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Acritarchs from Cambrian deposits of the southern part of the Łysogóry unit in the Holy Cross Mountains, Poland

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The palynology of the Cambrian claystones and mudstones of the Góry Pieprzowe Shale Formation in the southern part of the Łysogóry region (Holy Cross Mts., Poland) are described. These deposits had been referred to the Middle Cambrian of the *Paradoxides paradoxissimus* and *Paradoxides forchhammeri* Superzones. Here, rocks from 10 shallow drillings and several exposures in the Opatów region have been examined. Scarce and poorly preserved acritarch assemblages contain several forms that are indicative for the Upper Cambrian, while the genera *Acanthodiacrodium, Cymatiogalea, Stelliferidium, Trunculumarium, Nellia, Impluviculus, Calyxiella,* and *Veryhachium* excludes the possibility of a Middle Cambrian age. Rather, these forms suggest the Upper Cambrian, most probably its middle and upper part. The occurrence of the rocks of this age to both north and south of the Łysogóry quartzite outcrops indicates tectonic repetition of the geological structure in the Main Range of the Holy Cross Mountains.
The dark colours of palynoflora from the Pieprzowe Mountains in Sandomierz are identical with the colours of the Cambrian microflora from the Łysogóry region, and differ from the bright colours characterising organic matter in the Kielce region of the Holy Cross Mountains. This suggests a tectonic relation of the Pieprzowe Mountains with the Łysogóry region rather than with the Kielce region, as hitherto thought.

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Key words: Holy Cross Mts., Łysogóry unit, Cambrian, acritarchs.

INTRODUCTION

The Cambrian rocks that are widely distributed in the Holy Cross Mountains have prompted much discussion (Stupnicka, 1988; Pożaryski and Tomczyk, 1993; Kowalczewski, 1995; Orłowski and Mizerski, 1995; Kowalczewski and Dadlez, 1996; Znosko, 1996), mainly concerning their stratigraphy. Trilobites, although long noted, come from too few localities to resolve the stratigraphy or constrain tectonic and palaeogeographic models.

The most neglected Cambrian rock formation in the Holy Cross Mountains is the Góry Pieprzowe Shale Formation (Orłowski, 1975). Middle Cambrian trilobites have been found, in the Kamień Łukawski quarry and on Pączek hill (Gürich, 1892, Orłowski, 1964, 1985), but only from part of the succession, which achieves substantial thicknesses. The rocks along the southern slopes of the Main Range (Fig. 1), included in this formation, had not yielded fossils, while lithological correlation was uncertain. These rocks were most commonly ascribed to the Middle Cambrian — to the *P. paradoxissimus* and *P. forchhammeri* Superzones (Samsonowicz 1934; Tomczykowa, 1968; Orłowski, 1975, 1988), although the Lower Cambrian has also been suggested (Czarnocki, 1947, 1957; Żak, 1962; Kowalczewski *et al.*, 1976; Kowalczewski, 1995).

Since the 1960's, acritarchs have become increasingly important in dating early Palaeozoic rocks. Acritarchs from the southern part of the Holy Cross region and from the Nida Basin (Vidal in: Pożaryski *et al.*, 1981; Lendzion *et al.*, 1983; Moczydłowska in: Kowalczewski *et al.*, 1984, 1987) provided a detailed Cambrian biostratigraphy, which in turn constrained the geological structure. In this paper, acritarchs are used to date the mudstones and claystones of the Łysogóry region, which up to now were devoid of palaeontological documentation. These studies have been encouraged by preliminary work (Moczydłowska in: Kowalczewski *et al.*, 1987), which outlined the problems of age and structure in the Main Range of the Holy Cross Mountains.

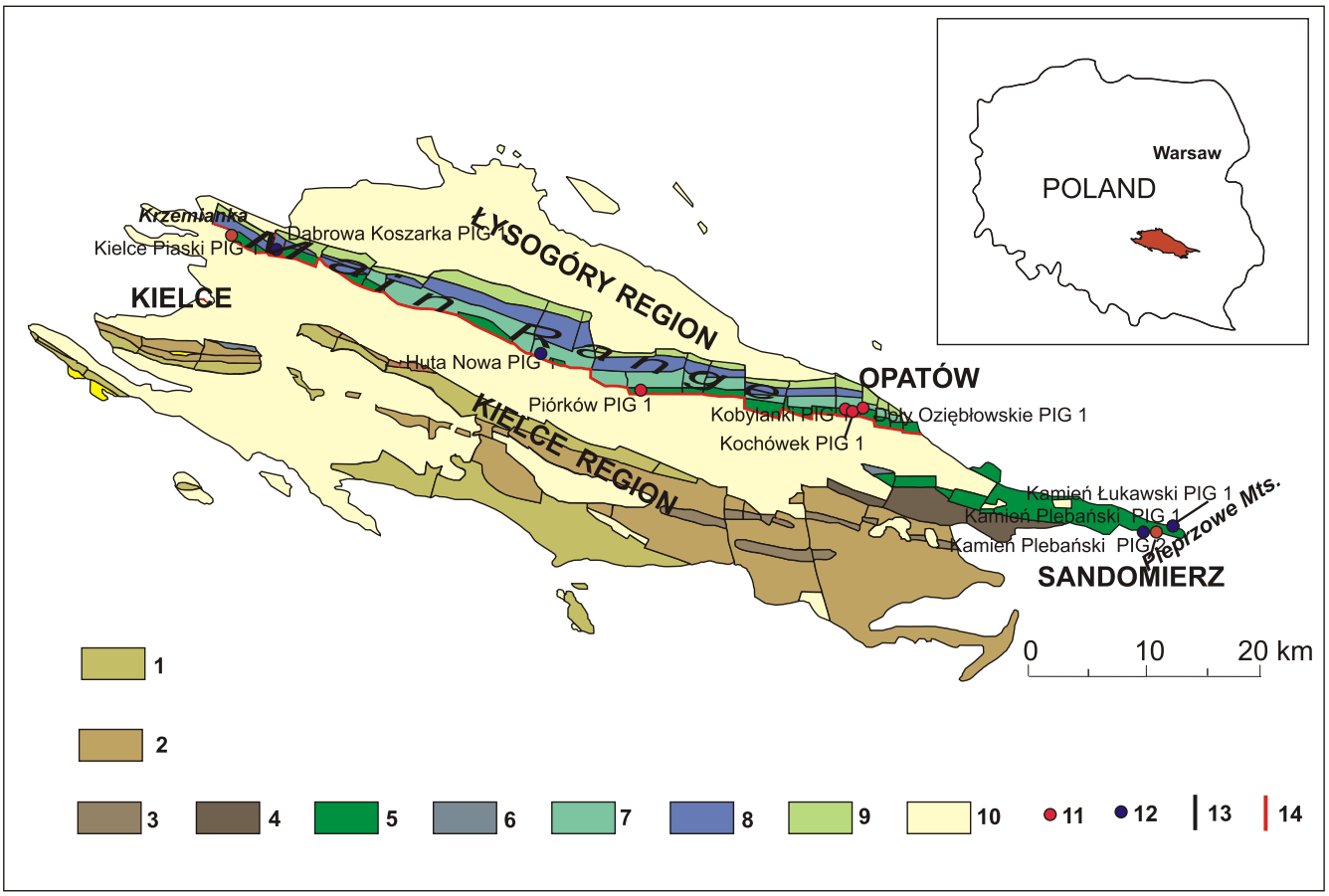


Fig. 1. Location of the boreholes drilled, and Cambrian outcrops in the Holy Cross Mountains

1— Czarna Shales, 2 — Ociesęki Sandstones and Kamieniec Shales, 3 — Słowiec Sandstones, 4 — Usarzów Sandstones, 5 — Góry Pieprzowe Shales (part of the Góry Pieprzowe Shale Formation), 6 — Ublinek Beds, 7 — Krajno Beds (part of the Góry Pieprzowe Shale Formation), 8 — Wąworków Sandstones, Łysogóry Quartzites (Wiśniówka Quarzitic Sandstone Formation), 9 — Mąchocice Beds, Łysogóry Beds (Klonówka Shale Formation), 10 — deposits younger that Cambrian, 11 — boreholes, in which acritarchs were found, 12 — boreholes, in which acritarchs were not found, 13 — faults, 14 Holy Cross Fault

AIM OF STUDIES

Early attempts at finding acritarchs in the Góry Pieprzowe Shale Formation from field exposures were not successful. Therefore, 10 shallow (up to 40 m) boreholes were drilled into unweathered rock, in order to recover stratigraphically useful microflora.

