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CAMBRIAN ORGANIC MICROFOSSILS AT THE BORDER AREA OF THE EAST- AND WEST-EUROPEAN PLATFORMS (SE POLAND AND WESTERN UKRAINE)

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Abstract: This paper contains palynological and stratigraphical characteristics of the selected Cambrian sections encountered in the basement of the north-eastern part of the Carpathian Foredeep and the Outer Carpathian margin in south-eastern Poland and western Ukraine, as well as verification of the stratigraphical position of rocks recognised so far in several sections in western Ukraine. The acritarch assemblages of the Cambrian System Series 2 are dominated by species of the characteristic early Cambrian genus *Skiagia*. The Cambrian Series 3 beds are documented by the assemblages with numerous specimens of the *Adara alea*, *Cristallinium cambriense*, *Heliosphaeridium notatum*, *Eliasum llaniscum*, *Multiplicisphaeridium martae*, and *Comasphaeridium longispinosum*. Furongian sediments are evidenced by strongly taxonomically diversified assemblages with large quantities of acritarchs, containing genera *Timofeevia*, *Vulcanisphaera*, *Ninadiacrodium*, *Pirea*, *Leiofusa*, *Lusatia*, or *Polygonium*, as well as taxa characterized by diacrodial symmetry. These assemblages are dominated by such genera, as: *Dasydiacrodium* or *Acanthodiacrodium*, and also by specimens with large polar opening of the central body, belonging to acritarchs of the "galeate" group. Within the studied Cambrian sediments, nine acritarch assemblages of differing composition were distinguished. These assemblages were correlated with faunistic zones. Ages younger than Palaeozoic, identified in some of the analysed Ukrainian sections, were determined basing on very well preserved assemblages of spores and pollen.

Key words: Cambrian, palynology, acritarchs, stratigraphy, SE Poland, West Ukraine.

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INTRODUCTION

During the last several decades, organic microfossil assemblages of an informal *Acritarcha* group were successfully applied in stratigraphical subdivision of the Palaeozoic, especially of the Lower Palaeozoic rocks (Molyneux *et al.*, 1996). These microfossils, the number of which can exceed 10,000 specimens in 1 gram of rock, are usually regarded as unicellular marine algal cysts. Their cell membranes are built of extraordinary chemically resistant organic substance. This indicates a dormant stage of the organisms. Massive occurrence of these fossils in marine sediments suggests their planktonic way of life. Therefore, rich and determinable acritarch assemblages could be recovered from small-size rocks samples, even of few grams of weight, only. That is why positive results were obtained also from studies of small fragments of well cores or even of small percussion drillings cuttings (Downie, 1984; Martin, 1993).

In the Lower Palaeozoic, acritarchs were very quickly changing, and new morphological types appeared. They have very high stratigraphical value for Cambrian rocks, especially for sediments devoid of macrofossils. After the Late Ediacaran crisis, the number of acritarch species in Cambrian sediments was growing rapidly. Marine phytoplankton content substantially changed several times (Volkova, 1990). Massive appearance of acritarch assemblages in Cambrian sediments and their distinct taxonomic differentiation allowed for development of the reliable palaeontological zonation, broadly used in palaeontological records. The oldest Cambrian acritarch associations, which in many areas have been closely correlated with faunistic zones (Martin & Dean, 1984, 1988; Volkova, 1990; Jankauskas & Lendzion, 1992; Parsons & Anderson, 1996, 2000), have cosmopolitan character in geographical sense. This allowed for detail correlation of the areas that were sometimes very distant from each other.

On the base of various acritarch associations, Cambrian sediments were subdivided in detail within the East-European Craton (Volkova *et al.*, 1983; Moczydłowska, 1991, 1999; Volkova, 1990; Jankauskas & Lendzion, 1992; Jankauskas, 2002), Scandinavia (Hagenfeldt, 1989a, b; Welsch,

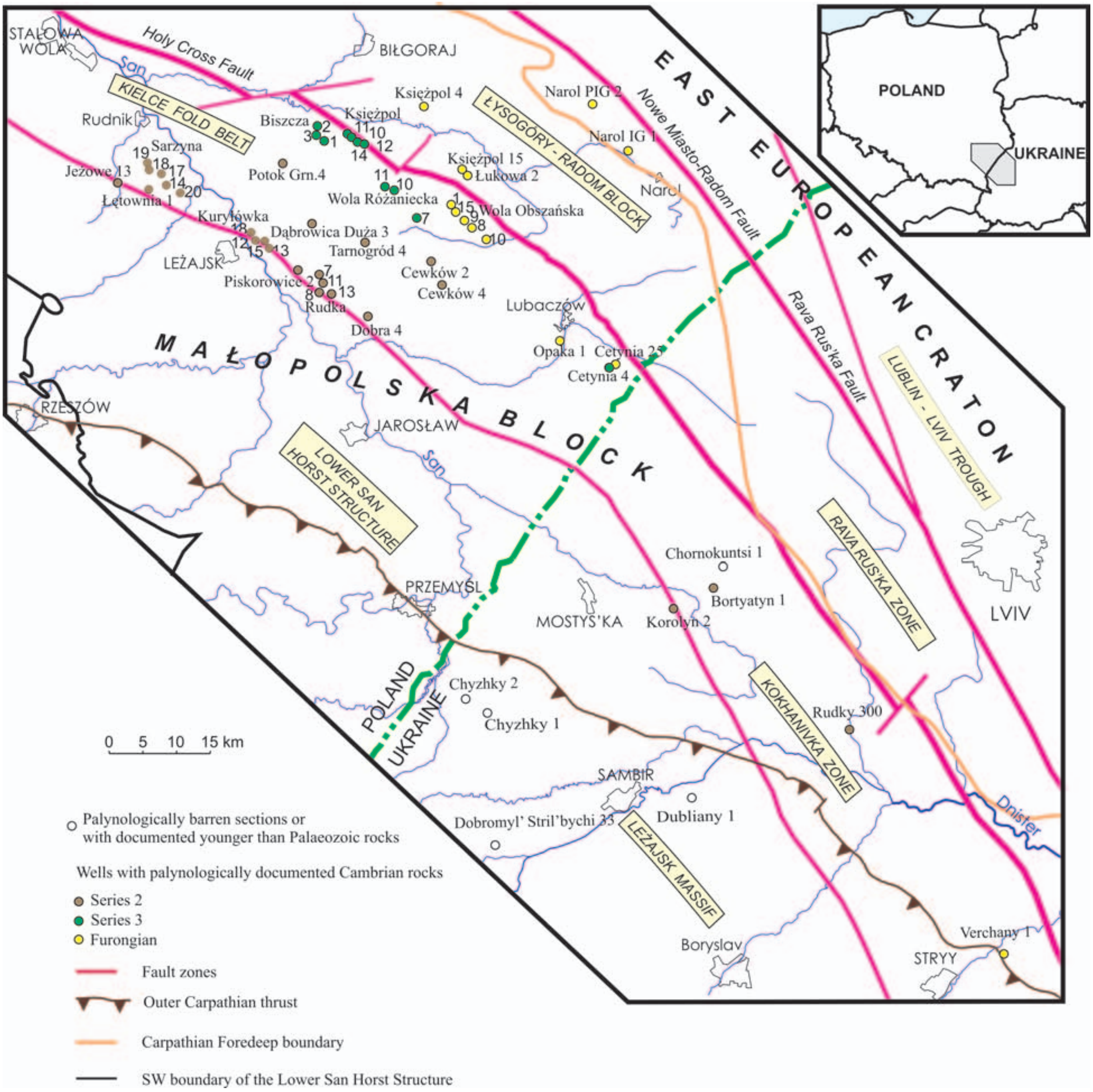


Fig. 1. Location of the investigated well profiles

1986), Newfoundland (Martin & Dean, 1981, 1988), Belgium, and France (Vanguestaine & Van Looy, 1983). A dozen or so acritarch zones have been distinguished in Cambrian sediments within these areas, from *Platysolenites* zone to begin with, up to the Cambrian and Ordovician boundary. The proposed subdivisions have been correlated with the Cambrian occurrences in other areas, for instance, in Northern Africa (Albani *et al.*, 1991), Spain (Fombella, 1977, 1978, 1979; Mette, 1989; Palacios, 2008, 2010), and the Bohemian Massif (Fatka, 1989). The well- known Cambrian acritarch assemblages from the areas located nearest to the investigated region were the ones reported from the Holy Cross Mountains (Szczepanik, 2009; Żylińska & Szczepanik, 2009), from the Upper Silesian Block (Jachowicz, 1994; Buła & Jachowicz, 1996; Jachowicz-Zdanowska, 2010), and from the Lublin-Podlasie Slope of the East-European Craton (Moczydłowska, 1991, 1999).

There were disputes for many years on the age of the sediments occurring in south-eastern Poland, in the Outer Carpathian Mountains, and in the Carpathian Foredeep basement. Karnkowski and Głowacki (1961) claimed that the basement is built up mainly of the Precambrian phyllite schists, and of Cambrian sediments of an enigmatic stratigraphical position.

The first palynological investigations of these rocks were carried out by Jagielska (1962). The results of more detailed acritarch investigations of the Miocene basement in the eastern part of the Carpathian foreland were presented by Głowacki *et al.* (1963). They suggested the first subdivision of these Palaeozoic sediments, based on the microflora assemblages. Unfortunately, it is difficult to verify their taxonomic determinations because of incomplete photographic record of the investigated associations. On the other hand, in the Ryszkowa Wola 3a well located within the discussed area, the presence of the determinable assemblages of Cambrian acritarchs has been recognised by Pożaryski *et al.* (1981). The Cambrian sediments documented in this well have been correlated with the *Holmia* beds from the Holy Cross Mountains. Based on the palynological investigations, carried out on the fragmentary cores collected from few wells located SW of the Lubaczów Elevation, Dziadzio and Jachowicz (1996) proved that the Carpathian Foredeep basement is built up by Lower Cambrian rocks, and not by Precambrian rocks as it was formerly assumed (Karnkowski & Głowacki, 1961).

The systematic palynological investigations, carried out by the author of this paper, have brought about much new information on the occurrence and extent of the Precambrian and Lower Palaeozoic rocks in south-eastern Poland. These investigations have been commissioned by the Polish Oil & Gas Company (POGC); and some of the results have already been published (Jachowicz & Moryc, 1995; Dziadzio & Jachowicz, 1996; Moryc & Jachowicz, 2000, Dziadzio & Probulski, 1997; Kowalska *et al.*, 2000; Maksym *et al.*, 2003). The stratigraphical data, presented in the mentioned above and in an unpublished report (Jachowicz *et al.*, 2002), have been taken into consideration when constructing the geological model of the Precambrian and Palaeozoic rocks from south-eastern Poland: the Outer Carpathian Mountains and the Carpathian Foredeep basement (Buła & Habryn, *eds*., 2008).

The main aim of this paper is to summarise the results of palynological investigations of the Cambrian from the Stalowa Wola–Lubaczów area in Poland, and to compare them with the information obtained from the study of wells drilled in the Ukraine (Fig.1). At the same time, the published Ukrainian stratigraphic data (Drygant, 2000) are verified with the use of new palynological information.

GEOLOGICAL SETTING

The analysed area, covering south-eastern Poland and western Ukraine, is located within the Trans-European Suture Zone (TESZ), which extends along the south-western edge of the East-European Craton (Buła & Habryn, 2011). It constitutes a boundary between the old Precambrian craton and the West-European Palaeozoic platform, consolidated during the multiple diastrophic processes (Mizerski & Stupka, 2005). Within this area, the Precambrian and Palaeozoic rocks (from Cambrian to Carboniferous) are covered by the younger sediments of the Carpathian flysch and the Carpathian Foredeep (Ślączka *et al.*, 2006). They are known from the subsurface, drilled by numerous wells.

The Precambrian and Palaeozoic rocks, recognised in the area, are located within the following tectonic units: the Małopolska and Łysogóry-Radomsko blocks in Poland, as well as the Leżajsk Massif, and Kokhanivka and Rava Rus'ka zones in the Ukraine (Buła & Habryn, 2011) (Fig. 1). These units are usually considered fragments of the Palaeozoic European platform (Mizerski & Stupka, 2005). The Małopolska Block is regarded as a passive part of the East-European Craton (Żelaźniewicz *et al.*, 2009). It is usually being connected, together with some other tectonic units, with the terrane group of the Teisseyre–Tornquist Zone (the Teisseyre–Tornquist Terrane Assemblage, TTA) (Nawrocki & Poprawa, 2006; Żelaźniewicz *et al.*, 2009). The position of Cambrian rocks in relation to the Precambrian ones, is not known in this area because of incompleteness of the available Cambrian sections. The transition zones between particular Cambrian stages (between Series 2 and Series 3 of the Cambrian system, as well as between Cambrian Series 3 and Furongian) are also not known (Fig. 2).

The Cambrian clastic sediments were well recognised in the areas adjacent to the investigated region: the Holy Cross Mountains (Szczepanik, 2009) and the Lublin-Podlasie Slope of the East-European Platform (Moczydłowska, 1991) (Fig.2). However, in the western part of the Małopolska Block no sediments of that system have been found (Fig. 2).

MATERIAL AND METHODS

Palynological investigations were carried out on samples from the cored intervals of fourty-two wells, drilled by the POGC within the Carpathian Foredeep basement, in the Stalowa Wola–Lubaczów area. Below the Jurassic or Miocene sediments, clastic rocks were encountered, with no organic remnants that would define their age (Fig. 1; Tables 1–3). In western Ukraine, palynological investigations were carried out on nine well sections; four of which (Chyzhky 1, 2, Dobromyl Strilbychi 33, and Dublyany 1) were located within the Leżajsk Massif, and the remaining five wells (Korolyn 2, Chornokuntsi 1, Bortyatyn 1, Rudky 300, and Verchany 1) were drilled within the Kokhanivka zone (Fig. 1; Tables 4, 5).

Samples of claystones, siltstones, sandy siltstones and sandstones, often interbedded by siltstones (heteroliths), were collected for palynological analyses. Standard palynological techniques (Wood *et al.*, 1996) have been applied. Most of the analysed samples contained fairly abundant and well preserved specimens of the acritarchs; usually 150 up to over 300 specimens within a standard microscope slide. Several thousand acritarchs have been found in slides from the Furongian rocks.

ACRITARCH SUCCESSION IN THE STALOWA WOLA–LUBACZÓW ZONE

Various acritarch assemblages were recognised in the studied wells. Examination of these assemblages allowed for detailed subdivision of the fragmentary Cambrian sections. Based on differentiated organic microfossils, nine characteristic acritarch assemblages were distinguished in the studied area. They clearly differed from each other by the genera and species content. The first two assemblages, I and II, were related to the Cambrian Series 2 (Fig. 3); the assemblages III and IV documented the Cambrian Series 3 beds, and the remaining assemblages, from V to IX, belonged to the Furongian sequence (Fig. 4).

