Acta Geologica Polonica, Vol. 56 (2006), No. 4, pp. 443-461

Cambrian of the Holy Cross Mountains, Poland; biostratigraphy of the Wiśniówka Hill succession

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ABSTRACT:

ŻYLIŃSKA, A., SZCZEPANIK, Z. & SALWA, S. 2006. Cambrian of the Holy Cross Mountains, Poland; biostratigraphy of the Wiśniówka Hill succession. *Acta Geologica Polonica*, **56** (4), 443-461. Warszawa.

New acritarch data combined with the trilobite record date most of the Wiśniówka Hill succession (western part of Łysogóry, Holy Cross Mts.) as early Furongian (early late Cambrian). The taxonomic diversity and abundance of the acritarch assemblages allow a more precise age determination than previous studies, as well as correlation with contemporary associations from Baltica, Avalonia and West Gondwana. The stratigraphic significance of trilobite trace fossils within the succession is evaluated.

Key words: Cambrian, Furongian Series/Epoch, Wiśniówka, Trilobita, Acritarcha, Trace fossils, Holy Cross Mountains, Poland, TESZ.

INTRODUCTION

The Holy Cross Mountains (HCM) represent the only Palaeozoic structure exposed in the immediate vicinity of the East European Craton (EEC), with Variscan folds composed of Lower Cambrian through the Lower Carboniferous rocks and their post-orogenic Permian cover. Located south-westwards of the Teisseyre-Tornquist Line (TTL) (Text-fig. 1a), which is regarded as the plate boundary of the EEC and interpreted as the primary suture between Gondwana and Baltica (BELKA & *al*. 2000), the HCM are part of the Trans-European Suture Zone (TESZ), one of the most prominent geotectonic domains in Europe (BERTHELSEN 1992). The formation of the crustal blocks within the TESZ and the time of their accretion to Baltica are some of the major issues investigated over the last few years (e.g., BELKA & *al*. 2000; NAWROCKI 2000; VALVERDE-VAQUERO & *al*. 2000; NAWROCKI & POPRAWA 2006; NAWROCKI & *al. in press*). In this respect, new biostratigraphic data on the oldest, poorly constrained Cambrian part of the HCM succession are of critical importance in an attempt to resolve the accretionary history of particular elements of the TESZ mosaic.

The quarries on Wiśniówka Hill in the westernmost part of the area are some of the very few large exposures of Cambrian strata in the HCM (Text-fig. 1b). This area has aroused the interest of many structural geologists since the time when the first quarries were established (CZARNOCKI 1929) and interpretations of its structure have been highly

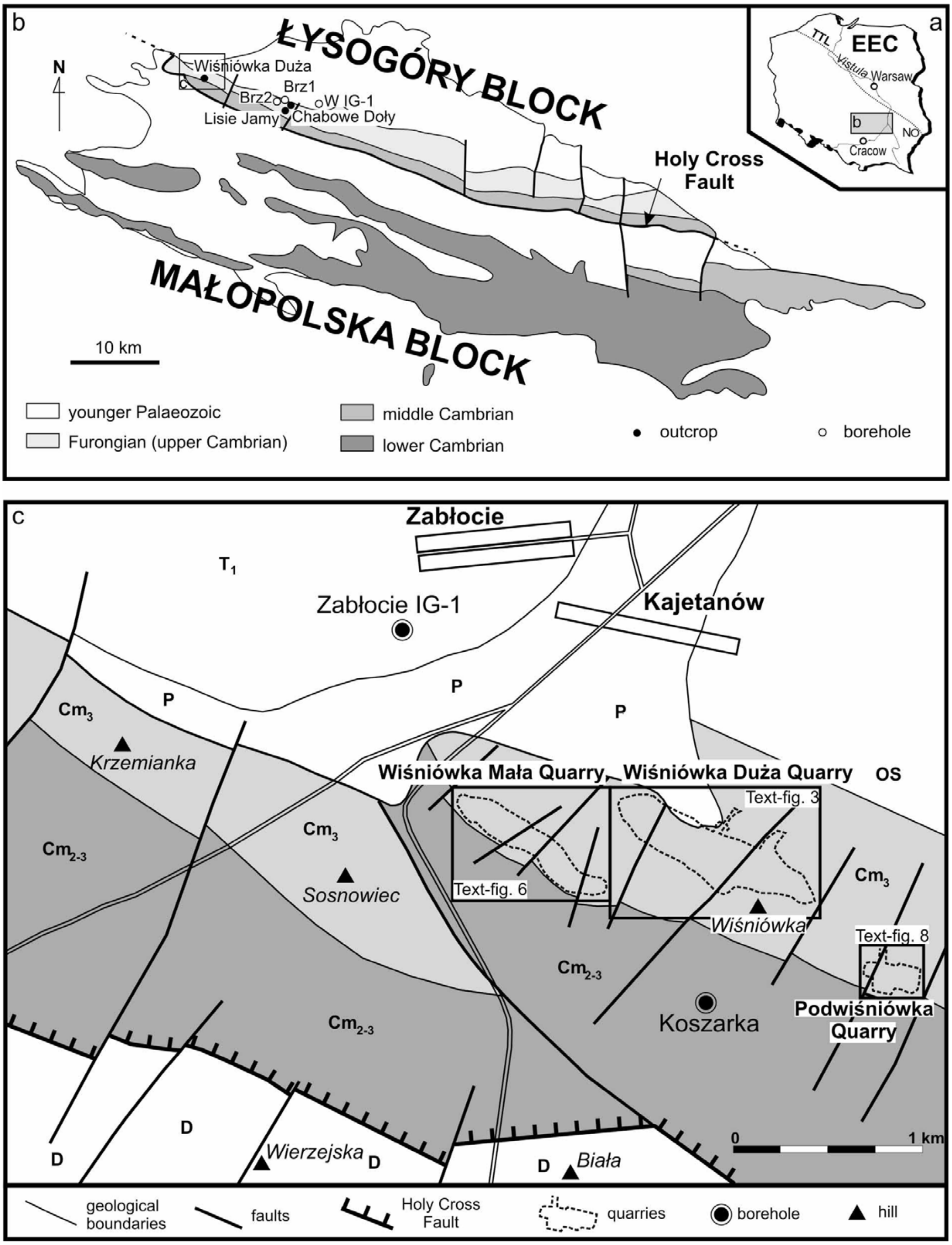


Fig. 1a. Location of the Holy Cross Mountains (HCM) in relation to the East European Craton (EEC). TTL – Teisseyre-Tornquist Line, N – Narol PIG 2 Borehole. 1b. Geological sketch-map of the HCM with location of study area (inset c) and outcrops and boreholes discussed in text, modified after ORŁOWSKI (1992b). Brz 1 – Brzezinki 1, Brz2 – Brzezinki 2 and W IG-1 – Wilków IG-1 boreholes. 1c. Geological sketch-map of the Wiśniówka Hill area with the Wiśniówka Duża, Wiśniówka Mała and Podwiśniówka quarries and the Koszarka and Zabłocie IG-1 boreholes. Cm_{2-3} – middle to upper Cambrian (Furongian); Cm_3 – upper Cambrian (Furongian); OS – Ordovician and Silurian; D – Devonian; P – Permian; T_1 – Lower Triassic

Fig. 2a. View of the eastern part of the Wiśniówka Duża Quarry, with location of some of the productive acritarch samples, trilobites, brachiopods and '*Peytoia*' sp. For explanations of symbols see Text-fig. 3. 2b. View of the western part of the Wiśniówka Mała Quarry with location of the productive acritarch samples. 2c. View of the western wall of the Podwiśniówka Quarry with location of some of the productive acritarch samples. All photographs were taken in autumn 2005

controversial. Equally controversial have been conclusions about the age of its stratigraphical succession, with interpretations ranging from middle Cambrian to early Ordovician (CZARNOCKI 1950; SAMSONOWICZ 1956 ORŁOWSKI 1968, 1988, 1992b; KOWALCZEWSKI & *al.* 1986; STUDENCKI 1994; JENDRYKA-FUGLEWICZ & MALEC 1997; Wiesław BEDNARCZYK *unpublished opinion* 2001). Neither trilobites nor acritarchs, the main stratigraphical groups in the succession, were regarded as biostratigraphically unequivocal (KOWALCZEWSKI 1995; ORŁOWSKI & MIZERSKI 1995).

This paper reports on a newly obtained acritarch record discussed within the framework of a recently revised trilobite zonation (ŻYLIŃSKA 2001, 2002). The biostratigraphical discussion adds more detailed information to the earlier studies by ŻYLIŃSKA & SZCZEPANIK (2002a, b) and is set in the context of the recent structural interpretation of the Wiśniówka Hill area.

GEOLOGICAL SETTING

The Wiśniówka Hill area is located in the southwesternmost part of the Łysogóry Range, and is located on the Łysogóry Block (Text-fig. 1b), which is one of the structural elements composing the TESZ in central Poland. The structure of the range is variously interpreted and, consequently, it is referred to as the Łysogóry Fold (Anticline) (CZARNOCKI 1950, 1957), Łysogóry Slice (ZNOSKO 1962), or the Łysogóry Unit (MIZERSKI & OZIMKOWSKI 1978; STUPNICKA 1989). The first interpretation is applied herein, although the actual structure of this unit has turned out to be more complex.