This sampling took place in the southern part of the Łysogóry region, adjacent to the Main Holy Cross Fault and in the Pieprzowe Mountains (Fig. 1), which as regards overall structure are included in the Kielce region of the Holy Cross Mountains.

In the west part of the area sampled, the drilling took place along the southern slopes of the Main Range, in an area limited to the south by the Main Holy Cross Fault, and to the north by the Wiśniówka Quartzitic Sandstone Formation (Orłowski, 1975). Four shallow boreholes: Kielce-Piaski PIG 1, Dąbrowa-Koszarka PIG 1, Huta Nowa PIG 1, Piórków PIG 1 (Fig. 1) were drilled here.

In the Opatów region, where most of the surface sampling was concentrated, the topography is lower and outcrop pattern is not so distinct. Acritarchs from the Kochówka, Kania and Opatówka valleys, and from the Kochówek PIG 1, Kobylanki PIG 1 and Doły Oziębowskie PIG 1 boreholes were studied (Fig. 2).

Around Sandomierz the rocks from three boreholes were studied: Kamień Plebański PIG 1, Kamień Plebański PIG 2 and Kamień Łukawski PIG 1 (Fig. 1).

LITHOLOGY AND TECTONICS OF THE ROCKS STUDIED

The borehole material obtained was generally poor, with cores often disintegrated. The cores are dominantly of dark grey and black claystones (Fig. 3), locally accompanied by mudstones of similar colour. Scarce, thin (up to 1 cm) sandstone interlayers occur.

All rocks studied are strongly tectonized (Fig. 3), with both brittle and plastic deformation. Where bedding is visible, dips are varied, and most commonly steep. Brecciation zones are common, as fine, randomly arranged claystone clasts bound by fine-grained claystone detritus. These are generally difficult to recognise, because of fracturing during drilling, and they were obtained only in the form of loose fragments. In some drillings

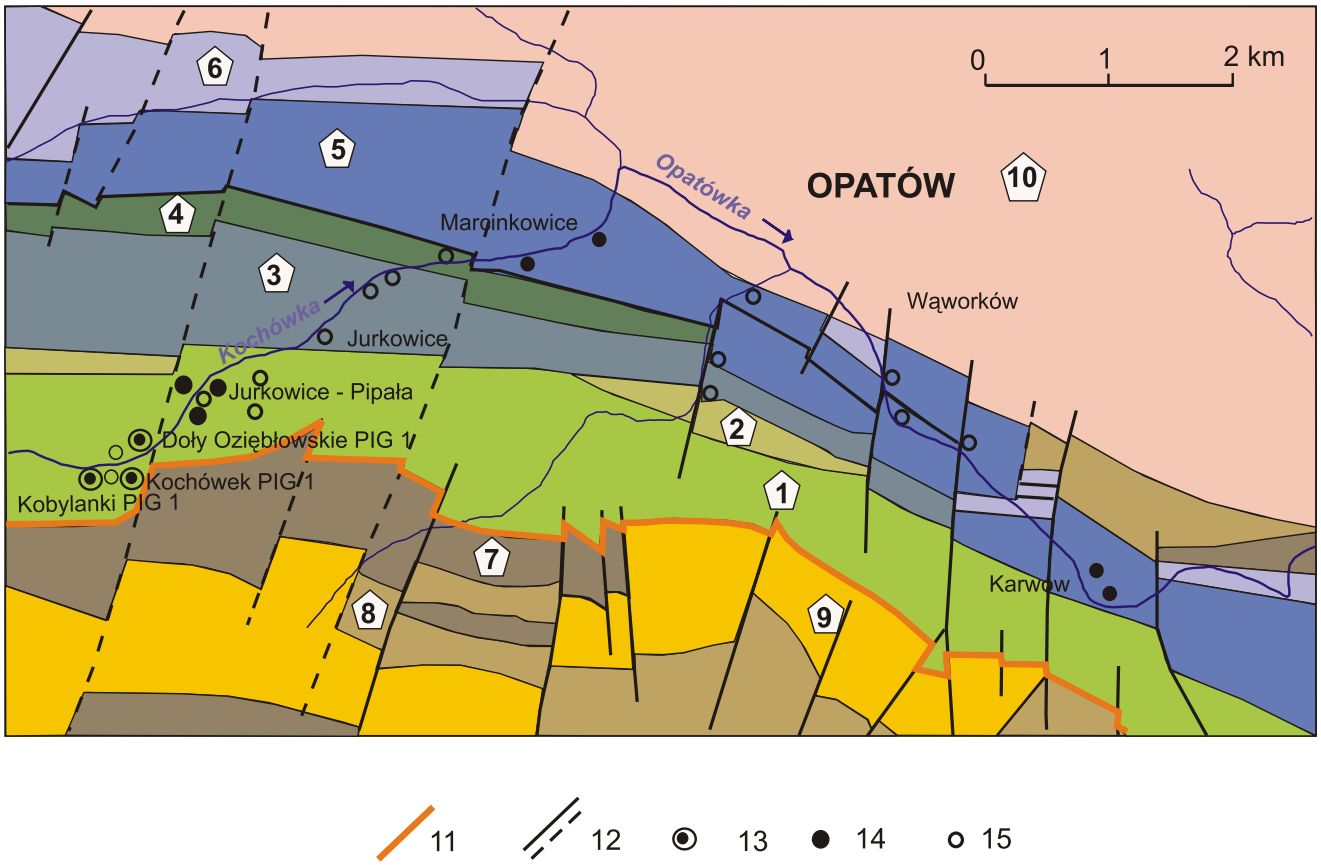


Fig. 2. Geological map of the Opatów area after Z. Kowalczewski (Kowalczewski *et al.*, 1976); age interpretation changed

1 — claystone package (Upper Cambrian, most probably the middle part of the Upper Cambrian); 2 — mudstone-claystone succession (?Cambrian, age undetermined); 3 — sandstone-mudstone succession (? Cambrian, age undetermined); 4 — mudstone-claystone succession (? Cambrian, age undetermined); 5 — sandstone-quartzite-mudstone succession (Upper Cambrian, most probably lower part of the Upper Cambrian); 6 — Ordovician and Silurian; 7 — Lower Devonian; 8 — Middle Devonian; 9 — Upper Devonian; 10 — Permo-Mesozoic; 11 — Main Holy Cross Fault; 12 — faults: a — certain, b — probable; 13 — boreholes studied; 14 — localities of positive samples; 15 — localities of negative samples

(Kamień Plebański PIG 2, Piórków PIG 1) the fracturing was so extensive, that no material was obtained from intervals of several metres. Slickensides on bedding and fracture surfaces are common, while fracture surfaces are often inclined at about 30° bedding. Fracture patterns are often picked out by white minerals of the alum group, which also crystallized as veins and in spaces generated tectonically. Minor folds were rarely obseved.