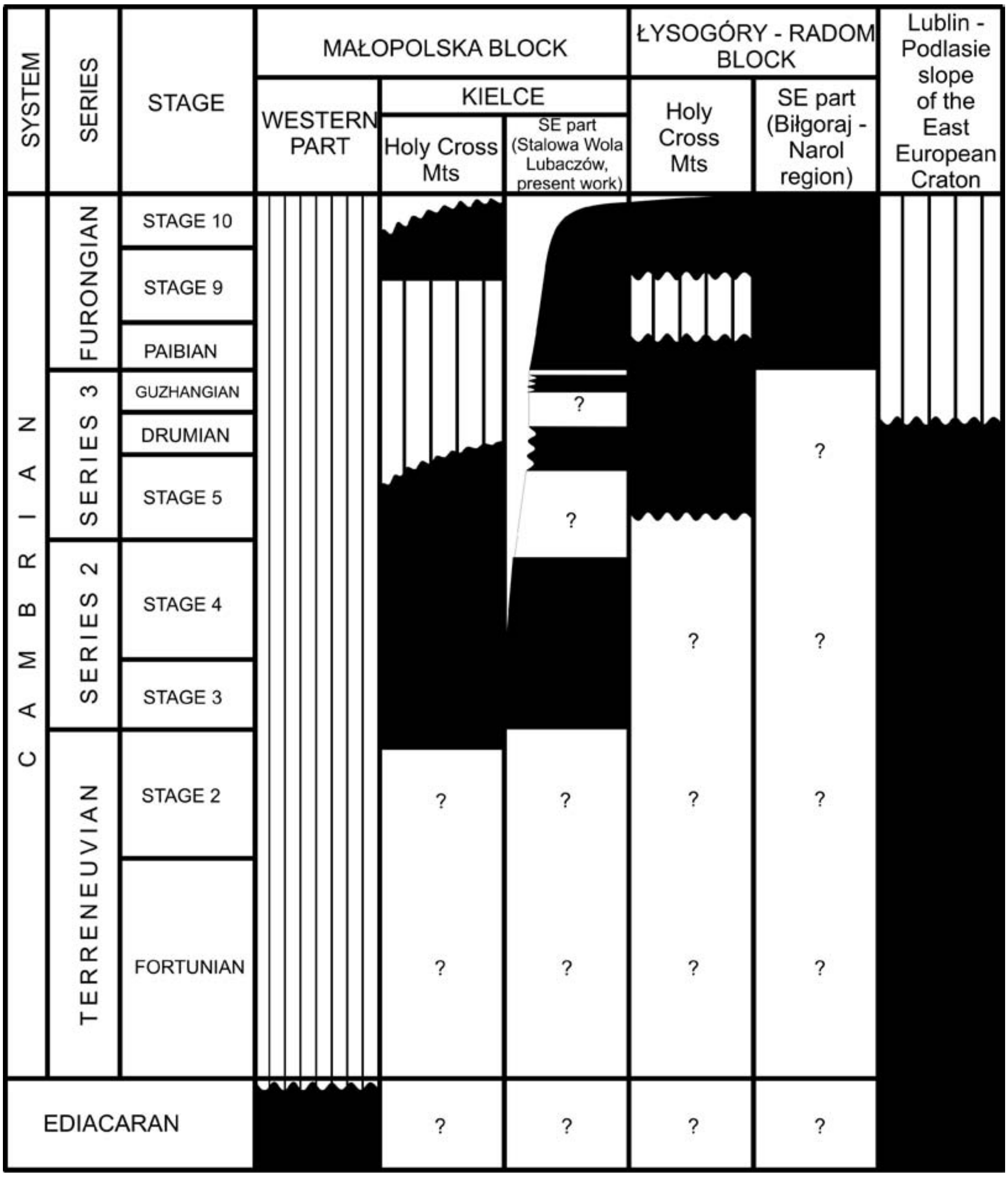


Fig. 2. Precambrian and Cambrian stratigraphic sections of south-eastern Poland (investigated and adjacent areas)

Series 2 – *Schmidtiellus mickwitzi-Holmia* Zones

The bottom of the Cambrian Series 2, using the recently accepted subdivision of the Cambrian system (Ogg *et al.*, 2008; Żylińska, 2008), is connected with the first appearance of trilobites. Within the old, three-partite Cambrian subdivision, the beginning of the "trilobitic" Cambrian was correlated with the bottom of the *Schmidtiellus mickwitzi* zone. Important changes of the marine plankton took place within this zone. Numerous forms of diverse morphology appeared, and the number of species has grown to over 100 (Gaucher & Sprechmann, 2009). Domination of the Acanthomorphitae (Downie *et al.*, 1963) forms within acritarch assemblages began. These characteristic forms with funnel-shape endings represent specimens of *Skiagia*, which is a typical Early Cambrian genus. They are clear indicators of the Cambrian System Stages 3 and 4 (Moczydłowska & Zang, 2006). Moreover, within the "trilobitic" early Cambrian sediments, many other species appear belonging mainly to the Acanthomorphitae subgroup (Downie *et al.*, 1963) (*Comasphaeridium*, *Asteridium* or *Heliosphaeridium*). Representatives of other subgroups, such as: Pteromorphitae (Downie *et al.*, 1963), Herkomorphitae (Downie *et al.*, 1963) or Netromorphitae (Downie *et al.*, 1963), are less abundant.

The first two acritarch associations were recognised within the south-western part of the analysed area, in a belt extending from Rudnik to the northwest, down to Lubaczów to the southeast (Fig. 1). In this area, acritarch assemblages typical for the Cambrian Series 2 were found in 22 wells (Table 1).

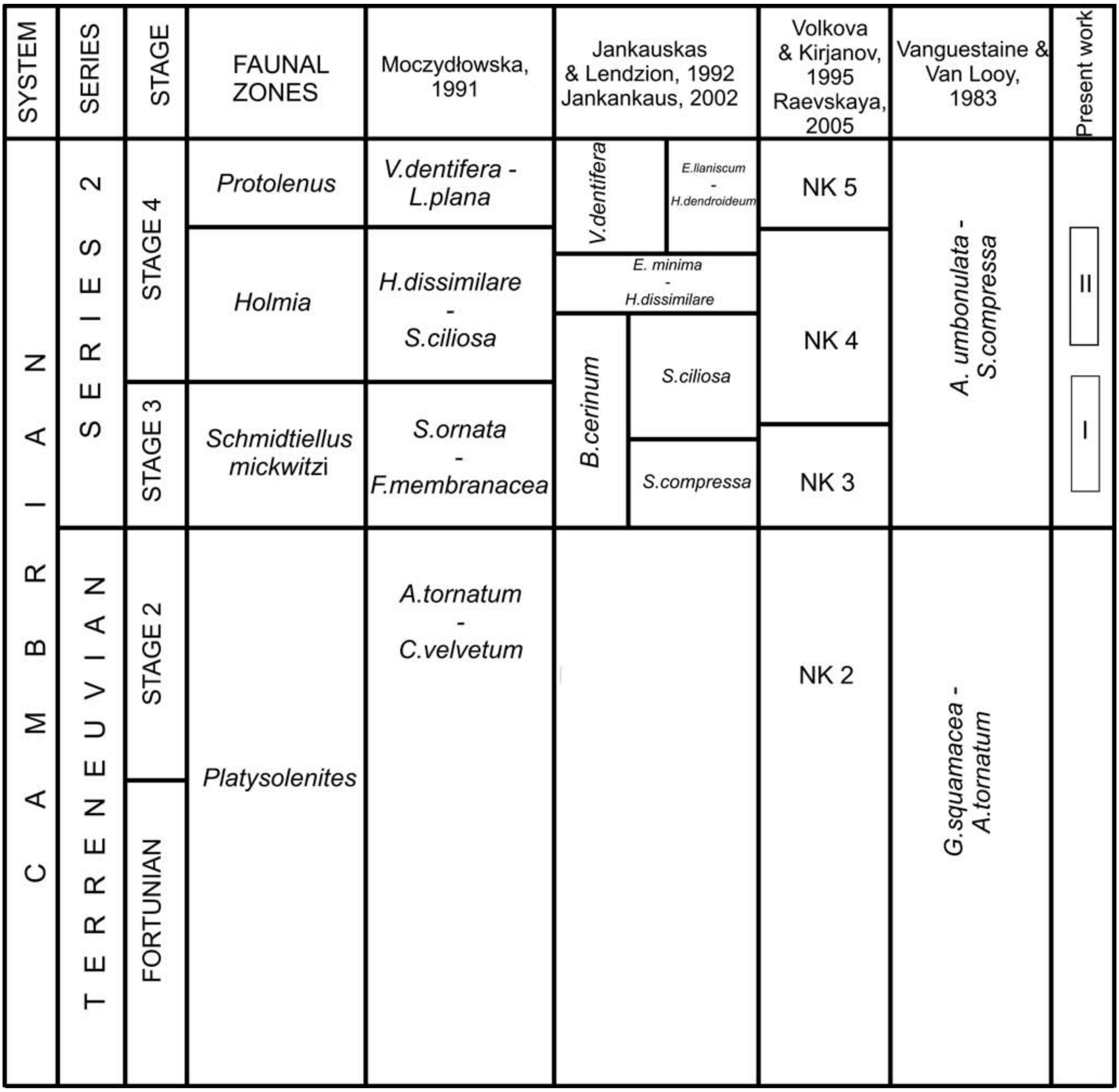


Fig. 3. Cambrian acritarch zonation of Terreneuvian and Cambrian Series 2

Assemblage I

This oldest assemblage is characterized by acritarch associations dominated by *Globosphaeridium*, *Comasphaeridium*, and *Lophosphaeridium* genera, and by the new index genus *Ichnosphaera* (*sensu* Jachowicz-Zdanowska, 2010). Acritarchs of the new genus *Ichnosphaera* were for the first time described as *Skiagia ornata* type 1 (Moczydłowska & Vidal, 1986), and then as *Electoriscos flexuosus* (Eklund, 1990). These specimens differ from the well-known Cambrian genus *Skiagia* ending these processes and the type of *Elektoriscos* differ in processes attachment to the specimen walls. Therefore, the author proposes for these forms a new typical species *Ichnosphaera flexuosa* n.comb. (Fig. 7: M) on the basis of detailed taxonomic studies of the great number of specimens from the Upper Silesian Block. This taxon, together with the new species, is described by the author in detail in the palaeontological part of the monograph (Jachowicz-Zdanowska, in press) on the palynology of the Cambrian from the Brunovistulicum area. Beside the Upper Silesian Block, this acritarch type has been described from Cambrian rocks of Scandinavia (Moczydłowska & Vidal, 1986; Eklund, 1990) and southern Ireland (Brück & Vanguestaine, 2004). These forms have usually been found, so far, in sediments correlated with the lower part of the early "trilobitic" Cambrian beds, in upper part of *Schmiditellus mickwizti* and in lower part of *Holmia* zones. For example, in Scandinavia they are known from the Holmia A level (Moczydłowska & Vidal, 1986). These characteristic acri-

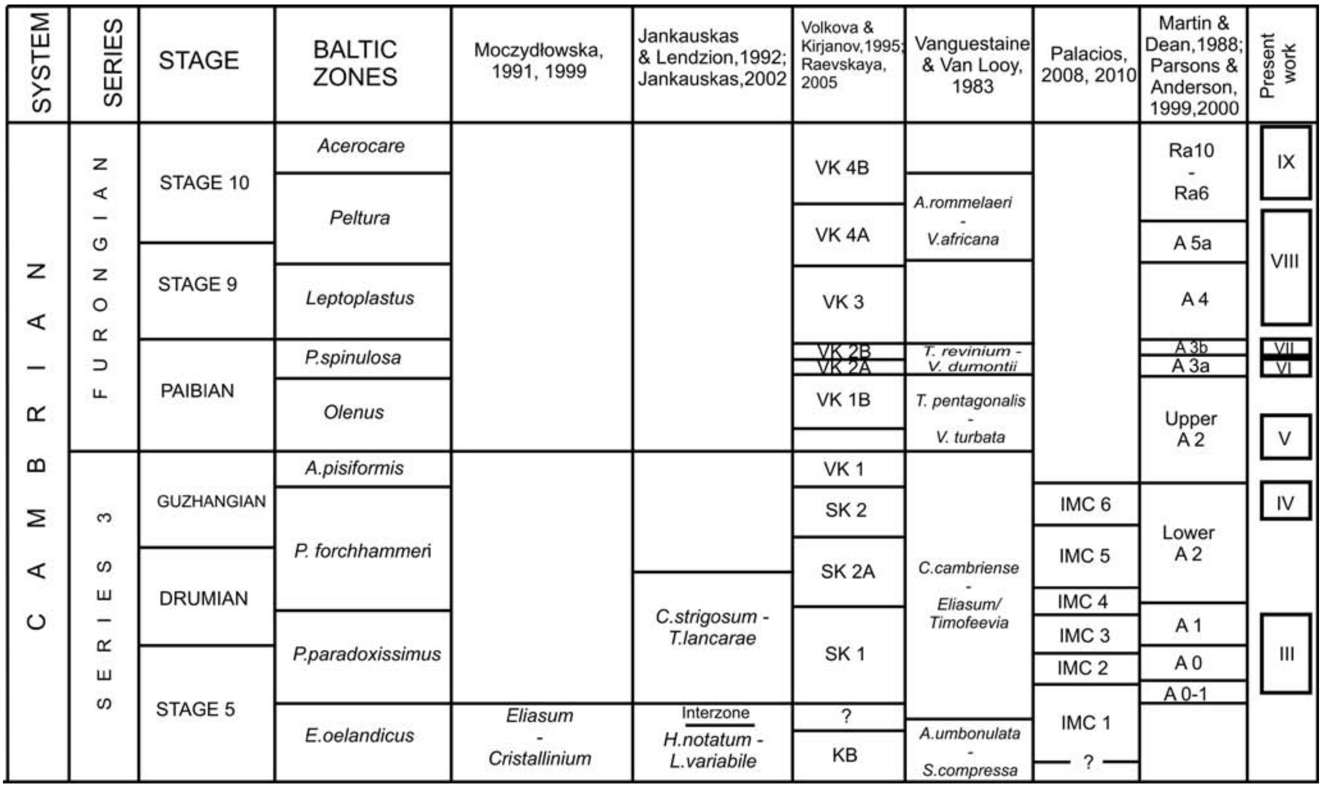


Fig. 4. Cambrian acritarch zonation of Cambrian Series 3 and Furongian

Table 1

List of palynologically dated sections of Cambrian Series 2 from Stalowa Wola-Lubaczów zone

Borehole		Investigated intervals (all positive)
1	Cewków 2	1545.0 m - 1547.0 m;
2	Cewków 4	1594.0 m - 1599.0 m; 1612.0 m -1615.0 m
3	Dąbrowica Duża 3	1473.0 m - 1482.0 m
4	Dobra 4	1501.0 m - 1506.0 m ; 1504.0 m - 1504.5 m; 1516.0 m - 1517.0 m
5	Jeżowe 13	878.0 m - 882.0 m
6	Kuryłówka 12	988.0 m - 994.0 m
7	Kuryłówka 13	1026.0 m - 1035.0 m; 1035.0 m - 1044.0 m; 1085.0 m - 1094.0 m
8	Kuryłówka 15	999.0 m - 1008.0 m
9	Kuryłówka 18	967.0 m - 976.0 m
10	Łętownia 1	884.0 m - 888.0 m
11	Piskorowice 2	1214. 0 m - 1219.0 m
12	Potok Górny 4	1171.0 m - 1180.0 m
13	Rudka 7	1493.0 m - 1496.0 m; 1506.0 m - 1510.0 m
14	Rudka 8	1254.0 m - 1262.0 m
15	Rudka 11	1272.0 m - 1281.0 m
16	Rudka 13	1302.0 m - 1311.0 m
17	Sarzyna 14	754.0 m - 758.0 m
18	Sarzyna 17	770.0 m - 779.0 m
19	Sarzyna 18	814.0 m - 823.0 m
20	Sarzyna 19	804.0 m - 813.0 m
21	Sarzyna 20	791.0 m - 796.0 m
22	Tarnogród 4	1568.4 m - 1573.0 m

tarchs were not previously recorded in the East-European Platform area, however, their numerous specimens are described from the "Mickwitzia sandstone" in central Sweden and from the "Green Shale" Formation in the Bornholm region (Moczydłowska & Vidal, 1992).

