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Organic microfossil assemblages from the late Ediacaran rocks of the Małopolska Block, southeastern Poland

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The results of palynological investigations of the oldest siliciclastic strata recognized in the Małopolska Block, situated in southeastern Poland, within the Trans-European Suture Zone (TESZ), are summarized in this paper. Siliciclastic flysch-type rocks without macrofossils have been encountered in over 1000 boreholes within the Małopolska Block, below Paleozoic, Mesozoic, and Cenozoic deposits of various ages (from Ordovician up Miocene). The lithostratigraphy of the pre-Ordovician basement in the Małopolska Block is not fully known. Thin tuffs or tuffites layers have been found in many sections of these rocks. In some of the boreholes (e.g., Książ Wielki IG 1), a late Ediacaran age has been determined for a tuffite interlayer of the rocks underlying Ordovician strata, by U-Pb dating of zircons recovered from that tuffite, that indicated 549 ±3 Ma. This article describes the palynology of samples from twelve selected profiles which contained recognizable organic microfossils, in various states of preservation. The associations recovered are dominated by small spherical forms, without any ornamentation, belonging to the *Leiosphaeridia*, and by fossil cyanobacteria represented by straight or coiled thread-like fragmentary specimens. Similar organic microfossil associations, with poorly differentiated species and genera, are known from many late Ediacaran occurrences.

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INTRODUCTION

The majority of the organic microfossils encountered in Neoproterozoic rocks, are phytoplankton composed of tiny algae (acritarchs) and cyanobacteria (Moczydłowska, 2008*a*). Despite their microscopic size, their participation in and importance for the evolution of the Earth's biosphere was enormous (Knoll, 1996). Those microorganisms were the very first organic matter mass producers, and at the same time, they constituted they initial link of the food chain. These primary organisms were mostly photosynthetic, having contributed to the change of an anaerobic atmosphere into an oxygenated one (Jankauskas, 1989; Huntley *et al*., 2006; Sergeev, 2006).

Acritarchs are very often the only fossils within Precambrian rocks (an informal geochronological unit representing over 90% of the Earth history). During the evolution of the oldest phytoplankton, several significant stages, characterized by the occurrence of morphologically differentiated assemblages, have been noted (Sergeev, 2006; Gaucher and Sprechmann, 2009). These microorganism associations, appearing in succession within Tonian, Cryogenian, and Ediacaran strata, have been used in practical stratigraphic division (Sergeev, 2006; Veis *et al*., 2006; Grey, 2007; Gaucher and Sprechman, 2009). Several turnovers of the marine phytoplankton assemblages, observed within Neoproterozoic strata, were caused by global climatic changes occurring during that time (Knoll, 2000; Huntley *et al*., 2006).

The appearance of differentiated assemblages of large Ediacaran acanthomorphs (ECAP – Ediacaran Complex Acanthomorphs Palynoflora) has been recognized in many regions: China (Zhang *et al*., 1998; Zhou *et al*., 2007), Siberia (Kolosova, 1991; Moczydłowska *et al*., 1993; Moczydłowska, 2005; Vorob'eva *et al*., 2006, 2008, 2009), Scandinavia (Vidal, 1990) and Australia (Grey, 2005; Gaucher and Sprechmann, 2009; Fig. 1). In the last of these areas standard acritarchs horizons have been defined (Grey, 2005, 2007) on the basis of different microfossils characterized by rich ornamentation and by diameters often exceeding 500 μm (Grey, 2005; Moczydłowska, 2005).

In Ediacaran strata, just before the appearance of the characteristic acanthomorphs (ECAP), there occur associations of

