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PALYNOMORPH ASSEMBLAGES FROM THE UPPER ORDOVICIAN IN NORTHERN AND CENTRAL POLAND

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Abstract: Palynological studies have been done to compare the Upper Ordovician strata in various geological units of northern and central Poland (epi-Caledonian Platform, East European Platform, Małopolska Block and Holy Cross Mountains–Łysogóry Fold Zone and Kielce Fold Zone). Two distinct palynological assemblages have been distinguished in the studied material: the Caradoc assemblage I and the Ashgill assemblage II (with two sub-assemblages IIa and IIb), thus demonstrating usefulness of the Upper Ordovician palynomorphs for biostratigraphy. Thermal maturity of organic matter was studied using the TAI method. The palynological analysis, palynostratigraphy, and estimates of thermal maturity were done with the aim at palynological characterization of three ancient units: the Avalonia, Baltica and the Małopolska Block, all now participating in structures of the present-day geological units of northern and central Poland.

Key words: palynological assemblages, palynostratigraphy, palaeotemperatures, Upper Ordovician, Poland.

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INTRODUCTION

This paper presents a palynological reconnaissance of the Upper Ordovician deposits (Darriwilian, Sandbian, Katian and Hirnantian) in various geological units of northern and central Poland that were parts of Palaeozoic continents. Differences between the palynomorph assemblages are presented and interpreted.

The studied material comes from: the epi-Caledonian Platform (Koszalin–Chojnice Zone), East European Platform (Peribaltic Syneclise, Podlasie Syneclise, Lublin Synclinorium), Holy Cross Mountains (Łysogóry Fold Zone) and the Małopolska Block (Holy Cross Mountains–Kielce Fold Zone and Nida region; Fig. 1).

These four regions belonged in Late Ordovician time to palaeogeographically separate realms: Avalonia, Baltica and the Małopolska Block (Torsvik & Rehnström, 2003). Sampling of four units with different geological history provided opportunity for demonstration of differences and similarities between the palynomorph assemblages in these units and for drawing stratigraphical and palaeoecological conclusions.

Previous palynostratigraphical and palaeogeographical studies of the Upper Ordovician in these areas were only fragmentary, except for the Koszalin–Chojnice Zone. No data of that type have been published for the Nida region (Małopolska Block) and the Lublin Synclinorium (East European Platform), and no study exists that would compile and compare evidence from all these units together.

The material used for the study comes mainly from deep boreholes drilled by the Polish Geological Institute (Instytut Geologiczny) and Enterprise for Petroleum Prospecting (Przedsiębiorstwo Poszukiwań Naftowych) in the 1960s and 1970s. The material is unique; most of the tested cores have been degraded or no more exist.

For the boreholes studied by Górka (1969, 1979, 1980), Szczepanik (2000), Trela and Szczepanik (2009), data from which were used in this paper, no tables with identified palynomorphs are presented here, but only references to the respective publications. The names of these boreholes are shown in italics in the figures.

PREVIOUS PALYNOLOGICAL STUDIES ON THE UPPER ORDOVICIAN OF POLAND

Palynological studies of the Upper Ordovician (Caradoc, Ashgill) have begun quite recently and are rather limited, both in Poland and worldwide. Published palynological data for this stratigraphic interval are limited to the areas of Western Pomerania (Bednarczyk *et al.*, 1999; Szczepanik, 2000; Wrona *et al.*, 2001), Peribaltic Syneclise (Górka, 1969, 1979, 1990), Podlasie (Górka, 1969, 1980), and the southern region of the Holy Cross Mountains (Jagielska, 1962; Stempień, 1990; Kremer, 1998, 2001; Trela *et al.*, 2001; Masiak *et al.*, 2002; Szczepanik, 2002; Masiak *et al.*, 2003; Trela & Szczepanik, 2009). Dating of

