kotuszow A, slide 4992; L – Zbrza PIG 2, 57.0 m, slide 6629); **M, N** – *Comasphaeridium agglutinatum* Moczydłowska, 1988, Zbrza PIG 2 (M – 20.2 m, slide 6327; N – 57.0 m, slide 6629); **O, P** – *Comasphaeridium molliculum* Moczydłowska and Vidal, 1988 (O – Zbrza PIG 2, 63.0 m, slide 6630; P – Kotuszów C, slide 4990n); **Q, R** – *Pterospermella* cf. *inordinata* Jachowicz-Zdanowska, 2013 (Q – Kotuszów C, slide 4990n, R – Zbrza PIG 2, 69.0 m, slide 6631); **S, T** – *Pterospermella velata* Moczydłowska, 1988 (S – Zbrza PIG 1, 128.0 m, slide 6363; T – Zbrza PIG 2, 63.0 m, slide 6630); **U** – *Pterospermella solida* (Volkova) Volkova in Volkova et al., 1979, Zbrza PIG 2, 51.2 m, slide 6628; **V** – *Pterospermella vitalis* Jankauskas in Volkova et al., 1979, Zbrza PIG 2, 51.2 m, slide 6628; **W** – *Pterospermella* sp., Kotuszów A, slide 4992. **X** – *Tasmanites* sp., Kotuszów B, slide 4989; scale bars equal 10 mm boreholes, this succession has yielded the largest number of barren samples, which may be the effect of heating and complete carbonization of organic matter in the numerous shear zones.

EXPOSURES IN THE KOTUSZÓW AREA

KOTUSZÓW A

This small exposure is located to the south of Kotuszów Village, on the western side of the road between Kotuszów and Kurozwęki (Fig. 2B). Olive-green mudstones are occasionally exposed along a small embankment of a dirt path near the main road. The thickness of the rocks exposed does not exceed 1 m. This exposure was noted in our previous paper (Szczepanik and Żylińska, 2016) as Locality 1. Three samples were collected, however, only one contained a low abundance (~30 specimens on the slide) but taxonomically diverse assemblage.

KOTUSZÓW B

This exposure occurs on the eastern embankment of the Czarna River valley. It is located directly along the dirt road, ~50 m to the east of the bridge across the Czarna. Along ~10 m of the embankment is exposed a succession of grey-brownish mudstones, containing thin but abundant sandstone interbeds. This exposure was noted in our previous paper (Szczepanik and Żylińska, 2016) as Locality 3. Three samples were collected in close vicinity to each other, but a low abundance assemblage was recognized in only one of them.

KOTUSZÓW C

This is a small exposure of grey mudstones in the embankment of a local pond located in the northern part of Kotuszów, close to the cemetery (Fig. 2B). Due to poor exposure, a more precise lithological characterization is not possible. It was noted in our previous paper (Szczepanik and Żylińska, 2016) as Locality 4. A single sample yielded a low-abundance and poorly preserved assemblage.

OUTLINE OF ACRITARCH BIOSTRATIGRAPHY IN THE LOWERMOST CAMBRIAN

The first attempts to use lower Cambrian acritarch assemblages in biostratigraphy date from the late 1970s (Volkova et al., 1979, 1983). As a result, six acritarch horizons (Rovno, Lontova, Talsy, Vergale, Rausve and Kibartu) were distinguished in the western part of the East European Craton (EEC). Later these regional units were adopted also for the lower Cambrian of Scandinavia as the Rovnian, Lontovan, Dominopolian, “Ljubomlian”, Vergalian-Rausvian and Kibartian stages (Nielsen and Schovsbo, 2011). Many proposals for local and regional biostratigraphic schemes were based on this initial subdivision (e.g., Vidal, 1981; Hagenfeldt, 1989; Eklund, 1990; Jankauskas and Lendzion, 1992). The initial concept was best developed and described by Moczydłowska (1991), who distinguished five acritarch zones on the Lublin slope of the EEC (Fig. 5), of which the first three: Cyanobacteria–*Leiosphaeridia* (the upper part of which corresponds to the Rovnian), *Asteridium tornatum–Comasphaeridium velvetum* (corresponding to the Lontovan) and *Skiagia ornata–Fimbriaglomerella membranacea* (corresponding to the Dominopolian) represent the lowermost Cambrian. The zones distinguished, defined as assemblage zones, reflect two explosive microplankton radiations in the earliest Cambrian and allow distinction of three types of acritarch microflora (Moczydłowska, 1991; Vidal and Moczydłowska-Vidal, 1997). The appearance of a characteristic succession of acritarch associations, separated by episodes of rapid taxonomic radiation, seems to be clearly recognized globally in areas with lower Cambrian rocks (e.g., Palacios and Vidal, 1992; Palacios and Moczydłowska, 1998; Jachowicz-Zdanowska, 2013; Palacios et al., 2017, 2020), regardless of the controversies related to the use of acritarch assemblages as isochronous tools for chronostratigraphic correlation (e.g., Landing et al., 2013; Geyer, 2020; Peng et al., 2020). In general, there is a liberal approach to recognizing acritarch assemblages, which in the original scheme of Moczydłowska (1991) were distinguished as formal assemblage zones: the taxonomic composition of these assemblages often does not reflect the abundance and diversity as described in the original concept. A more conservative approach to identifying acritarch assemblage zones seems more appropriate to ensure better correlation.

RESULTS OF ACRITARCH ANALYSIS

The Zbrza PIG 2 assemblage is the richest both in diversity and abundance.

ZBRZA PIG 2

The assemblage is dominated by representatives of *Leiosphaeridia* (Fig. 3O, W–Y), *Comasphaeridium* (Fig. 4L–O), *Granomarginata* (Fig. 3S, T), *Leiomarginata* (Fig. 3I), *Leiovalia* (Fig. 3L, M), *Lophosphaeridium* (Fig. 4B–D), and *Pterospermella* (Fig. 4R, T–V). Acritarchs representing *Pulvinosphaeridium* (Fig. 3A–E), *Globus* (Fig. 3Q), *Asteridium* (Fig. 3P) and *Variosphaeridium* gen. nov. (Fig. 6E–M) are much rarer. Single forms, recalling *Dictyotidium* (Fig. 4A), *Ichnosphaera* (Fig. 7D), *Fimbriaglomerella* (Fig. 7J, Q) and a new unidentifiable taxon (Fig. 6A) have also been noted in the assemblage. Fragments of Cyanophyta (Fig. 6Q, R, T) are relatively numerous.