The study area is built mostly of the Cambrian (Text-fig. 1c), subdivided lithostratigraphically (ORŁOWSKI 1975) into the Pepper Mts. Shale, the Wiśniowka Sandstone and the Klonówka Shale formations (see Text-fig. 3). The Pepper Mts. Formation, building the southernmost part of the area, is composed of clays and silts, and was documented geophysically (KOWALCZEWSKI & *al.* 1986) and a shallow borehole in Koszarka (SZCZEPANIK 1996) (Text-fig. 1c). Based on data from its type area (ORŁOWSKI 1964), the formation is commonly regarded as of middle Cambrian age. However, there is evidence that at least part of the formation may already represent the Furongian[1] (SZCZEPANIK 1996, 2001; SZCZEPANIK & STUDENCKI 1997). In the southern part of the study area, the succession is dominated by claystones, whereas to the north the amount of silty, sandy and quartzitic intercalations increases.

The succeeding Wiśniówka Formation is composed of thick-bedded quartzitic sandstones with intercalations of black, grey and reddish claystones, of variable thicknesses (ORŁOWSKI 1975; Text-fig. 4). The study area is its stratotype area. The presence of thick quartzitic sandstones, an important resource for the building and chemical industries, was the reason why three quarries were opened on the slopes of the Wiśniówka Hill: Wiśniówka Duża, Wiśniówka Mała and Podwiśniówka (CZARNOCKI 1929; KOWALCZEWSKI & *al.* 1986). The quartzitic sandstones originally represented fine-grained quartz arenites with a disordered texture and loose packing. Well-rounded and sorted grains indicate a mature sediment, which is also confirmed by its mineral composition consisting predominantly of quartz grains and a very small admixture of grains of siliceous rocks and accessory minerals (zircons, tourmalines). Trace quantities of feldspars are partly replaced by clayey pseudomorphs (CZERMIŃSKI 1959; SIKORSKA 2000). Recrystallization, which also affected the matrix, gave the rock a characteristic packed structure and obscured the original grain boundaries. Quartzitic sandstones (CZERMIŃSKI 1959) intercalate with black, grey and reddish claystones of various thicknesses, some of which are tuffites and bentonites, what is evidenced e.g. by the presence of pseudomorphs after glass or feldspars. In some cases the tuffites pass laterally into fine-grained sandstones representing arkosic or lithic greywackes (KOWALCZEWSKI & *al.* 1986). The sandstones are interpreted as representing the proximal zone of the inner-shelf, and the siltstones the distal zone of the inner-shelf and the outer-shelf (STUDENCKI 1994, 1995; JAWOROWSKI & SIKORSKA 2006). The influence of oscillation currents and storms is evidenced by horizontal and ripple bedding, as well as rare hummocky cross-stratification (STUDENCKI 1994, 1995).

The stratigraphically highest Klonówka Formation is composed of shales, siltstones, and thin sandstone intercalations. According to

[1] The Furongian is the Upper Cambrian *sensu* WESTERGÅRD (1922) excluding the *Agnostus pisiformis* Zone; its base is marked by the worldwide appearance of *Glyptagnostus* WHITEHOUSE (see PENG & *al.* 2004), an event equivalent to the base of the *Homagnostus obesus* Zone.

ORŁOWSKI (1975), its lower boundary lies in the southern end of the main quarry road to the Wiśniówka Duża Quarry. However, the clayey-silty deposits exposed there differ from typical deposits of this formation as known from the Zabłocie IG-1 Borehole northwest of the Wiśniówka quarries (SZCZEPANIK & *al*. 2004b; Text-fig. 1c), the Lisie Jamy and Chabowe Doły exposures and the Brzezinki 1, Brzezinki 2 and Wilków IG 1 boreholes to the east (Text-fig. 1b) (TOMCZYKOWA 1968; ORŁOWSKI 1975; ŻYLIŃSKA 2002). Additionally, these typical occurrences are always dated as belonging to an interval ranging from the *Peltura* to the *Acerocare* zones (ŻYLIŃSKA 2002; ŻYLIŃSKA & SZCZEPANIK 2002a, b). Therefore it is assumed that the clayey-silty complex exposed in the main quarry road can either be part of the Wiśniówka Formation (MALEC 2004) or represents a separate lithostratigraphic unit, possibly of Tremadocian age (see below – KOWALCZEWSKI & *al*. 1986; see also Text-fig. 4). Consequently, the Klonówka Formation is not present in any of the Wiśniówka quarries or their quarry roads. According to MOCZYDŁOWSKA (in KOWALCZEWSKI & *al.* 1986), the acritarch assemblage in the main quarry road to the Wiśniówka Duża Quarry is of early Ordovician (Tremadocian) age (see Text-figs 3-4), although very close to the location of her samples two specimens of the early Furongian trilobite *Protopeltura aciculata* (ANGELIN) (see below; Text-figs 2a, 3) have been found. Due to barren samples from the main quarry road to the Wiśniówka Duża Quarry (Text-fig. 3), the stratigraphic conclusions of MOCZYDŁOWSKA (*op. cit.*) could not be confirmed in this research, however the proximity of Tremadocian acritarch assemblages and lower Furongian trilobites can be explained if a complex structure of the Łysogóry Fold is assumed (see below).

STRUCTURAL BACKGROUND

The first geologist actively working on the succession exposed on the Wiśniówka Hill was CZARNOCKI (1929, 1950, 1958a-c), who observed strong isoclinal folding of the strata. Intensive folding was later postulated by other authors, including a more complex thrust-and-fold process of deformation, resulting in a series of obsequent, N- to S-vergent slices (SAMSONOWICZ 1934; KOWALCZEWSKI & *al*. 1976, 1986; KOWALCZEWSKI 1981, 1994; KOWALCZEWSKI & STUDENCKI 1983; ZNOSKO 1988, 1996; STUDENCKI 1994, 1997; KOWALCZEWSKI & DADLEZ 1996; SALWA 2002, 2004). A marginal thrust-and-fold belt has been suggested for the area by DADLEZ & *al.* (1994). STUPNICKA (1988, 1989, 1992) assumed the S-nappe thrusting of the Cambrian of the Łysogóry along the HCF, taking place during the Variscan Orogeny (STUPNICKA 1989; BEDNARCZYK & STUPNICKA 2000).

An entirely different interpretation has been presented by MIZERSKI (e.g., 1979, 1991, 1994, 1998, and in ORŁOWSKI & MIZERSKI 1995). His model assumes a platform structure with homoclinal NE-dipping beds. The folds and reverse dips observed in exposures are explained as a local change of bedding linked to fault formation, and a different susceptibility of the Cambrian strata to deformation in the vicinity of the HCF (see also FILONOWICZ 1973).

A new interpretation of the tectonic style of the Łysogóry Fold was based on radar images (MASTELLA & MIZERSKI 2002, 2003; GRANICZNY & *al*. 2005). It assumes the thrust-character of the deformation resulting in the formation of a dextral shear zone during the Variscan Orogeny or even as late as the Laramide phase.

The recent structural studies in the Wiśniówka area (SALWA & SZCZEPANIK 2001; SALWA 2004, 2006) confirm its complex tectonic structure, with intense folding and faulting. The co-occurrence of thrust faults and synkinematic folds, resulting from E-W and NW-SE compression, has been observed, and at least two deformation stages of different age are suggested (STUDENCKI 1994; SALWA & SZCZEPANIK 2001; SALWA 2004; SALWA & JAROSIŃSKI 2006). Strike-slip faults are as common as thrust faults. The steep, eastward dipping fault surfaces are sub-perpendicular or diagonal to the strike of the Cambrian strata, and the faults trend NE-SW to N-S. The rarest faults, and at the same time the youngest tectonic structures detected in the area, are normal faults, with N-S trending and W-dipping fault surfaces.

The observed structural deformations evidence the complex geology of the Wiśniówka Hill area. The most important are thrust faults with accompanying folds of synkinematic origin, separating the study area into tectonic blocks differing in their tectonic style, facies and stratigraphy.

ACRITARCHS

Sampling

Eighty-five rock samples from the three quarries of the Wiśniówka Hill area (Text-figs 2, 3-4, 6, 8) have been collected, spanning the entire exposed succession and all tectonic blocks recognised. Samples were taken from the clayey-silty beds (40 from the Wiśniówka Duża Quarry, 20 from the Wiśniówka Mała Quarry, and 25 from the Podwiśniówka Quarry); the thick quartzitic sandstones that form a large part of the exposed succession are barren. Numerous samples from the main quarry road to the Wiśniówka Duża Quarry were taken to test the previous biostratigraphic results based on acritarchs (MOCZYDŁOWSKA in KOWALCZEWSKI & *al*. 1986; Text-fig. 3). Similarly, more samples were taken from the southern wall of this quarry to evaluate the age of the brachiopod-bearing strata (JENDRYKA-FUGLEWICZ & MALEC 1997; Wiesław BEDNARCZYK *unpublished opinion* 2001).