All boreholes are similarly affected, suggesting that the whole southern part of the Łysogóry region and Pieprzowe Mountains were subject to intensive tectonic deformation.

METHODOLOGY

200–400 g samples were macerated by acid dissolution and flotation. Glycerine-gelatine preparations were made of all macerates, and were studied in transmitted light. Pictures of the specimens were recorded as graphic computer files on to a database, and used as illustration in this paper.

Individual samples vary in acritarch frequency. The least common assemblages were found in the Pieprzowe Mountains, where only *ca.* 10% of the samples contain scarce palynomorphs. Acritarchs were most frequent in the Kochówek-Oziębłów region. Along the southern slopes of the Main Range, acritarchs were found in only two out of four boreholes. In the Kielce-Piaski PIG 1 borehole, three samples yielded scarce but stratigraphically useful assemblages of poorly preserved palynomorphs. In the Piórków PIG 1 borehole an assemblage yielded numerous microspores determined by E. Turnau (pers. inf.) as mixed Devonian and Carboniferous, together with individual acritarchs of Lower Cambrian to lower Middle Cambrian age. The palynomorphs are relatively well preserved and their colours are bright.

The acritarchs are mostly thermally altered, with colours ranging from dark brown to black. No fractures or traces of abrasion that could indicate redeposition were found. The poor preservation state mean that most determinations are at generic level.

RESULTS OF PALYNOLOGICAL STUDIES

PIEPRZOWE MOUNTAINS

Three boreholes were drilled in the Pieprzowe Mountains. Two (Kamień Plebański PIG 1 and Kamień Plebański PIG 2) were drilled along the western limit of the Pieprzowe Moun-

Table 1

Occurrence of acritarch species

Species	Kamień Pomorski PIG 1	Kamień Pomorski PIG 2	Kamień Łukawski PIG 1	Kochówek PIG 1	Doły Orzechowskie PIG 1	Kobylarki PIG 1	Półków PIG 1	Huta Nowa PIG 1	Dąbrowa Koszalińska PIG 1	Kicko-Piaski PIG 1	Jutkowice-Pipela	Marcinkowice	Kerwów
Acanthodiacrodium sp.										+	-		
?Acanthodiacrodium sp.											-		
Acritarcha "galeate"												-	
Adara cf. *alea* Martin						+							
Aranidium sp.						+				-			
?Aranidium sp.						+				+			
Asteridium cf. *spinosum* (Volkova)	+												
Asteridium sp.					+					-	-		
Asteridium tornatum (Volkova)										+			
?Calyxiella sp.											-		
Calyxiella cf. *izhoriensis* Golub et Volkova	-												
Calyxiella sp.					-								
Comasphaeridium sp.				+		+				+	-		
?Comasphaeridium sp.					-	+							
Cristallinium cambriense (Slavikova)	+			+	+	+				+	-	-	+
Cristallinium sp.	+			-	-	+				+	+	-	+
?Cristallinium sp.					+	+				+			
Cymatiogalea sp.					+	+					-	-	
?Cymatiogalea sp.					+	-					+	+	
Cymatiosphaera sp.				+	+	+						-	
?Cymatiosphaera sp.	+			+								+	
Diacromorphitae gen. et sp. ind.										-	+	+	
Dictyotidium sp.					+	+				+			
?Dictyotidium sp.												+	
Eliasum llanisicum Fombella						+				+			
Eliasum sp.	+					+				+			
Granomarginata sp.											+		
Heliosphaeridium sp.						+				+	+		
Implviculus sp.	+					-				+		+	
Izhoria angulata Golub et Volkova					-								
?Ladogiella sp.										+			
Leiofusa sp.											+		
Leiosphaeridia sp.	+			+		+				+	+	-	-
Lophodiacrodium sp.											+		
?Lophodiacrodium sp.											+		
Lophosphaeridium sp.	+			+	-	+	+			+	+	+	
Micrhystridium cf. *lanceolatum* Vanguestaine	+			+									
Micrhystridium lanceolatum Vanguestaine	+												
Micrhystridium sp.	-					+				+	-		
Multiplicisphaeridium martae Cot D						+					+		
Multiplicisphaeridium sp.						-				+	+	+	
Nellia magna Volkova										-			
Nellia sp.										+			
Polygonium cf. *martinae* Moczydłowska						+							
Polygonium cf. *minimum* (Timofeev)										+	+		
Polygonium cf. *pugens* (Timofeev)					-								
Polygonium martinae Moczydłowska						+							
Polygonium minimum (Timofeev)						+				+	+		
Polygonium div. sp.	-				-	+				+	+	+	+
Pterospermella sp.					-	+				+			
?Pterospermella sp.							+						
Retisphaeridium sp.					-	+				+			
?Retisphaeridium sp.													+
Stelliferidium sp.					.	+							
?Stelliferidium sp.						+				+	+		
Timofeevia cf. *phosphoritica* Vanguestaine												-	
Timofeevia phosphoritica Vanguestaine					+	+				-		+	+
Timofeevia sp.				+	+	+				+		+	+
Trunculumarium revinium (Angelin)										+	+		
Veryhachium sp.						-					+		
?Vogtlandia sp.											+		