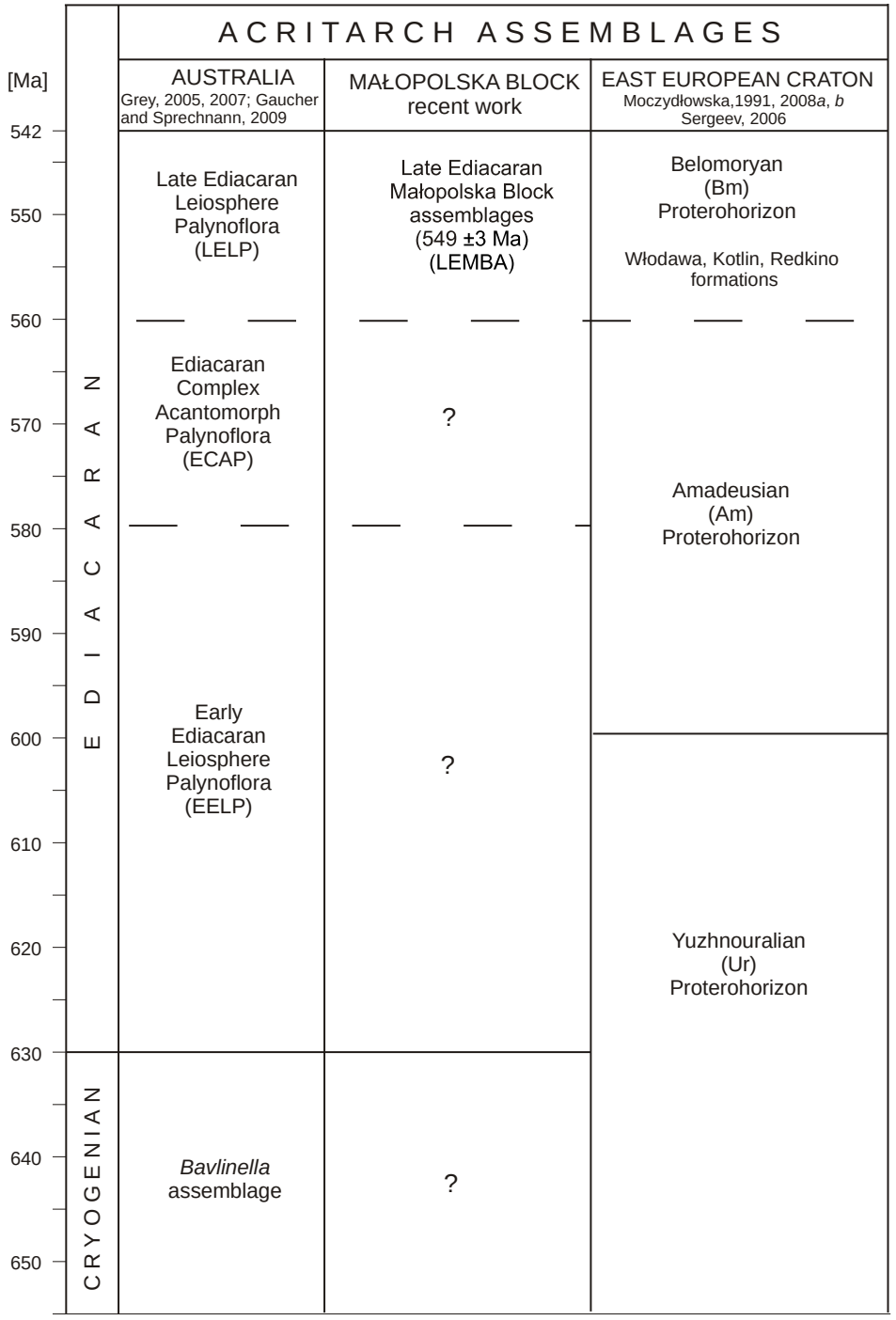

Fig. 1. Precambrian organic microfossil assemblages

organic microfossils, dominated by spherical forms of the *Leiosphaeridia* with diameters of up to several hundred microns (Gaucher *et al*., 2008). Those palynomorph associations, called the Early Ediacaran Leiosphere Palynoflora (EELP) (Fig. 1), appeared after the critical period of the Cryogenian glaciations (635 – *ca*. 580 Ma; Grey, 2005, 2007; Gaucher and Sprechmann, 2009).

In most regions, assemblages of large acanthomorphs, known also as the Pertatataka microfossils, appeared about 580 Ma years ago, after the global glaciations of the snowball Earth interval (Grey *et al*., 2003; Huntley *et al*., 2006). The only exception were the assemblages described from Southern China, where they appear in deposits dated at 635 ±0.5 Ma years (Zhou *et al*., 2007).

Disappearance of the characteristic Ediacaran microfossil associations took place synchronously over all the regions discussed, before the appearance of the famous Ediacaran fauna, about 555 Ma years ago (Grey, 2005). At that time, a drastic

turnover of the palynoflora occurred that was followed by the next crisis period. Morphologically differentiated associations, with specimens up to several hundred microns in diameters (large for microplankton), characterized by complicated ornamentation, were replaced by tiny, simple, spherical forms of the late Ediacaran assemblages, called the Late Ediacaran Leiosphere Palynoflora (LELP; Gaucher and Sprechmann, 2009). Numbers of sculptured acritarchs declined, and were replaced by small forms of *Asteridium*, *Heliosphaeridium* and *Comasphaeridium* species only (Volkova, 1968, 1969*a*, *b*; Jankauskas, 1989; Tiwari, 1999; Raevskaya, 2005). In the late Ediacaran deposits, besides these, there are also these poorly morphologically differentiated cyanobacterial assemblages which survived the snowball Earth conditions (Moczydłowska, 2008*a*). Late Ediacaran microfloras, dated at 550–542 Ma, are widely recognized, including examples from the East European Craton area, from the Redlino, Kotlin – Russia formations (Sergeev, 2006), as well as from the Lublin Slope of the East European Platform (EEP), adjacent to Małopolska Block (Moczydłowska, 2008*b*).

GEOLOGICAL BACKGROUND

Two regional tectonic units have been distinguished within southeastern Poland, and described as the Upper Silesian and the Małopolska blocks (Buła and Jachowicz, 1996; Buła *et al*., 1997). They are separated by the Kraków–Lubliniec Fault Zone (Figs. 2 and 3), and are located in the East European Craton foreland as a part of the Teisseyre Terrane Assemblage (TTA; Fig. 3; Nawrocki and Poprawa, 2006; Żelaźniewicz *et al*., 2009).

The Małopolska Block represents a tectonic unit of unknown age (Cadomian? or Grampian; Pożaryski and Tomczyk, 1968; Pożaryski *et al*., 1992). Its northwestern, southern, and southeastern boundaries are also not known. The southwestern boundary of the Małopolska Block is demarcated by the precisely defined Kraków–Lubliniec Fault Zone at the contact with the Upper Silesian Block (Buła *et al*., 2008). It is the best defined extension of the unit, to date (Buła, 2000). Into the Block, the Kielce part of the Holy Cross Mountains is included (Pożaryski, 1990; Pożaryski *et al*., 1992). The northern boundary of the Małopolska Block is demarcated, therefore, by the Holy Cross Mountains Fault, the extension of which to the east or the south-east, to Sandomierz, is still discussed (Buła and Habryn, 2008). To the south-east of Sandomierz, it most probably continues to Lubaczów, where it passes on to the territory of Ukraine, together with the Małopolska Block (Fig. 3; Buła and Habryn, 2008, 2011).

In the Małopolska Block, crystalline Precambrian basement has not yet been encountered. The geophysical investigations results suggest that it may occur at the depths exceeding 10 km (Malinowski *et al*., 2005). The oldest Precambrian rocks recognized within the Małopolska Block are clayey-muddy-sandy deposits interbedded with conglomerates or sandy gravels. These rocks vary in colour from greyish-green, grey-ashen, to cherry red-brownish, and are characterized by rhythmic (turbidite), as well as by normal, grading that shows their flysch character (Buła, 2000; Żelaźniewicz *et al*., 2009).

These rocks have undergone strong diagenesis or only slight metamorphism (anchimetamorphism). The bedding dips vary between a few and 90°, with a predominance of steep dips – above 50°. In some borehole cores, fold hinges are visible. In places, clayey mudstone rocks have undergone phyllitisation processes.

These rocks used to be considered as Precambrian (Riphean and Vendian) or Early Cambrian in age (Samsonowicz, 1955; Głowacki and Karnkowski, 1963; Pożaryski and Tomczyk, 1968; Jurkiewicz, 1975; Karnkowski, 1977; Kowalski, 1983; Kowalczewski, 1990; Buła, 2000; Moryc and Łydka, 2000).

In many sections of these strata from the Małopolska Block area, thin layers of tuff or tuffite have been encountered. The age of a tuffite interlayer from the rocks that underlie Ordovician strata in the Książ Wielki IG 1 borehole has been determined. U-Pb dating of zircons from that tuffite, yielded an age of 549 ±3 Ma (Compston *et al*., 1995). Furthermore, the results of isotopic studies (U-Pb SHRIMP II method) of zircon grains from presumed Ediacaran rocks, from several boreholes (including the fossil-dated Zalasowa 1 profile), show a significant proportion of zircon grains which grew in their parent rocks as whole crystals (or their rims) between 720 and 550 Ma (Żelaźniewicz *et al*., 2009). These data clearly support the suggested late Ediacaran age of the Małopolska Block flysch deposits.