Methods

The samples were processed using a standard palynological method by acid digestion. Samples of *ca*. 100g in weight were macerated twice in hydrofluoric acid, with filtration between the two processes. The obtained residuum was boiled in concentrated hydrochloric acid, and then centrifuged in a heavy liquid solution. Finally, the residuum was filtrated on 15μm mesh membranes. Next, glycerine-gelatine microscope slides were made and studied using bright-field microscopy (Leitz Laborlux S microscope) under magnifications between 300 and 1200×. The acritarch specimens were documented as graphic files with the help of a microcamera attached to a computer.

Preservation of organic material

Only twenty-one out of a total 85 samples analysed appeared to be fossiliferous; five from the Wiśniówka Duża Quarry, nine from the Wiśniówka Mała Quarry, and seven from the Podwiśniówka Quarry (Text-figs 5, 7, 9). The abundance of acritarchs is variable, ranging from sporadic (Podwiśniówka – samples 5, 11, 16 and Wiśniówka Mała – samples 9, 10, 15), through numerous (all samples from Wiśniówka Duża), to very abundant – over a thousand acritarchs in a single microscope slide (Podwiśniówka – sample 17 and Wiśniówka Mała – samples 19, 20).

The state of preservation of the palynomorphs varies significantly. Generally, due to a high degree of thermal alteration and intense coalification of the vesicle walls, the specimens are strongly affected by mechanical destruction of the processes and abrasion of the surface ornament. In some samples, however, the palynomorphs are relatively well preserved.

Acritarch record in Wiśniówka Duża

The acritarchs have been found in samples from the central and northern parts of the quarry, representing the middle and upper part of the exposed succession (Text-figs 2a-4). With the exception of sample 3, all samples yielded a similar assemblage.

The most characteristic feature of the Wiśniówka Duża acritarch assemblage, and its major difference in comparison to assemblages from the two other quarries, is the great abundance and high morphological variability of the 'galeate' forms, represented by *Cymatiogalea* cf. *C. cristata* (DOWNIE) RAUSCHER (Pl. 1, figs 16-17), *C. velifera* (DOWNIE) MARTIN (Pl. 1, figs 18), *C. fimbriata* VOLKOVA (Pl. 1, fig. 19), *C. bellicosa* DEUNFF (Pl. 1, figs 20-23) and *Stelliferidium* sp. (Pl. 1, fig. 24). *Vulcanisphaera turbata*[2] MARTIN in MARTIN & DEAN (Pl. 1, figs 5-6) is known only from the Wiśniówka Duża Quarry. Other species of this genus, *V. spinulifera* (VOLKOVA) PARSONS & ANDERSON (Pl. 1, figs 3-4) and *V. africana* DEUNFF (Pl. 1, figs 9-10) were also found in samples from the other quarries. The assemblage is

[2] In the material studied the acritarchs assigned to *Vulcanisphaera turbata*, *V. spinulifera* and *V. obsoleta* often do not have the conical processes which serve as the base for the secondary processes and are diagnostic for *Vulcanisphaera* (DEUNFF) RASUL. The bunches of secondary processes observed on the specimens studied do not rise from the same base and therefore, despite their close similarity to *Vulcanisphaera*, the generic assignment of the above-mentioned species is questionable. VOLKOVA (1990) established the genus *Raphesphaera* for such specimens, but PARSONS & ANDERSON (2000) in their revision assigned all of them to *Vulcanisphaera*. This problem requires further detailed taxonomic studies

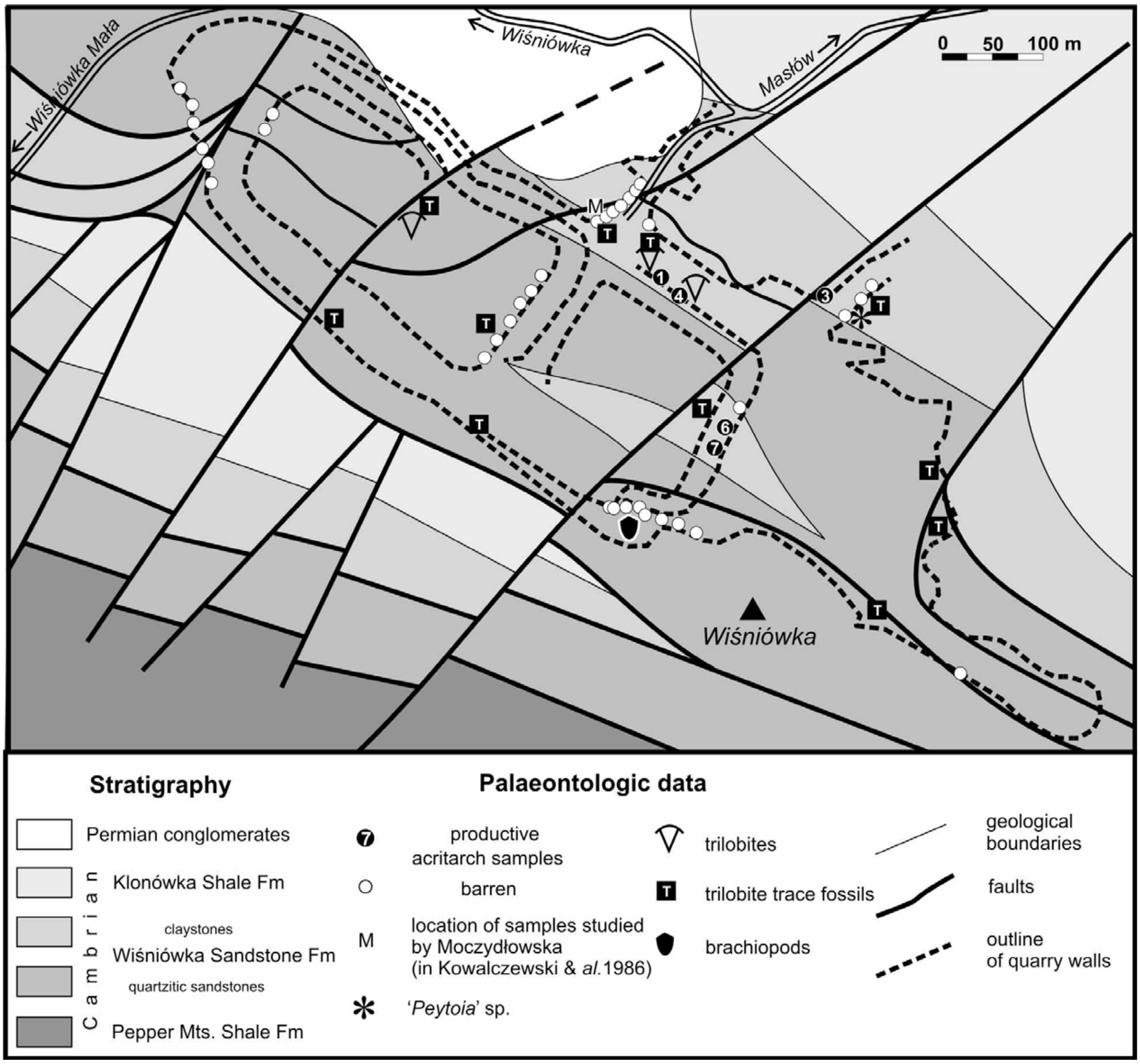


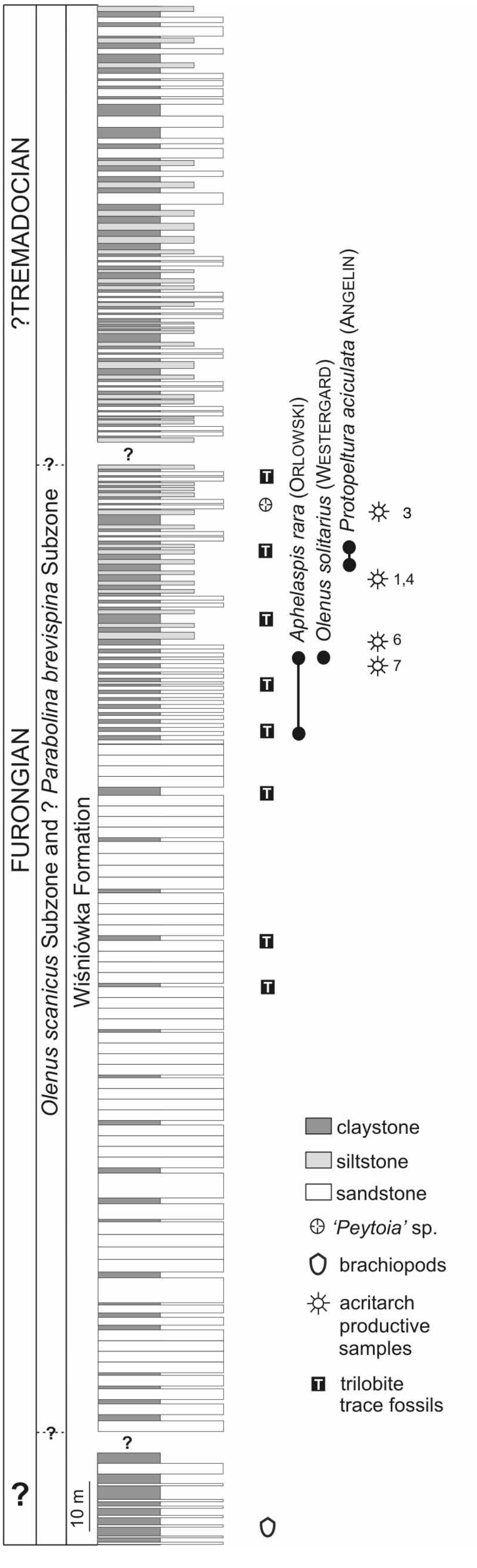
Fig. 3. Detailed plan of the Wiśniówka Duża Quarry with: lithological complexes, faults, location of acritarch samples, occurrences of trilobites and their traces, and other macrofauna