The taxonomic composition of the microflora in the samples is similar, although the abundances of individual assemblages vary considerably. Among all the successions analysed, rocks from Zbrza PIG 2 contain the most abundant acritarch association.

The acritarchs recognized correlate well with those defining the *Asteridium tornatum–Comasphaeridium velvetum* Zone on the Lublin Slope of the EEC (Moczydłowska, 1991). Both index taxa are present (Figs. 3P and 4L), as well as numerous other forms characterizing the zone in other areas, e.g. *Comasphaeridium agglutinatum* (Fig. 4M, N), *Granomarginata prima* (Fig. 3S, T) and *Pterospermella velata* (Fig. 4T). Typical elements of this assemblage in Zbrza PIG 2 are the newly recognized *Variosphaeridium sanctacrucensis* gen. et sp. nov. (Fig. 6E–M; see Systematic Part) and the stratigraphically indicative *Pulvinosphaeridium antiquum* (Fig. 3A–C), which is noted for the first time in the Holy Cross Mountains and which has also not yet been noted in the successions of the East European Craton (e.g., Moczydłowska, 1991).

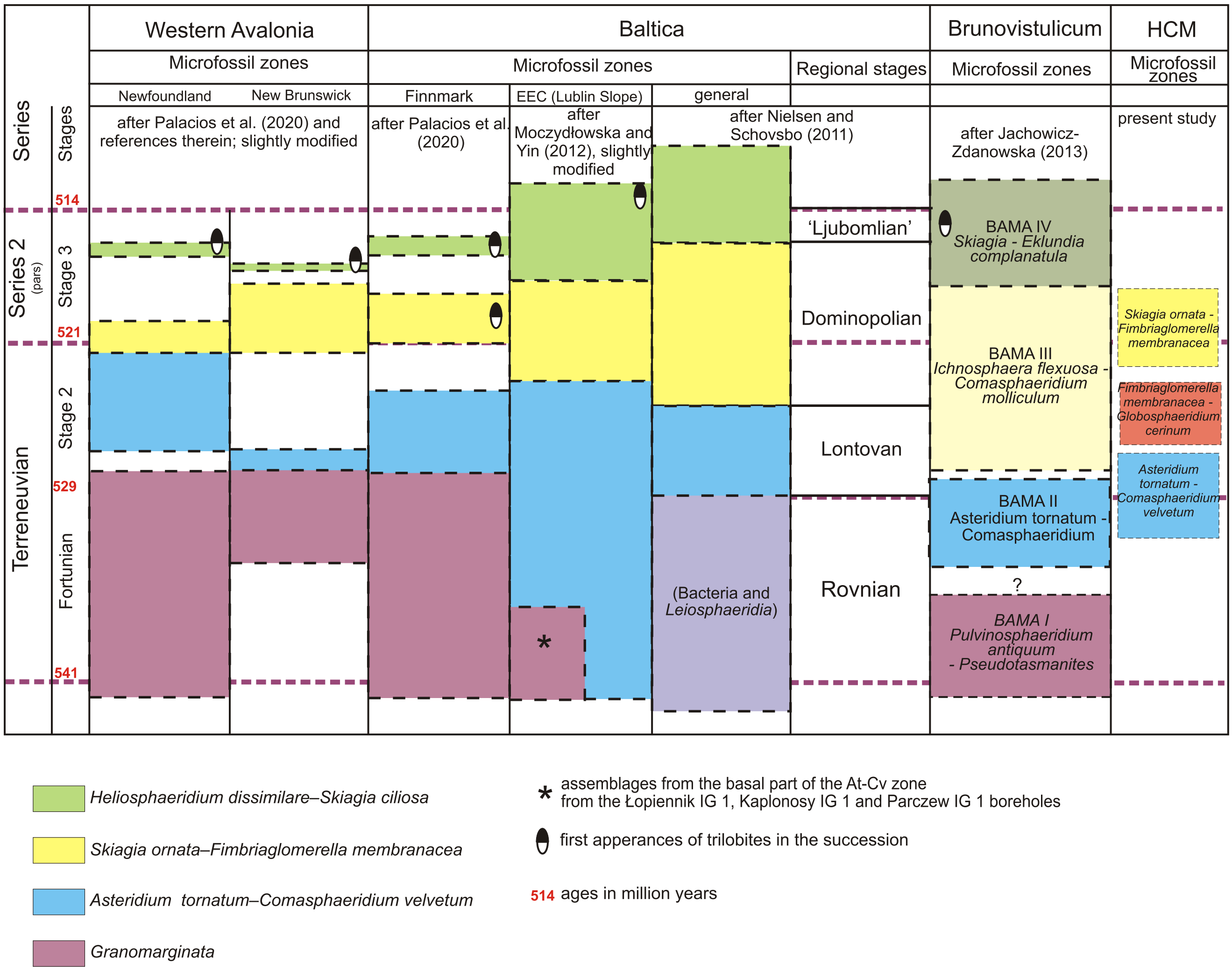

Fig. 5. Chronostratigraphic position of the Terreneuvian and Cambrian Stage 3 acritarch assemblage zones of the Holy Cross Mountains against the inventory of microfossil assemblages in coeval strata of western Avalonia (Newfoundland and New Brunswick), Baltica (Finnmark and Lublin Slope of the EEC) and Brunovistulicum, with Baltic regional stages modified after Nielsen and Schovsbo (2011); chronostratigraphic interpretation of zones distinguished by other authors follows detailed literature studies; geochronological ages after Peng et al. (2020)

Moczydłowska (1991) noted the presence of such an assemblage in strata representing the *Platysolenites antiquissimus* Zone encompassing the upper part of the Rovnian and the Lontovan, i.e. a larger part of the Terreneuvian. The observations of Palacios et al. (2017) in Newfoundland indicate that their Assemblage 3 (*Asteridium* interval zone) with a taxonomic composition similar to that of the *Asteridium tornatum–Comasphaeridium velvetum* Zone is present only in the Random Formation, considered to correspond to the upper part of Cambrian Stage 2. Below, in the Fortunian of the stratotype section on Burin Peninsula in Newfoundland occurs a less diverse microflora, in which *Leiosphaeridia* is accompanied only by *Granomarginata* (*Granomarginata* interval zone).