The detailed characteristics of the Małopolska Block Precambrian rocks are discussed in a number of papers (Głowacki and Karnkowski, 1963; Głowacki *et al*., 1963; Łydka and Siedlecki, 1963; Jawor, 1970; Kicuła and Wieser, 1970; Łydka, 1973; Jurkiewicz, 1975; Karnkowski, 1977; Kowalczewski, 1990; Moryc, 1992, 1996, 2006; Buła, 2000; Moryc and Łydka, 2000; Moryc and Jachowicz, 2000; Żelaźniewicz *et al*., 2009), in which their close similarities to the Vendian schists of Dobrudja are noted (Głowacki and Karnkowski, 1963; Żelaźniewicz *et al*., 2009).

Such flysch-type rocks have been recognized in over 1000 boreholes, drilled in the area between Częstochowa and Przemyśl (Fig. 3). They occur below sedimentary rocks of various ages, from Ordovician up to Miocene one (Buła and Habryn, 2008; Buła, 2000).

The lower Paleozoic rocks of the Małopolska Block are represented by clastic Cambrian rocks, and by clastic and carbonate rocks of Ordovician and Silurian age (Buła and Habryn, 2008). Clastic Cambrian rocks occur in the northern and eastern parts of the Małopolska Block, only (Buła and Habryn, 2008; Jachowicz-Zdanowska, 2011). Their only surface outcrops are in the Kielce region of the Holy Cross Mountains, and further towards Stalowa Wola and Lubaczów (Fig. 3; Dziadzio and Jachowicz, 1996; Kowalska *et al*., 2000; Buła and Habryn, 2008, 2011; Jachowicz-Zdanowska, 2011). Unfortunately, the Cambrian rocks have not been penetrated drilling. Therefore, it has not been possible to determine their tectonic position in relation to the Precambrian basement rocks. Silurian and Ordovician strata have been preserved locally within the Małopolska Block. They are represented by lithologically and facially differentiated clastic and carbonate rocks that are unconformably overlie Precambrian or Cambrian rocks (Trela, 2006; Buła and Habryn, 2008).

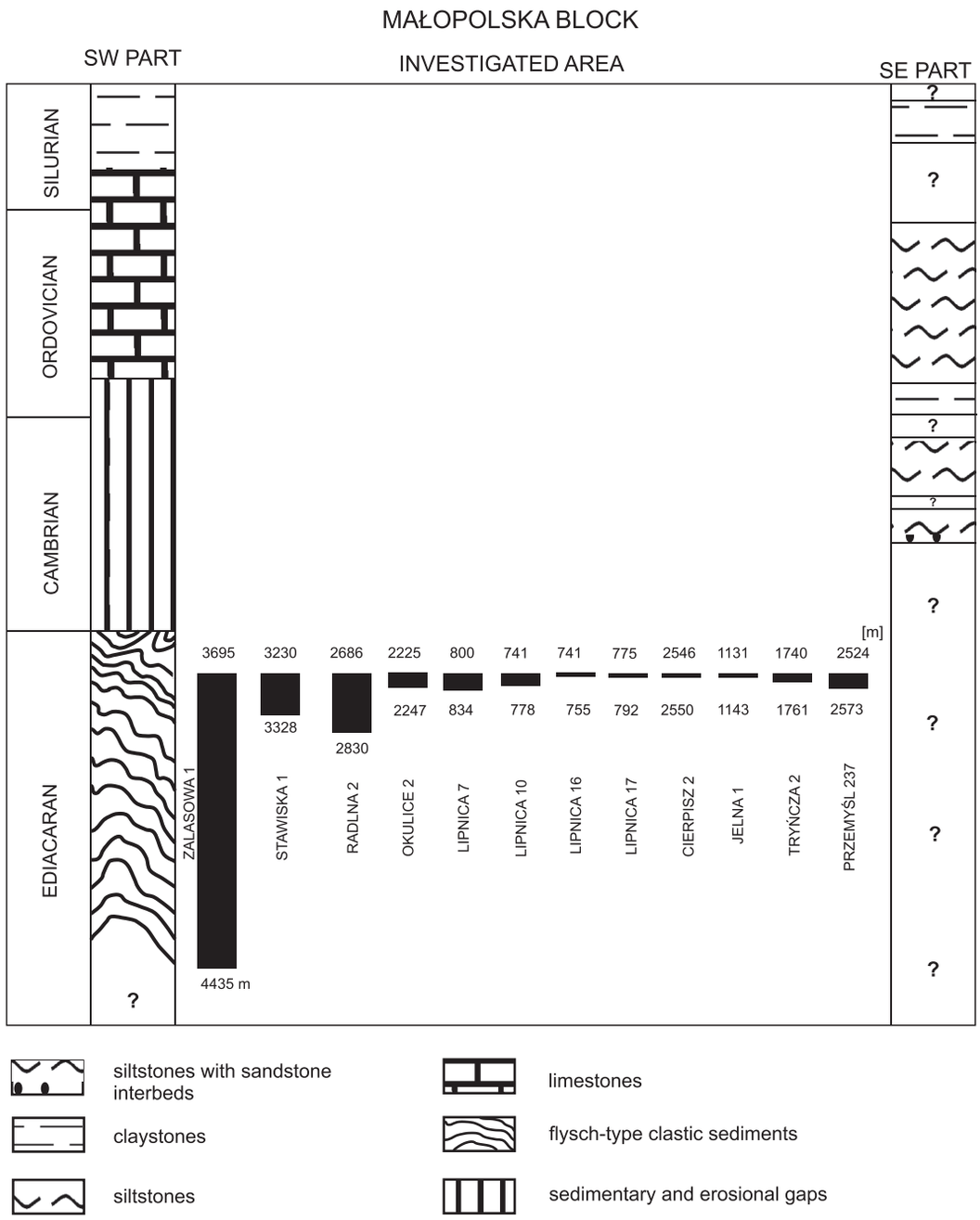

Fig. 2. Upper Ediacaran and lower Paleozoic schematic successions of the SW and SE parts of the Małopolska Block with approximate stratigraphic ranges of palynologicaly productive boreholes

PALYNOLOGICAL INVESTIGATIONS

This paper summarises the existing information on the microfloral assemblages encountered during the author's studies of the oldest rocks of the Małopolska Block. During these studies, several hundred samples of the flysch siliciclastic rocks from the Małopolska Block have undergone detailed investigations in the search for Precambrian microflora suitable for palynological determinations. Precambrian rocks have been encountered in boreholes drilled in various Małopolska Block areas, and at various depths, from several hundred to over three thousand metres (Fig. 2 and Table 1). Those boreholes were drilled by the Polish Oil and Gas Company for oil and gas exploration and were incompletely cored. Thus, only parts of the profiles of those boreholes have been investigated.