also characterised by rare *Timofeevia phosphoritica* VANGUESTAINE (Pl. 1, figs 1-2) and *T. pentagonalis* (VANGUESTAINE) VANGUESTAINE (Pl. 1, fig. 7) and quite common *Pirea orbicularis* VOLKOVA (Pl. 1, fig. 14), *Pirea* sp. (Pl. 1, fig. 15) and *Poikilofusa* sp. (Pl. 1, fig. 13).

The significantly different assemblage of sample 3 (Text-figs 2a, 3-5), with much less abundant acritarch material, is characterised by a complete lack of representatives of the genus *Timofeevia*, by the presence of small, taxonomically unrecognisable 'galeate' forms, and numerous sphaeroidal representatives of the genera *Leiosphaeridia* and *Lophosphaeridium*.

Acritarch record in Wiśniówka Mała

Because of flooding many parts of this abandoned quarry are inaccessible. Productive samples were collected from claystones in the northern wall of the quarry (Text-figs 2b, 6-7). Samples 10 and 20 (Text-figs 2b, 6) display the taxonomically most diverse assemblages, which are, however, different from each other (Text-fig. 7). Sample 10 (eastern part) contains numerous *Timofeevia lancarae* and less frequent *T. phosphoritica*. *Leiosphaeridia* sp. and *Multiplicisphaeridium* sp. are very abundant, as is *Pterospermella* sp. Single specimens of *Cristallinium* sp., *Adara* sp., *Vulcanisphaera* cf. *spin-*



ulifera and 'galeate' forms were also found. In contrast, in sample 20 from the western part of the northern wall the abundance of *T. phosphoritica* (Pl. 2, figs 8-10) is much higher, and this species dominates over *T. lancarae* (Pl. 2, figs 5-6). *Vulcanisphaera spinulifera* (Pl. 2, figs 12-14) is equally numerous, whereas acritarchs of the genus *Cymatiogalea* (*C. velifera* – Pl. 2, figs 21-22, *C.* cf. *velifera* – Pl. 2, fig. 23, and *C.* cf. *cristata* – Pl. 2, fig. 24) show only moderate abundance. *Stelliferidium*

No. of sample **Taxon**	**1**	**3**	**4**	**6**	**7**
acritarcha of the 'galeate' group	+	+	+	+	+
Cristallinium sp.	+				
Cymatiogalea bellicosa	+	cf.	+	?	
Cymatiogalea cf. *C. cristata*				+	+
Cymatiogalea fimbriata				+	
Cymatiogalea velifera	+				
Cymatiogalea cf. *C. virgulta*	+				
Cymatiogalea sp.	+	+	+	+	
Cymatiosphaera sp.					+
?*Eliasum* sp.				+	
Leiosphaeridia sp.	+	+	+	+	+
Lophosphaeridium sp.		+	+	+	
Multiplicisphaeridium div. sp.	+	+	+	+	+
Ovulum sp.				+	
Pirea orbicularis					+
Pirea sp.	+				
Poikilofusa sp.				+	
Pterospermella sp.	+			+	+
Stelliferidium sp.	+		+	+	+
?*Stelliferidium* sp.	+		+	+	+
Timofeevia pentagonalis			+		
Timofeevia phosphoritica	+		+	+	+
Timofeevia sp.	+	?	+	+	+
Vulcanisphaera africana	+		+		
Vulcanisphaera spinulifera	+		+	+	?
Vulcanisphaera turbata	+		+	+	
Vulcanisphaera sp.	+	+	+	+	+

Fig. 5. Distribution of acritarchs in productive samples from the Wiśniówka Duża Quarry. For location of samples see Text-figs 2a and 3

Fig. 4. Schematic lithological column of strata from the central part of the Wiśniówka Duża Quarry (after Żylińska 1992), with brachiopod record from Jendryka-Fuglewicz & Malec (1997), location of '*Peytoia*' sp. after Masiak & Żylińska (1994), and location of trilobites after Żylińska (2002). The supposed Tremadocian age for the upper part of the succession is after Moczydłowska (in Kowalczewski & *al.* 1986)

Fig. 6. Detailed plan of the Wiśniówka Mała Quarry with: lithological complexes, faults and location of acritarch samples. For explanations see Text-fig. 3

sp. and *Multiplicisphaeridium* sp. (Pl. 2, fig. 26) occur sporadically. The state of preservation is much better here than in the other samples, although the acritarchs are strongly coalified and often crushed. The preservation is much worse in the remaining part of the material analysed and, in most samples, the specimens were determined only to genus level (Text-fig. 7).

No. of sample / **Taxon**	**9**	**10**	**11**	**15**	**16**	**17**	**18**	**19**	**20**
acritarcha of the 'galeate' group		+	+			?	+	+	+
?*Adara* sp.		+							
Cristallinium cambriense		+					+		
Cymatiogalea cf. *C. cristata*									+
Cymatiogalea velifera									+
Cymatiogalea cf. *C. velifera*									+
Cymatiogalea sp.							+	+	+
Dictyotidium sp.							+		+
Granomarginata sp.		+					+		
Leiosphaeridia sp.	+	+		+	+		+	+	+
Lophosphaeridium sp.		+			+		+		+
Multiplicisphaeridium div. sp.		+					+		+
Pirea orbicularis									+
Pterospermella sp.	+				?				
?*Stelliferidium* sp.									+
Timofeevia lancarae	?	+	+					+	+
Timofeevia cf. *lancarae*									+
Timofeevia phosphoritica		+							+
Timofeevia sp.	+	+		+	+	+		+	+
Vulcanisphaera obsoleta		?					+		
Vulcanisphaera spinulifera		?	?				+	+	+
V. spinulifera transitional to *V. turbata*									+
Vulcanisphaera sp.		+					+	+	

Fig. 7. Distribution of acritarchs in productive samples from the Wiśniówka Mała Quarry. For location of samples see Text-figs 2b and 6

Acritarch record in Podwiśniówka

Although seven samples from the Podwiśniówka Quarry (Text-fig. 8) were productive (Text-fig. 9), sufficiently abundant and well preserved acritarch material for analysis comes only from sample 17, from the southern quartzitic complex (Text-figs 2c, 8; Pl. 2, figs 7, 11, 15, 20). The specimens are brownish-black to black, typically broken, abraded, and damaged by crystallization of pyrite. The sample is dominated by *Timofeevia* species (over 80% of the assemblage): abundant *T. lancarae* (Pl. 2, fig. 7) and less numerous *T. phosphoritica* (Pl. 2, fig. 11). Numerous are *Multiplicisphaeridium* (Pl. 2, fig. 20), *Lophosphaeridium* and *Leiosphaeridia*. The species *Vulcanisphaera spinulifera* is rare (Pl. 2, fig. 15). Taxonomically unrecognisable representatives of the 'galeate' group also occur sporadically.