In Brunovistulicum (Upper Silesia and Brno blocks), Jachowicz-Zdanowska (2013) distinguished two distinct microfloral zones in the Terreneuvian. The older assemblage zone (BAMA I *Pulvinosphaeridium antiquum–Pseudotasmanites*) encompasses acritarchs with a “Vendian” outline, composed of large, morphologically simple forms with *Pulvinosphaeridium antiquum*, the index species for the Terreneuvian. The younger assemblage zone (BAMA II *Asteridium tornatum–Comasphaeridium velvetum*) is correlated with the same zone distinguished in the EEC. The presence of the latter zone in Brunovistulicum is limited, however, to a single, low-diversity sample from the Menín borehole on the Brno Block (Jachowicz-Zdanowska, 2013). It is thus difficult to correlate the BAMA II interval with the high-diversity assemblage from Zbrza PIG 2. In turn, the latter is generally comparable to the subsequent zone distinguished by Jachowicz-Zdanowska (2013), i.e. the BAMA III *Ichnosphaera flexuosa–Comasphaeridium molliculum* Zone. Although the Zbrza PIG 2 assemblage does not contain *Ichnosphaera* or *Skiagia* (representatives of the latter genus appear in stratigraphically younger strata in the Holy Cross Mountains, see Szczepanik and Żylińska, 2016), practically all characteristic taxa, including the index taxon *Comasphaeridium molliculum* (Fig. 4O) and *Lechistania magna* (Fig. 7H), the zonal index of BAMA III, can be found here. Moreover, our assemblage contains also *Pulvinosphaeridium antiquum*, which in Brunovistulicum occurs only in BAMA I.

In the acritarch zonation of Jankauskas and Lendzion (1992), the *Granomarginata prima* Zone is defined by the presence of a low-diversity microfloral assemblage composed

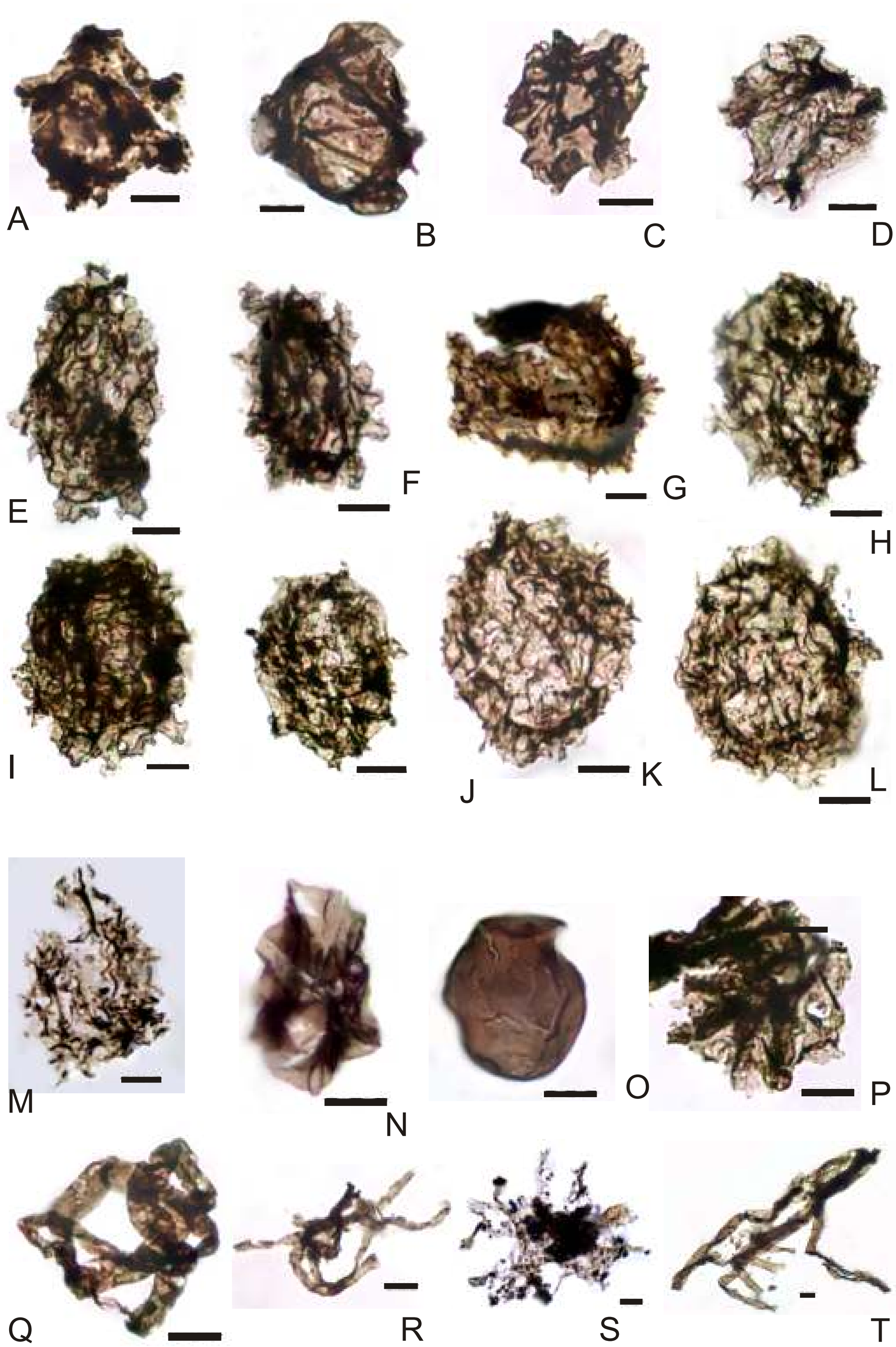

Fig. 6. Acritarchs from the Czarna Formation in the Holy Cross Mountains

A, B – Gen. nov. A (A – Zbrza PIG 2, 20.2 m, slide 6327; B – Kotuszów B, slide 4989); **C, D** – Gen. nov. B, Kotuszów B, slide 4989; **E**–**M** – *Variosphaeridium sanctacrucensis* gen. et sp. nov., Zbrza PIG 2, E–J – 57.0 m, slide 6629 (K, L – 63.0 m, slide 6630, M – 20.2 m, slide 6327); **N** – *Cymatiosphaera* sp., Kotuszów B, slide 4989; **O** – ?*Leiosphaeridia* sp., Kotuszów B, slide 4989; **P** – ?*Liepaina* sp., Kotuszów A, slide 4992; **Q**–**T** – Cyanophyta (Q, T – Zbrza PIG 2, 57.0 m, slide 6629; R – Zbrza PIG 2, 63.0 m, slide 6630; S – Zbrza PIG 1, 124.0 m, slide 6362); scale bars equal 10 mm