Within the Assemblage I, typical *Skiagia* specimens are rare and belong to *S. ornata* mainly. This microflora has been found in samples collected from a few wells, *e.g.*, Sarzyna 18 and Dąbrowica Duża 3. Similar acritarch assemblages commonly occur within the Głogoczów Bioturbated Sandstones (Mb) sediments, in the Upper Silesian Block (Jachowicz-Zdanowska, 2010). The latter, together with the Brno Block in the Czech Republic, form a much larger tectonic unit Brunovistulicum (Buła *et al.*, 1997). These assemblages still have no precise faunistic characteristics. It is known, however, that they are located between the *Platysolenites* (Brno Block) (Vavrdová *et al.*, 2003) and *Holmia* zones (Upper Silesian Block) beds (Orłowski, 1975). Therefore, they may represent *Schmidtiellus mickwitzi* zone or the lower part of the *Holmia* zone (Fig. 3). The presence of associations with similar composition has been reported from the Lower Cambrian sediments in the Holy Cross Mountains area (Szczepanik, 2009).

Assemblage II

This association is characterized by domination of the genus *Skiagia*, represented by various species: *S. orbiculare*, *S. ciliosa*, *S. ornata*, or *S. pura*. Within the analysed samples, they are accompanied by such genera and species, as: *Granomarinata prima*, *G. squamacea*, *Heliosphaeri-*

dium dissimilare, *Archeodiscina umbonulata*, *Estiastra minima*, *Solisphaeridium implicatum*, *Asteridium* sp., and *Comasphaeridum* sp. Associations of this type are known from many Cambrian occurrences. They were recorded within the sediments of the *Schmidtiellus mickwitzi-Holmia* beds (Volkova, 1968, 1969a,b; Moczydłowska, 1991; Jankauskas & Lendzion, 1992, Jankauskas, 2002) (Fig. 3).

Series 3 –*Paradoxides paradoxissimus*, ? *Agnostus pisiformis* Zones

During the transition time between the Series 2 and Series 3 of the Cambrian System, the global changes in the microplankton composition occurred. Very clear changes appeared within acritarch assemblages. That was a second massive phytoplankton exchange after the Ediacaran time (Vidal & Knoll, 1983). Numerous early Cambrian acritarch associations, dominated by *Skiagia* genus, became extinct. They were replaced by numerous representatives of the *Herkomorphitae* subgroup, with such genera, as: *Cristallinium, Eliasum* or *Timofeevi*a, index for the Cambrian Series 3. The occurrence of the index taxon *Adara alea*, characterized by fairly short appearance time, and very often by numerous populations, is especially important in sediments of this age.

Acritarchs of the Cambrian Series 3 were studied in detail in many areas: Canada (Martin & Dean, 1988; Parsons & Anderson, 1996, 2000; Palacios *et al.,* 2009), Spain (Cramer & Diez, 1972; Fombella,1978; Palacios, 2008; 2010), and the East-European Craton (Volkova, 1990; Jankauskas & Lendzion, 1992). The suggested biozonation of the Cambrian sequence, from *Eccaparadoxides oelandicus* zone up to *Paradoxides forchhammeri* one, have very good faunistic evidences (Martin & Dean, 1988; Parsons & Anderson, 1996, 2000; Palacios, 2008, 2010; Palacios *et al.*, 2009) (Fig. 4).

Three distinct stages of the Cambrian Series 3 microfloral development may be distinguished at present. The first one is connected with the oldest zone – *Eccaparadoxides oelandicus*. In its bottom, assemblages dominated by such genera and species, as: *Eliasum*, *Cristallinium*, *Retisphaeridium*, *Comasphaeridium silesiense*, *Solisphaeridium implicatum*, and *Heliosphaeridium notatum* species appeared. The last one is acknowledged as the index taxon of this zone (Jankauskas & Lendzion, 1992; Palacios, 2008). The second stage is represented by microflora of the *Adara alea* zone (Martin & Dean, 1988). It is delimited by the extent of the index taxon from the *Paradoxides paradoxissimus* beds. Its stratigraphic position is very well marked by trilobite fauna (Martin & Dean, 1981, 1988). Within the younger Series 3 beds, from the higher part of the *Paradoxides paradoxissimus* zone, and further on, within the almost whole *Paradoxides forchhammeri* zone, species of the genus *Timofeevia* dominate in the acritarch assemblages. Next to it, for the first time in the highest part of the Series 3, genus *Vulcanisphaera* appears. These two latter genera have continued their occurrence within the Furongian beds. Some of their species were also found within the oldest Ordovician rocks.

Table 2

List of palynologically dated sections of Cambrian Series 3 from Stalowa Wola-Lubaczów zone

Borehole		Investigated intervals (all positive)
1	Biszcza 1	966.0 m - 967.5 m; 1002.0 m - 1004.0 m; 1006.2 m; 1040.0 m - 1044.0 m; 1044.0 m - 1055.0 m
2	Biszcza 2	989.0 m - 1001.0 m; 1026.0 m - 1037.0 m
3	Biszcza 3	977.0 m - 986.0 m; 991.0 m - 994.0 m
4	Cetynia 4	1047.0 m - 1050.0 m
5	Księżpol 11	931.0 m - 940.0 m
6	Księżpol 12	946.0 m - 955.0 m
7	Księżpol 14	956.0 m - 965.0 m
8	Wola Różaniecka 7	1128.0 m - 1137.0 m; 1150.0 m - 1159.0 m; 1174.0 m - 1183.0 m; 1201.0 m - 1210.0 m
9	Wola Różaniecka 10	1074.0 m - 1092.0 m
10	Wola Różaniecka 11	1025.0 m - 1034.0 m; 1092.0 m - 1094.0 m

Assemblage III

In ten wells drilled in the central part of the analysed area (Fig.1, Table 2), similar acritarch assemblages were documented. These associations are dominated by *Adara alea* specimens regarded as the index species, which occurred in the beds correlated with the *Paradoxides paradoxissimus* zone (Martin & Dean, 1988). Besides the index taxon, composing often over 60% of the analysed spectrum, other genera and species appear within the discovered assemblages. These are as follows: *Multiplicisphaeridium martae*, *Eliasum llaniscum*, *Cristallinium cambriense*, and *Comasphaeridium silesiense*. Such acritarch associations were described from the *Paradoxides paradoxissimus* beds of Newfoundland, very well documented by fauna (Martin & Dean, 1988). Similar acritarch assemblages have also been well documented in the adjacent areas: in the Upper Silesian Block (Buła & Jachowicz, 1996) and in the Holy Cross Mountains (Szczepanik, 2007).

Assemblage IV

An acritarch assemblage with numerous specimens of genus *Timofeevia*, with *T. phosphoritica* and *T. microretis*, and of genus *Vulcanisphaera*, with *V. obsoleta* and *V. spinulifera*, was found in one sample from the Cetynia 4 well (at a depth of 1,047–1,050 m) (Figs. 1, 5; Table 2). Associations of similar composition were described from Cambrian rocks of Newfoundland (Martin & Dean, 1988). Their stratigraphical position was established by trilobites of the *Agnostus pisiformis* zone, which is regarded at present as the highest member of the Cambrian Series 3 (Peng *et al.*, 2004). Similar microflora has also been described from the areas adjacent to the analysed region: from the Holy Cross Mountains, and from the Narol PIG2 well, located at the south-western margin of the East-European Craton (Szczepanik, 2009). These are the oldest microflora associations from the Cambrian section of the Narol PIG2 well, correlated with rocks from the borderland of the Series 3 and the Furongian bottom (Szczepanik, 2009).

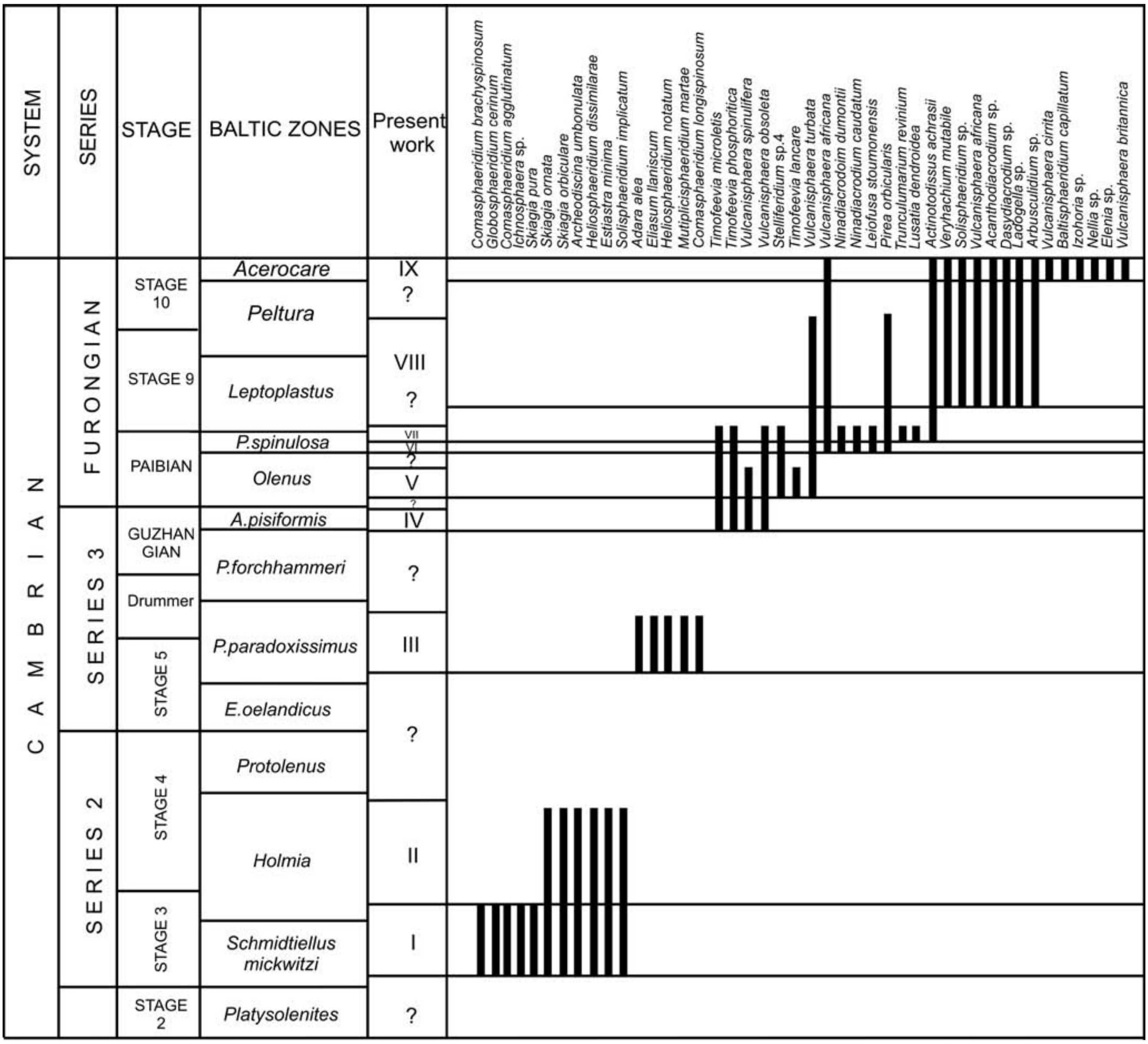


Fig. 5. First appearance and distribution of the selected acritarchs in Cambrian sections of the study area

Furongian

In the highest Cambrian – Furongian, acritarchs were developing even quicker than within the former series. The number of the suggested microfloristic zones was rapidly growing, especially within its highest beds. The best example of this process is represented by the *Peltura* and *Acerocare* zones, subdivided in detail within the Eastern Newfoundland area (Fig. 3) (Martin & Dean, 1988; Parsons & Anderson, 1996, 2000).

The appearance of the first distinct forms of the two new morphological types of the acritarchs is a characteristic feature of the Furongian assemblages. The "galeate" acritarchs are the first type. These spherical specimens, with a broad opening at one of their poles, are appearing as the first at the Furongian bottom. The second characteristic acritarch group consists of the so called "diacrodians" – forms with elongated body and with grouped processes at the opposite poles. The massive appearances of the distinct, easy for identification, morphological acritarch types in the highest Cambrian beds allow for unmistakable distinction of the Furongian microflora assemblages from the assemblages of the older Cambrian Series. The subsequent acritarch zones of this period are easily recognisable (Volkova, 1990). They are usually defined on the base of the newly appearing species, and the domination of the characteristic taxa.