The first palynological investigations of the Małopolska Block oldest rocks were carried out in the 1960s and 1970s by Jagielska (Jagielska, 1966; Jagielska in: Karnkowski and Głowacki, 1961; Głowacki and Karnkowski, 1963; Głowacki *et al*., 1963; Jaworowski *et al*., 1967; Kicuła and Wieser, 1970; Jurkiewicz, 1975; Karkowski, 1977). These recognized or-

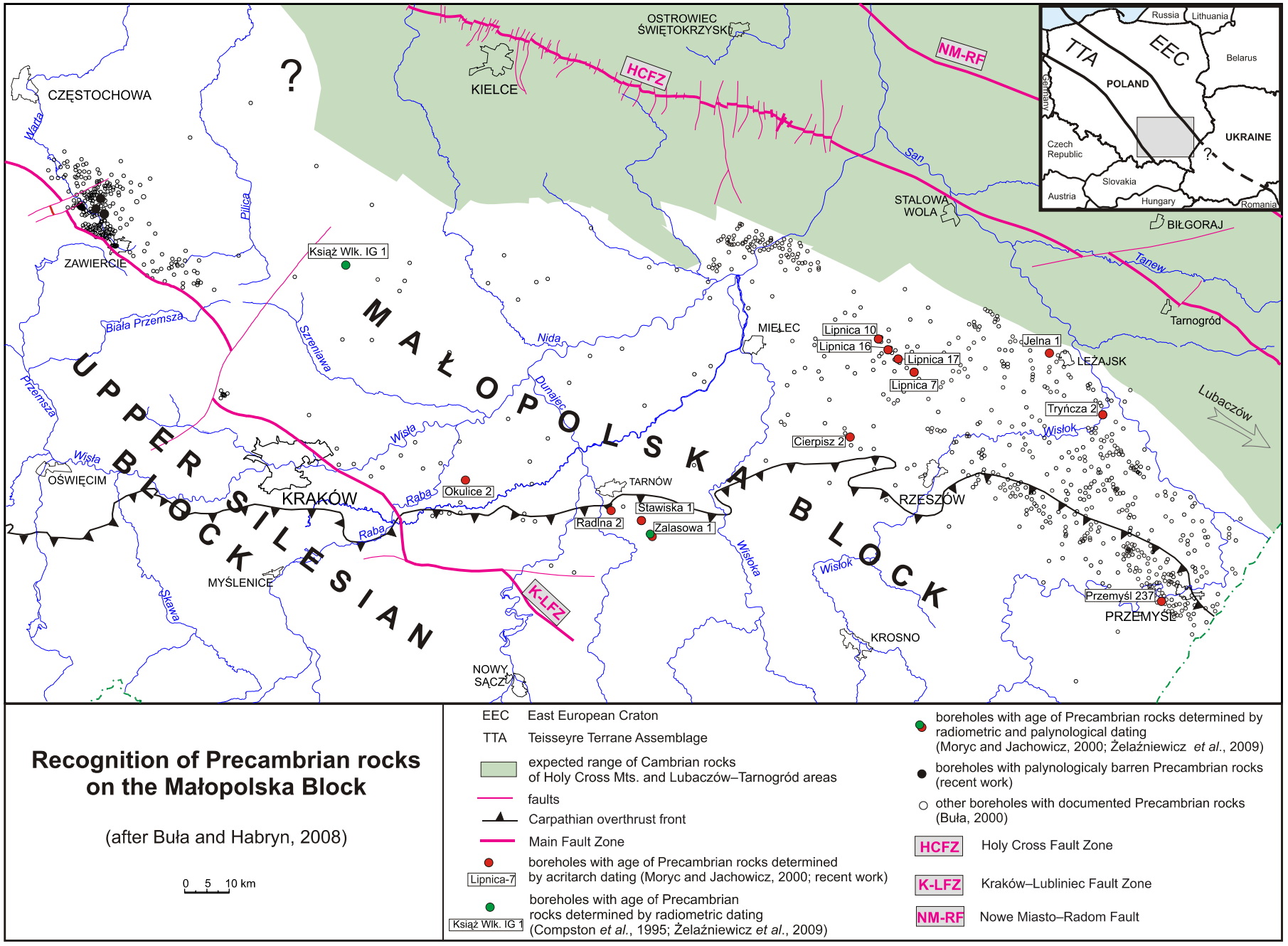

Fig. 3. Recognized Precambrian profiles of the Małopolska Block

Table 1

Location of palynologicaly productive samples with their depth in each borehole

Boreholes	Intervals [m]
Okulice 2	2242.1, 2244.3, 2245.5, 2246.9
Zalasowa 1	3680, 3842, 3849, 3898, 3903, 3957, 3961, 3971, 4026, 4137, 4224, 4256, 4294, 4323, 4398, 4427
Stawiska 1	3254, 3256, 3259, 3260, 3291, 3293, 3296, 3298, 3320, 3324, 3326
Radlna 2	2758, 2808, 2813
Lipnica 7	810, 815, 830
Lipnica 10	770
Lipnica 16	751
Lipnica 17	787
Cierpisz	2546.5, 2547.3, 2548.5, 2549.3, 2549.8
Jelna 1	1138, 1140
Tryńcza 2	1749
Przemyśl 237	2570–2573

ganic-walled microfossil assemblages in the rocks. Unfortunately, the terminology then used, after Timofeev (1959), has not been revised or correlated with that presently used in the palynological literature. There was also little or no illustration of the microfossils. Consequently, it is difficult to compare that information with the previous studies.

The present data were collected from siliciclastic flysch-type rocks, from several tens of boreholes, located in various Małopolska Block regions. So far, positive palynological results have been obtained from twelve investigated profiles only (Table 1 and Fig. 3).

Organic microfossils have not been found in the flysch siliciclastic rocks from the many boreholes drilled in the northwestern part of the Małopolska Block (Zawiercie vicinity; Fig. 3), probably because of the contact and regional metamorphism of those rocks (Buła, 2000; Żelaźniewicz *et al*., 2009).

Organic microfossil assemblages, suitable for determinations, have been documented in the following regions (and boreholes) of the Małopolska Block (Table 1 and Fig. 3): in the western part of the block (Okulice 2 borehole, Kraków region); in its southern part (Zalasowa 1, Stawiska 1 and Radlna 2 boreholes, Tarnów region), as well as in its central part (5 boreholes: Lipnica 7, 10, 16, 17 and Jelna 1, situated to the east of Mielec); in individual boreholes located to the west (Cierpisz 2 borehole) and to the north-east (Tryńcza 2 borehole) of Rzeszów; and in the southeastern part of the block (Przemyśl 237 borehole).