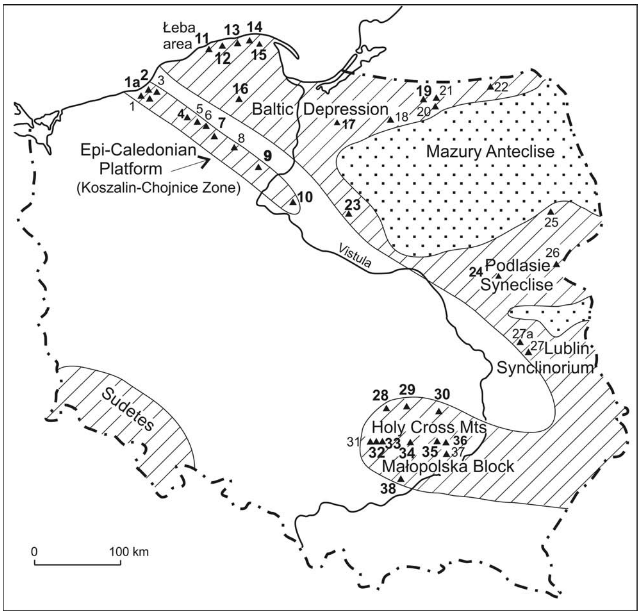


Fig. 1. Location of boreholes and outcrops (1–38): 1 – Jamno IG2, 1a – Jamno IG1, 2 – Skibno 1, 3 – Karsina 1, 4 – Miastko1, 5 – Brda 3, 6 – Nowa Wieś 1, 7 – Nowa Karczma 1, 8 – Chojnice 5, 9 – Polskie Łąki PIG 1, 10 –Toruń 1, 11 – Łeba 8, 12 – Białogóra 1, 13 – Białogóra 2, 14 – Dębki 2, 15 – Piaśnica 2, 16 – Kościerzyna IG 1, 17 – Pasłęk IG 1, 18 – Olsztyn 1, 19 – Sokolica 1, 20 – Łankiejmy IG 1, 21 – Kętrzyn IG 1, 22 – Gołdap IG 1, 23 – Szczawno1, 24 – Żebrak IG 1, 25 – Mielnik IG 1, 26 – Strabla, 27 – Tarkawica 1, 27a – Wierzbica 1, 28 – Wilków IG 1, 29 – Bukowiany IG 1a, 30 – Pobroszyn, 31 – Zbrza trench, 32 – Zbrza 2, 33 – Zbrza 3, 34 – Niestachów, 35 – Bardo Stawy, 36 – Zalesie Nowe and 37 – Szumsko Kolonia 2, 38 – Strożyska 5. The boreholes sampled by author are marked by bold letters

these strata was hitherto based mainly on graptolites, brachiopods and lithological analogy (*e.g.*, Bednarczyk, 1964, 1971b; Podhalańska & Modliński, 2006; Trela, 2006a, b).

Earliest results, precursory on the European scale, were presented by Jagielska (1962). Her work deals with the palynomorphs of the Arenig and Caradoc of the area near Brzeziny and Zbrza in the southern part of the Holy Cross Mountains. The paper includes short descriptions and drawings of the identified specimens. Forms known and now identified in the Upper Caradoc strata of this area can be recognized on the drawings (*e.g.*, micrhystrids, multiplicisphaerids, baltisphaerids and leiosphaerids), but in most cases unequivocal identification of diagnostic taxonomical characteristics is precluded by the small size of the drawings. Obsolete nomenclature presents another difficulty in the use of the paper.

The successive papers on palynology of the Upper Ordovician strata, published already in the 1970s and later, include standard descriptions and precise drawings and photographs of palynomorphs. The quality and size of the illustrations restrict their usefulness for comparisons. The material from these papers is used and described in the chapter dedicated to microphytoplankton in the four geological units described here, in the part dealing with comparisons and in conclusions.

MATERIAL AND METHODS

The Upper Ordovician material that was a subject to palynological studies comes from 40 boreholes and exposures, whose location is shown in Fig. 1. Twenty six of them were studied personally by the author, who collected and analysed 292 palynological samples. The other 14 boreholes studied by Górka in years 1969, 1979, 1980, 1990 (Olsztyn 1, Pasłęk IG 1, Kętrzyn IG 1, Gołdap IG 1, Żebrak IG 1, Strabla, Mielnik IG 1), Szczepanik (2000; Jamno IG 2, Karsina 1, Brda 3, Nowa Wieś 1, Chojnice 5) and Trela & Szczepanik (2009; Zbrza trench Szumsko Kolonia 2) were used for the purpose of palynological comparisons. The boreholes sampled by the present and other authors are marked in Fig. 2. The palynological samples were taken mainly from grey, dark-grey and black claystones and mudstones and from argillaceous intercalations among limestones.