In the north-eastern part of the analysed area, in the Biłgoraj–Lubaczów belt, acritarch associations typical for the Furongian beds were recognised by the author in ten well sections (Fig. 1; Table 3). In this area, various sections of clastic rocks, from several up to over 190 m in thickness, were encountered below the Miocene or, in places, below the Ordovician and Silurian beds. Within these beds, no macrofossils have been found so far. Their age was established on the base of rich, strongly differentiated acritarch assemblages. As a result of palynological investigations

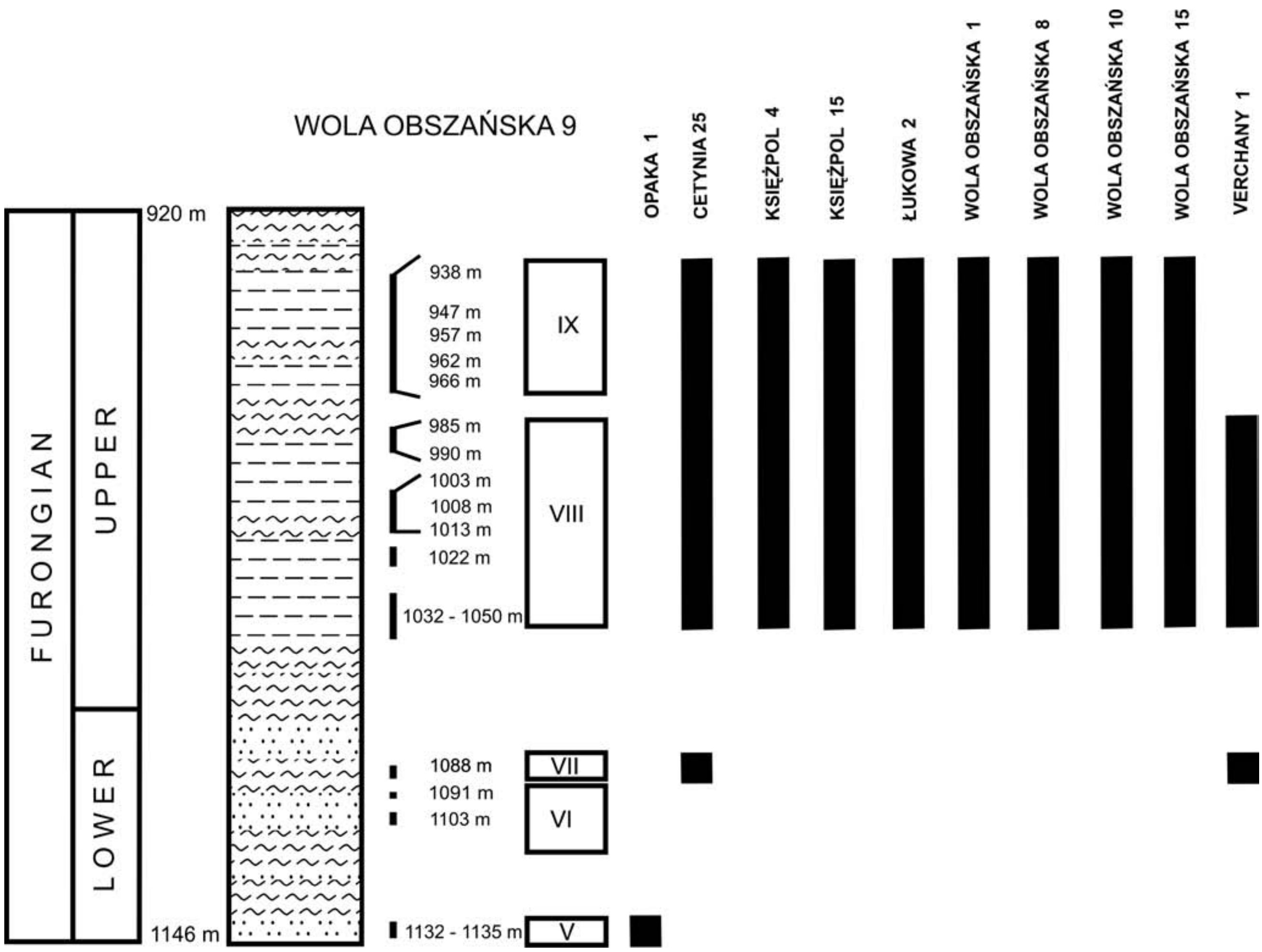


Fig. 6. Correlation of the investigated Furongian sections

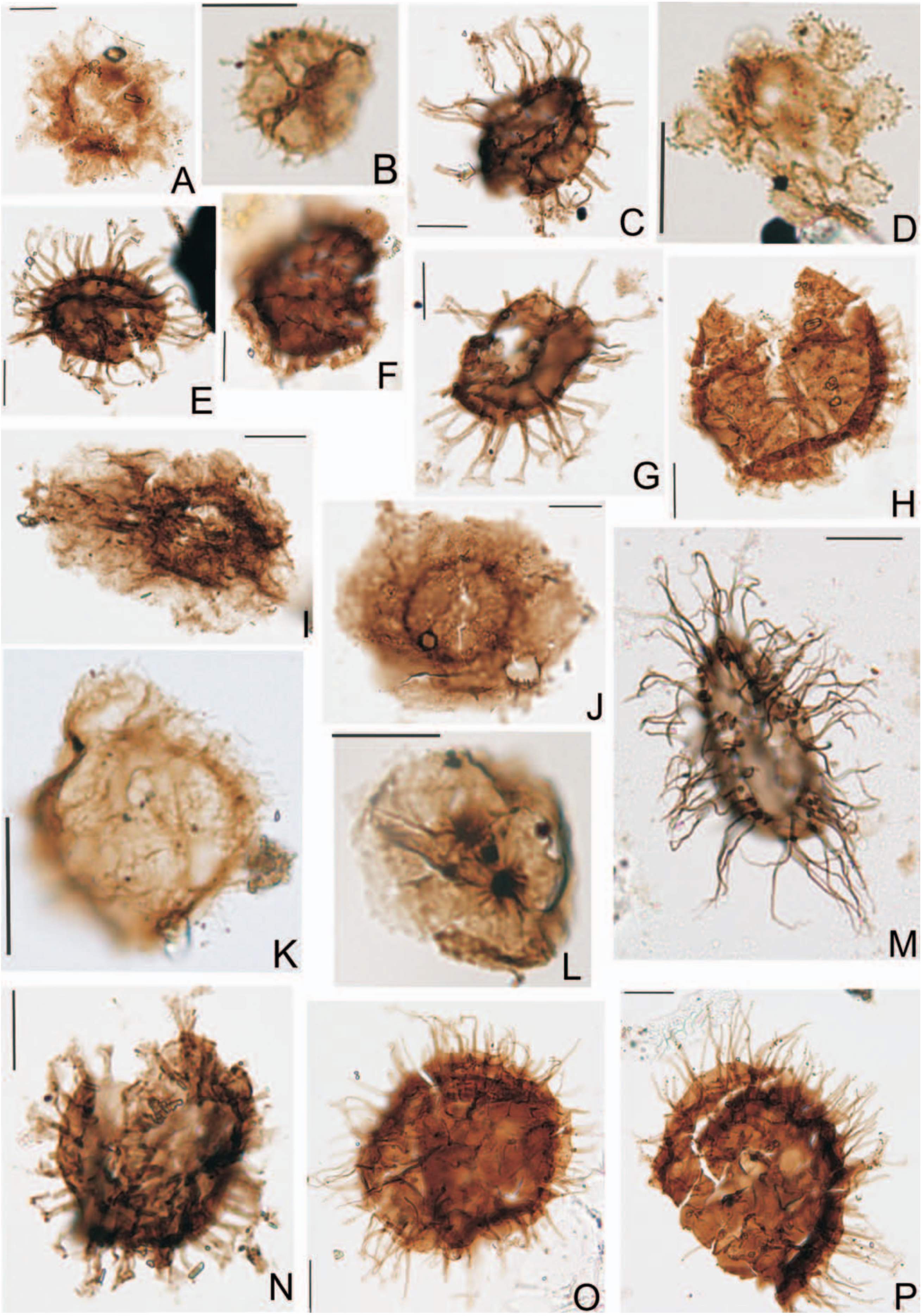
several characteristic microfloral assemblages are recognised within the Biłgoraj–Lubaczów area. They dated several Furongian sections, from the oldest bottom sediments, up to the youngest ones, known already from the Cambrian–Tremadoc boundary. In this paper, only preliminary subdivision and age dating of the differentiated microflora assemblages was made, as the availability of the analysed samples was limited by fragmentary coring of the Furongian sections. However, the available associations are placed on a vertical profile, as far as it was possible (Fig. 6).

Especially important for the recognition of the succession of the Furongian acritarch assemblages within the investigated area are the results of analysis of core material from the Wola Obszańska 9 well. An over 190-m-long section of the clastic rocks was penetrated there, below the Ordovician carbonate sediments. The Late Cambrian age of these rocks was determined on the palynological investigations. Palynological investigations were carried out on 16 rocks samples collected from the cored sections, wherein the intervals between studied samples ranged from 3 to 55 m. As a result, five subsequent characteristic acritarch assemblages were distinguished in the Furongian beds of the Wola Obszańska 9 well (assemblages V–IX) (Figs. 5, 6).

Table 3

List of palynologically dated sections of Cambrian Series 3 from Stalowa Wola-Lubaczów zone

Borehole		Investigated intervals (all positive)
1	Cetynia 25	988.0 m - 994.0 m ; 1046.0 m - 1050.0 m
2	Księżpol 4	1094.0 m - 1100.0 m; 1120.0 m - 1125.0 m; 1125.0 m - 1130.0 m
3	Księżpol 15	893.0 m - 895.0 m; 963.1 m - 977.1 m
4	Łukowa 2	890.0 m - 899.0 m
5	Opaka 1	1278.0 m - 1284.0 m
6	Wola Obszańska 1	974.9 m - 975.7 m
7	Wola Obszańska 8	1003.0 m - 1012.0 m; 1060.0 m - 1063.0 m; 1091.0 m - 1093.0 m; 1093.0 m - 1100.0 m
8	Wola Obszańska 9	938.0 m; 941.0 m; 957.0 m; 962.0 m; 966.0 m; 985.0 m; 990.0 m; 1003.0 m; 1008.0 m; 1013.0 m; 1022.0 m; 1032.0 m - 1050.0 m; 1088.0 m; 1091.0 m; 1103.0 m; 1132.0 m - 1135.0 m
9	Wola Obszańska 10	1193.0 m; 1197.0 m; 1228.0 m; 1242.0 m; 1271.0 m; 1273.0 m
10	Wola Obszańska 15	945.0 m - 954.0 m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Lower Furongian – Olenus-Parabolina spinulosa Zones

Assemblage V

The oldest Furongian acritarch assemblage was found in a sample from a depth of 1,132–1,135 m in the Wola Obszańska 9 well (Table 3; Figs. 5, 6). It was dominated by numerous specimens of the genus *Timofeevia* with *T. lancare*, accompanied by massive specimens of the genus *Stelliferidum*. The latter one is the first representative of the "galeate" acritarchs, generally connected with the Furongian bottom. Besides, typical specimens of the genus *Vulcanisphaera* with *V. turbata* appear in the recognised associations. The microflora of similar genera and species composition was also found within the analysed area in the Opaka 1 well, in two samples obtained from a depth of 1,278–1,284 m (Table 3; Fig. 6). Similar acritarch assemblages were reported from the Eastern Newfoundland, from the rocks containing trilobites of the *Homagnostus obesus* zone (Martin & Dean, 1988). They also appeared in the areas adjacent to the investigated region, namely in the Wiśniówka Mała quarry (Holy Cross Mountains), and in the bottom part of the Narol PIG2 well section (Szczepanik, 2009), where the oldest Furongian rocks have been dated by trilobitic fauna (Jendryka-Fuglewicz, 1995).

Assemblage VI

The succeeding acritarch associations appeared in two samples from the depths of 1,091 m and 1,103 m (Fig. 6). In these rocks, abundant new acritarch taxa occur, such as: *Vulcanisphaera africana*, *Leiofusa stoumonensis*, *Pirea*, *Ninadiacrodoium dumontii*, and *N. caudatum*. Moreover, specimens of the *Timofeevia*, *Cristallinium*, and acritarchs of the "galeate" genera are still present. Similar assemblages are known from the *Parabolina spinulosa* zone encountered in other area, where they were evidenced in detail on the basis of faunal studies (Martin & Dean, 1988; Żylińska *et al.*, 2006).

Assemblage VII

In a sample collected 3 m above the former section (at a depth of 1,088 m) (Fig. 6), an acritarch assemblage dominated by the index "diacrodian" forms appears for the first time. The association is dominated by *Trunculumarium revinium* specimens. The rest of tiny "diacrodians" is represented by *Acathodiacrodium achrasii*, which is accompanied by many forms of the *Polygonium* genus. The described microflora is accompanied by several specimens of the *Impluviculus* genus, and by the first acantomorfs with the large diameters, preliminarily included into the genus *Solisphaeridium*.

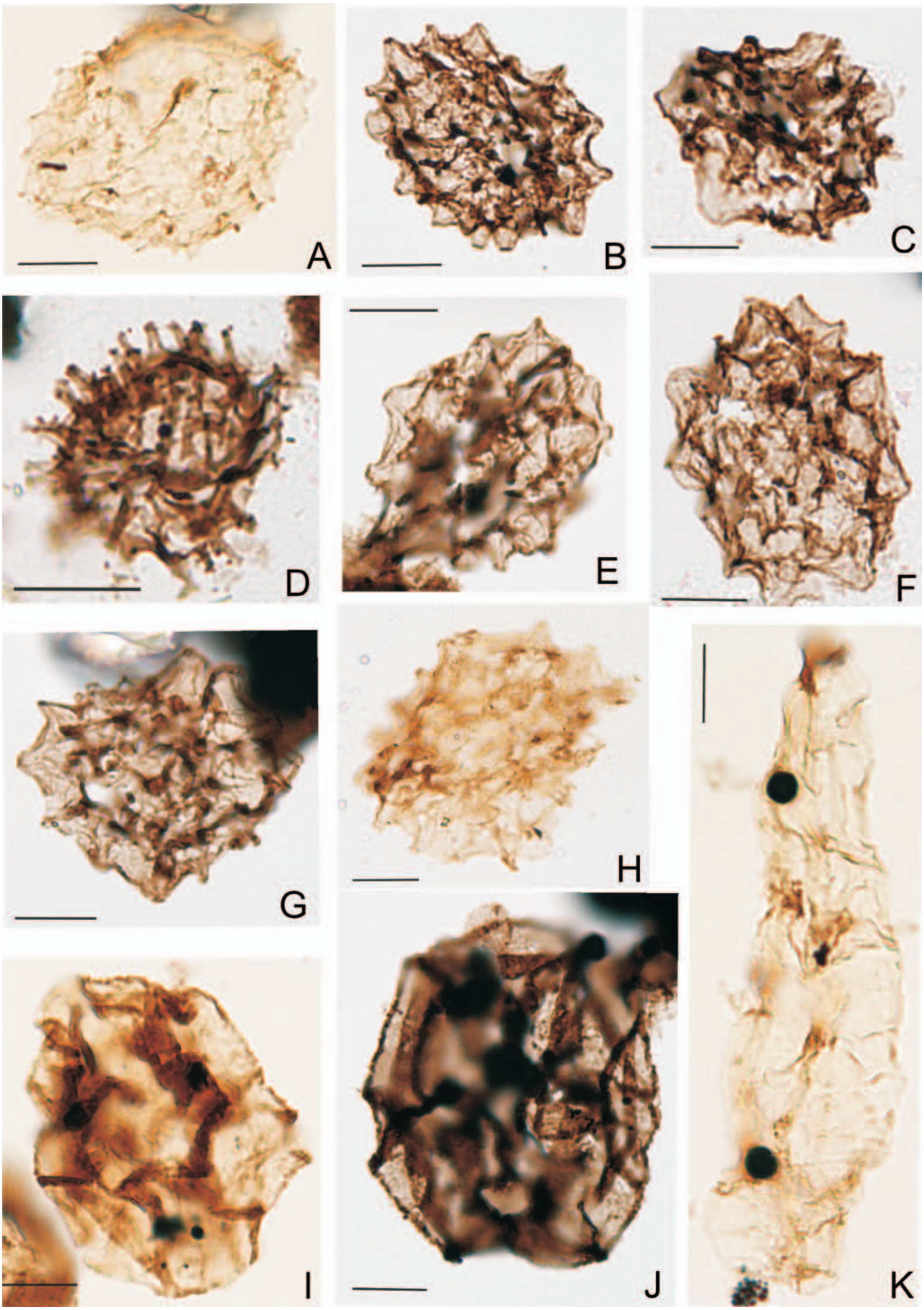
The new forms are accompanied within the analysed association by many acritarch genera and species occurring in other older Furongian assemblages. They included, *i.a.*, *Ninadiacrodium*, *Vulcanisphaera*, *Timofeevia, Leiofusa*, and *Stelliferidium.* One more species, *Lusatia dendroidea*, has to be mentioned in the connection with this sample. These characteristic late Cambrian forms (Albani *et al.*, 2007) appear for the first and the last time in the analysed section. They were very abundant, and within a standard microscopic slide were represented by over 150 specimens. This species is regarded by some specialists as the typical one for the Upper Furongian. Its co-existence with the Middle Furongian forms has been explained by the redeposition of the latter ones (Patersons & Anderson, 2000; Szczepanik, 2009). It should be mentioned, however, that its occurrence has been evidenced lately within the Furongian sediments from the High Zagros Mountains area, in southern Iran (Ghavidel-syooki & Vecoli, 2008). It was characterized there by a short stratigraphical extent, because it was an index species for the zone IVa, correlated with the top of the *Parabolina spinulosa* zone. It shows similar content of genera and species like the microfloristic associations found in the discussed sample from the Wola Obszańska 9 well. The microfloristic zone, characterized by bloom of the *Trunculumarium revinium*, was described in many areas of the Furongian occurrences (Vanguestaine & Van Looy, 1983; Welsch, 1986; Martin & Dean, 1988; Parsons & Anderson, 1996, 2000). Its extent was limited to the higher part of the *Parabolina spinulosa* zone (Parsons & Anderson, 1996, 2000).