Samples chosen for analyses were macerated using standard methods (Wood *et al*., 1996). In most of the rock samples investigated, a palynological residue with low or very low contents of organic matter was obtained. Therefore, in order to recognize microflora suitable for determinations, planimetric analyses of 10 standard microscopic slides (22 × 22 mm of the area), were made. The only exceptions were samples from the southern parts of the Małopolska Block (Zalasowa 1, Stawiska 1, Radlna 2; Table 1 and Fig. 3), where distinctly higher organic matter contents were found. That was seen in the microscopic slides, clearly richer in organic microfossils and in amorphous organic matter.

Palynological analyses of the samples investigated proved the presence of poorly differentiated assemblages of organic-walled microfossils. Within these assemblages, simple spherical forms with no ornamentation referred to species of *Leiosphaeridia*, occur (Fig. 4). These single-walled forms belonging to the eukaryotic planktonic microalgae (Moczydłowska, 2008*a*) are accompanied by filamentous specimens, straight or coiled, being fragments of fossil osillatoriacean cyanobacteria (Moczydłowska, 2008*a*, *b*). The cyanobacterial genera are represented by specimens of *Siphonophycus* Schopf, 1968; *Obruchevella* Reitlinger, 1959 and *Eoschizothrix* Seong-Joo and Golubic, 1999. Sporadically, representatives of *Eoenthophysalis* Hofmann, 1976 appeared as tiny, spherical or ellipsoidal, usually uniform, interconnected specimens. In several slides, individual, tiny specimens of *Granomarginata prima* Naumova, 1960 were documented.

The preservation state of the specimens recovered is fairly good. Quite a lot the fossils have been preserved as a whole, and the brown and dark brown colours of their walls indicates thermal alteration temperatures below 180°C (Batten, 1980).

Associations found in the southwestern and southern parts of the Małopolska Block (Okulice 2, Zalasowa 1, Stawiska 1 and Radlna 2 boreholes) were dominated by numerous thread-like fragments of cyanobacteria. The latter forms, characteristically coiled, represented *Obruchevella* species, known from Precambrian rocks (Jankauskas, 1989; Knoll, 1996). It is interesting that within the associations described, specimens of the *Leiosphaeridia* species are very few, only 1–3 specimens with diameters between 5–20 μm, within a standard microscopic slide. Sometimes, a few forms of *Eoenthophysalis* sp. occurred.

Microfossil assemblages, documented in the profiles from the central and southeastern parts of the Małopolska Block, were characterized by high contents of small *Leiosphaeridia* specimens, which were accompanied by rare straight fragments of cyanobacteria. Characteristic *Obruchevella* specimens were absent. Sometimes individual, tiny specimens of *Granomarginata prima* were documented in the slides. Generally, the palynofacies of the investigated rocks from the discussed area are characterized by low levels of organic matter.

REMARKS AND CONCLUSIONS

Recognizable organic-walled microfossil assemblages have been palynologically identified within twelve profiles of the upper Ediacaran clastic rocks obtained from the Małopolska Block basement. The late Ediacaran age of that rock succession has been radiometrically established in Zalasowa 1 borehole profile (Żelaźniewicz *et al*., 2009). The Zalasowa 1 profile has also been palynologically studied, though no macrofossils were found in either of the profiles studied. The organic-walled microfossil assemblages, in part radiomerically dated, are the first records of that kind.

Despite generally small differences in the overall species content of the microflora encountered, some qualitative and quantitative differences could be observed in the microfossil