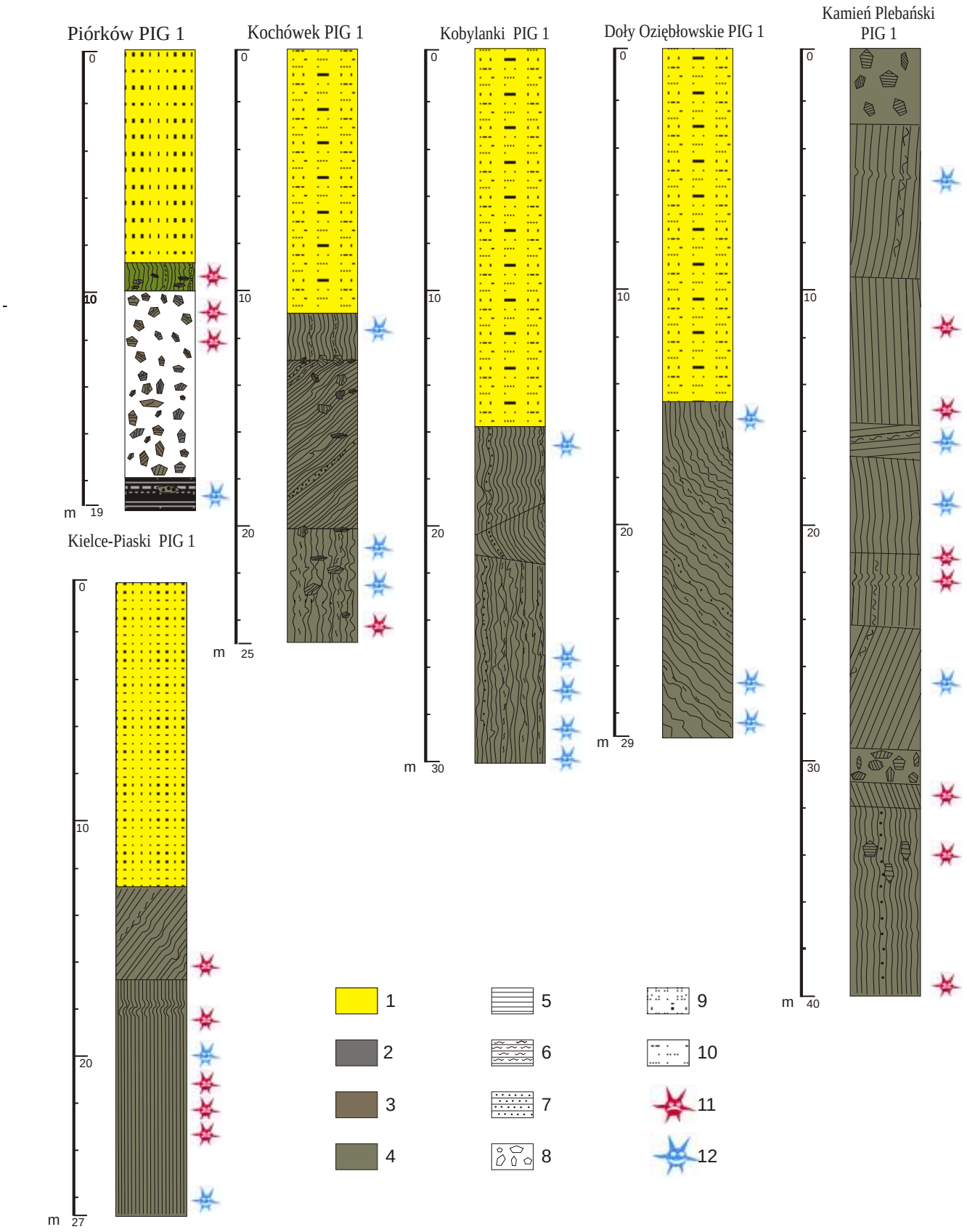


Fig. 3. Profiles of selected boreholes

1 — Quaternary, 2 — Carboniferous, 3 — Devonian, 4 — Cambrian, 5 — claystones, 6 — mudstones, 7 — sandstones, 8 — breccias, 9 — loess sands, 10 — sands, 11 — samples, in which no microflora has been found, 12 — samples, in which microflora has been found

tains escarpment (Fig. 1), one where the flood dam reaches the escarpment and one in the Kamień Łukawski village (Fig. 1). These investigated the rocks on either side of the old sandstone quarry which had yielded a Middle Cambrian trilobite fauna.

All boreholes made in the Sandomierz region reached the monotonous black claystones of the Góry Pieprzowe Shale Formation (Fig. 3). These contain little or no coarser material or sedimentary structures, perhaps exacerbated by the steep bedding dip (70–90°) and therefore a small true thickness of the succession studied.

Only one of these boreholes, on the western side of the quarry (Kamień Plebański PIG 1), yielded acritarchs, which were scarce and badly preserved (Table 1). Most common here are *Eliasum* sp. and *Cristallinium cambriense* (Slavikova), with poorly preserved forms referable to *Micrhystridium*, including *M. lanceolatum* Vanguestaine. Most of these forms show long stratigraphic ranges, from the Middle Cambrian to the Tremadoc, or even younger, though this type of assemblage is most commonly found in the Middle Cambrian. However, the acritarchs include Upper Cambrian forms: *Calyxiella* cf. *izohoriensis* Golub et Volkova (Pl. I, Fig. 26) and *Impluviculus*. Both genera occur no earlier than the middle or upper (*Calyxiella*) part of the Upper Cambrian.

Two stratigraphic interpretations are possible:

— an atypical Upper Cambrian assemblage, dominated by long-ranging forms with only a minor contribution of typical Upper Cambrian acritarchs; in such a case, the uppermost Cambrian may be excluded, because characteristic "galeate" and Diacriodae forms were already very common at that time;

— tectonic mixing of the claystones in the Kamień Plebański PIG 1 borehole; these are strongly crumpled and slickensided and contain common brecciation levels (Fig. 3); Middle Cambrian claystones could have been tectonically interleaned with Upper Cambrian deposits.

The first of these hypotheses seems more probable in explaining the presence of typical Upper Cambrian genera.

OPATÓW AREA

Bulk of the Cambrian claystone outcrops of the Opatów area, indicated on the geological maps and mentioned in the older papers, do not exist any more. In this context, the samples from the three shallow boreholes (Fig. 2) are very useful. 12 samples were studied, and acritarchs were found in 11 of them (Fig. 3, Table 1).

Several hundred acritarchs were recovered. Their poor preservation and low frequency limit assignation to the Upper Cambrian (Fig. 4), and reference to the precise biostratigraphy proposed for the East European Craton (Volkova, 1990) (Fig. 4) is not possible. In general, though, the acritarch assemblages are similar to those described from the former USSR (Volkova and Golub, 1985; Volkova, 1990).

Generally positive results have been obtained from 4 regions (Fig. 2, Table 1). These are:

— Oziębłów-Kochówek region, in the extreme south of the area studied,

— exposures near the Jurkowice-Pipała farmstead,

— exposures in the valley escarpment at Marcinkowice,

— Karwów-Krowieniec region.

KOCHÓWEK-OZIĘBŁÓW REGION

The area is located along the Main Holy Cross Fault zone, between the villages of Bratków, Kobylanki and Kochówek (Fig. 2). Rocks from three boreholes were studied: Kobylanki PIG 1, Kochówek PIG 1 and Doły Oziębłowskie PIG 1 (Fig. 3), and also from exposures in Kobylanki and Kochówek. Positive results were obtained only from the borehole cores (Table 1), which were mainly of claystones with thin sandy interlayers and laminae. Sedimentological analysis was restricted by the poor core preservation, with material obtained only as clasts. This probably results both from deep weathering and from strong tectonic fracturing.

The poorest assemblage was recognised in the Kochówek PIG 1 borehole (Table 1). The acritarchs here have a wide stratigraphic range of Middle and Upper Cambrian to Lower Tremadoc. The presence of *Timofeevia* suggests a level not older than the Middle Cambrian *P. paradoxissimus* Superzone (Volkova, 1990; Lendzion and Jankauskas, 1992).

A similar, but more abundant assemblage was found in the Doły Oziębłowskie PIG 1 borehole (Table 1), mostly comprising forms ranging from the Middle to the Upper Cambrian: *Cristallinium cambriense* (Slavikova) (Pl. III, Fig. 2), *Micrhystridium* div sp. with scarcer *Timofeevia phosphoritica* Vanguestaine, *Dictyotidium* sp., *Eliasum llaniscum* Fombella, *Comasphaeridium* sp., *Polygonium* div. sp., and *Pterospermella* sp. These long-ranging (Lower/Middle Cambrian to Tremadoc; Welsch, 1986; Martin and Dean, 1988; Volkova, 1990; Moczydłowska, 1995) forms are accompanied by *Izohoria* sp., *Calyxiella* sp. (Pl. I, Fig. 27) and poorly preserved forms most probably representing *Cymatiogalea* sp. and *Stelliferidium* sp. (Pl. I, Figs. 18, 22). These are not known from deposits younger than Upper Cambrian.

The most numerous and best preserved assemblage was found in the Kobylanki PIG 1 borehole (Table 1): *Cymatiogalea* sp. (Pl. I, Fig. 17), *Stelliferidium* sp. (Pl. I, Fig. 23), *Impluviculus* sp. (Pl. II, Figs. 17, 18), *Veryhachium* sp. (Pl. II, Fig. 13), *Adara* cf. *alea* Martin (Pl. III, Fig. 13), *Eliasum llaniscum* Fombella (Pl. II, Figs. 10, 11), *Lophosphaeridium* sp., *Polygonium* sp., *Timofeevia* sp. (Pl. III, Fig. 14) and others. This assemblage suggests a level not older than WK 2 (*Olenus*) of the Upper Cambrian and probably not younger than WK 5 (*Peltura*) of the Upper Cambrian (Fig. 4).

The Upper Cambrian acritarchs are accompanied by a single specimen of *Adara* cf. *alea* Martin, which has been thought to be of lower Middle Cambrian age (Volkova, 1990). Moczydłowska (1998) suggests that this form reaches the Upper Cambrian and this find supports this interpretation.