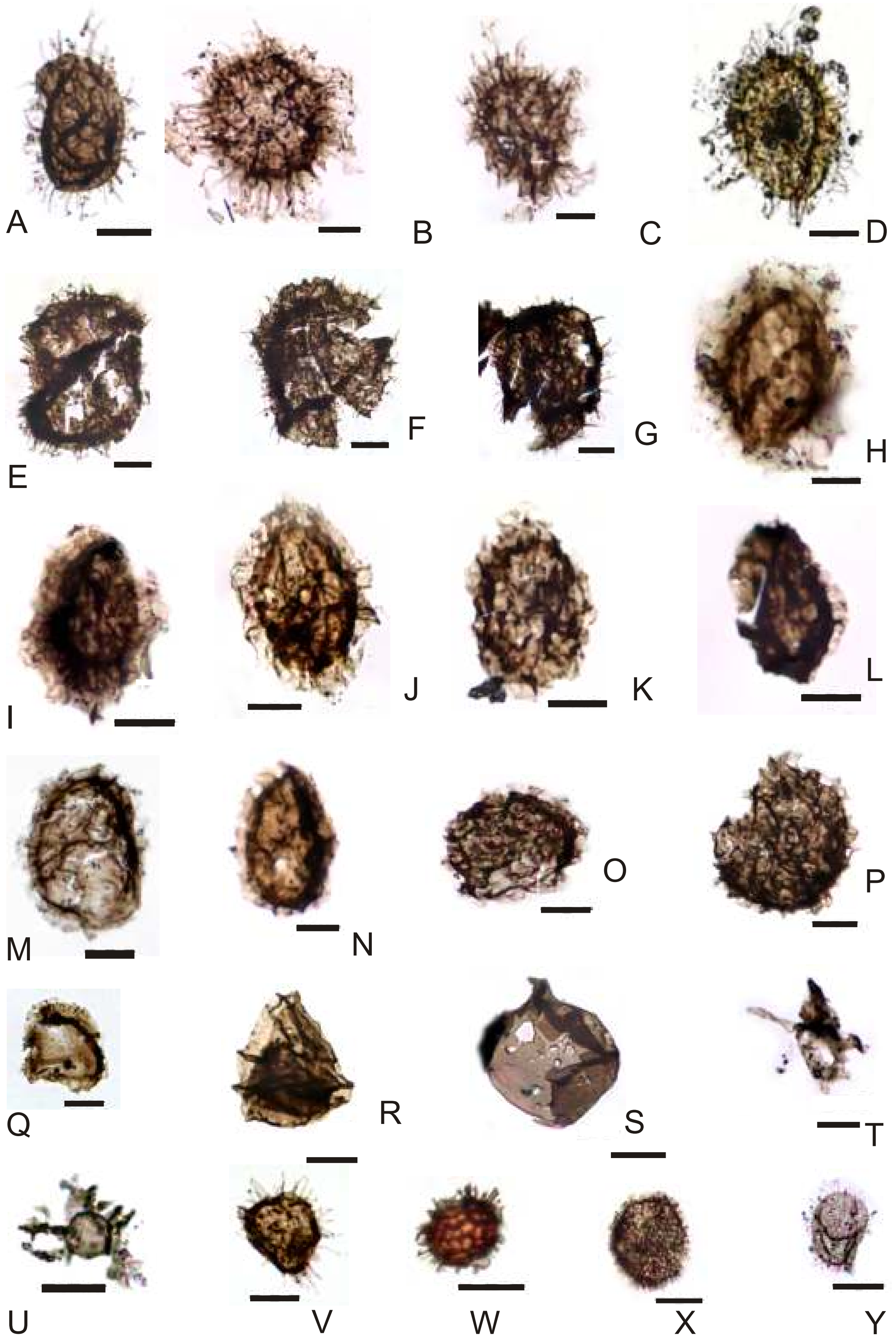

Fig. 7. Acritarchs from the Czarna Formation in the Holy Cross Mountains

A – *Ichnosphaera* cf. *delicata* Jachowicz-Zdanowska, 2013, Strazsniów PIG 1, 36.0 m, slide 6597; **B, C** – *Ichnosphaera* sp., Kotuszów C, slide 4990; **D** – ?*Ichnosphaera* sp., Zbrza PIG 2, 69.0 m, slide 6631; **E**–**G** – *Globosphaeridium cerinum* (Volkova) Moczydłowska, 1991, Kotuszów B, slide 4989; **H, I** – *Lechistania magna* Jachowicz-Zdanowska, 2013 (H – Zbrza PIG 2, 69.0 m, slide 6631; I – Kotuszów A, slide 4992n); **J, K** – ?*Fimbriaglomerella* sp. (J – Zbrza PIG 2, 63.0 m, slide 6630; K – Kotuszów C, slide 4990n); **L**–**P** – *Fimbriaglomerella membranacea* (Kiryanov) Moczydłowska and Vidal, 1988 (L – Kotuszów C, slide 4990n; M – Kotuszów B, slide 4989, N – Zbrza PIG 3, 99.0 m, slide 6295; O, P – Kotuszów A, slide 4992); **Q** – *Fimbriaglomerella* cf. *minuta* (Jankauskas) Moczydłowska and Vidal, 1988, Zbrza PIG 2, 51.2 m, slide 6628; **R** – *Cymatiosphaera* sp., Kotuszów C, slide 4990n; **S** – *Aliumella baltica* Vanderflit in Umnova and Vanderflit, 1971, Kotuszów B, slide 4989n; **T, U** – *Heliosphaeridium longum* (Moczydłowska) Moczydłowska, 1991 (T – Kotuszów C, slide 4990n, U – Kotuszów B, slide 4989n); **V** – *Heliosphaeridium* cf. *dissimilare* (Volkova) Moczydłowska, 1991, Strazsniów PIG 1, 36.0 m, slide 6597; **W** – *Heliosphaeridium* sp., Kotuszów C, slide 4990n; **X** – *Asteridium tornatum* (Volkova) Moczydłowska, 1991, Kotuszów A, slide 4992; **Y** – *Asteridium lanatum* (Volkova) Moczydłowska, 1991, Kotuszów B, slide 4989; scale bars equal 10 mm mainly of the index taxon and simple *Leiosphaeridia*. It resembles thus the assemblages described by Jachowicz-Zdanowska (2013) from Brunovistulicum (BAMA I) and by Palacios et al. (2017) from Newfoundland (*Granomarginata* interval zone). According to Jankauskas and Lendzion (1992), the richer microfloral assemblage of the *Asteridium tornatum–Comasphaeridium velvetum* Zone recognized by Moczydłowska (1991) was supposed to be a local association composed of forms with a restricted geographic range, characteristic of the Lublin Slope of the EEC and occurring in their *Granomarginata prima* Zone. However, these conclusions are not correct. Both the index taxa of the *Asteridium tornatum–Comasphaeridium velvetum* Zone, as well as most accompanying species, are widely distributed in lower Cambrian rocks around the world (Moczydłowska, 1991; Vavrdová et al., 2003; Vavrdová, 2006; Jachowicz-Zdanowska, 2013; Palacios et al., 2017, 2020). Analysis of available biostratigraphic data indicates that the *Asteridium tornatum–Comasphaeridium velvetum* Zone should be correlated not with the entire Terreneuvian, but only with its upper part, roughly corresponding to Stage 2. The assemblage from Zbrza PIG 2, with a taxonomic composition directly corresponding to that of Moczydłowska (1991) may be thus considered to represent Cambrian Stage 2. Such a suggestion is supported by the presence of *Pulvinosphaeridium antiquum*, considered as an index species for the Terreneuvian, and in the EEC known so far only from the upper part of the Lontovan (Paškevičiene, 1980). A restudy of data for particular boreholes in the Lublin Slope of the EEC (Moczydłowska, 1991: pp. 91, 93) shows the presence of very low-diversity microfloral assemblages at the base of the *Asteridium tornatum–Comasphaeridium velvetum* Zone, corresponding to the *Granomarginata* associations of Jankauskas and Lendzion (1992) and Palacios et al. (2017). Likewise, in samples from boreholes situated to the south of the localities analysed there occur very low-diversity acritarch assemblages that may probably correspond to the *Granomarginata* associations.

ZBRZA PIG 1