Rock samples were disintegrated applying the standard method (Wood *et al.*, 1996), using acetic, fluoric and fuming nitric acids and heavy liquid (zinc chloride of density *ca.* 2.2g/cm^3). Cover glasses were glued with a glycerine and gelatine jelly or *Elvacite* glue. The total number of slides amounted to 690 (two from each sample, additionally one, two or three from each positive sample, depending on the amount of material). The slides were of the size of a cover glass that is 24 × 24 mm.

Only 73 of the now studied samples (of 291 taken) contained identifiable palynomorphs. Additionally used data came from 20 positives palynological samples described by the author in the last years (Małopolska Block, Holy Cross Mountains–Kielce Fold Zone, Bardo Syncline – 10 samples, Masiak *et al.,* 2003; Holy Cross Mountains–Łysogóry Fold Zone, Pobroszyn – 6 samples, Bednarczyk & Stempień-Sałek, 2010; Niestachów – 4 samples, Stempień, 1990).

Palynomorph frequency has been calculated in a uniform way for all samples (except for Jamno IG1 and Miastko 1). The organic residues obtained after complete dissolution of 5 grams of rock were supplemented to a volume of 4 ml with methyl alcohol. For each slide, 0.5 ml of well-mixed solution were counted. From each sample level, arithmetic mean was calculated from one slide. The number of all palynomorphs determined in one slide is accepted as 100%. This procedure allows for comparison of palynomorph numbers in various slides.

In general, the Upper Ordovician material subject to palynological sampling is scarce and poorly preserved. Only few of the positive samples do include multispecific palynomorph assemblages. Many specimens of acritarchs lack ornamentation.

In those specimens, in which it has been preserved, such elements as the type of contact of appendages with vesiculum, structure of appendages and structure of their terminations – the most important diagnostic features – are obliterated. Because of this state of preservation, acritarch identifications are in most cases given in open nomenclature, which seriously imparts the certainty and precision of stratigraphic interpretation. This does not concern the material from boreholes Strożyska 5 (Nida region, Małopolska