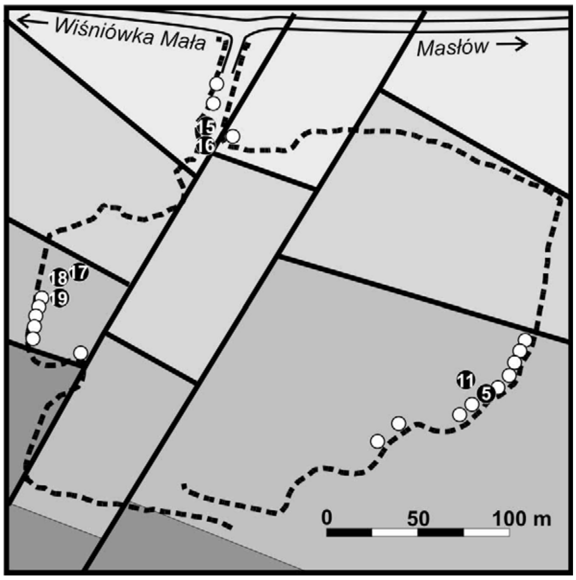


Fig. 8. Detailed plan of the Podwiśniówka Quarry with: lithological complexes, faults and location of acritarch samples. For explanations see Text-fig. 3

Taxon / No. of sample	5	11	15	16	17	18	19
acritarcha of the 'galeate' group				+	+		?
Comasphaeridium sp.					+		
Leiosphaeridia sp.	+		+	+	+	+	
Lophosphaeridium sp.	+	+		+	+		
Multiplicisphaeridium div. sp.		+	+	+	+	+	
Timofeevia lancarae				?	+	+	?
Timofeevia phosphoritica		+			+		+
cf. *Timofeevia*	+		+	+	+	+	+
Vulcanisphaera spinulifera		+			+		?
Vulcanisphaera sp.		+			+	+	+

Fig. 9. Distribution of acritarchs in productive samples from the Podwiśniówka Quarry. For location of samples see Text-figs 2c and 8

Stratigraphic significance of the acritarch assemblages

The most important new observation arising from the analysis of the palynological assemblages from the quarries in the Wiśniówka Hill area is the presence of numerous 'galeate' forms, referred to the genera *Stelliferidium* and *Cymatiogalea*. These genera first appear in the lowest Furongian (MARTIN & DEAN 1981, 1988; VANGUESTAINE & VAN LOOY 1983; WELSCH 1986; VOLKOVA 1990), thus placing the lower age limit of the acritarch assemblages recognized in the Wiśniówka Duża (Text-fig. 5, Pl. 1) and Wiśniówka Mała (Text-fig. 7, Pl. 2, figs 1-19, 21-26) quarries (assemblages 3 and 2, respectively, in Text-fig. 10). The assemblage from the Podwiśniówka Quarry (Text-fig. 9, Pl. 2, figs 6, 11, 15, 20) might, however, represent middle Cambrian (assemblage 1 in Text-fig. 10). The assemblages from the Wiśniówka Duża and Wiśniówka Mała quarries display large differences in their character, expressed in the different mutual abundances of the main acritarch morphotypes.

The presence of *Cymatiogalea fimbriata* and *Vulcanisphaera obsoleta* in the Wiśniówka Hill assemblage allows its correlation with the WK2 (upper Cambrian 2) Zone of the EEC (VOLKOVA 1990). Similarly, *C. velifera* and *C.* cf. *cristata* indicate the WK2 or a younger horizon. The *Timofeevia* species, as well as other *Vulcanisphaera* species have wider stratigraphic ranges, but their co-occurrence and great abundance are significant, this having been often noted elsewhere in the uppermost middle Cambrian and lowermost Furongian (MARTIN & DEAN 1981, 1984, 1988; VANGUESTAINE & VAN LOOY 1983; WELSCH 1986; VOLKOVA 1990).

The assemblage from Wiśniówka Duża contains *Vulcanisphaera africana*, which points to slightly younger strata of the Furongian Series. In Newfoundland, *V. africana* appears in the bottom of Zone A3a, which corresponds to the lower part of the *Parabolina spinulosa* Zone (MARTIN & DEAN 1988) (Text-fig. 10). The occurrence of this taxon in younger strata is also confirmed by the microfloral record from the Narol PIG 2 Borehole in south-eastern Poland (see Text-fig. 1a) (SZCZEPANIK *unpublished data*), where *V. africana* appears distinctly above assemblages with *Vulcanisphaera turbata*, *V. spinulifera*, *Timofeevia phosphoritica* and *T. lancarae.*

Summing up, the acritarch assemblages from the Wiśniówka area are equivalent to the WK2 Zone of the EEC (VOLKOVA 1990) and the A3a Zone in Newfoundland (MARTIN & DEAN 1981, 1988) (Text-fig. 10). In the standard Scandinavian trilobite zonation these units correspond to the *Homagnostus obesus* and to the lower part of the *Parabolina spinulosa* zones. The presence of *V. africana* and the high content of the 'galeate' acritarchs in the Wiśniówka Duża assemblage suggest its position in the latest *H. obesus* / early *Parabolina spinulosa* zones.

The early Furongian age of the Wiśniówka Duża and of the Wiśniówka Mała assemblages is also confirmed by the lack of acritarchs of the

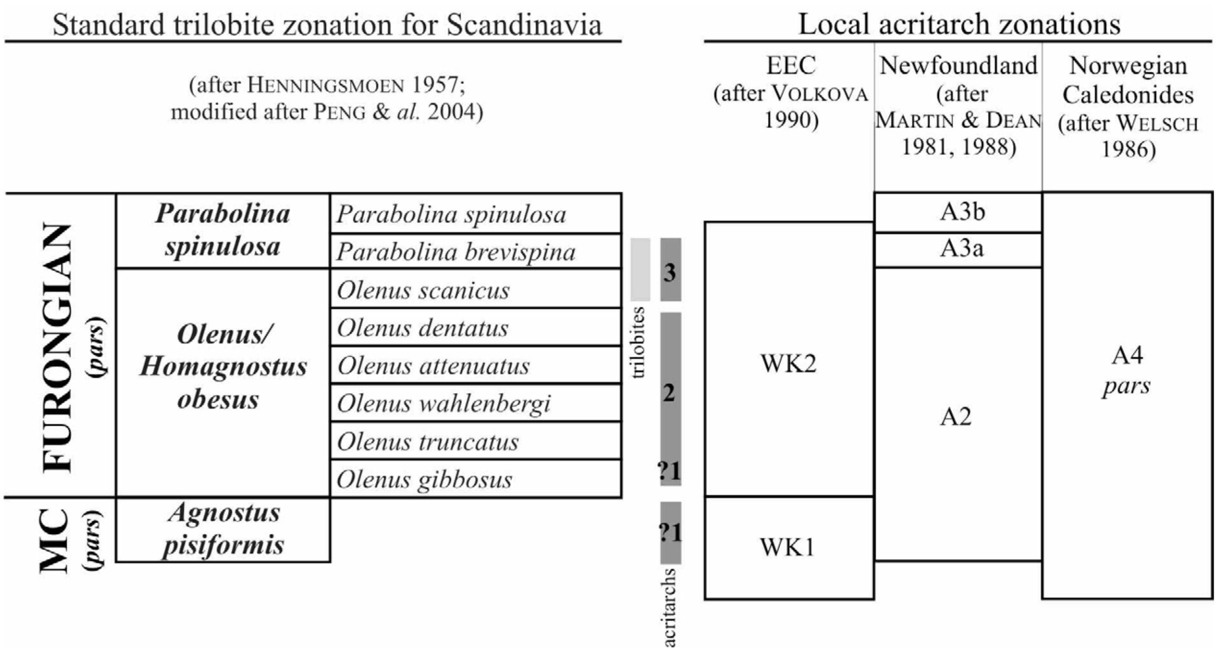


Fig. 10. Stratigraphic position of the Wiśniówka biotic assemblages (T – trilobites and * – acritarch assemblages: 1 – Podwiśniówka Quarry, 2 – Wiśniówka Mała Quarry, 3 – Wiśniówka Duża Quarry) with regard to the standard trilobite zonation for the uppermost middle Cambrian and Furongian of Scandinavia and local acritarch zonations of the EEC, Newfoundland and Norwegian Caledonides. MC – middle Cambrian

Diacromorphitae group. The group is a characteristic element of the late Furongian and Tremadocian microfloral assemblages (MARTIN & DEAN 1981, 1988; VANGUESTAINE & VAN LOOY 1983; WELSCH 1986; VOLKOVA 1990; PARSONS & ANDERSON 1996, 2000; MOCZYDŁOWSKA & STOCKFORS 2004; ALBANI & *al.* 2006), and is well represented in the late Furongian of the HCM (ŻYLIŃSKA & SZCZEPANIK 2002a, b; SZCZEPANIK & *al*. 2004a, b).

The assemblages reported herein compare closely with those from Newfoundland (MARTIN & DEAN 1981, 1988), the East European Craton (VOLKOVA & GOLUB 1985; VOLKOVA 1990) and the Norwegian Caledonides (WELSCH 1986). The assemblages from all these regions resemble each other both in the taxonomic diversity and in the pattern of the first appearances of particular taxa. Assemblages from northern Africa (VANGUESTAINE & VAN LOOY 1983) are also quite close, as are those described from Spain (FOMBELLA 1977, 1979; FOMBELLA & ANDRADE 1996), Iran (GHAVIDEL-SYOOKI 1996), Belgium (VANGUESTAINE 1974) and Turkey (ERKMEN & BOZDOGAN 1981). The closest area where assemblages similar to those from the study area have been recognised is the Narol PIG 2 Borehole (Text-fig. 1a) (SZCZEPANIK *unpublished data*), where they co-occurr with trilobites of the *Homagnostus obesus* Zone (JENDRYKA-FUGLEWICZ 1995).