The assemblage recognized is dominated by *Leiosphaeridia* sp. (Table 1 and Appendix 1). Present are also *Granomarginata squamacea* (Fig. 3U), various species of *Pterospermella*, including *P. velata* (Fig. 4S), characteristic of the *Asteridium tornatum–Comasphaeridium velvetum* Zone, as well as *Comasphaeridium* div. sp. (Fig. 4J), *Lophosphaeridium* sp., *Granomarginata* div. sp. (Fig. 3U), ?*Globosphaeridium* sp. (Fig. 4I), *Synsphaeridium* sp., *Globus gossipinus* (Fig. 3R), and numerous thread-like Cyanophyta (Fig. 6S, Table 1 and Appendix 1). Such a microfloral assemblage points to an early Cambrian age of the succession. It is very close to the assemblage of the classical *Asteridium tornatum–Comasphaeridium velvetum* Zone recognized on the Lublin Slope of the EEC (Moczydłowska, 1991). The Zbrza PIG 1 assemblage is, however, of low abundance, with the exception of the sample from depth level 128 m, and the preservation of the acritarchs is rather poor; most of them are not assignable at genus level. It is similar to the assemblage from Zbrza PIG 2 (see above), but the taxonomic composition is distinctly poorer. Despite that, the taxa recognized allow for the identification of the *Asteridium tornatum–Comasphaeridium velvetum* Zone (Moczydłowska, 1991) and assignment of the rocks analysed to the upper Terreneuvian (Fig. 5).

ZBRZA PIG 3

The assemblage recognized is characterized by low abundance and low diversity (Table 1 and Appendix 1). As in the assemblages described above, the most abundant are representatives of *Leiosphaeridia*, *Comasphaeridium* and *Granomarginata* (Fig. 3V). Among forms with biostratigraphic significance occurs one specimen of *Fimbriaglomerella membranacea* (Fig. 7N). This taxon, which is not present in any other Zbrza borehole, may point to a slightly younger age compared to the assemblages discussed above. A similar, slightly younger age of the strata may be inferred from a single specimen of ?*Globosphaeridium* sp. (Fig. 4H). Despite *Fimbriaglomerella membranacea* being the index taxon of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone (Moczydłowska, 1991), the assemblage in which it occurs differs significantly from the characteristics of this zone in other areas (Moczydłowska, 1991; Jachowicz-Zdanowska, 2013; Palacios et al., 2017, 2020). The very low taxonomic composition of the assemblage does not allow for an explicit assignment of the microflora to any known palynological zone. The single occurrence of *F. membranacea* may only suggest that rocks from Zbrza PIG 3 might be slightly younger than the strata from the other two Zbrza boreholes. This suggestion is also supported by the finding of *Lophosphaeridium* cf. *dubium* (Fig. 4G, Table 1 and Appendix 1), observed by Moczydłowska (1991) in rocks representing the *Skiagia ornata–Fimbriaglomerella membranacea* Zone.

STRASZNIÓW PIG-1

Only two samples contain a relatively abundant acritarch assemblage; five remaining samples contain only strongly degraded sphaeromorphs, probably representing *Leiosphaeridia* sp. Specimens of small acritarchs representing *Leiosphaeridia*, *Asteridium* (Fig. 3N), *Synsphaeridium* (Fig. 3Z), *Pterospermopsimorpha* sp. (Fig. 3J, K), *Leiomarginata* (Fig. 3H) and *Heliosphaeridium* (Fig. 7V), often in the form of colonies composed of several individuals (Fig. 3N, Z) are relatively numerous. The single specimen of *Ichnosphaera* cf. *delicata* (Fig. 7A, Table 1 and Appendix 1) allows correlation of this assemblage with the *Ichnosphaera flexuosa–Comasphaeridium molliculum* Zone (Jachowicz-Zdanowska, 2013), although it is much less diverse than the association defining this zone in Brunovistulicum. *Pulvinosphaeridium* sp. (Fig. 3G, Table 1 and Appendix 1) is present. Representatives of this genus have been described only from the oldest Cambrian microfloral associations. Therefore rocks from Straszniów PIG 1 indicate an interval transitional between the BAMA I *Pulvinosphaeridium antiquum–Pseudotasmanites* Zone and the BAMA III *Ichnosphaera flexuosa–Comasphaeridium molliculum* Zone, and should be assigned to the upper Terreneuvian.