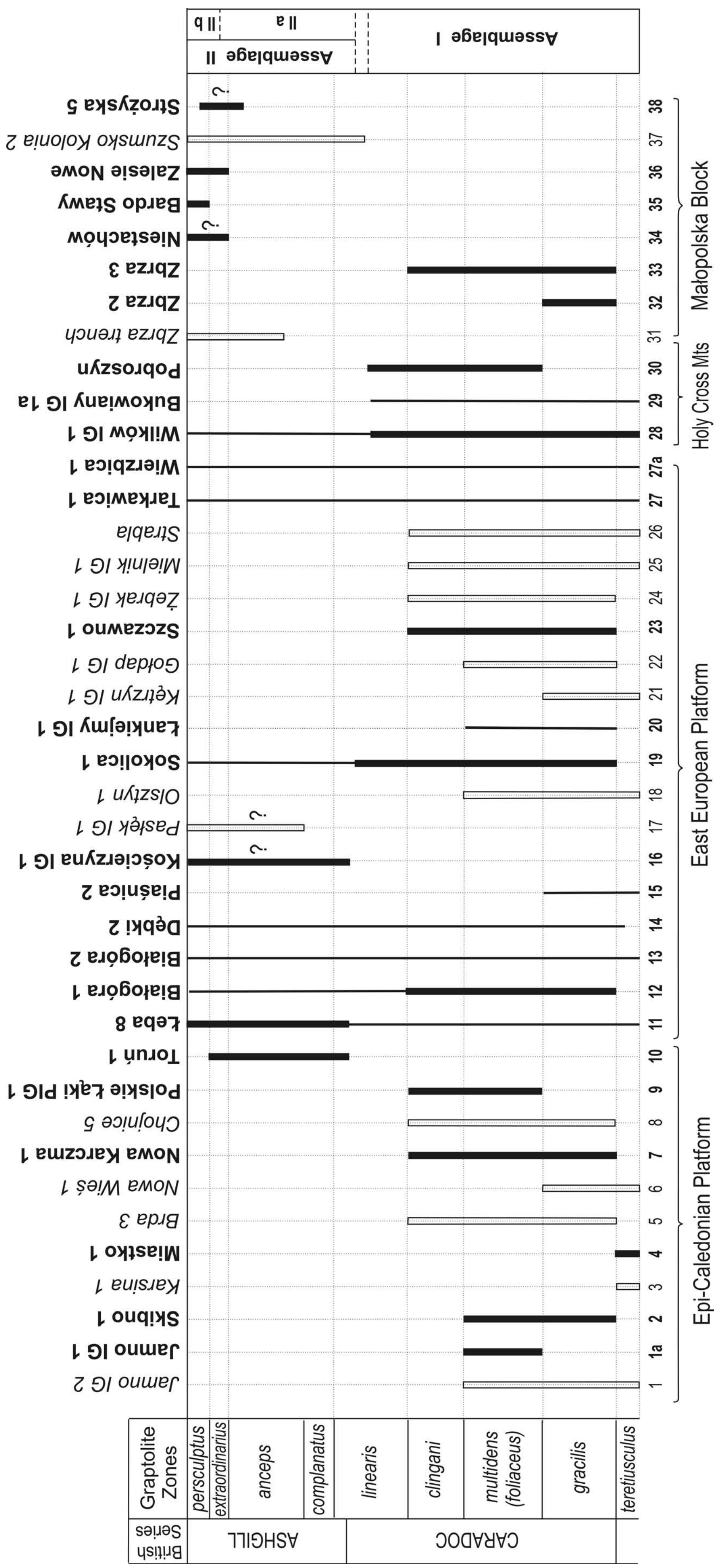


Fig. 2. Correlation scheme of boreholes and outcrops in the Upper Ordovician of northern and central Poland. The boreholes sampled by author are marked by vertical large (positive samples) and fine (negative samples) bars and filled in black and by bold letters; those studied by Górka (1969, 1979, 1980, 1990) and Szczepanik (2000) are marked by empty bars

Block), Miastko 1 and Jamno IG 1 (Koszalin–Chojnice Zone), Sokolica 1 (east part of the Baltic Syneclise) and Zbrza 2 and Zbrza 3 (Małopolska Block, southern part of the Holy Cross Mountains), which is better preserved and more diversified. The Lublin Synclinorium region has not been discussed, as it did not contain any positive palynological samples.

Palynological material from "rich" boreholes and palynological information from the others, provide base for conclusions on stratigraphy, palaeotemperatures and palaeogeography of the Upper Ordovician in Poland.

List of negative samples (together 218 negative samples):

1. Epi-caledonian Platform: borehole Skibno 1 (samples S.1.1, S.1.7 – S.1.9), borehole Nowa Karczma 1 (samples NK.1.1–NK.1.4, NK.1.8, NK.1.11, NK.1.17, NK.1.18).

2. East European Platform: borehole Łeba 8 (samples Łb.11, Łb.13–Łb.23), borehole Białogóra 1 (samples B.1.7, B.1.8, B.1.10, B.1.14, B.19–B.1.23, B.1.28), borehole Białogóra 2 (samples B.2.2–B.2.11), Dębki 2 (samples D.2.1–D.2.11), Piaśnica 2 (samples P.2.7–P.2.10), Kościerzyna IG 1 (samples K.10–K.36), borehole Sokolica 1 (samples So.1–So.1.8, So.1.14), borehole Łankiejmy IG 1 (sample Ła.1), borehole Szczawno1 (samples Sz.1.1–Sz.1.5, Sz.1.8, Sz.1.9, Sz.1.11–Sz.1.13, Sz.1.15, Sz.1.18, Sz.1.23, Sz.1.24), borehole Tarkawica 1 (samples Ta.1.1–Ta.1.13) and Wierzbica 1 (samples Wie.1.1–Wie1.12).

3. Holy Cross Mountains: borehole Wilków IG 1 (samples W.1.1 – W.1.17, W.1.27 – W.1 32, W.1.34 – W.1.39, W.1.41), borehole Bukowiany IG 1a (samples Bu.1.1 – Bu.1.46).