Except for the Wola Obszańska 9 well, the discussed zone was recorded within the analysed area in the Cetynia 25 well, at a depth of 1,046–1,050 m (Table 3; Fig. 6). It has also been described from the Narol PIG2 well (Szczepanik, 2009), located in the adjacent area.

Upper Furongian – *Leptoplastus*, *Peltura*, *Acerocare* Zones

One of the more important moments in the evolution of Cambrian microflora was the appearance of the morphologically different acritarch species with diacrodial symmetry. Its precise positioning within the Furongian section of the

Fig. 7. Cambrian Series 2 acritarch assemblages from the Stalowa Wola-Lubaczów zone (south-eastern Poland). Scale bar is 10 µm. **A**. *Comaspheridium agglutinatum* Moczydłowska, 1988 – Sarzyna 18 well, depth 814–823 m; **B.** *Heliosphaeridium* sp. – Sarzyna 20 well, depth 791 – 796 m; **C**. *Skiagia orbiculare* (Volkova, 1968) Downie, 1982 – Rudka 11 well, depth 1,272–1,281 m; **D.** *Asteridium pallidum* (Volkova, 1968) Downie, 1982– Sarzyna 20 well, depth 791 – 796 m; **E.** *Skiagia orbiculare* (Volkova, 1968) Downie, 1982 – Rudka 11 well, depth 1,272–1,281 m; **F**. *Skiagia pura* Moczydłowska, 1988 – Sarzyna 18 well, depth 814–823 m; **G**. *Skiagia orbiculare* (Volkova, 1968) Downie, 1982 – Dąbrowica Duża 3 well, depth 1,476 m; **H**. *Skiagia* sp. – Sarzyna 18 well, depth 814–823 m; **I**. *Granomarginata squamacea* Volkova, 1968 – Rudka 11 well, depth 1,272–1,281 m; **J.** *Granomarginata squamacea* Volkova, 1968 – Rudka 11 well**.** depth 1,272–1,281 m; **K.** *Comasphaeridium brachyspinosum* (Kirjanov, 1974) Moczydłowska & Vidal, 1988 – Sarzyna 18 well, depth 814–823 m; **L.** *Archaeodiscina umbonulata* Volkova, 1968 – Sarzyna 20 well, depth 791 – 796 m; **M.** *Ichnosphaera flexuosa* np. sp. – Dąbrowica Duża 3 well, depth 1,476 m; **N.** *Skiagia* sp. – Rudka 11 well, depth 1,272–1,281 m; **O.** *Globosphaeridium cerinum* (Volkova, 1968) Moczydłowska , 1991 – Sarzyna 18 well, depth 814–823 m; **P**. *Globosphaeridium cerinum* (Volkova, 1968) Moczydłowska, 1991 – Sarzyna 18 well, depth 814–823 m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Wola Obszańska 9 well is a very important piece of information, because it is an excellent reference zone for the correlation of other fragmentary Cambrian sections encountered within the analysed area. The morphologically differentiated diacrodian acritarchs were a dominant component of the microfloral assemblages, obtained from twelve samples collected from the Wola Obszańska 9 well, at the depth interval of 938–1,050 m (Figs 5, 6). In this part of the section, diacrodian acritarchs are characterised by enormous morphological variation. Successive genera with numerous species appear. Some of them may represent new forms. Within the standard microscopic slides of 22 × 22 mm plane, several thousand specimens are present. Certainly, such a rich palaeontological material would require detail taxonomic studies, which were not in the scope of this paper. The evolution stages of the Diacromorphitae group (Downie *et al.*, 1963), recognised within the analysed section, have certainly enormous stratigraphic potential. Their detail studies, with analysis of the taxonomic succession, should enable for a detail subdivision of this Furongian section. Two characteristic stages of the microplankton development were separated for this paper, taking into consideration acritarch associations with approximate contents of genera and species.

Assemblage VIII

Within the analysed samples from the discussed well, collected down to a depth of 985 m (Figs 5, 6), numerous diacrodian forms with the distinct asymmetry, containing *Dasydiacrodium*, *Arbusculidium*, or *Ladogella* genera, appear within the acritarch associations. The majority of them is characterised by rather small diameters of their bodies. An additional distinct peculiarity of these associations is the appearance of large *Veryhachium mutabile* specimens. This form, described for the first time from the *Peltura scarabaeoides* zone (Di Milia *et al.*, 1989), is characterised by the high morphological variations and for sure it requires detail taxonomic studies (Servais *et al.*, 2007). Within some samples, it is represented by numerous specimens which occur up to the top of the analysed section. Moreover, specimens of the genera *Vulcanisphaera*, *Timofeevia*, and *Cristallinium*, as well as morphologically differentiated "galeate" group, are still present within the analysed samples.

Assemblage IX

The last and the youngest of the Furongian assemblages from the Wola Obszańska 9 well (966–938 m depth interval) (Figs 5, 6), is characterized, first of all, by the presence of large diacrodian forms of the *Arbusculidium* and *Ladogella* genera. Within these associations, large diameters are characteristic also for such taxa, as: *Trichosphaeridium*, *Baltisphaeridium capillatum*, and *Solisphaeridium*. In addition, within the youngest assemblage, not only new genera appear, such as *Izohoria*, *Nellia* or *Elenia*, but also new species of the genera known from the older sediments, for instance *Vulcanisphaera cirrita* and *V. britannica*.

Acritarch associations, with similar composition of genera and species to that found within the upper part of the Wola Obszańska 9 section, are present in the Furongian *Peltura* and *Acerocare* zones in many areas of the Cambrian rocks occurrences (Vanguestaine & Van Looy, 1983; Martin & Dean, 1988; Parsons & Anderson, 1996, 2000; Ghavidel-syooki & Vecoli, 2008). They are also known from the adjacent areas of the Holy Cross Mountains and from the Narol PIG2 well (Szczepanik, 2009).

Within the Biłgoraj–Lubaczów area, except for the Wola Obszańska 9 well, the Upper Furongian microflora associations were evidenced in further eight well sections: Cetynia 25, Księżpol 4 and 15, Łukowa 2, Wola Obszańska 1, 8, 10, and 15 (Table 3; Fig. 6).

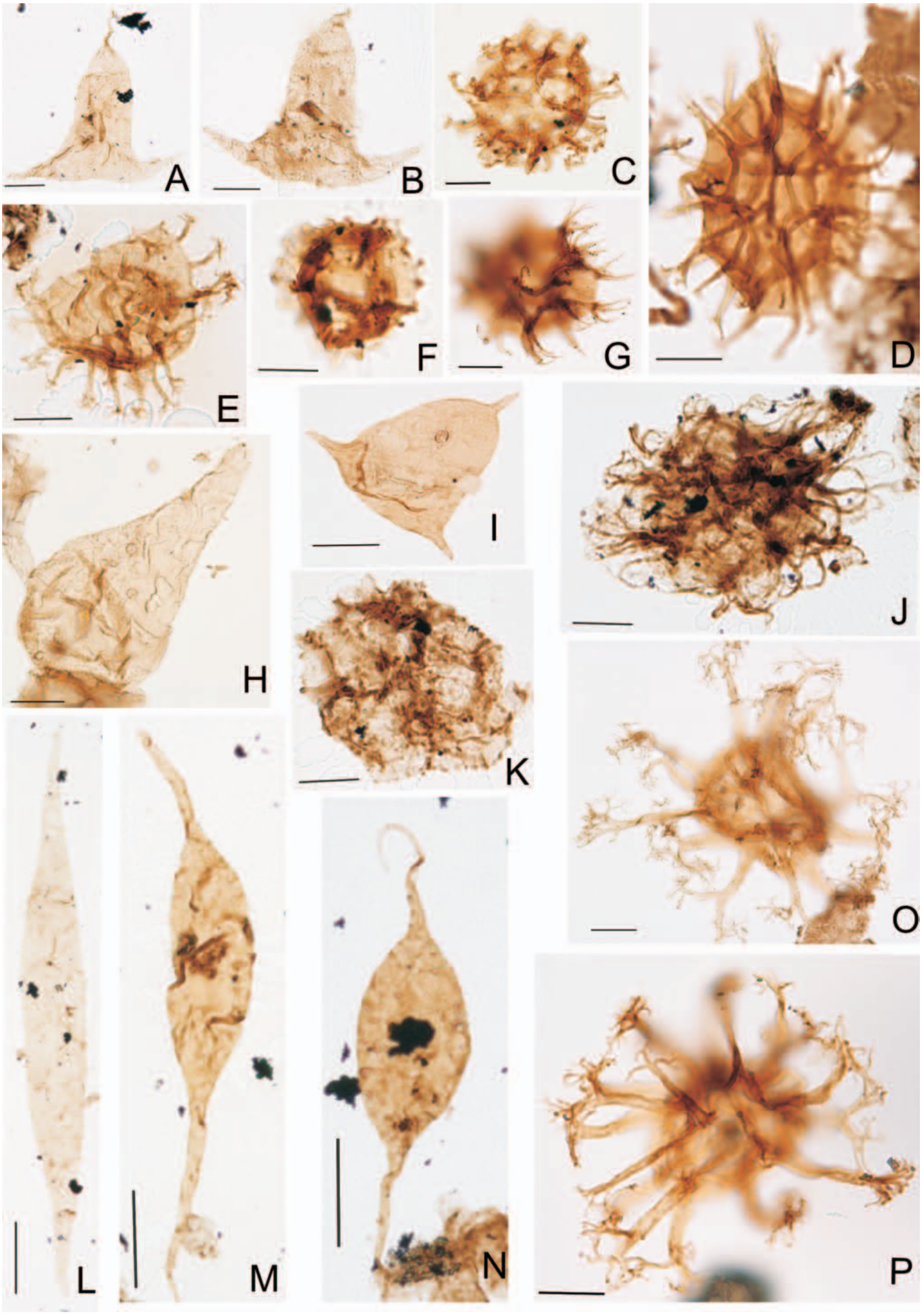
RESULTS OF PALYNOLOGICAL INVESTIGATIONS IN WESTERN UKRAINE

Palynological analyses carried out by the author provided stratigraphical data different to the published ones (Drygant, 2000) on many investigated sections. According to published information, Precambrian or Palaeozoic rocks (first of all, the Lower Palaeozoic) should be present within the analysed sections (Drygant, 2000).

Studies of cores from the wells drilled within the Leżajsk Massif area, where mainly Lower Palaeozoic or Precambrian rocks have been supposed to exist, revealed a very rich and well preserved microflora younger than the Palaeozoic, dominated by spores-pollen assemblages, most probably Mesozoic: Triassic and Jurassic (Table 4). That covered all the investigated samples from the Chyzhky 1, Dobromyl Strilbychi 33, and Dublyany 1 wells, as well as samples from the Chyzhky 2 section (2,729–3,599 m interval). In two samples from the latter well (from the depths of 3,906–3,915 m and 3,934–3,940 m), neither traces of microflora nor organic matter were found.

Determinable acritarch assemblages, evidencing the Cambrian age of the investigated beds, were found within sections of three wells drilled within the Kokhanivka zone, in the south-western Ukraine (Table 5). The microflora

Fig. 8. Cambrian Series 3 acritarch assemblages from the Stalowa Wola-Lubaczów zone (south-eastern Poland). Scale bar is 10 µm. **A.** *Adara alea* Martin, in Martin & Dean, 1981 – Biszcza 2 well, depth 989–1,001 m; **B.** *Adara alea* Martin, in Martin & Dean, 1981 – Księżpol 11 well, depth 931–940 m; **C.** *Adara alea* Martin, in Martin & Dean, 1981 – Księżpol 11 well, depth 931–940 m; **D.** *Multiplicisphaeridium martae* Cramer & Diez, 1972 – Księżpol 11 well, depth 931–940 m; **E.** *Adara alea* Martin, in Martin & Dean, 1981 – Księżpol 11 well, depth 931–940 m; **F.** *Adara alea* Martin, in Martin & Dean, 1981 – Księżpol 11 well, depth 931–940 m; **G.** *Adara alea* Martin, in Martin & Dean, 1981 – Księżpol 11 well, depth 931–940 m; **H.** *Adara alea* Martin, in Martin & Dean, 1981 – Wola Różaniecka 11 well, depth 1,025–1,034 m; **I.** *Cristallinium cambriense* (Slaviková, 1968) Vanguestaine, 1978 – Biszcza 2 well, depth 989–1,001 m; **J.** *Cristallinium cambriense* (Slaviková, 1968) Vanguestaine, 1978 – Księżpol 14 well, depth 956–965 m; **K.** *Eliasum llaniscum* Fombella, 1977 – Biszcza 2 well, depth 989–1,001 m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characteristic for the Cambrian Series 2 was determined in the Bortyatyn 1 and Rudky 300 wells. These index assemblages for the Furongian sediments were documented in the Ver- chany 1 well.