KOTUSZÓW A

This assemblage is dominated by sphaeromorphs referred to *Leiosphaeridia* sp. They are accompanied by morphologically diverse *Comasphaeridium* (Fig. 4K), *Granomarginata*, *Lophosphaeridium* and *Pterospermella* (Fig. 4W) (Szczepanik and Żylińska, 2016: pl. 1). Generally the taxonomic composition of this assemblage is very similar to the association representing the *Asteridium tornatum–Comasphaeridium velvetum* Zone distinguished by Moczydłowska (1991) on the Lublin Slope of the EEC, and commonly recognized in other areas (e.g., Vavrdová et al., 2003; Vavrdová, 2006; Jachowicz-Zdanowska, 2013; Palacios et al., 2017, 2020). The presence of both zonal indices was observed in the samples (Figs. 4K, 7X, Table 1 and Appendix 1). However, the assemblage contains also *Fimbriaglomerella membranacea* (Fig. 7O, P, Table 1 and Appendix 1), which is the index taxon of the stratigraphically younger *Skiagia ornata–Fimbriaglomerella membranacea* Zone (Moczydłowska, 1991). Such a microfloral assemblage seems transitional between the two zones. Acritarchs known from the Zbrza boreholes are present, i.e. *Pulvinosphaeridium* sp. (Fig. 3F), *Lechistania magna* (Fig. 7I), and a specimen resembling *Liepaina* (Fig. 6P) in general outline.

KOTUSZÓW B

As in all earlier described cases, the assemblage is dominated by sphaeromorphs assigned to *Leiosphaeridia* sp. (Fig. 6O). However, this assemblage contains also numerous representatives of *Lophosphaeridium* and other taxa (Szczepanik and Żylińska, 2016: pl. 2). For the first time in the succession analysed, there appear forms with slightly longer, spine-like simple processes, representing *Globosphaeridium cerinum* (Fig. 7E–G, Table 1 and Appendix 1). The sample contains also poorly preserved specimens of *Fimbriaglomerella membranacea* (Fig. 7M). Other forms observed in the assemblage include *Tasmanites* sp. (Fig. 4X), *Cymatiosphaera* sp. (Fig. 6N), *Aliumella baltica* (Fig. 7S), *Heliosphaeridium longum* (Fig. 7U), *Asteridium lanatum* (Fig. 7Y), and forms representing so far undescribed acritarch genera (Fig. 6B–D). Such an assemblage points to an impoverished *Skiagia ornata–Fimbriaglomerella membranacea* Zone (Moczydłowska, 1991) without representatives of *Skiagia.*

KOTUSZÓW C

The assemblage recognized has a taxonomic composition similar to that described from Kotuszów B (Table 1 and Appendix 1). Common are *Lophosphaeridium* div. sp. (Fig. 4E, F), *Comasphaeridium* div. sp. (Fig. 4P), *Heliosphaeridium* div. sp. (Fig. 7T, W), *Cymatiosphaera* sp. (Fig. 7R) and *Pterospermella* div. sp. (Fig. 4Q; Szczepanik and Żylińska, 2016: pl. 3). Of biostratigraphic significance are *Lophosphaeridium dubium* (Fig. 4F), *Fimbriaglomerella membranacea* (Fig. 7L), ?*Fimbriaglomerella* sp. (Fig. 7K) and *Ichnosphaera* sp. (Fig. 7B, C). Such a composition may indicate the presence of the BAMA III *Ichnosphaera flexuosa–Comasphaeridium molliculum* Zone (Jachowicz-Zdanowska, 2013) or an impoverished *Skiagia ornata–Fimbriaglomerella membranacea* Zone (Moczydłowska, 1991) without representatives of *Skiagia*.

BIOSTRATIGRAPHIC ANALYSIS

MICROFLORAL ASSEMBLAGES

In general, three types of lowermost Cambrian microfloral assemblage have been recognized in the samples analysed. The oldest assemblage from Zbrza PIG 1 and Zbrza PIG 2 represents the typical *Asteridium tornatum–Comasphaeridium velvetum* Zone, with a full taxonomic inventory for this interval, including the zonal indices, and additionally with *Pulvinosphaeridium antiquum,* the index species for the Terreneuvian (Paškevičiene, 1980; Jachowicz-Zdanowska, 2013), which was not observed in assemblages from the Lublin Slope of the EEC (Moczydłowska, 1991).

A stratigraphically younger microfloral assemblage occurs in Kotuszów A and Zbrza PIG 3. The assemblage, although less abundant, is generally similar to the oldest microflora, but differs in the presence of *Fimbriaglomerella membranacea*, the index taxon of the following *Skiagia ornata–Fimbriaglomerella membranacea* Zone, and acritarchs representing *Lophosphaeridium* with well-developed sculpture elements, i.e. *L. truncatum* and *L.* cf. *dubium.* However, the taxonomic composition of this assemblage is much less diverse than the classical *Skiagia ornata–Fimbriaglomerella membranacea* assemblage zone as defined by Moczydłowska (1991). Analysis of the composition of assemblages considered as equivalent to that zone shows that the zonal index *Fimbriaglomerella membranacea* is not always present in them (e.g., Jachowicz-Zdanowska, 2013). In the Lublin Slope succession (Moczydłowska, 1991), the index taxon was noted solely at depth level 1892 m of the Parczew IG 1 borehole, where the presence of *Skiagia* was not observed. Likewise, in the Kościerzyna IG 1 borehole in the Pomerania area, *Fimbriaglomerella membranacea* appears stratigraphically earlier than representatives of *Skiagia* (Szczepanik, 2000: table 1). A similar case seems to be present in the succession from the Holy Cross Mountains studied herein. Although detailed studies cannot be performed due to the large thickness of the lower Cambrian strata, strong folding, and lack of continuous sections, it has been observed that *Fimbriaglomerella* clearly predates *Skiagia* in the succession. Therefore, the assemblage recognized seems transitional in character and represents a separate biostratigraphic unit at the base of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone. Apart from Kotuszów A, a similar microflora has been recognized in Zbrza PIG 3, where a slightly impoverished assemblage with *Fimbriaglomerella* sp. is present. Other taxa that appear in this association, distinguishing it from the assemblage characterising the *Asteridium tornatum–Comasphaeridium velvetum* Zone, include *Lophosphaeridium truncatum* and *Lophosphaeridium* cf. *dubium.*