JURKOWICE-PIPAŁA REGION

This region includes the southern Kochówka valley, south of Jurkowice, where the claystones and mudstones, similar to those of the Kochówek-Kobylanki region are exposed. Three of the samples yielded abundant acritarchs, including a dozen or so acritarchs of the distinctive group Diacromorphitae (Table 1, Figs. 6–8, 11, 12, 24, 25), which occur abundantly not earlier than in the upper part of the Upper Cambrian. In samples 115 and 116 a few specimens of *Trunculumarium revinium* Vanguestaine (Pl. I, Figs. 2–5) were also found, indicating the

middle Upper Cambrian, i.e. the *Trunculumarium revinium-Veryhachium dumonti* Superzone (Vanguestaine and Van Looy, 1983) or WK3 *T. revinium, D. caudatum* Zone (Volkova, 1990) (Fig. 4) corresponding to the (3–4) *Parabolina spinulosa-Leptoplastus* Zones of the standard trilobite zonation. This stratigraphic interpretation is consistent with other observations:

— the "galeate" forms of Herkomorphitae group with a broad umbo in polar position (Pl. I, Figs. 13, 14, 19) indicate an age not older than WK 2 of the Upper Cambrian of the East European Craton (Fig. 4), and therefore corresponding at least to the *Olenus* (2) Zone in the standard trilobite zonation;

— the presence of *Veryhachium* sp. (Pl. II, Fig. 14) and ?*Vogtlandia* sp. (Pl. I, Fig. 29); these are Upper Cambrian taxa, which occur not earlier than in WK 2 of the Upper Cambrian (Fig. 4), i.e. in deposits not older than the *Olenus* (2) Zone.

MARCINKOWICE REGION

Here the Cambrian rocks are well exposed, but dominated by sandstones and quartzitic sandstones, while claystones and mudstones are rare. Scarce and poorly preserved microflora assemblages have been obtained. 7 samples were studied, and positive results were obtained only from 2. The assemblages are dominated by poorly preserved *Timofeevia*, *Cristallinium* and *Retisphaeridium*. Individual specimens referable to Upper Cambrian "galeate" forms and *Impluviculus*, have, however, also been found (Pl. I, Fig. 15; Pl. II, Figs. 15, 16).

KARWÓW-KROWIENIEC REGION

Four samples have been collected from this region, two of which contained a poor microflora (Table 1). The assemblage is dominated by compact forms with a surface divided into polygonal fields including: *Cristallinium* sp., *Retisphaeridium* sp., *Timofeevia* sp., *Multiplicisphaeridium* sp. and *Micrhystridium* sp. These indicate a Middle Cambrian-Tremadoc interval.

THE SOUTHERN SLOPES OF THE MAIN RANGE

The area is a 50 km long strip of land between Piórków near Łagów (southern slopes of the Jeleniowskie Range) and the northern suburbs of Kielce (southern slopes of Krzemianka Mountain). The deposits adjoining the Main Holy Cross Fault were studied where geoelectrical studies indicated low-resistivity clay deposits. The boreholes (Figs. 1 and 3) reached unweathered Cambrian deposits at relatively shallow depths with relatively good core preservation.

The deposits are represented by claystones with scarce sandy intercalations. Bedding dips are high 30–90°, and the rocks are strongly tectonized (Fig. 3). Two out of 4 boreholes yielded acritarchs: Piórków PIG 1 and Kielce-Piaski PIG 1, while two (Huta Nowa PIG 1 and Dąbrowa-Koszarka PIG 1) were barren.

The Piórków PIG 1 borehole (Fig. 1) was drilled in the zone of the Main Holy Cross Fault. The claystones penetrated are thoroughly shattered, and core recovery was poor. The samples from this tectonic breccia yielded no acritarchs (Table 1, Fig. 3). Instead, numerous perfectly preserved, bright spores of Devonian and Carboniferous age were found (Turnau, 1996, pers. com.). In the samples from beneath the breccias abundant Devonian and Carboniferous spores occur (more than 99% of the material), together with individual acritarchs referable to *Leiosphaeridia*, *Lophosphaeridium* and *Skiagia*?, which suggest a Lower Cambrian-lower Middle Cambrian age. Their preservation, relative to those in other boreholes in the Łysogóry region, is suprisingly good, with brightly coloured palynomorph walls. This may be due to tectonic interleaving. Alternatively, the brecciated claystones at the base may represent the Devonian and Carboniferous of the Kielce region.

The most interesting results came from the Kielce-Piaski PIG 1 borehole located in the extreme west of the area studied, on drift-covered outcrops of dark Cambrian claystones, on the southern slopes of the Krzemianka Mountain (Fig. 1). Here (Fig. 3), typically Upper Cambrian acritarchs were found: ?*Stelliferidium* sp. (Pl. I, Fig. 16), *Nellia magna* Volkova (Pl. I, Fig. 28), *Trunculumarium revinium* Vanguestaine (Pl. I, Fig. 1), ?*Ladogiella* sp. (Pl. II, Fig. 19), *Impluviculus*, *Acanthodiacrodium* sp. (Pl. I, Figs. 9, 10). These forms indicate at least the 3 Zone of the Upper Cambrian (Volkova, 1990) (Fig. 4).

In the Kielce-Piaski PIG 1 borehole, as at Opatów, the upper age limit is difficult to establish. The low proportion of forms with diacroidal symmetry, the numerous *Cristallinium*, and the relatively simple structure of the *Acanthodiacrodium* taxa do not suggest very high levels in the Upper Cambrian. This opinion is supported by the occurrence of a single poorly preserved specimen of *Trunculumarium*, a genus known only from the middle part of the Upper Cambrian.

STRATIGRAPHIC SIGNIFICANCE OF THE ASSEMBLAGES AND COMPARISON WITH OTHER AREAS

The acritarch assemblages recognised represent the Middle Cambrian to Upper Cambrian and Tremadoc interval. Despite more than 30 years of study of this interval, there is not yet a coherent zonation. Biostratigraphical work needs to make use of various regional zonations (Vanguestaine, 1974; Martin and Dean, 1981, 1988; Vanguestaine and Van Looy, 1983; Di Mila *et al*., 1989; Volkova, 1990; Martin, 1992) (Fig. 4).