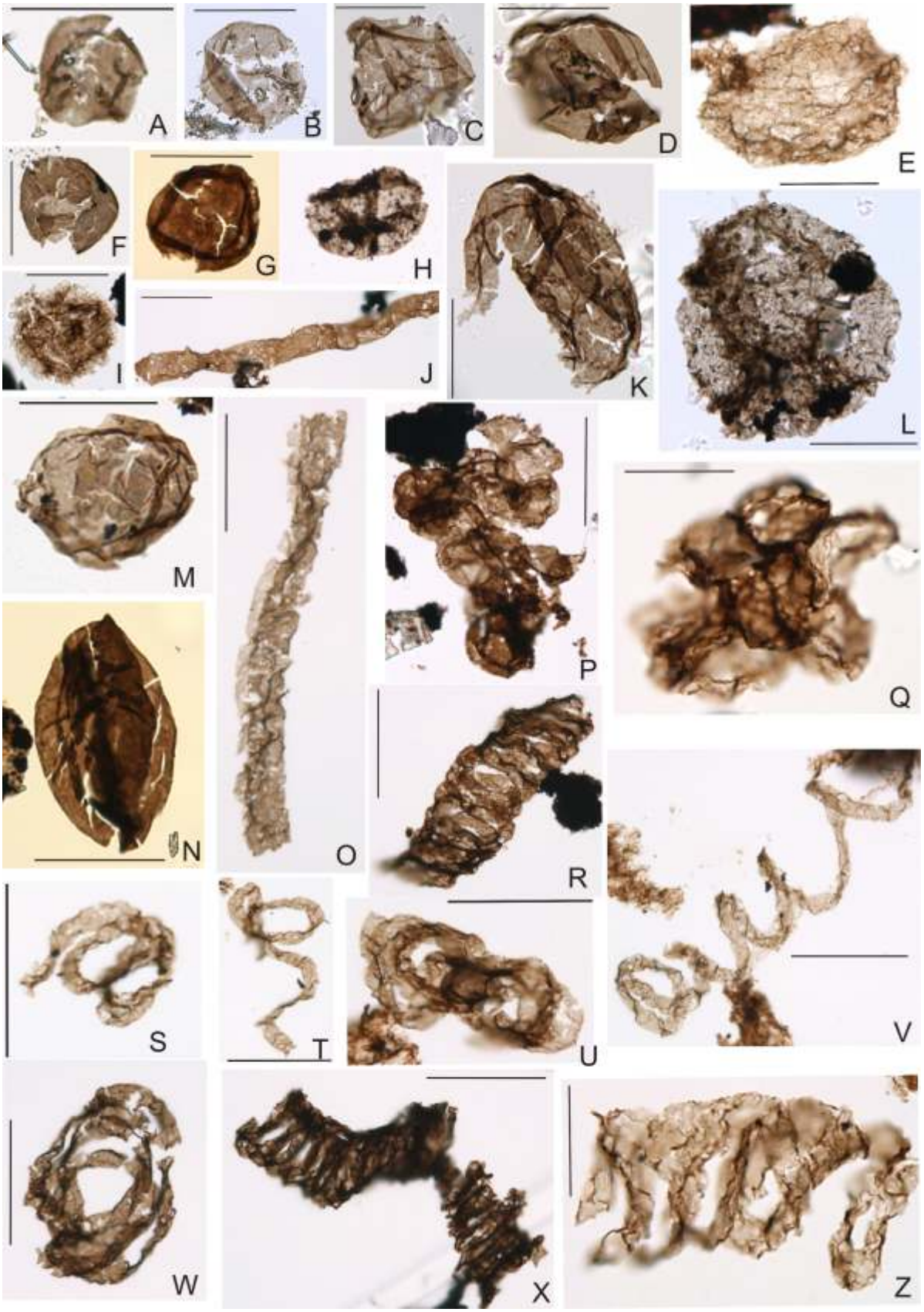

Fig. 4. Late Ediacaran organic microfossils of the Małopolska Block

A–**H**, **K**–**N** – *Leiosphaeridia* sp., **I** – *Granomarginata prima* Naumova, 1960; **J –** *Siphonophycus* sp.; **P**, **Q** – *Eoenthophysalis* sp.; **O** – *Eoschizothrix* sp.; **R**–**Z –** *Obruchevella* sp.; A, B, F – Jelna 1 borehole depth 1138–1143 m; C–E, K–L – Lipnica 10 borehole depth 770 m; H, P – Okulice 2 borehole depth 2242.1 m; I, G, M, N – Przemyśl 237 borehole depth 2570–2573 m; J, O, Q–Z **–** Radlna 2 borehole depth 2758 m; scale bare – 20 μm for: A–G, I, K–N, Q; 50 μm for: H, P, R, S–Z; 100 μm for: J, O

assemblages reoccurred, as well as in their extent over the Małopolska Block area. The organic microfossil associations in the southern part of the Małopolska Block (Kraków and Tarnów regions) are characterized by a domination of the thread-like cyanobacteria (above 90% of the recovered spectrum), with very rare *Leiosphaeridia* specimens. In contrast to these assemblages, microflora encountered in the central and southeastern parts of the Małopolska Block are characterized by high contents of small *Leiosphaeridia* specimens (above 80% of the analysed spectrum), which are accompanied by straight fragments of cyanobacteria.

Similar, poorly taxonomically differentiated phytoplankton assemblages are known from the late Ediacaran deposits of many areas (Jankauskas, 1989; Moczydłowska, 1991; Jankauskas and Lendzion, 1992; Grey, 2005; Gaucher *et al*., 2008). At that time, a drastic change of the phytoplankton took place at the boundary with the Cambrian system, and the Ediacaran acanthomorphs were replaced by simple, tiny sphaeromorphs as well as by intermittently numerous cyanobacteria assemblages (Jankauskas, 1989; Moczydłowska, 1991; Knoll, 1996; Sergeev, 2006; Gaucher and Sprechmann, 2009).

Microflora similar to the one obtained from the Małopolska Block are characteristic of the acritarch horizons 1 (cyanobacteria) and 2 (cyanobacteria, *Leiosphaeridia* sp.), recognized in the Lublin–Podlasie Slope of the East European Craton, adjacent to the Małopolska Block (Moczydłowska, 1991). Assemblages of horizons 1 and 2, recovered from deposits of well-documented absolute age, were dominated by simple specimens of prokaryotic cyanobacteria and by spherical acritarchs, belonging to species of *Leiosphaerida*, and regarded as phytoplankton (Moczydłowska, 2008*b*).

It is quite possible that the differentiated organic microfossil assemblages documented in the Małopolska Block area might represent two different sections of the late Ediacaran flysch succession. However, it is impossible to reconstruct their vertical succession at the present stage of investigation because the amount of data available remains insufficient.

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REFERENCES

BATTEN D. J. (1980) – Use of transmitted light microscopy of sedimentary organic matter for evaluation of hydrocarbon source potential. IV Internat. Palynol. Conf. Proc., **2**: 589–594.

BUŁA Z. (2000) – Lower Paleozoic of Upper Silesia and West Małopolska (in Polish with English summary). Pr. Państw. Inst. Geol., **171**: 1–89.

BUŁA Z. and HABRYN R. (2008) – Geological-structural atlas of the Paleozoic basement of the Outer Carpathians and Carpathian Foredeep. Państw. Inst. Geol., Warszawa.

BUŁA Z. and HABRYN R. (2011) – Precambrian and Paleozoic basement of the Carpathian foredeep and the adjacent Outer Carpathians (SE Poland and West Ukraine). Ann. Soc. Geol. Pol. (in press).

BUŁA Z. and JACHOWICZ M. (1996) – The Lower Paleozoic sediments in the Upper Silesian Block. Geol. Quart., **40** (3): 299–336.

BUŁA Z., JACHOWICZ M. and ŻABA J. (1997) – Principal characteristics of the Upper Silesian Block and Małopolska Block border zone (southern Poland). Geol. Mag., **133** (5): 669–677.

BUŁA Z., ŻABA J. and HABRYN R. (2008) – Tectonic subdivision of Poland southern Poland (Upper Silesian Block and Małopolska Block) (in Polish with English summary). Prz. Geol., **56** (10): 912–920.

COMPSTON W., SAMBRIDGE M. S., REINFRANK R. F., MOCZYDŁOWSKA M., VIDAL. G. and CLAESSONS S. (1995) – Numerical ages of volcanic and earliest faunal zone within the Late Precambrian of east Poland. J. Geol. Soc. London., **152**: 599–611.

DZIADZIO P. and JACHOWICZ M. (1996) – Geological structure of the Miocen substrate SW Lubaczów Uplift (SE Poland) (in Polish with English summary). Prz. Geol., **44** (11): 1124–1130.

GAUCHER C., BLANCO G., CHIGLINO L., POIRÉ D. and GREMS G. J. B. (2008) – Acritarchs of Las Ventas Formation (Ediacaran, Uruguay): implications for the timing of coeval rifting and glacial events in western Gondwana. Gondwana Res., **13**: 488–501.

GAUCHER C. and SPRECHMANN P. (2009) – Neoproterozoic acritarch evolution. In: Neoproterozoic-Cambrian Tectonics, Global Change and Evolution: a Focus on Southwestern Gondwana (eds. C. Gaucher, A. N. Sial, G. P. Halverson and H. E. Frimmel). Develop. Precambrian Geol., **16**: 319–326.

GŁOWACKI E. and KARNKOWSKI P. (1963) – Comparison of the Upper Precambrian (Riphaean) of Middle Carpathian Foreland with a series of green schists of Dobrudja (in Polish with English summary). Kwart. Geol., **7** (2): 187–195.