The next characteristic microfloral assemblage was distinguished in Kotuszów B and C. It contains more specimens of *Lophosphaeridium* and *Comasphaeridium* and has a proportionally lower contribution of *Leiosphaeridia* sp. The taxa recognized include: *Fimbriaglomerella membranacea*, *Globosphaeridium cerinum*, *Lophosphaeridium dubium*, *L. truncatum* and *Ichnosphaera* sp. In the EEC and in other areas with lower Cambrian strata, these forms are characteristic of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone, but the assemblages from Kotuszów do not contain representatives of *Skiagia.* This taxon, represented by the species *S. ornata* and *S. orbiculare*, was recognized in stratigraphically younger strata of the Cambrian succession in the Holy Cross Mountains, in exposures located to the north of the sites discussed herein (Kotuszów Locality 5 of Szczepanik and Żylińska, 2016) and in shallow boreholes located to the north of Kotuszów (Kowalczewski et al., 1987). Thus, as in the case of the earlier assemblage, the microflora from Kotuszów B and C is transitional between the *Asteridium tornatum–Comasphaeridium velvetum* and the *Skiagia ornata–Fimbriaglomerella membranacea* zones according to the original definition of Moczydłowska (1991), and additionally contains taxa new for this interval, i.e. *Globosphaeridium cerinum*, *Lophosphaeridium dubium*, *Ichnosphaera* sp. and *Aliumella baltica.*

As our observations are restricted to individual, isolated sections, it would be inconsistent to treat the two transitional assemblages as two separate biostratigraphic zones. Analysis of the microflora transitional between those characteriszing the *Asteridium tornatum–Comasphaeridium velvetum* and the *Skiagia ornata–Fimbriaglomerella membranacea* zones allows to distinguish a new assemblage zone, i.e. the *Fimbriaglomerella membranacea–Globosphaeridium cerinum* Assemblage Zone (Fig. 8).

The establishment of the genus *Ichnosphaera* (Jachowicz-Zdanowska, 2013) poses some difficulties as regards the identification of particular biostratigraphic zones in the lower Cambrian. In some cases its synonymy includes forms assigned earlier to *Skiagia*. An intrinsic feature of *Skiagia* is the presence of funnel-shaped terminations of the processes. In poorly preserved material, however, when the terminations of the processes are destroyed, *Skiagia* may be confused with *Ichnosphaera*. For example, such doubts arise when analysing the specimens from Newfoundland assigned to *S. ornata* and *S. orbiculare* (Palacios et al., 2017: fig. 6g, h; 2020: fig. 4a, b, d, e), indicative of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone, which resemble rather *Ichnosphaera* than *Skiagia*. Additionally, if the specimens from the lower part of the Lower Member of the Duolbagáisá Formation of the Digermulen Peninsula assigned by Palacios et al. (2020) to *Skiagia* may be reinterpreted as *Ichnosphaera*, then they clearly also predate the appearance of trilobites in that formation (Palacios et al., 2020: fig. 2). Our observations in the Cambrian succession of the Holy Cross Mountains indicate that forms without characteristic funnel-shaped terminations of the processes (*Ichnosphaera*) appear much earlier than the typical *Skiagia*. Jachowicz-Zdanowska (2013) correlated her BAMA III *Ichnosphaera flexuosa–Comasphaeridium molliculum* Zone with the *Skiagia ornata–Fimbriaglomerella membranacea* Zone, but indicated also that specimens of *Skiagia* are only sporadically represented in BAMA III among the numerous specimens of *Ichnosphaera* (Jachowicz-Zdanowska, 2013: p. 31). In some boreholes in Upper Silesia, e.g. Piotrowice IG 1, the appearance of *Ichnosphaera* evidently predates *Skiagia* (see Jachowicz-Zdanowska, 2013). Taking this into account, as well as the fact that the BAMA III assemblages also yield taxa characteristic of the *Asteridium tornatum–Comasphaeridium velvetum* Zone, e.g. *Comasphaeridium velvetum*, *C. agglutinatum* and *Pterospermella velata*, it should be considered that at least the lower part of BAMA III may correspond to the newly proposed *Fimbriaglomerella membranacea–Globosphaeridium cerinum* Assemblage Zone*.* This conclusion is supported by the occurrence of *Ichnosphaera* sp. and *Lechistania magna*, noted in this interval in Upper Silesia (Jachowicz-Zdanowska, 2013) and in the interval analysed from the Holy Cross Mountains (Zbrza PIG 3 and Kotuszów A).

CHRONOSTRATIGRAPHIC POSITION OF THE MICROFLORAL ASSEMBLAGES

A separate issue is the precise chronostratigraphic position of the lower Cambrian acritarch zones. Particularly significant is the chronostratigraphic position of the base of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone, which in its classical definition is supposed to be close to the first appearance of the *Schmidtiellus mickwitzi* Zone trilobites. In the Polish part of the EEC, where the *Skiagia ornata–Fimbriaglomerella membranacea* Zone was originally defined (Moczydłowska, 1991; however, the author related the *Skiagia ornata–Fimbriaglomerella membranacea* Zone to an interval 'equivalent to the *Schmidtiellus mickwitzi* Zone'), so far there are no trilobite finds pointing to the *Schmidtiellus mickwitzi* Zone, whereas the acritarch assemblages of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone occur substantially below the first appearance of trilobites in the succession (see e.g., Pacześna, 2008; Fig. 5). In Baltica, the oldest trilobites appear in the Lükati Formation of the Dominopolian regional stage in Estonia (e.g., Ahlberg et al., 1986; Schoenemann et al., 2017), in beds with *Volbortella tenuis*, considered as representing the Dominopolian regional stage, in the Ukraine (Volyn) (Kiryanov and Chernysheva, 1967), and in beds corresponding to the upper part of the Dominopolian stage in the Norretorp Member in Scania (S Sweden) (e.g., Bergström 1973). Nielsen and Schovsbo (2011) have also shown that in Scandinavia the *Skiagia ornata–Fimbriaglomerella membranacea* Zone in its lower part corresponds to the traditional *Rusophycus* Zone, but because it is not clear whether the *Rusophycus* isp. trace fossils were made by trilobites or other arthropods, they suggest that it is uncertain whether the *Rusophycus* Zone corresponds to the Terreneuvian or Cambrian Series 2. Moczydłowska and Yin (2012) used radiometric data to indicate that the assemblages of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone appeared earlier than the first trilobites, i.e. already in the late Terreneuvian.