Associations dominated by the index *Skiagia* genus were found in seven samples collected in the Bortyatyn 1 well (from the depth interval of 3,986–4,297 m), and in ten samples obtained from the Rudky 300 well (from the depth interval of 3,176–4,501.9 m) (Fig. 13). The recovered microflora is very poorly preserved, and specimens processes were very often broken. All this made determinations of the species difficult. That is why many of the contained specimens have generic names only. Except for the index genus *Skiagia*, the following forms were determined within the investigated material: *Granomarginata squamacea*, *Solisphaeridium implicatum*, *Comasphaeridium strigosum*, and *Pterospermopsimorpha* genera. The optimum appearance of the assemblages of similar content was found in the higher part of the *Holmia* beds. Some of them, such as *Solisphaeridium implicatum* or *Comasphaeridium strigosum*, are also known from the Cambrian Series 3 beds (Moczydłowska, 1998; Jankauskas, 2000). It is impossible to establish the detailed stratigraphic units within the investigated sections, because of a very poor preservation of the recovered acritarch assemblages. It may be assumed, to the best present knowledge, that within the analysed Bortyatyn 1 well section, the Cambrian Series 2 beds were encountered. They were also present within the majority of the investigated samples collected from the Rudky 300 well. As to the latter section, the continuation of the Cambrian sedimentation into the Series 3 can not be excluded. Within a sample from the depth interval of 3,176–3,180 m, specimens of *Solisphaeridium implicatum*, and of the form recognised as *Comasphaeridium strigosum* (Jankauskas, 2000) appear. It highly reminded *Comasphaeridium silesiense* species, regarded as the index one for the Cambrian Series 3 sequence (Moczydłowska, 1998). This last interpretation may have not been, however, entirely precise because of the limited amount of palaeontological material, and at the same time, of a rather poor microflora preservation. One can be fairly sure, though, that within the Rudky 300 well section, at the depth of 3,176– 4,501.9 m, Cambrian sediments not younger than *Eccoparadoxides oelandicus* zone were recognised. Also, the age of acritarch associations obtained from three samples collected from the Korolyn 2 well cores is very difficult for the assessment. At the depth interval of 4,423–4,465 m, very poorly preserved specimens were found, determined as *Skiagia*, *Granomarginata*, and *Leiosphaeridia* forms. The latter two genera occurred within a long stratigraphic sequence, while the presence of *Skiagia* genus indicated the Early Cambrian age,

Table 4

List of palynologically dated sections, younger than Palaeozoic from western Ukraine

Borehole		Investigated intervals (positive and barren)
1	Chyzhky 1	1925-1935; 3642-3652; 3812-3819; 3878-3883; 3946-3953; 3992-3997
2	Chyzhky 2 2* barren samples	2729-2734; (2 samples); 3414-3424; 3590-3599; 3906-3915*; 3934-3940*
3	Dublyany 1	4112-4122; 4290-4300; 4300-4310; 4310-4314; 4404-4412; 4412-4420; 4544-4554; 4545-4558; 4580-4586
4	Dobromyl Strilbychi 33	5130-5140; 5156-5162; 5305-5312; 5316-5323; 5335-5345; 5377-5384; 5400; 5401-5408; 5443-5450 (2 samples)
5	Korolyn 2	3696-3702.3; 4196-4204 (2 samples); 4204.3-4209

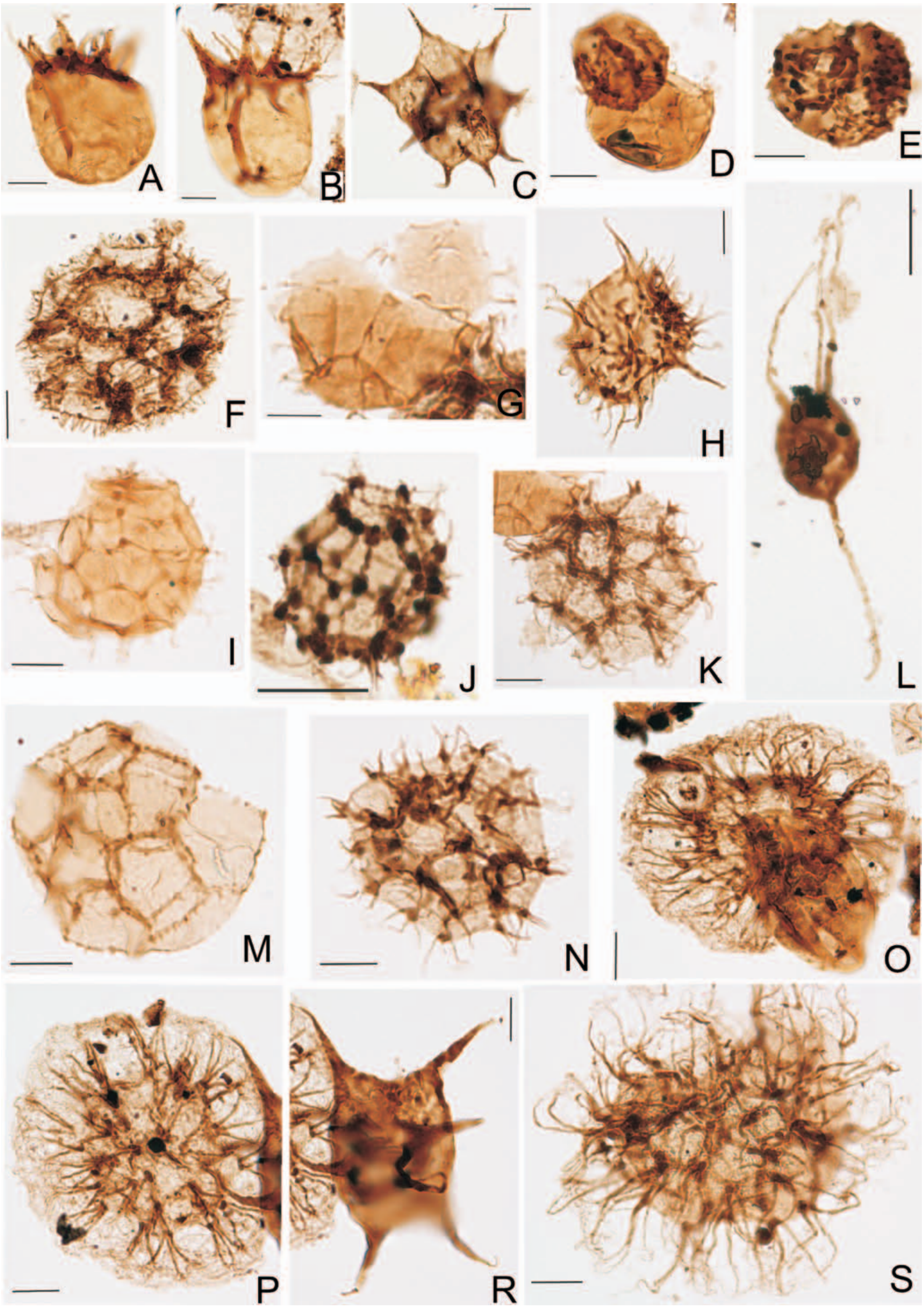
Table 5

List of palynologically dated sections of the Furongian and Cambrian Series 2 from the Kokhanivka zone, western Ukraine

Borehole		Investigated intervals (all positive)
1	Bortyatyn 1	3986-3991; 4001-4003; 4149-4154; 4202-4207; 4274-4279; 4290-4292; 4295-4297
2	Rudky 300	3176-3180; 3208-3109; 3241-3246; 3299-300.5; 3444-3445.2; 3558-3560.4; 3657.3-3660.3; 3814-3817; 3853-3856; 4499-4501.9
3	Korolyn 2	4423-4428; 4508.9-4518.5; 4556-4565
4	Verchany 1	1996-2003.5 (2 samples); 2050-2051.5; 2055-2056.8

◄

Fig. 9. Lower Furongian acritarch assemblages from the Stalowa Wola-Lubaczów zone (south-eastern Poland). Scale bar is 10 µm. **A.** *Ninadiacrodium dumontii* (Vanguestaine, 1973) Raevskaya & Servais, 2009 – Wola Obszańska 9 well, depth 1,091 m; **B.** *Ninadiacrodium dumontii* (Vanguestaine, 1973) Raevskaya & Servais, 2009 – Wola Obszańska 9 well, depth 1,091 m; **C.** *Timofeevia phosphoritica* Vanguestaine, 1978 – Wola Obszańska 9 well, depth 1,103 m; **D.** *Timofeevia pentagonalis* (Vanguestaine, 1974) Vanguestaine, 1978 – Wola Obszańska 9 well, depth 1,132 m; **E.** *Cymatiogalea* sp. – Wola Obszańska 9 well, depth 1,103 m; **F.** *Cymatiogalea* sp. – Wola Obszańska 9 – well, depth 1,103 m; **G.** *Vulcanisphaera spinulifera* (Volkova, 1990) Parsons & Anderson, 2000 – Opaka 1 well, depth 1,278–1,284 m; **H**. *Pirea orbicularis* Volkova, 1990 – Wola Obszańska 9 well, depth 1,103 m; **I.** *Ninadiacrodium caudatum* (Vanguestaine, 1973) Raevskaya & Servais, 2009 – Wola Obszańska 9 well, depth 1,087 m; **J.** *Vulcanisphaera turbata* Martin, in Martin & Dean, 1981 – Wola Obszańska 9 well, depth 1,103 m; **K.** *Cristallinium dubium* Volkova 1990 – Wola Obszańska 9 well, depth 1,103 m; **L.** *Leiofusa* sp. – Wola Obszańska 9 well, depth 1,103 m; **M.** *Leiofusa stoumonensis* Vanguestaine, 1973 – Wola Obszańska 9 well, depth 1,103 m; **N.** *Leiofusa stoumonensis* Vanguestaine, 1973 – Wola Obszańska 9 well, depth 1,103 m; **O.** *Timofeevia lancarae* (Cramer & Diez de Cramer, 1972) Vanguestaine, 1978 – Opaka 1 well, depth 1,278–1,284 m; **P**. *Timofeevia lancarae* (Cramer & Diez de Cramer, 1972) Vanguestaine, 1978 – Wola Obszańska 9 well, depth 1,132 m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only. On the other hand, in the Korolyn 2 well, the microflora younger than Palaeozoic occurred already at a depth of 4,204–4,209 m.

Rich associations typical for the Furongian beds were recognised in the Verchany 1 well, in the depth interval of 1,996– 2,056.8 m (Figs 6, 14). They were encountered below the Ordovician sediments, the age of which was determined on the base of the author's palynological investigations (samples from the interval of 1,967–1,975.4 m). Acritarch assemblages with numerous specimens of the index species *Trunculumarium revinum*, characteristic for the *Parabolina spinulosa* zone, were found in a sample from a depth of 2,055–2,056.8 m. Within the remaining samples (depths of 1,996–2,003.5 m and 2,051.5 m), acritarchs belonging to such forms, as: *Vulcanisphaera spinulosa*, *V. turbata*, *V. africana*, *Cristallinium*, *Orthosphaeridium extensum*, *Timofeevia*, and *Izohoria* appear. Within the analysed spectrum, "galeate" and "diacrodian" acritarchs with the *Actinotodissus achrasii* or *Dasydiacrodium* specimens appear in great number. In addition, the microfossil assemblages contained large specimens of the *Veryhachium mutabile* species and acantomorfs of large diameters, assigned to the genus *Solisphaeridium*. On the base of the recovered acritarch associations, it has been assumed that the rocks encountered at the depth of 1,996–2,051.5 m in the Verchany 1 well represented the Upper Furongian beds, older than *Acerocare* zone.

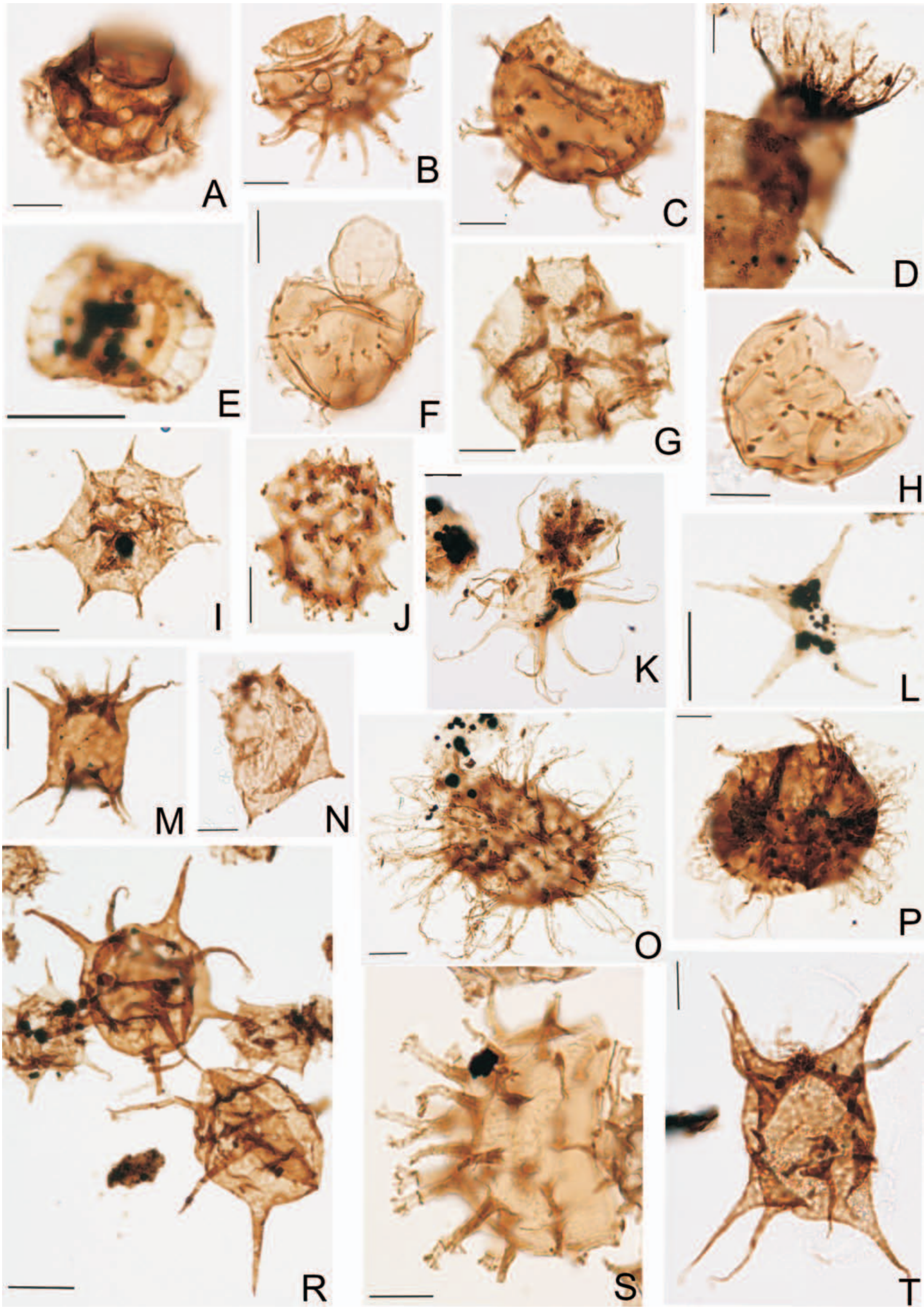
Palynological investigations were also carried out on samples from the Chornokuntsi 1 well. Unfortunately, their hitherto made analyses gave negative results. From the thirteen investigated samples, only intensively destroyed fragments of indeterminable microfossils, and a large amount of the amorphous organic matter were recovered. The reliable age determination of these beds is at present impossible.