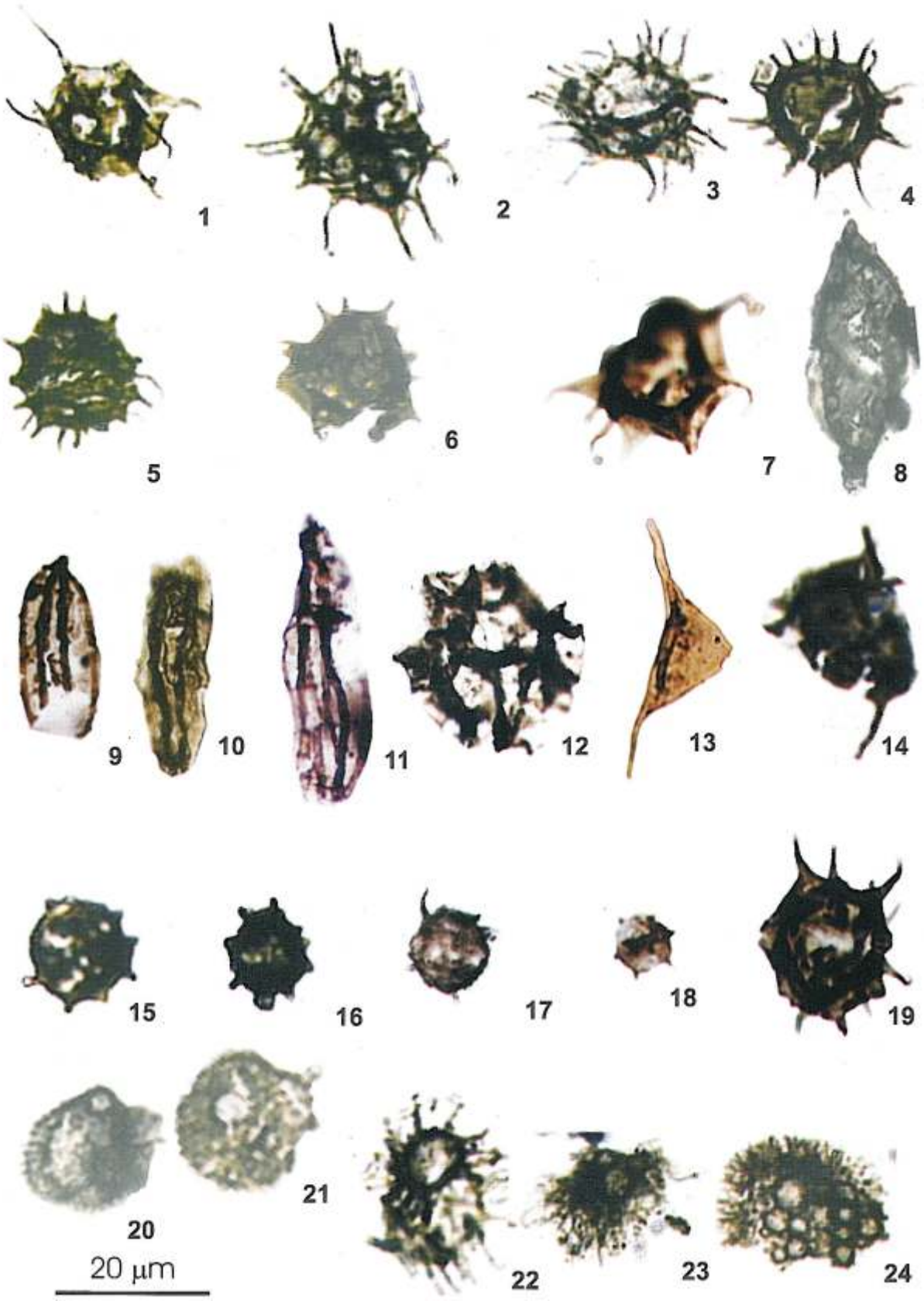
The stratigraphy used here is based mainly on the zones recognised by Volkova (1990) on the East European Craton (Fig. 4), with which the microflora recognised in this study show strong affinity. Use was made also of work in Newfoundland and Canada by F. Martin (Martin and Dean, 1988; Martin, 1992) (Fig. 4), where the stratigraphic scheme developed is correlated with the trilobite zonation. In Newfoundland, however, substantially fewer acritarch taxa were determined than on the East European Craton.

The oldest acritarch assemblage recognised was in the Kochówek PIG 1 borehole and in outcrops in the Karwów-Krowieniec region. The acritarch assemblage occurring here, with numerous *Cristallinium cambriense* (Slavikova), *Eliasum llaniscum* Fombella, *Micrhystridium*

PLATE I

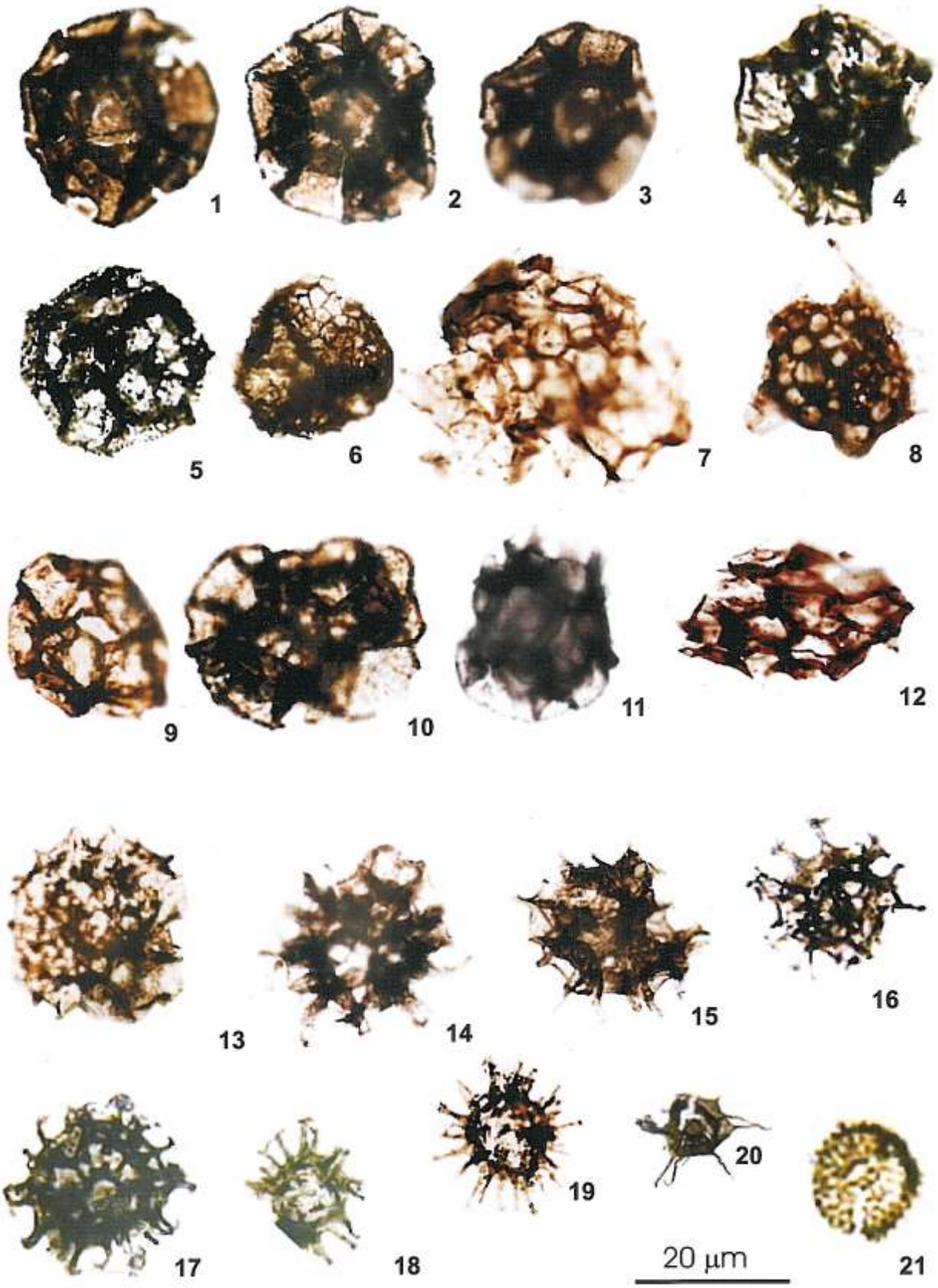
1. *Trunculumarium revinium* Vanguestaine, Kielce-Piaski PIG 1. ***2–5***. *Trunculumarium revinium* Vanguestaine, Jurkowice-Pipała. ***6, 8, 11***. *Dasydiacrodium* sp., Jurkowice-Pipała. ***7, 12***. *Acanthodiacrodium* sp., Jurkowice-Pipała. ***9, 10***. *Acanthodiacrodium* sp., Kielce-Piaski PIG 1. ***13, 14***.?*Cymatiogalea* sp., Jurkowice-Pipała. ***15***. *Acritarcha* — „galeate", Marcinkowice. ***16***.?*Stelliferidium* sp., Kielce Piaski PIG 1. ***17, 21***. *Cymatiogalea* sp., Kobylanki PIG 1. ***18***. *Stelliferidium* sp., Doły Oziębłowskie PIG 1. ***19***. *Cymatiogalea* sp., Jurkowice-Pipała. ***20***. *?Calyxiella* sp., Jurkowice-Pipała. ***22***. *Cymatiogalea* sp., Doły Oziębłowskie PIG 1. ***23***. *Stelliferidium* sp., Kobylanki PIG 1. ***24, 25***. ?*Lophodiacrodium* sp., Jurkowice-Pipała. ***26***. *Calyxiella* cf. *izohoriensis* Golub et Volkova, Kamień Plebański PIG 1. ***27***. *Calyxiella* sp., Doły Oziębłowskie PIG 1. ***28***. *Nellia magna* Volkova, Kielce-Piaski PIG 1. ***29***. ?*Vogtlandia* sp., Jurkowice-Pipała. ***30***. ?*Vulcanisphaera* sp., Jurkowice-Pipała