THE TRILOBITES AND THEIR TRACES

The trilobites, the key group for the Cambrian biostratigraphy of the HCM, are extremely rare in the study area; only 11 body specimens, all from the Wiśniówka Duża Quarry, are available (most are illustrated in Text-fig. 11, including some published previously: ORŁOWSKI 1968; ORŁOWSKI & *al*. 1970; ŻYLIŃSKA 2001), These comprise six specimens of *Aphelaspis rara* (ORŁOWSKI), a single specimen of *Olenus solitarius* (WESTERGÅRD) and four specimens of *Protopeltura aciculata* (ANGELIN). Most of the specimens were found loose; only two specimens of *Protopeltura aciculata* and a thorax of *Aphelaspis rara* were collected from the quarry walls (Text-figs 2a, 3).

In the Wisniówka Duża Quarry the extremely rare trilobite body fossils are accompanied (Text-figs 3-4) by relatively rich trilobite traces, composed of various cruziana- and rusophyciform fossils. The most characteristic in the Wiśniówka ichnocoenosis

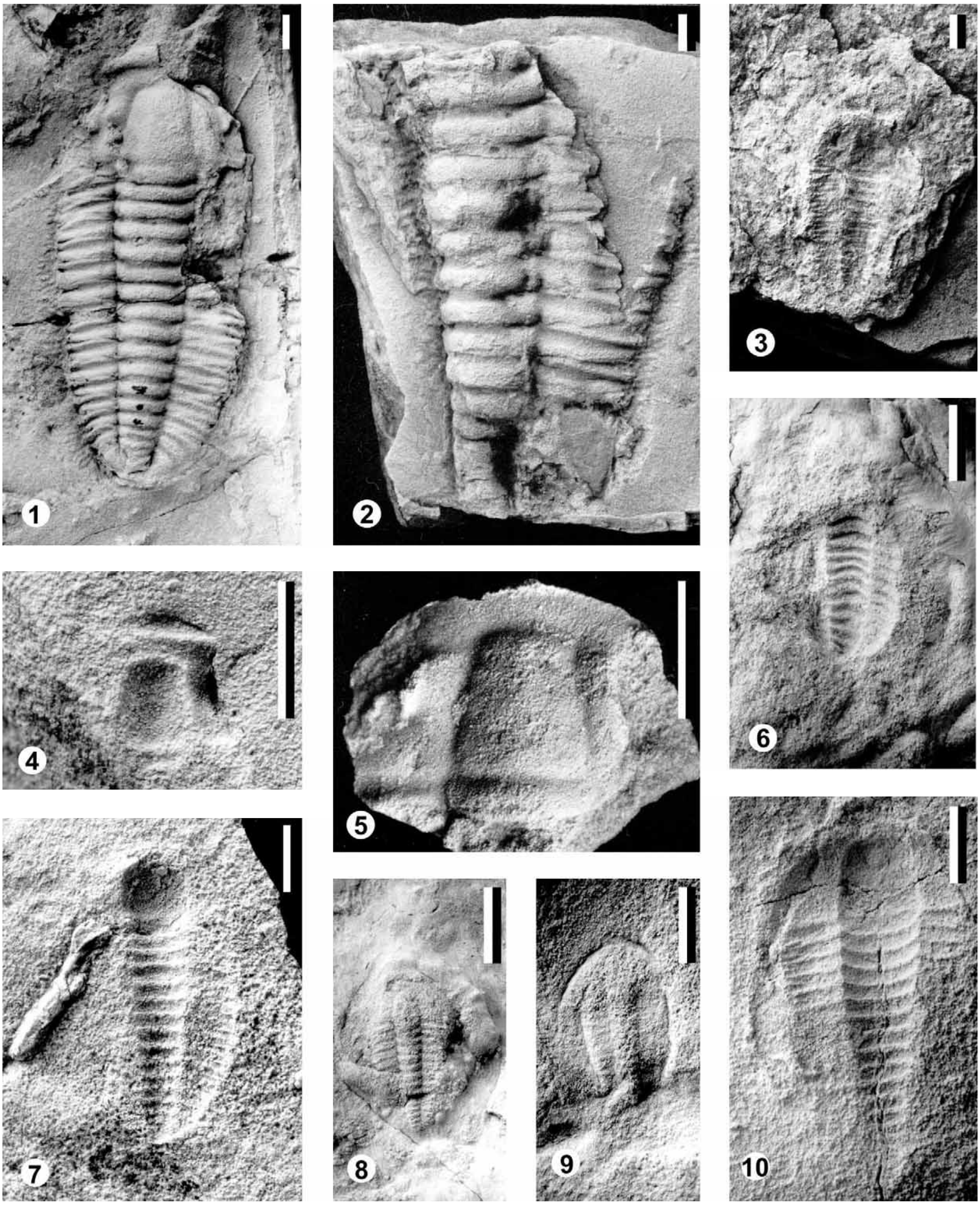


Fig. 11. Trilobites from the Wiśniówka Formation in the Wiśniówka Duża Quarry. Scale-bar equals 0.5 cm. **1-6** – *Aphelaspis rara* (Orłowski, 1968); 1 – MUZWG ZI/29/0001, original of Orłowski & *al*. (1970, pl. 3a) and Żylińska (2001, pl. 18, fig. 4); 2 – MUZWG ZI/29/0002, incomplete thorax, original of Orłowski & *al*. (1970, pl. 3d); 3 – MUZWG ZI/29/0003, effaced specimen; 4 – MUZWG ZI/29/0004, incomplete cranidium, original of Orłowski (1968b, pl. 4, fig. 12); 5 – incomplete cranidium; 6 – thorax, unnumbered specimen, Department of Geology, University of Vilnius, Lithuania; original of Żylińska (2001, pl. 19, fig. 11); **7-9** – *Protopeltura aciculata* (Angelin, 1854); 7 – almost complete specimen; 8 – almost complete specimen; 9 – almost complete specimen, MUZWG ZI/29/0685, original of Żylińska (2001, pl. 17, fig. 2); **10** – *Olenus solitarius* (Westergård, 1922), almost complete specimen, MUZWG ZI/29/0684, original of Orłowski (1968b, pl. 7, fig. 12a) and Żylińska (2001, pl. 4, fig. 4)

is *Rusophycus polonicus* ORŁOWSKI, RADWAŃSKI & RONIEWICZ[3] (RADWAŃSKI & RONIEWICZ 1963; ORŁOWSKI & *al*. 1970, 1971; SEILACHER 1970; ORŁOWSKI 1992a), ascribed to the activity of *Olenus rarus* ORŁOWSKI (ORŁOWSKI & *al*. 1970, 1971) (now: *Aphelaspis rara* – ŻYLIŃSKA 2001). Although the affinity of its tracemaker is controversial (acrocephalid – BERGSTRÖM 1973; paradoxidid – STUDENCKI 1994), it was obviously made by a trilobite with at least 12 thoracic segments, a relatively wide pygidium and long genal spines. The only trilobite in the assemblage fitting these characters is *Aphelaspis rara (*Text-fig. 11.1-11.6); the other species are small, with narrow and short thoraxes, narrow pygidia and rather short genal spines (Text-fig. 11.7-11.10). *R. polonicus* has been recently considered to be produced (ACEÑOLAZA 2003) by *Angelina hyeronimi* (KAYSER), an olenid trilobite with 15 segments, relatively wide pygidium and long genal spines (e.g., HARRINGTON & LEANZA 1957), thus of a similar general morphology to *Aphelaspis rara*. However, the trace fossils discussed by ACEÑOLAZA (2003) belong more probably to *Rusophycus moyensis* MÁNGANO, BUATOIS & MUÑIZ-GUINEA (MÁNGANO & *al*. 2005).

Cruziana semiplicata SALTER is another common trilobite trace fossil in the Wiśniówka Duża Quarry (RADWAŃSKI & RONIEWICZ 1963, 1972; ORŁOWSKI & *al*. 1970; BIRKENMAJER & BRUTON 1971; ORŁOWSKI 1992a) and its interpretation is similarly controversial. ORŁOWSKI & *al*. (1970) and ŻYLIŃSKA (1999) ascribed this trace fossil to *Aphelaspis rara*, whereas FORTEY & SEILACHER (1997) indicated *Maladioidella* cf. *colcheni* SHERGOLD, LIÑAN & PALACIOS as the trace maker. With a rostral plate, a well developed border and tapering glabella, *Aphelaspis rara* fits the general concept of *Maladioidella*. Similarities can also be observed in the outline of the free cheeks and pygidium. *Maladioidella* species, however, have a long frontal area (in *A. rara* it is 29±2% of total cranidial length – ŻYLIŃSKA 2001), distinct oblique eye ridges, and possess glabellar furrows. In many cases there is a slight indentation of the anterior cranidial border furrow. These features do not alter the outline of the cephalon, where the free cheeks are responsible for the creation of the longitudinal ridges in *C. semiplicata*.

Besides the large and easily recognizable *C. semiplicata* and *R. polonicus*, the Wiśniówka ichnocoenosis includes much smaller, coffee-bean-shaped *Rusophycus* and shorter, narrower, but relatively deeper *Cruziana* trace fossils (ŻYLIŃSKA 1992, pl. 1, fig. 5; see also Text-fig. 12). These small trace fossils were interpreted as a result of the activity of young *A. rara* (PRZEWŁOCKI 1999), however the small olenid *Protopeltura aciculata*, present in the trilobite assemblage, should also be considered (see also BERGSTRÖM 1973, pp. 56-57).