REMARKS ON THE STATE OF PRESERVATION STATE AND THE DEGREE OF THERMAL ALTERNATION OF THE RECOVERED MICROFOSSILS

Acritarchs, like spores and pollen grains of terrestrial plants, are built of the very resistant organic matter, that in principle is visibly changing under the thermal alternations. This feature is used for the very important practices. The changeable colours of the plant organic microfossils, from bright yellow, through orange, brown, up to the black one, were correlated with the temperature intervals, of which the given rock underwent during its geological history. On this base, scales of colours TAI (*Thermal Alternation Index*) 10-point *Spore Color Index (SCI)* (Fisher *et al.*, 1980), or 7-point *Thermal Alternation Scale (TAS)* (Batten, 1980) were developed. They represent different stages of the organic matter alternation, and the main stages of the hydrocarbon generation connected with them. This method is very important in petroleum geology, because it allows for an easy defining of the geothermal conditions suitable for generation of deposits of liquid and gaseous hydrocarbons. All the above mentioned scales compare the value of the *Ro* and *TAI (TAI=TAS)* coefficients to the maturity stages of organic matter, to the generation phases of its products, as well as to their respective temperatures that are controlling the possibility of hydrocarbon generation and preservation. Three basic stages of hydrocarbon generation can be easily distinguished within the studied rocks. They correspond with three clearly different colour groups: the light yellow and yellow colours correspond with the immature phase of the hydrocarbon generation; colours from orange, through light-brown, to dark-brown are connected with the mature phase of the liquid and gaseous hydrocarbon generation; and finally, very dark-brown to black colours are connected with the initial phase of the organic matter metamorphosis, during which gaseous fractions of the hydrocarbons could be generated.

The Cambrian microflora obtained from the analysed areas: Stalowa Wola–Lubaczów zone in SE Poland and Kokhanivka zone in western Ukraine, is typified by a variable state of preservation. The worst preserved associations were found in the Kokhanivka zone, in the Bortyatyn 1, Rudky 300, and Korolyn 2 wells. The Cambrian microflora from these wells was rare, its specimens were rarely preserved as a whole, and their delicate morphological elements, usually processes, were in most cases damaged. Almost black or deeply brown colour indicated a high thermal alternation stage (above 200°C) of the analysed formation. Slightly better preserved were numerous assemblages of the Furongian acritarchs documented in the Verchany 1 well, located farther to the southeast of the Kokhanivka zone. Dark-brown colour of these forms corresponded, in accordance with the TAI (*Thermal Alternation Index*) Batten (1980)

Fig. 10. Lower Furongian acritarch assemblages from the Stalowa Wola-Lubaczów zone (south-eastern Poland). Scale bar is 10 µm for A–K, M–S; 25 µm for L. **A.** *Trunculumarium revinium* (Vanguestaine, 1973) Loeblich & Tappan, 1976 – Wola Obszańska 9 well, depth 1,087 m; **B.** *Trunculumarium revinium* (Vanguestaine, 1973) Loeblich & Tappan, 1976 – Wola Obszańska 9 well, depth 1,087 m; **C.** *Polygonium* sp. – Wola Obszańska 9 well, depth 1,087 m; **D.** *Cymatiogalea cuvillieri* (Deunff, 1961) Deunff, in Deunff *et al.*, 1964 – Wola Obszańska 9 well, depth 938 m; **E**. *Acanthodiacrodium snookense* Parsons & Anderson, 2000 – Wola Obszańska 9 well, depth 938 m; **F**. *Cristallinium pilosum* Volkova, 1990 – Wola Obszańska 9 well, depth 1,013 m; **G**. *Cymatiogalea* sp. – Wola Obszańska 9 well, depth 1,087 m; H. *Dasydiacrodium* sp. – Wola Obszańska 9 well, depth 938 m; **I.** *Cymatiogalea* sp. – Wola Obszańska 9 well depth 1,087 m; **J**. *Vulcanisphaera* sp. – Wola Obszańska 9 well, depth 1,091 m; **K.** *Vulcanisphaera spinulifera* (Volkova, 1990) Parsons & Anderson, 2000 – Wola Obszańska 9 well, depth 1,087 m; **L.** *Lusatia dendroidea* (Burmann, 1970) Albani *et al.*, 2007 – Wola Obszańska 9 well, depth 1,087 m; **M.** *Cristallinium dubium* Volkova 1990 – Wola Obszańska 9 well, depth 1,087 m; **N.** *Vulcanisphaera turbata* Martin, in Martin & Dean, 1981 – Wola Obszańska 9 well, depth 1,103 m; **O.** *Vulcanisphaera cirrita* Rasul, 1976 – Wola Obszańska 9, well, depth 938 m; **P**. *Vulcanisphaera cirrita* Rasul, 1976 – Wola Obszańska 9, well, depth 938 m; **R**. ?*Acanthodiacrodium* sp. – Wola Obszańska 9, well, depth 938 m; **S**. *Vulcanisphaera africana* Deunff, 1961 – Wola Obszańska 9, well, depth 1,087 m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scale, with the intermediate stage between the mature and metamorphosed phases of the organic matter. This stage was being connected with disappearance of the wet and dry gases.

The Stalowa Wola–Lubaczów zone is an area of numerous, very well preserved Cambrian organic microfossils. In the majority of the analysed sections, occurrence of the light-brown and brown microfossils has been noticed. These colours indicated the mature phase of hydrocarbon generation. It is interesting to note that within several sections of the Cambrian Series 2 (Sarzyna 20), Cambrian Series 3 (Biszcza 2, Wola Różniecka 11) and Furongian (Opaka 1), acritarchs of pale vesicles: yellow or orange, were found. These colours are connected with the immature phase of the organic matter thermal alternation.

Within the adjacent areas, in the Holy Cross Mountains and in the Lublin-Podlasie Slope of the East-European Craton, investigations of the Palaeozoic rocks thermal maturity with the use of the palynological methods have been conducted for a long time (Moczydłowska, 1988, 1991; Szczepanik, 1997, 2007). Based on differentiated colours of the Cambrian acritarchs, analyses of the thermal maturity distribution within these regions have been performed, and they were related to diastrophic events that could generate the increase of the heat flux (Moczydłowska, 1991; Szczepanik, 2007). Based on thermal maturity of the Cambrian organic matter within the Holy Cross Mountains area, a scheme of the palaeotemperatures has been prepared showing a distinct gradient along the Holy Cross Mountains fault (Szczepanik, 2007). The Cambrian microflora of the Holy Cross Mountains, in the Kielce region, was characterized by a good and very good preservation state, and by low thermal alternation grade. On the other hand, the Cambrian assemblages from the Łysogóry area of the Holy Cross Mountains represented a very high thermal maturity grade, and very often a very poor preservation state, similarly to the associations documented in the Narol PIG2 well (Szczepanik, 2007).

Morphology of the recovered assemblages from the Stalowa Wola-Lubaczów area and from the Kokhanivka zone (western Ukraine), their preservation state, and their thermal alternation grade, are illustrated in Figures 7–14. The investigated palynological material is stored in the Upper Silesian Branch of the Polish Geological Institute – National Research Institute.

CONCLUSIONS

As a result of palynological investigations carried out in the Stalowa Wola-Lubaczów area, the index acritarch assemblages were documented for the Cambrian Series 2, Series 3 and Furongian (Figs 7–12). The Cambrian rocks of this area contain numerous, well preserved, and differentiated organic microfossil assemblages. Nine succeeding characteristic acritarch assemblages were distinguished on this base. They clearly differed from each other by both genera and species content (Fig. 5).

The first two acritarch assemblages documented in several wells within the south-western part of the analysed area were correlated with the *Schmidtiellus mickwitzi-Holmia* zones. The assemblages III and IV occurring in wells located within the central part of the region are known from the *Paradoxides paradoxissimus* and probably from the *Agnostus pisiformis* zone. Other assemblages, from V to IX, which were present in wells situated in the northern part of the area, dated almost all the Early and Late Furongian faunistic zones.

Acritarch assemblages of the oldest Cambrian Series, Terreneuvian, have not been clearly documented in the analysed area, as yet (Figs 1, 3, 5). These microfossils are poorly differentiated, and express high similarity to the late Ediacaran microflora. The precise dating of the recovered Terreneuvian acritarch assemblages is, therefore, very often impossible, especially in the case of fragmentary sections. In some sections, poorly morphologically differentiated microfossil associations were recorded. They still require, however, additional investigations in order to get reliable proof for the existence of sediments older than "trilobitic" Cambrian. The above mentioned data were, therefore, not included into the present paper. No acritarch assemblages typical for the highest part of the Cambrian Series 2, with index forms for *Protolenus* zone, such as *Liepaina* or *Volkovia*, were found in the discussed area. However, such forms have been very well defined within the adjacent Holy Cross Mountains area (Szczepanik, 2009). This information may be important from the viewpoint of regional geology.

Up to now, the obtained stratigraphical data indicate a zonal distribution pattern of the Cambrian deposits in the Stalowa Wola-Lubaczów region. The oldest deposits (Series 2) occur in the south-western area (Fig. 1). Farther towards the northeast, Series 3 and Furongian sediments are

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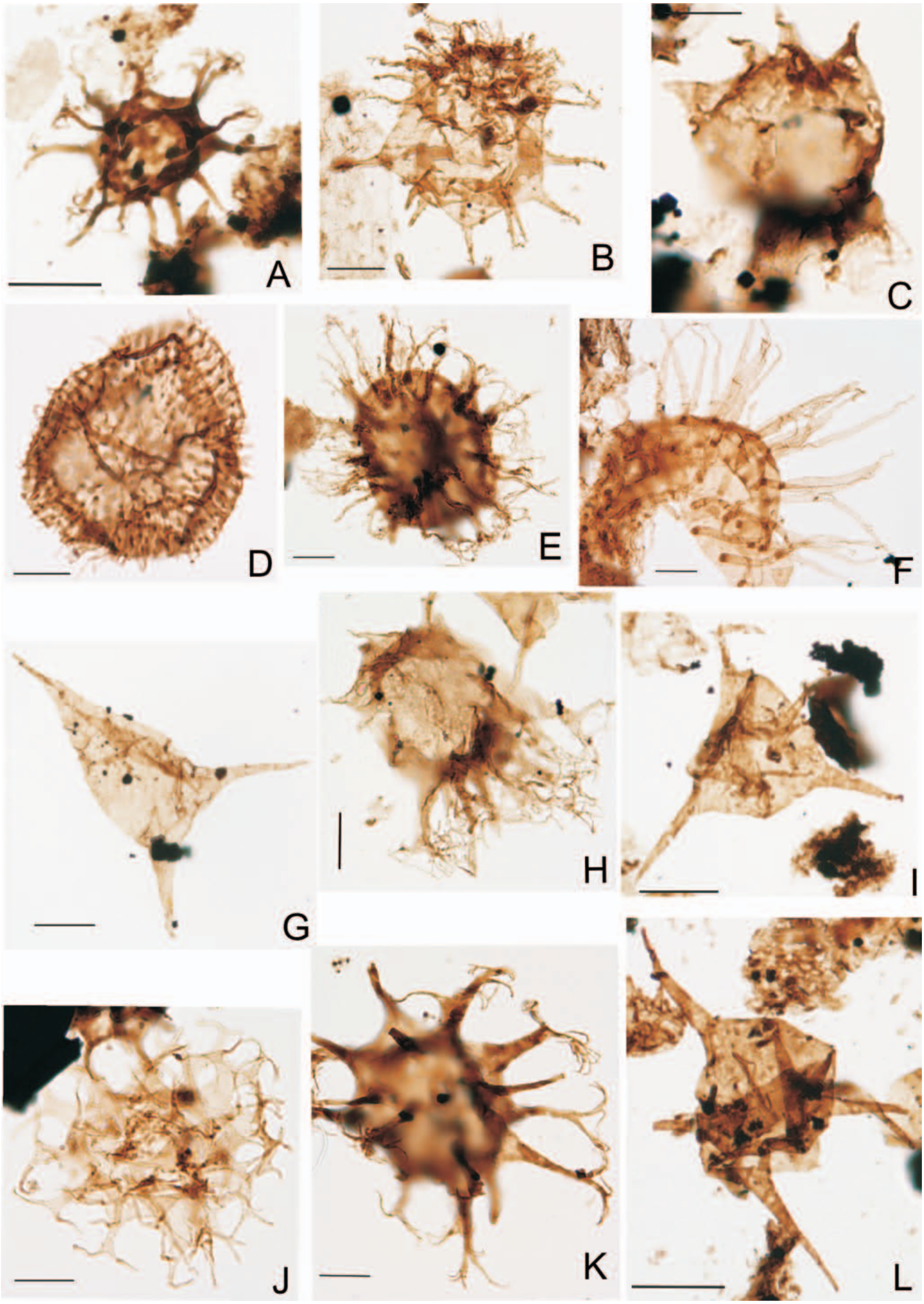
Fig. 11. Furongian acritarch assemblages from the Stalowa Wola-Lubaczów zone (south-eastern Poland). Scale bar is 20 μm for A–L, N–P, S; 50 μm for M, R, T. **A.** *Elenia armillata* (Vanderflit, in Umnova & Vanderflit, 1971) Volkova, 1990 – Wola Obszańska 10 well, depth 1,193 m; **B.** *Cymatiogalea* sp. – Wola Obszańska 10 well, depth 1,273 m; **C.** *Cymatiogalea bellicosa* Deunff, 1961 – Wola Obszańska 10 well, depth 1,193 m; **D.** *Arbusculidium* sp. – Wola Obszańska 9 well, depth 938 m; **E.** *Cymatiogalea velifera* (Downie, 1982) Martin, 1988 – Wola Obszańska 9 well, depth 938 m; **F.** *Cymatiogalea cristata* (Downie, 1958) Rasul, 1974 – Wola Obszańska 10 well, depth 1,193 m; **G.** *Izohoria angulata* Golub, in Volkova & Golub, 1985 – Wola Obszańska 9, depth 957 m; **H**. *Cymatiogalea cristata* (Downie, 1958) Rasul, 1974 – Wola Obszańska 10, well, depth 1,193 m; **I.** *Impluviculus* sp. – Wola Obszańska 9 well, depth 1,022 m; **J.** ?*Acantodiacrodium* sp. – Wola Obszańska 9 well, depth 938 m; **K.** *Polygonium gracile* Vavrdová, 1966 – Wola Obszańska 9 well, depth 1,273 m; **L.** *Polygonium* sp. – Wola Obszańska 9 well, depth 938 m; **M.** *Dasydiacrodium* sp. – Wola Obszańska 9 well, depth 938 m; **N.** *Ladogella* sp. – Wola Obszańska 10 well, depth 1,228 m; **O**. *Acanthodiacrodium* sp. – Wola Obszańska 9 well, depth 957 m; **P**. *Acanthodiacrodium* sp. – Wola Obszańska 9 well, depth 957 m; **R**. *Solisphaeridium* sp. – Wola Obszańska 9 well, depth 1,022 m; **S**. *Stelliferidium* sp. – Wola Obszańska 9 well, depth 1,037 m; **T**. *Ladogella* sp. – Wola Obszańska 10 well, depth 1,228 m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e subcropping under the Ordovician, Mesozoic and Miocene deposits (Fig. 1).