PLATE II



1–4. *Polygonium* sp. 1, Jurkowice-Pipała. ***5, 6***. *Polygonium* sp. 2. Jurkowice-Pipała. ***7***. *Stellechinatium* sp., Kobylanki PIG 1. ***8***. *Leiofusa* sp., Jurkowice-Pipała. ***9***. *Eliasum* sp., Kobylanki PIG 1. ***10, 11***. *Eliasum llaniscum* Fombella, Kobylanki PIG 1. ***12***. *Izohoria angulata* Golub et Volkova, Kobylanki PIG 1. ***13***. *Veryhachium* sp., Kobylanki PIG 1. ***14***. *Veryhachium* sp., Jurkowice-Pipała. ***15, 16***. *Impluviculus* sp., Marcinkowice. ***17, 18***. *Impluviculus* sp., Kobylanki PIG 1. ***19***. ?*Ladogiella* sp., Kielce-Piaski PIG 1. ***20–22***. *Aranidium* sp., Jurkowice-Pipała. ***23, 24***. *Comasphaeridium* sp., Jurkowice-Pipała

PLATE III



1. *Cristallinium cambriense* (Slavikova), Kobylanki PIG 1. ***2***. *Cristallinium cambriense* (Slavikova), Doły Oziębłowskie PIG 1. ***3***. *Cristallinium* sp., Kobylanki PIG 1. ***4***. *Cristallinium* sp., Jurkowice-Pipała. 5. *Cristallinium* sp., Marcinkowice. ***6, 8***. *Dictyotidium* sp., Kobylanki PIG 1. ***7***. *Retisphaeridium* sp., Doły Oziębłowskie PIG 1. ***9***. ?*Retisphaeridium* sp., Kobylanki PIG 1. ***10***. *Cymatiosphaera* sp., Kochówek PIG 1. ***11***. ?*Cymatiogalea* sp., Doły Oziębłowskie PIG 1. ***12***. *Retisphaeridium* sp., Kielce-Piaski PIG 1. ***13***. *Adara* cf. *alea* Martin, Kobylanki PIG 1. ***14***. *Timofeevia* sp., Kobylanki PIG 1. ***15***. *Timofeevia* sp.,Kielce-Piaski PIG 1. ***16***. *Timofeevia* cf. *phosphoritica* Vanguestaine, Karwów. ***17***. *Timofeevia phosphoritica* Vanguestaine, Marcinkowice. ***18***. *Multiplicisphaeridium* sp., Jurkowice-Pipała. ***19***. *Multiplicisphaeridium* sp., Kobylanki PIG 1. ***20***. *Heliosphaeridium* sp., Jurkowice-Pipała. ***21***. *Asteridium* sp., Jurkowice-Pipała

div. sp., *Timofeevia* sp., *Retisphaeridium* sp. and others (Table 1) is difficult to interpret stratigraphically. It may represent a broad time span of the Middle Cambrian, or a depleted Upper Cambrian assemblage. Until recently *E. llaniscum* Fombella would suggest the Middle Cambrian. However, newer data (Moczydłowska, 1995, 1998) suggests that it is present also in Upper Cambrian deposits. On balance, a Middle Cambrian assemblage, not older than the *P. paradoxissimus* Superzone, is present in the Kochówek PIG 1 borehole. It resembles assemblages in SK 2 of the Middle Cambrian of the East European Craton (Volkova, 1990) and the lower part of the A2 microflora in Newfoundland (Martin and Dean, 1988). However, it most resembles Superzone *C. cambriense, Eliasum, Timofeevia* (Vanguestaine and Van Looy, 1983) (Fig. 4), correlated with the upper part of the *E. oelandicus* Superzone and lower part of the *P. forchhammeri* Superzone. Such assemblages are known from other areas, such as the Czech Republic (Vavrdová, 1982), Turkey (Erkmen and Bozdogan, 1981), Morocco (Vanguestaine and Van Looy, 1983), Belgium (Vanguestaine, 1974) and Spain (Fombella, 1977, 1979).

In the Kobylanki PIG 1, Doły Oziębłowskie PIG 1 and Kielce-Piaski PIG 1 boreholes, as well as in the Jurkowice-Pipała outcrop, a younger assemblage has been found. This includes numerous *Cristallinium cambriense* (Slavikova) and *Polygonium* sp., and individual specimens of *P. minimum* (Timofeev), *P. martinae* (Moczydłowska), *Timofeevia lancarae* (Cramer et Diez), *Izohoria* sp., *Impluviculus* sp., *Cymatiogalea* sp., *Stelliferidium* sp., *Eliasum* sp., *Trunculumarium* cf. *revinium* Vanguestaine, *Micrhystridium* sp. and *Acanthodiacrodium* sp. The genera *Stelliferidium, Cymatiogalea, Impluviculus, Izohoria, Acanthodiacrodium, Trunculumarium* and *Nellia* are known exclusively from Upper Cambrian and younger deposits. The genera *Impluviculus, Izohoria, Acanthodiacrodium, Trunculumarium* and *Nellia* occur not earlier than the middle part of the Upper Cambrian, and therefore, most probably, the deposits drilled here represent the middle or the upper part of the Upper Cambrian. The assemblages found in the Kielce-Piaski PIG 1 borehole and in the Jurkowice outcrop most compare with the WK 3–WK 4A Zones of the Upper Cambrian of the East European Craton (Fig. 4), while the Kobylanki PIG 1 and Doły Oziębłowskie PIG 1 boreholes and the outcrops at Marcinkowice may represent the WK 2–WK 4B Zones of this division (Fig. 4).

The scarce Upper Cambrian forms found in the Kamień Plebański PIG 1 borehole are difficult to locate biostratigraphically. *Calyxiella* suggests the upper part of *Peltura* (5) Zone, which approximately corresponds with the WK 4B Zone of the Cambrian of the East European Craton (Volkova, 1990) (Fig. 4). Earlier works by this author (Volkova and Golub, 1985), though, noted this taxon also in the *Leptoplastus* Zone of the standard trilobite zonation. Outside of the former USSR this form has been recognised on Öland (Sweden) in the *Peltura* (5) Zone (Di Mila *et al.*, 1989) and also in of the Ublinek PIG 1 bis borehole (Szczepanik, 1997*a*), where it co-occurs with specimens suggesting the Cambrian/Tremadoc boundary.

The Upper Cambrian assemblages are quantitatively dominated by taxa with long stratigraphic ranges [e.g. *Cristallinium cambriense* (Slavikova) and *Micrhystridium* div. sp.]. *Polygonium* is also common, represented by small forms with relatively short outgrowths.