On the basis of the occurrence of *Cruziana barbata* SEILACHER in the southern part of the Wiśniówka Duża Quarry, ORŁOWSKI (1992a, b) suggested a middle Cambrian age for the basal part of the succession exposed there. Referring to the opinion of Sören JENSEN (see KOWALCZEWSKI 1995, p. 463), who refused to regard *C. barbata* as an index fossil of the uppermost middle Cambrian, ORŁOWSKI's suggestion was questioned by KOWALCZEWSKI (1995). Moreover, it appeared subsequently that *C. barbata* also occurs in other parts of the Wiśniówka Duża succession (ŻYLIŃSKA 1992), including the strata yielding *C. semiplicata* and *R. polonicus* (see the opinion of JENSEN in KOWALCZEWSKI 1995, p. 463). Consquently, *C. barbata* definitely possesses a much wider stratigraphic range and should not be regarded as a marker of the late middle Cambrian.

The trilobite assemblage of the Wiśniówka Duża succession suggests either the *Parabolina brevispina* Subzone (lower part of the *Parabolina spinulosa* Zone) or a wider interval encompassing the *Olenus scanicus* (upper part of the *Homagnostus obesus* Zone) to *P. brevispina* subzones (ŻYLIŃSKA 2002) (Text-fig. 10). Because the makers of the trilobite trace fossils found in the Wiśniówka Duża section seem to be quite convincingly identified, the biostratigraphic conclusions based on trilobites can be extended to the whole intervals using trace fossils even where the trilobite body fossils are missing (Text-figs 3-4).

[3]According to GÁMEZ-VINTANED (1995) and ACEÑOLAZA (2003), *Rusophycus polonicus* of ORŁOWSKI, RADWAŃSKI & RONIEWICZ, 1970 is not a valid taxonomic name. The same volume (CRIMES & HARPER 1970) contains a paper by SEILACHER (1970), which gives a taxonomic description of the species as *Cruziana polonica* sp. nov. As a result, both GÁMEZ-VINTANED (1995) and ACEÑOLAZA (2003) refer to *Rusophycus polonicus* (SEILACHER). Because the paper by ORŁOWSKI & *al.* (1970) has page priority over the paper by SEILACHER (1970), according to the International Code of Zoological Nomenclature the first three authors can be considered as authors of this taxon (see also ORŁOWSKI & *al.* 1971; and discussion in MÁNGANO & *al*. 2005)

OTHER MACROFAUNA

Apart from trilobites, the other faunal remains include an anomalocaridid jaw-apparatus, '*Peytoia*' sp. (MASIAK & ŻYLIŃSKA 1994) (Text-fig. 12), found in the eastern quarry road to the Wiśniówka Duża Quarry, and brachiopods collected from the southernmost wall of the quarry (JENDRYKA-FUGLEWICZ & MALEC 1997) (Text-figs 2a, 3-4).

Anomalocaridids and related forms occur in the lower and middle Cambrian and are very rare in the Furongian (CONWAY MORRIS 1989; DZIK 1993; MCHENRY & YATES 1993). However, as suggested by MASIAK & ŻYLIŃSKA (1994), '*Peytoia*' sp. may be related to the arthropods from the Furongian '*orsten*' assemblages (WALOSSEK & MÜLLER 1990).

The brachiopods from the southern wall of the Wiśniówka Duża Quarry (JENDRYKA-FUGLEWICZ & MALEC 1997) are represented by ten specimens, all found on a single rock slab. The specimens have not yet been published, and their taxonomy and stratigraphic position remain unclear. Bronisława JENDRYKA-FUGLEWICZ (*personal communication*) compared them to the Furongian material from Wales and maritime Canada, whereas Wiesław BEDNARCZYK (*unpublished opinion* 2001) and subsequently Lars HOLMER (*personal communication* 2005) referred them to Tremadocian or even Arenigian obolids. This fauna therefore requires detailed investigation before it can be used for biostratigraphical interpretations.

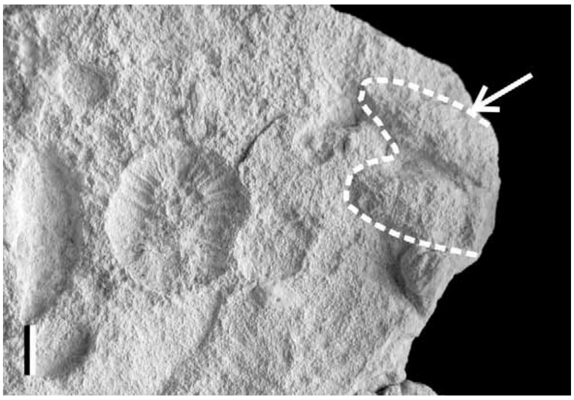


Fig. 12. '*Peytoia*' sp. from the Wiśniówka Formation in the Wiśniówka Duża Quarry, UWIPG B/III/1, original of MASIAK & ŻYLIŃSKA (1994, text-fig. 7). Arrow points to *Rusophycus* sp. Scale-bar equals 0.5 cm

As in the case of the trilobites, the original richness of benthic invertebrates in the Cambrian sea of the area is evidenced by the rich and diverse ichnocoenosis (RADWAŃSKI & RONIEWICZ 1960, 1963, 1967, 1972; ORŁOWSKI 1968, 1992a; ORŁOWSKI & *al*. 1970, 1971; ORŁOWSKI & ŻYLIŃSKA 1996). The possible trace-makers include non-trilobite arthropods, molluscs, priapulids, and other unknown soft-bodied animals.

CONCLUSIONS

1. The acritarch and trilobite record suggests an early Furongian age for most of the strata exposed in the Wiśniówka Duża Quarry. Unfortunately, this age cannot confidently be inferred for the entire succession due to its complex tectonics. Strata exposed in the Wiśniówka Mała Quarry are also of a similar age and those from the Podwiśniówka Quarry are probably of middle Cambrian age.

2. The acritarch assemblages closely resemble contemporaneous associations from the palaeocontinents of Baltica (Russia) and Avalonia (Newfoundland, Belgium). Correlatives can also be found in successions from West Gondwana (Spain, Turkey, Iran), which points to a unification of the acritarch flora in these realms in Furongian times.

3. The good coincidence between the datings based on acritarchs and trilobites shows that future studies on the Cambrian in the HCM require the application of both groups of fossils in biostratigraphic analysis.

Acknowledgements

The manuscript was significantly improved by the constructive revisions by Małgorzata MOCZYDŁOWSKA-VIDAL, Uppsala University, and Zdzisław BEŁKA, Adam Mickiewicz University, Poznań. Gratitude is expressed to Monika WOJCIECHOWSKA (Warsaw) and Michał POROS (Kielce) for access to trilobites collected by them in the Wiśniówka Duża Quarry. Financial support was provided by the Faculty of Geology (individual BW grants to AŻ) and the Holy Cross Branch of the Polish Geological Institute (to ZS and SS).

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Manuscript submitted: 18th July 2006
Revision version accepted: 14th November 2006

PLATE 1

Acritarchs from the Wiśniówka Formation in the Wiśniówka Duża Quarry (WD), specimens from samples: 1 (slide 4838), 4 (slide 4835), 6 (slide 4836) and 7 (slide 4837). Scale-bars equal 10 μm

1-2 – *Timofeevia phosphoritica* Vanguestaine, 1978 (WD4)
3-4 – *Vulcanisphaera spinulifera* (Volkova) Parsons & Anderson, 2000 (WD1)
5-6 – *Vulcanisphaera turbata* Martin in Martin & Dean, 1981 (5 – WD6, 6 – WD4)
7 – *Timofeevia pentagonalis* (Vanguestaine) Vanguestaine, 1978 (WD4)
8 – *Granomarginata* sp. (WD6)
9-10 – *Vulcanisphaera africana* Deunff, 1961 (WD4)
11 – ?*Eliasum* sp. (WD6)
12 – ?*Ovulum* sp. (WD6)
13 – *Poikilofusa* sp. (WD6)
14 – *Pirea orbicularis* Volkova, 1990 (WD7)
15 – *Pirea* sp. (WD1)
16-17 – *Cymatiogalea* cf. *C. cristata* (Downie) Rauscher, 1974 (WD6)
18 – *Cymatiogalea velifera* (Downie) Martin, 1969 (WD1)
19 – *Cymatiogalea fimbriata* Volkova, 1990 (WD6)
20-23 – *Cymatiogalea bellicosa* Deunff, 1961 (20, 23 – WD4, 21-22 – WD1)
24 – *Stelliferidium* sp. (WD7)