Because of the fragmentary coring of the investigated wells, the author could not reveal the possible existence of sedimentary gaps or clarify the detailed sedimentation of the analysed Cambrian beds. Therefore, she limited her effort to the description of the documented acritarch assemblages and their age determination, usually based on the correlation with the associations known from other areas, and in the case of Furongian beds – on the reconstruction of the determined assemblages succession within the vertical profile.

In sum, it is worth to mention that although the Furongian sections from the Stalowa Wola–Lubaczów area have no faunistic evidences, the detailed palynological studies have provided an interesting view on their microfloral succession in the vertical profile. It has also allowed for the precise description of the first appearances of the index forms, as well as for presentation of their quantitative participation in the obtained associations. There is no doubt that the encountered Furongian sections, especially that of the Wola Obszańska 9 well, represent enormous cognitive potential. They require, however, very detailed investigations that would allow for clarification of the full succession of microfloristic assemblages. The partial Furongian sections, documented in several fragmentarily cored wells, correlated very well with the best recognised Furongian section of the Wola Obszańska 9 well.

The Cambrian acritarch assemblages found in the Stalowa Wola–Lubaczów area can be easily correlated with the associations recognised within the Ukrainian Cambrian sections of the Kokhanivka zone. Associations documented in the Bortyatyn 1 and Rudky 300 wells corresponded with the assemblage II, which is correlated with the *Holmia* zone, while microflora documented in the Verchany 1 well resembled assemblages VII and VIII recognised as the Lower and Upper Furongian (Fig. 6).

The Cambrian microflora recovered in the Stalowa Wola–Lubaczów and Kokhanivka zones was also characterized by different preservation state. The Cambrian acritarch assemblages from the Stalowa Wola–Lubaczów area were very well preserved. In most of the analysed sections, light-brown and brown coloured microfossils were recorded. These colours responded to the mature stage of the hydrocarbon generation. Associations of very low stage of the thermal alternation were documented in few wells. On the other hand, in the Kokhanivka zone, very poorly preserved associations were found, and their almost black colour indicated a very high degree of thermal alternation, corresponding to the metamorphic phase (Figs 12–14).

Acritarch associations documented in SE Poland and western Ukraine showed great similarity to the assemblages found in the adjacent regions, in the Holy Cross Mountains, in Narol in the Lublin area, and in Cambrian of the Lublin–Podlasie platform slope area.

Acknowledgements

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Fig. 12. Upper Furongian acritarch assemblages from the Stalowa Wola-Lubaczów zone (south-eastern Poland). Scale bar is 10 µm for B, C, J; 25 µm for A, C–I, K, L. **A**. *Vogtlandia notabilis* Volkova, 1990 – Wola Obszańska 9 well, depth 957 m; **B.** *Dasydiacrodoium* sp – Wola Obszańska 9 well, depth 1,008 m; **C.** *Nellia* sp. – Wola Obszańska 9 well, depth 962 m; **D.** *Trichosphaeridium hirtum* (Timofeev, 1959) Timofeev, in Timofeev *et al.* , 1976 – Wola Obszańska 10 well, depth 1,273 m; **E**. *Solisphaeridium* sp. – Wola Obszańska 9 well, depth 957 m; **F**. *Baltisphaeridium capillatum* (Naumova, 1950) Umnova, 1975 – Wola Obszańska 10 well, depth 1,228 m; **G.** *Veryhachium mutabile* Di Milia *et al.*, 1989 – Wola Obszańska 9 well, depth 1,013 m; **H**. *Arbusculidium* sp. – Wola Obszańska 9 well, depth, 957 m; **I.** *Veryhachium mutabile* Di Mila, Ribecai & Tongiorgi, 1989 – Wola Obszańska 9 well, depth 1,013 m; **J.** *Vulcanisphaera britannica* Rasul, 1976 – Wola Obszańska 9 well, depth 1,003 m; **K.** *Vogtlandia notabilis* Volkova, 1990 – Wola Obszańska 9 well, depth 957 m; **L.** *Veryhachium mutabile* Di Mila, Ribecai & Tongiorgi, 1989 – Wola Obszańska 9 well, depth 1,003 m

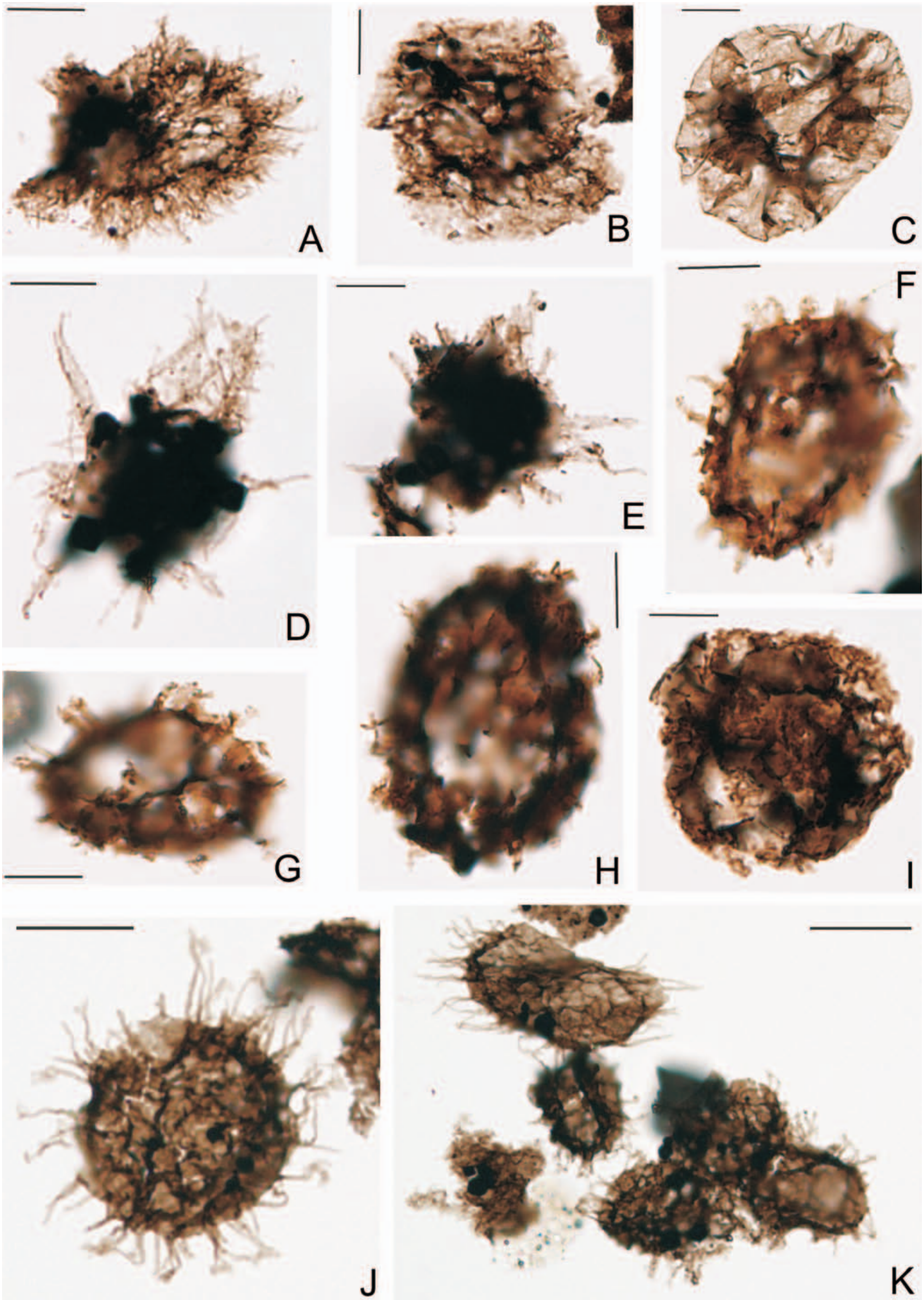
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Fig. 13. Cambrian Series 2 acritarch assemblages from the Kokhanivka zone (western Ukraine). Scale bar is 10 µm for A–K. **A**. *Comasphaeridium strigosum* (Jankauskas, in Jankauskas & Posti, 1976) Downie, 1982 – Rudky 300 well, depth 3,176–3,180 m; **B.** *Granomarginata squamacea* Volkova, 1968 – Rudky 300 well, depth 3,176–3,180 m; **C.** *Cymatiosphaera* sp. – Rudky 300 well, depth 3,176–3,180 m; **D.** *Solisphaeridium implicatum* (Fridrichsone, 1971) – Rudky 300 well, depth 3,176–3,180 m; **E**. *Solisphaeridum implicatum* (Fridrichsone, 1971) Moczydłowska, 1998 – Rudky 300 well, depth 3,176–3,180 m; **F**. *Skiagia* sp. – Bortyatyn 1 well, depth 4,295–4,297 m; **G.** *Skiagia* sp. – Bortyatyn 1 well, depth 4,295–4,297 m; **H**. *Skiagia* sp. – Bortyatyn 1 well, depth 4,295–4,297 m; **I.** *Pterospermopsimorpha* sp. – Bortyatyn 1 well, depth 4,295–4,297 m; **J.** *Skiagia ornata* (Volkova, 1968) Downie, 1982 – Rudky 300 well, depth 3,176–3,180 m; **K.** *Skiagia* sp. – Rudky 300 well, depth 3,176–3,180 m

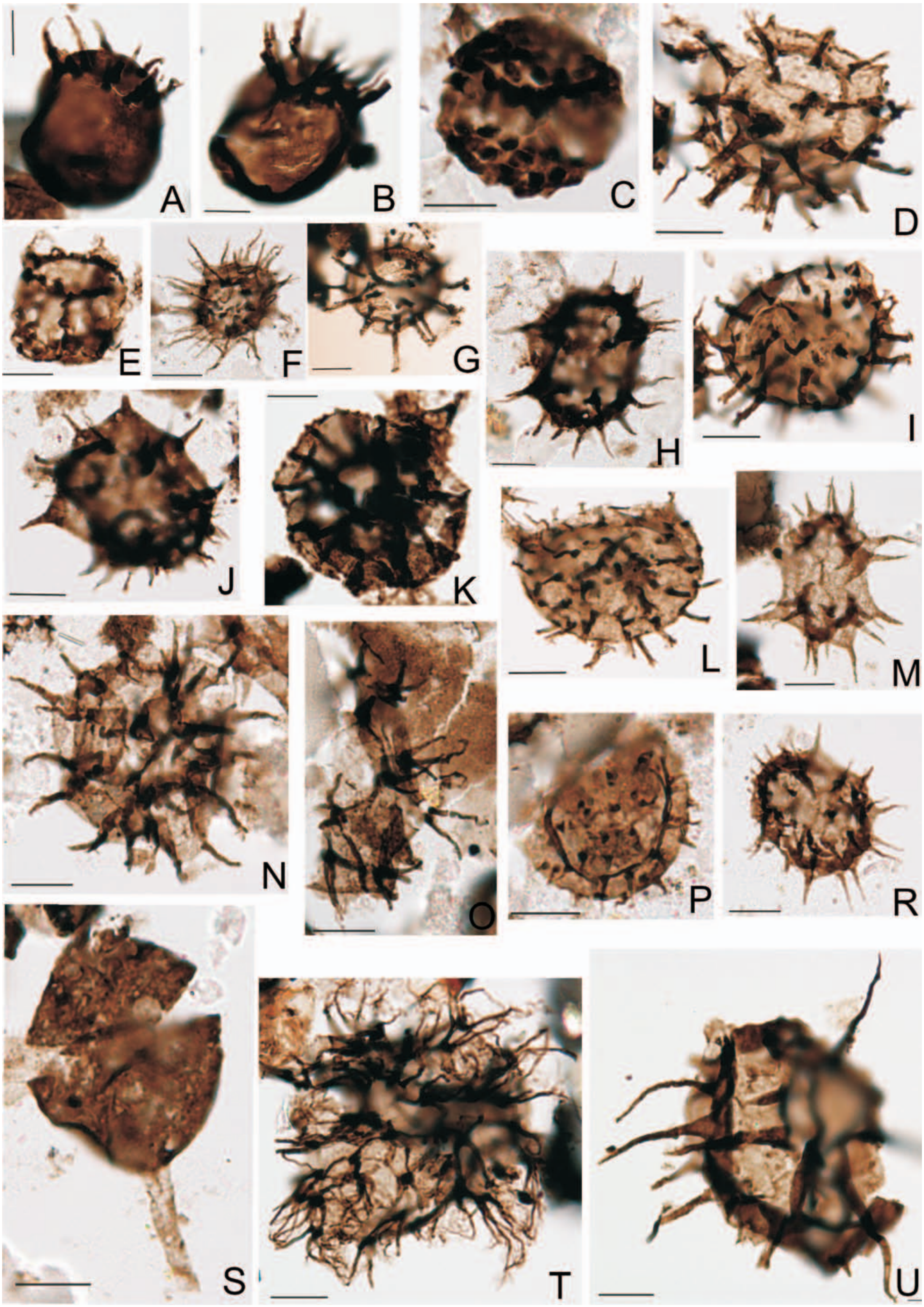
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Fig. 14. Furongian acritarch assemblages from the Verchany 1 well (western Ukraine). Scale bar is 10 μm for A–T; 25 μm for U. **A.** *Trunculumarium revinium* (Vanguestaine, 1973) Loeblich & Tappan, 1976 – Verchany 1 well, depth 2,055–2,056.8 m; **B.** *Trunculumarium revinium* (Vanguestaine, 1973) Loeblich & Tappan, 1976 – Verchany 1 well, depth 2,055–2,056.8 m; **C.** *Acanthodiacrodium snookense* Parsons & Anderson, 2000 – Verchany 1 well, depth 2,050–2,051.5 m; **D.** *Stelliferidium* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **E.** *Cymatiogalea* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **F.** *Polygonium* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **G.** *Stelliferidium* sp. Verchany 1 well, depth 2,050–2,051.5 m; **H.** *Acanthodiarodium achrasii* Martin, 1972 – Verchany 1 well, depth 2,055–2,056.8 m; **I.** *Stelliferidium* sp. – Verchany 1 well, depth 1,996–2,003.5 m; **J.** *Dasydiacrodium* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **K.** *Cristallinium dubium* Volkova, 1990 – Verchany 1 well, depth 2,055–2,056.8 m; **L.** *Cymatiogalea* sp. – Verchany 1 well, depth 1,996–2,003.5 m; **M.** *Acanthodiarodium achrasii* Martin, 1972 – Verchany 1 well, depth 2,050–2,051.5 m; **N.** *Izohoria* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **O.** *Vulcanisphaera turbata* Martin, in Martin & Dean, 1981 – Verchany 1 well, depth 2,055–2,056.8 m; **P**. *Cymatiogalea* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **R**. *Dasydiacrodium* sp. – Verchany 1 well, depth 2,050–2,051.5 m; **S**. *Ortosphaeridium ? extensum* Parsons & Andreson, 2000 – Verchany 1 well, depth 2,050–2,051.5 m; **T**. *Vulcanisphaera africana* Deunff, 1961 – Verchany 1 well, depth 2,055–2,056.8 m; **U**. *Solisphaeridium* sp. – Verchany 1 well, depth 2,055–2,056.8 m

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