GŁOWACKI E., KARNKOWSKI P. and ŻAK C. (1963) – Pre-Cambrian and Cambrian in the Basement of the Carpathian Foreland and the Holy Cross Mts. (in Polish with English summary). Rocz. Pol. Tow. Geol., **33**: 321–338.

GREY K. (2005) – Ediacaran palynology of Australia. Mem. Ass. Austral. Palaeont., **31**.

GREY K. (2007) – Advances in Ediacaran biostratigraphy in Australia. In: Recent Advances in Palynology (eds. P. Steemans and E. Javaux). Notebooks on Geology, Brest, Mem. 2007/03, Abstract 05 (CG2007_M01/05).

GREY K., WALTER M. R. and CALVER C. R. (2003) – Neoproterozoic biotic diversification: Snowball Earth or aftermath of the Acraman impact ? Geology, **31**: 459–462.

HOFMANN H. J. (1976) – Precambrian microflora, Belcher Islands, Canada, significance and systematics. J. Paleontol., **50**: 1040–1073.

HUNTLEY W. J., XIAO S. and KOWALEWSKI M. (2006) – 1.3 billion years of acritarch history: an empirical morphospace approach. Precambrian Res., **144**: 52–68.

JACHOWICZ-ZDANOWSKA M. (2011) – Cambrian organic microfossils at the border area of the East and West European Platforms (SE Poland and West Ukraine). Ann. Soc. Geol. Pol. (in press)

JAGIELSKA L. (1966) – Microflora in the Eocambrian and Lower Cambrian deposits in the eastern area of Poland (in Polish with English summary). Kwart. Geol., **10** (2): 251–261.

JANKAUSKAS T. V. (1989) – Mikrofossilii dokembriya SSSR (in Russian). Nauka, Moscow.

JANKAUSKAS T. and LENDZION K. (1992) – Lower and Middle Cambrian acritarch-based biozonation of the Baltic syneclise and adjacent areas (East-European Platform). Prz. Geol., **40** (9): 519–525.

JAWOR E. (1970) – The structure of the deep substratum in the region east of Cracow (in Polish with English summary). Acta Geol. Pol., **20** (4): 709–769.

JAWOROWSKI K., JURKIEWICZ H. and KOWALCZEWSKI Z. (1967) – Sinian and Paleozoic in the bore-hole Jaronowice IG 1 (in Polish with English summary). Kwart. Geol., **11** (1): 21–38.

JURKIEWICZ H. (1975) – The geological structure of the basement of the Mesozoic in the central part of the Miechów Trough (in Polish with English summary). Biul. Inst. Geol., **283**: 5–100.

KARNKOWSKI P. (1977) – Deep-seated basement of the Carpathians (in Polish with English summary). Prz. Geol., **25** (6): 289–297.

KARNKOWSKI P. and GŁOWACKI E. (1961) – Geological structure of sub-miocene sediments of the middle Carpathian foreland (in Polish with English summary). Kwart. Geol., **5** (2): 372–419.

KICUŁA J. and WIESER T. (1970) – Precambrian sediments and lamprophyres in the bore-hole Opatkowice 1 (in Polish with English summary). Rocz. Pol. Tow. Geol., **40** (1): 111–129.

KNOLL A. H. (1996) – Chapter 4. Archean and Proterozoic paleontology. In: Palynology: Principles and Applications (eds. J. Jansonius and D. C. McGregor). Am. Ass. Strat. Palynol. Found., **1**: 51–80.

KNOLL A. H. (2000) – Learning to tell Neoproterozoic time. Precambrian Res., **100**: 3–20.

KOLOSOVA S. P. (1991) – Late Precambrian acanthomorphic microfossils of the eastern Siberian Platform. Algologiya, **1**: 53–59.

KOWALCZEWSKI Z. (1990) – Coarse grained Cambrian rocks in central south Poland (lithostratigraphy, tectonics, paleogeography) (in Polish with English summary). Pr. Państw. Inst. Geol., **131**: 1–82.

KOWALSKA S., KRANC A., MAKSYM A. and ŚMIST P. (2000) – Budowa geologiczna podłoża miocenu w północno-wschodniej części zapadliska przedkarpackiego, w rejonie Lubaczów–Biszcza. Nafta-Gaz, **3**: 158–178.

KOWALSKI W. (1983) – Stratigraphy of the Upper Precambrian and lowest Cambrian strata in southern Poland. Acta. Geol. Pol., **33**: 183–217.

ŁYDKA K. (1973) – Late-Precambrian and Silurian in the Myszków area (in Polish with English summary). Kwart. Geol., **17** (4): 700–712.

ŁYDKA K. and SIEDLECKI S. (1963) – On Algonkian deposits in the environs of Cracow. Bull. Acad. Pol. Sc., Sér. Sc. Géol. Géogr., **11** (2): 75–81.

MALINOWSKI M., ŻELAŹNIEWICZ A., GRAD M., GUTERCH A. and JANIK T. (2005) – Seismic and geological structure of the crust in the transition from Baltica to Paleozoic Europe in the SE Poland – CELEBRATION 2000 experiment, profile CEL02. Tecton., **401**: 55–77.

MOCZYDŁOWSKA M. (1991) – Acritarch biostratigraphy of the Lower Cambrian and the Precambrian-Cambrian boundary in southeastern Poland. Fossils and Strata, **29**: 1–127.

MOCZYDŁOWSKA M. (2005) – Taxonomic review of some Ediacaran acritarchs from the Siberian Platform. Precambrian Res., **136**: 283–307.

MOCZYDŁOWSKA M. (2008*a*) – The Ediacaran microbiota and the survival of Snowball Earth conditions. Precambrian Res., **167**: 1–15.

MOCZYDŁOWSKA M. (2008*b*) – New records of the late Ediacaran microbiota from Poland. Precambrian Res., **167**: 71–92.

MOCZYDŁOWSKA M., LANDING E., ZANG W. and PALACIOS T. (2011) – Proterozoic phytoplankton and timing of chlorophyte alga origins. Palaeontology, **54**: 1–13.

MOCZYDŁOWSKA M., VIDAL G. and RUDAVSKAYA V. A. (1993) – Neoproterozoic (Vendian) phytoplankton from the Syberian Platform, Yakutia. Paleontology, **36**: 495–521.

MORYC W. (1992) – Geological structure of Miocene substrate formations in Sędziszów-Rzeszów region and their prospects (in Polish with English summary). Nafta-Gaz, **9**–**10**: 205–223.

MORYC W. (1996) – The geological structure of Miocene substratum in Pilzno–Dębica–Sędziszów Młp. region (in Polish with English summary). Nafta-Gaz, **12**: 521–550.