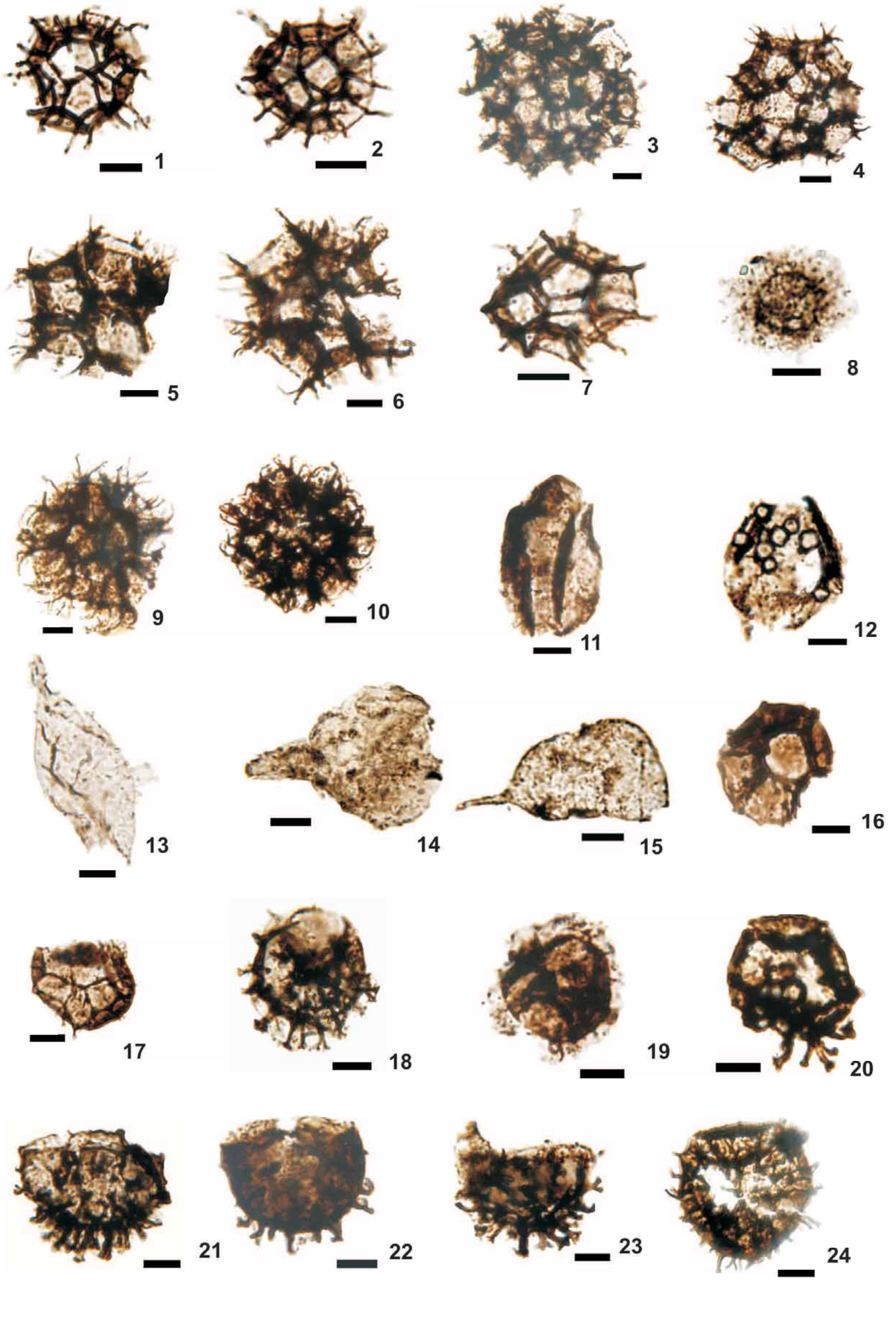
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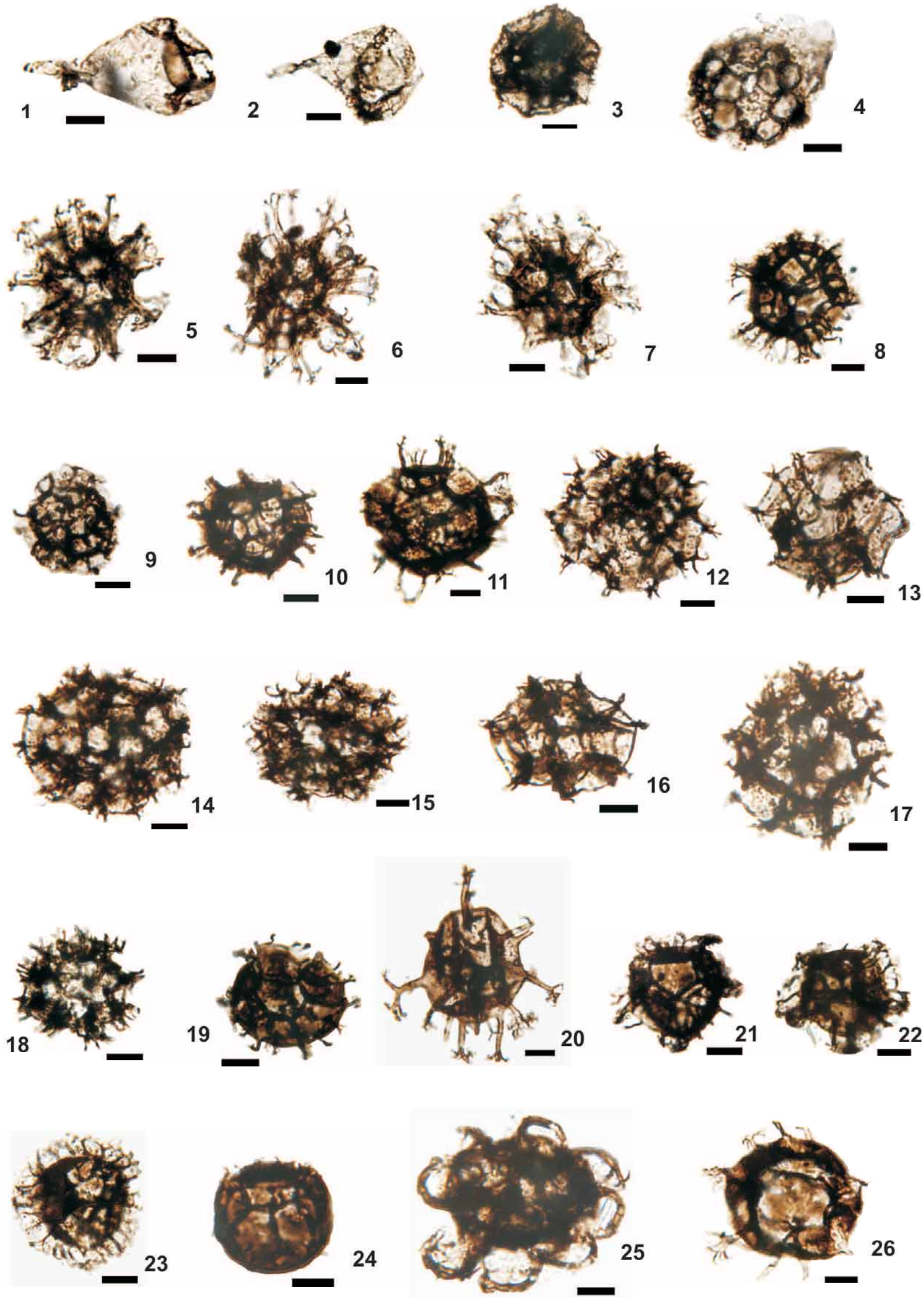
PLATE 2

Acritarchs from the Wiśniówka Formation in the Wiśniówka Mała (WM – all specimens from sample 20, slide 4745) and Podwiśniówka quarries (P – all specimens from sample 17, slide 4715); scale-bars equal 10 μm

1-2 – *Pirea orbicularis* VOLKOVA, 1990 (WM)
3 – *Cristallinium cambriense* (SLAVÍKOVÁ) VANGUESTAINE, 1978 (WM)
4 – *Dictyotidium* sp. (WM)
5-7 – *Timofeevia lancarae* (CRAMER & DIEZ) VANGUESTAINE, 1978 (5, 6 – WM, 7 – P)
8-11 – *Timofeevia phosphoritica* VANGUESTAINE, 1978 (8-10 – WM, 11 – P)
12-15 – *Vulcanisphaera spinulifera* (VOLKOVA) PARSONS & ANDERSON, 2000 (12-14 – WM, 15 – P)
16 – *Vulcanisphaera spinulifera* (VOLKOVA) PARSONS & ANDERSON, 2000 transitional to *Vulcanisphaera turbata* MARTIN in MARTIN & DEAN, 1981 (WM)
17-18 – *Vulcanisphaera obsoleta* (VOLKOVA) PARSONS & ANDERSON, 2000 (WM)
19 – *Timofeevia* sp. (WM)
20, 26 – *Multiplicisphaeridium* sp. (20 – P, 26 – WM)
21-22 – *Cymatiogalea velifera* (DOWNIE) MARTIN, 1969 (WM)
23 – *Cymatiogalea* cf. *C. velifera* (DOWNIE) MARTIN, 1969 (WM)
24 – *Cymatiogalea* cf. *C. cristata* (DOWNIE) RAUSCHER, 1974 (WM)
25 – ?*Cymatiogalea* sp. (WM)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