The most important difference vis-a-vis the platform is the longer stratigraphic range of *Eliasum llaniscum* Fombella, supporting the work of Moczydłowska (1995, 1998), and the smaller morphological diversity of *Cristallinium* and the earlier occurrence *Polygonium*.

No abundance peaks of *Timofeevia* were found, that could indicate the upper Middle Cambrian or lowermost Upper Cambrian. Such abundance peaks were found in claystones interbedded with quartzites in the Wiśniówka quarries (Moczydłowska in: Kowalczewski *et al.*, 1987). Deposits of this age were probably not encountered in the boreholes.

Nowhere in the Holy Cross Mountains have assemblages with common *Raphesphaera* been found; such assemblages are characteristic of the lower part of the Upper Cambrian, and are common on the East European Craton and in Newfoundland, and also near to the platform zone (Narol PIG 2 borehole).

The assemblages recognised closely resemble to the microfloras from Newfoundland, Belgian and French Ardennes, Scandinavian Caledonides and other areas (Vanguestaine, 1974; Martin and Dean, 1981, 1988; Vanguestaine and Van Looy, 1983; Welsch, 1986; Di Mila *et al.*, 1989; Martin, 1992).

ACRITARCH COLOUR AS A PALAEOTEMPERATURE INDICATOR — TECTONIC IMPLICATIONS

Acritarchs found are dark brown to black, suggesting burial temperatures of the order of 100–200°C (AMOCO 5+–6). Acritarchs from Wiśniówka (outside the study area) show even greater termal alteration (AMOCO 6+–7) (Szczepanik, 1997*b*). These observations are consistent with those observed by M. Moczydłowska (in: Kowalczewski *et al.*, 1986), although showing a narrower range.

The acritarchs from the Pieprzowe Mountains thus reveal palaeotemperatures typical of the Łysogóry region (over 100°C), though their tectonic setting has in the past been linked with the Kielce region. The lithology, tectonic style and palaeothermal observations rather, however, suggest connection with the southern peripheries of the Łysogóry region. With the geology of the eastern part of the Holy Cross Mountains in mind, faults perpendicular to the Main Holy Cross Fault may be inferred along which the eastern part of the Łysogóry region has been moved southwards.

The extent to which rock heating may have been influenced by local brittle tectonics (near-fault heating) needs consideration. However, bright Devonian spores occur directly along the Holy Cross Fault (Piórków PIG 1 borehole). The factor responsible for thermal alteration was therefore a regional temperature increase caused by overburden thickness and heat production during orogeny.

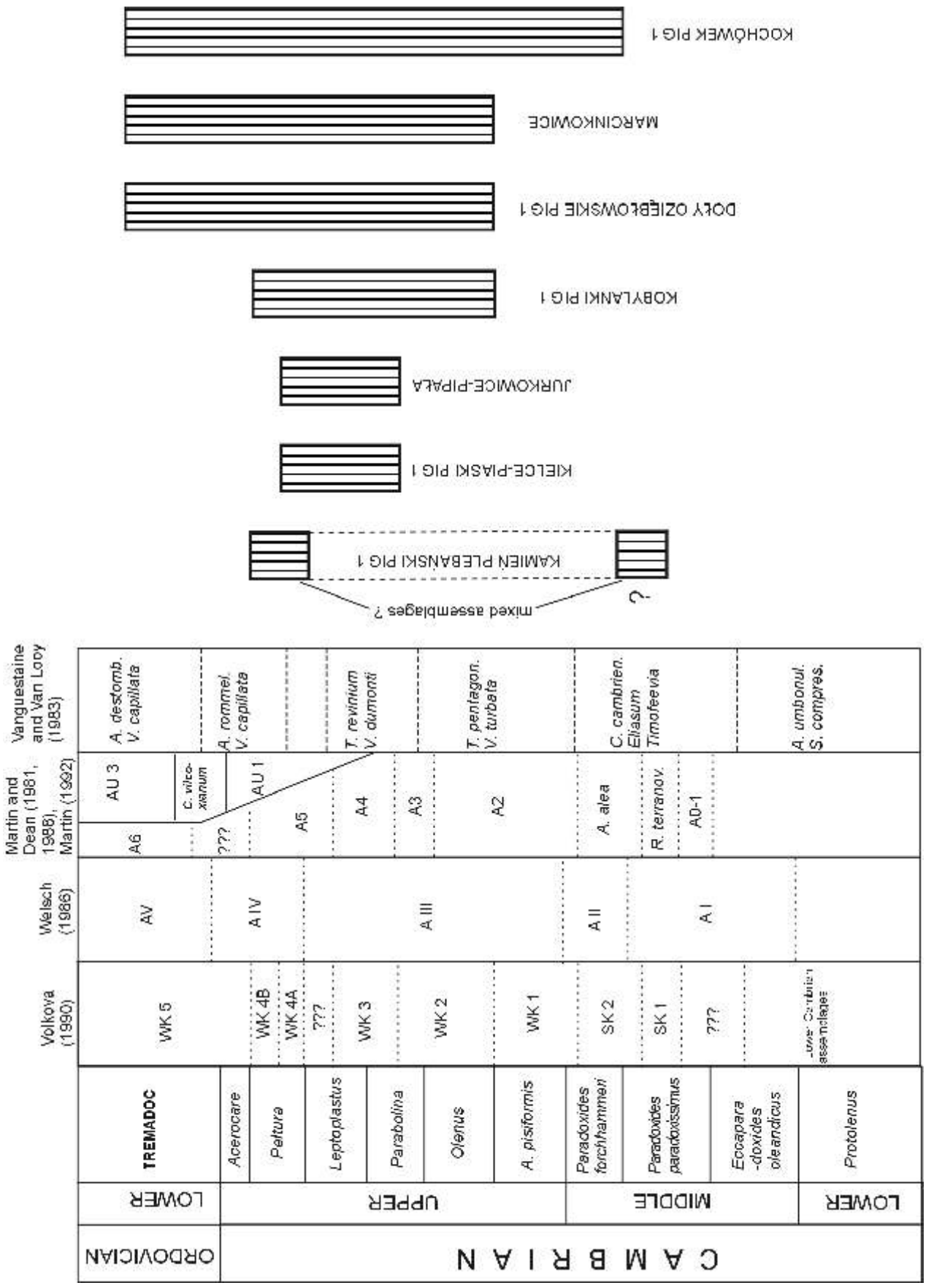


Fig. 4. Stratigraphic ranges of the assemblages found in particular outcrops and boreholes, together with the correlation of selected microfloral zones

CONCLUSIONS

Palynological studies in the southern part of the Łysogóry unit (boreholes: Kielce-Piaski PIG 1, Doły Oziębłowskie PIG 1, Kobylanki PIG 1 and exposures: Jurkowice-Pipała, Marcinkowice) document Upper Cambrian deposits in the southern part of the Łysogóry region, and this discovery complicates the tectonic picture of the Łysogóry region, and renders the hypothesis of a monoclinal structure in this area (Mizerski, 1992, 1994) improbable.

The acritarch assemblages of the study area resemble those from the East European Craton and Newfoundland, and also other areas, including the Peri-Gondwanan regions.

Acritarchs from the Pieprzowe Mountains show a similar preservation to those from the Łysogóry region. The degree of thermal maturity suggests heating to temperatures of 100°C and more, as in the Łysogóry region, but contrasting with that in the Cambrian rocks in the eastern part of the Kielce region, which is minimal.

The occurrence of a mixed Carboniferous-Devonian-Cambrian acritarch and spore assemblage from the Piórków PIG 1 borehole proves Variscan or post-Variscan activity along the Main Holy Cross Fault. The unaltered (bright) colours of this microflora suggests derivation of this assemblage from the Kielce region, in turn indicating an overthrust character (at least in the near-surface) for the Main Holy Cross Fault.

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