MORYC W. (2006) – Budowa geologiczna podłoża miocenu w rejonie Kraków–Pilzno. Cz. I. Prekambr i paleozoik (bez permu). Nafta-Gaz, **72**: 197–216.

MORYC W. and JACHOWICZ M. (2000) – Precambrian deposits in the Bochnia–Tarnów–Dębica area (southern Poland) (in Polish with Eanglish summary). Prz. Geol., **48** (7): 601–606.

MORYC W. and ŁYDKA K. (2000) – Sedimentation and tectonics of the Upper Proterozoic–Lower Cambrian deposits of the Southern Małopolska Massif (SE Poland). Geol. Quart., **44** (1): 47–58.

NAUMOVA S. N. (1960) – Sporogo-pyltsevye kompleksy rifejskikh I nizhnekembryjskich otlozhenij SSSR. 109–117. Akad. Nauk SSSR, Moscow.

NAWROCKI J. and POPRAWA P. (2006) – Development of Trans-European Suture Zone in Poland: from Ediacaran rifting to Early Palaeozoic accretion. Geol. Quart., **50** (1): 59–76.

POŻARYSKI W. (1990) – The Middle Europe Caledonides – wrenching orogen composed of terranes (in Polish with English summary). Prz. Geol., **38** (1): 1–9.

POŻARYSKI W., GROCHOLSKI A., TOMCZYK H., KARNKOWSKI P. and MORYC W. (1992) – The tectonic map of Poland in the Variscan epoch (in Polish with English summary). Prz. Geol., **40** (11): 643–651.

POŻARYSKI W. and TOMCZYK H. (1968) – Assyntian orogen in south-east Poland. Biul. Inst. Geol., **237**: 13–27.

RAEVSKAYA E. (2005) – Diversity and distribution of Cambrian acritarchs from the Siberian and East-European platform – generalized scheme. In: Pre-Cambrian to Paleozoic Palaeopalynology and Palaeobotany (eds. P. Steemans and E. Javaux). Notebooks on Geology, Brest, Mem. 2005/02, Abstract 07 (CG2005_M02/07).

REITLINGER E. A. (1959) – Atlas mikroskopicheskikh organicheskikh ostatkov i problematiki drevnikh tolshch Sibiri. Moskva, Izd-vo Akad. Nauk, SSSR.

SAMSONOWICZ J. (1955) – About pre-Cambrian in Poland (in Polish with English summary). Prz. Geol., **3** (12): 588–589.

SERGEEV V. N. (2006) – The importance of the Precambrian microfossils for modern biostratigraphy. Paleont. J., **40**: S664–S673.

SCHOPF J. W. (1968) – Microflora of the Bitter Springs Formation, Late Precambrian, central Australia. J. Paleont., **42**: 651–688.

SEONG-JOO L. and GOLUBIC S. (1999) – Microfossils populations in the contex of synsedimentary micrite deposition and acicular carbonate preparation: Mesoproterozoic Gaoyuzhuang Formation, China. Precambrian Res., **96**: 183–208.

TIMOFEEV B. V. (1959) – Drevnejshaya flora Pribaltiki (in Russian) Trudy VNIGRI, **129**: 1–129. Leningrad.

TIWARI M. (1999) – Organic-walled microfossils from the Chert-phosphorite Member, Tal Formation, Precambrian-Cambrian Boundary, India. Precambrian Res., **97**: 99–113.

TRELA W. (2006) – Lithostratigraphy of the Ordovician in the Holy Cross Mountains (in Polish with English summary). Prz. Geol., **54** (2): 622–631.

VEIS A. F., VOROB'EVA N. G. and GOLUBKOVA E. Yu. (2006) – The Early Vendian Microfossils first found in the Russian plate: taxonomic composition and biostratigraphic significance. Strat. Geol. Correl., **14**: 368–385.

VIDAL G. (1990) – Giant acanthomorph acritarchs from the upper Proterozoic in southern Norway. Palaeontology, **33**: 287–298.

VOLKOVA N. A. (1968) – Akritarkhi dokembrijskikh I nizhnekembrijskikh otlozhenij Estonii. In: Problematiki pogranichnykh sloev rifeya i kembriya Russkoj platform, Urala Kazakhstana (eds. N. A. Volkova, Z. A. Zhuravleva, V. E. Zabrodin and B. Sh. Klinger): 8–36. Nauka, Moskva.

VOLKOVA N. A. (1969*a*) – Raspredelenie akritatch v razrezakh severnovostochnoj Polshi. In: Tommotskij yarus I problema niznej granitsy kembriya (eds. A. Yu. Rozanov *et al.*): 74–76. Nauka, Moskva.

VOLKOVA N. A. (1969*b*) – Akritarkhi severo-zapada Russkoj platformy. In: Tommotskij yarus i problema niznej granitsy kembriya: 224–236. Nauka, Moskva.

VOROB'EVA N. G., SERGEEV V. N. and CHUMAKOV N. M. (2008) – New finds of early Vendian microfossils in the Ura Formation: revision of the Patom Supergroup Age, Middle Siberia. Dokl. Akad. Nauk, **419**: 782–787.

VOROB'EVA N. G., SERGEEV V. N. and KNOLL A. H. (2009) – Neoproterozoic microfossils from the northeastern margin of the East European Platform. J. Paleont., **83**: 161–196.

VOROB'EVA N. G., SERGEEV V. N. and SEMIKHATOV M. A. (2006) – Unique lower Vendian Kel'tma microbiota, Timan Ridge: new evidence for the paleontological essence and global significance of the Vendian System. Dokl. Earth Sc., **410**: 1038–104.

WOOD G. D., GABRIEL A. M. and LAWSON J. C. (1996) – Palynological techniques – processing and microscopy. In: Palynology: Principles and Applications (eds. J. Jansonius and D. C. McGregor). Am. Ass. Strat. Palynol. Found., **1**: 29–50.

ZHANG Y., YIN., XIAO S. and KNOLL A. H. (1998) – Premineralized fossils from the Terminal Proterozoic Doushantuo Formation, South China. Paleontol. Soc. Mem., **50**: 1–52.

ZHOU C., XIE G., McFADDEN K., XIAO S. and YUAN X. (2007) – The diversification and extinction of Doushantuo – Pertatataka acritarchs in South China: causes and biostratigraphic significance. Geol. J., **42**: 229–262.

ŻELAŹNIEWICZ A., BUŁA Z., FANNING M., SEGHEDI A. and ŻABA J. (2009) – More evidence on Neoproterozoic terranes in Southern Poland and southeastern Romania. Geol. Quart., **53** (1): 93–124.