Following these data, the chronostratigraphic position of the newly proposed *Fimbriaglomerella membranacea–Globosphaeridium cerinum* Zone corresponds to the middle and upper Terreneuvian (Cambrian Stage 2) and clearly predates the FAD of trilobites considered as a marker of the Terreneuvian/Cambrian Series 2 boundary. The age of the older *Asteridium tornatum–Comasphaeridium velvetum* Assemblage would point to the boundary interval between the Fortunian and Cambrian Stage 2.

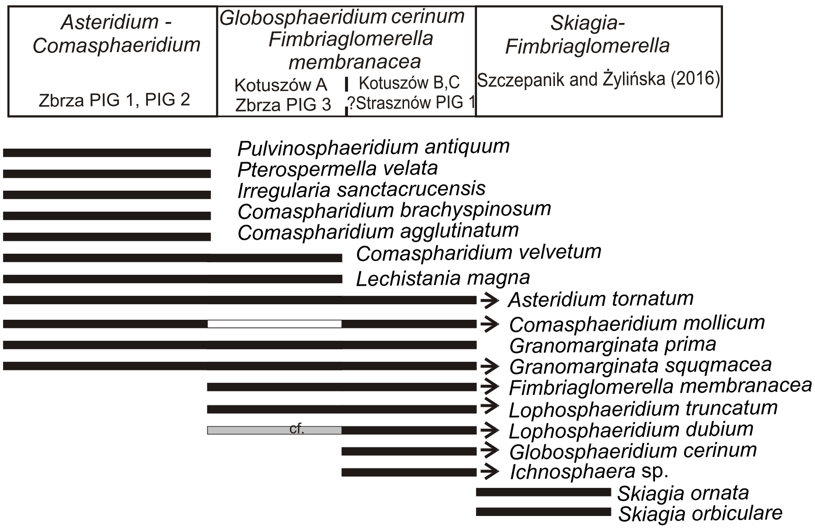

Fig. 8. Ranges of the acritarch taxa recognized with reference to the newly proposed assemblage zone

White bar refers to lack of data, grey bar refers to doubtful assignments

CONCLUSIONS

1. Well-preserved acritarch assemblages have been recognized in the Cambrian rocks from the southern peripheries of the Holy Cross Mountains in Poland. The assemblages contain taxa known from other areas in the world characterized by the presence of lower Cambrian rocks. Accordingly, the previously suggested Terreneuvian age of the rock succession, extremely poor in macrofossil remains, has been confirmed.

2. The recognition of *Pulvinosphaeridium antiquum*, not noted previously in the Holy Cross Mountains or the Polish part of the EEC, allows for direct age assignment of the assemblage characterising the *Asteridium tornatum–Comasphaeridium velvetum* Zone to the Terreneuvian. Moreover, the presence of acritarchs representing *Variosphaeridium* gen. nov. expands the hitherto recognized diversity of the oldest acritarch assemblages from the Cambrian.

3. Analysis of the palynological data obtained allows introduction of the *Fimbriaglomerella membranacea–Globosphaeridium cerinum* Zone, of transitional character between the previously recognized *Asteridium tornatum–Comasphaeridium velvetum* and *Skiagia ornata–Fimbriaglomerella membranacea* zones. The presence of the new transitional zone in the study area may be linked with larger thicknesses of the lowermost Cambrian resulting in lower condensation of the succession compared to other areas with equivalent strata.

SYSTEMATIC PALAEONTOLOGY

Genus *Variosphaeridium* n. gen.

Type species. – *Variosphaeridium sanctacrucensis* n. sp.

Derivation of name. – From Latin *varius*, diverse, with reference to the very variable shape of the processes.

Variosphaeridium sanctacrucensis n. sp.
(Fig. 6E–M)

Derivation of name. – The specific name, *sanctacrucensis*, is a Latinised reference to the Holy Cross Mountains as the region of the find.

Holotype. – Fig. 6G – OS PGI – 6629 – X40.

Material. – 26 well-preserved specimens.

Type locality. – Poland, Holy Cross Mountains, Zbrza PIG 2 borehole, Czarna Shale Formation.

Diagnosis. – Acritarchs with an oval, rarely elongated outline, with a unilayer vesicle wall. Numerous processes (8 to >30) with wide bases and trunks. The processes vary in shape, but usually one type is dominant on a single specimen. Processes with wide bases and very irregular shapes, from simple to multibranched. Trunks of the processes are straight, of even width along their entire length. Tips of the processes are usually rounded, with second order processes, forming shapes resembling fingered hands, spiny clubs or cylinders. A characteristic feature of the processes is their significantly large width. In extreme cases the width attains the same values as the length and in effect the processes become cube-shaped. The number of processes is inversely proportional to increasing process dimensions, i.e. smaller processes are more numerous and larger processes are less numerous. The vesicle surfaces are quite thick, usually smooth, often with swellings and foldings. Walls of the processes are thin and smooth. Bases of the processes are hollow and communicate with the inner cavity of the vesicle.

Remarks. – The characteristic unique type of the processes distinguishes *Variosphaeridium sanctacrucensis* gen. et sp. nov. from all other acritarch species.

Dimensions (N = 20):
- Length of central vesicle: 28–50 mm;
- Width of central vesicle: 22–38 mm;
- Number of processes: 20 to >40;
- Width of processes: 4–10 mm;
- Length of processes: 6–12 mm.

Present record: Terreneuvian, Czarna Shale Formation.

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