4. Małopolska Block: Zalesie Nowe (samples Z.1,2, Z.5), Bardo Stawy (sample BS.1), borehole Strożyska 5 (samples St.5.1, St.5.4).

The palynological samples are stored in the Institute of Geological Sciences, Polish Academy of Sciences (ING PAN) in Warsaw.

GEOLOGICAL SETTING

Epi-Caledonian Platform (Koszalin–Chojnice Zone)

The Koszalin–Chojnice Zone lies SW from the margin of the Precambrian East European Platform (Fig. 1). The Palaeozoic sedimentary cover includes Ordovician sediments identified in many boreholes, drilled mainly in the 1960s and 1970s (Tomczyk, 1968; Modliński, 1968, 1978, 1987; Bednarczyk, 1974; Dadlez, 1978, 1982a, b, 1993, 2000).

The crystalline basement of the Ordovician strata in the Koszalin–Chojnice Zone is supposed to be an Early Palaeozoic terrane derived from Gondwana, described as Eastern Avalonia (Tait *et al.*, 1997; Pharaoh, 1999; Jaworowski, 2000; Samuelsson *et al.*, 2002). The Lower Palaeozoic displays some similarities to the fragments of the Caledonian belt of Europe known, among others, from boreholes in Rügen (Servais & Katzung, 1993; Franke, 1994; Servais, 1994; Dadlez, 2000; Jaworowski, 2000; Podhalańska & Modliński, 2006).

The Upper Ordovician sediments together with the Silurian ones form the older Palaeozoic sequence. This sequence, composed mainly of shales (dark-grey and grey clayey-muddy sediments with scarce sandy, dolomitic and sideritic intercalations; *e.g.*, Krzemiński & Poprawa, 2006) and intensely folded, is overlain with an angular unconformity by the younger Palaeozoic sequence. The thickness of the strata above the Ordovician attains locally 4,000 m.

The Upper Ordovician in the Koszalin–Chojnice Zone is documented with graptolites of the *teretiusculus - gracilis, multidens* Zone and *clingani* Zone (Podhalańska & Modliński, 2006). Other groups of fossils, such as fragments of brachiopods and trilobites, chitinozoans and various trace fossils, occur sporadically (Bednarczyk, 1974; Wrona *et al.*, 2001; Podhalańska, 2007). Proposals of formal division were presented after Bednarczyk (1974), partly modified and supplemented by Podhalańska and Modliński (2006; Fig. 4). Correlation with global scheme is shown in Fig. 3.

East European Platform

Palynological material derived from the SW part of the East European Platform comes from the Peribaltic Syneclise (western and eastern parts of the Peribaltic Syneclise, western slope of the Mazury Anteclise and Podlasie Syneclise). The Precambrian basement is built up by the Lower Palaeozoic, Mesozoic and Tertiary sediments and belonged to the Baltic palaeo-basin in Ordovician time (Pokorski & Modliński, 2007). Ordovician sediments have been reached only by boreholes.

The Upper Ordovician in the East European Platform is developed generally as shaly glauconitic, shaly-calcareous, calcareous and calcareous-dolomitic deposits, though facies differ between the western and eastern parts. The lithological descriptions of certain borehole sections are to be found *e.g.* in Tomczyk (1962), Tomczykowa (1964), Bednarczyk (1968, 1971a, 1996a, 1998, 1999a), Bednarczyk *et al.* (1996), Podhalańska (1980, 1999, 2003a, b, c), Przybyłowicz (1980), Modliński and Szymański (1997) and Modliński and Szymański (2008). The Upper Ordovician sediments are overlain, also with sedimentary continuity, by graptolite shales of the lowermost Silurian. Proposals of formal lithostratigraphic division for the western part of the Peribaltic Syneclise were presented after Modliński and Szymański, (1997; Fig. 5), and for the eastern part – after Modliński and Szymański (1997) and Bednarczyk (1999; Fig. 6).

Some of these rocks yielded abundant marine faunas, such as: graptolites (Podhalańska, 1980; Podhalańska & Modliński, 2006), trilobites and inarticulate brachiopods (Bednarczyk, 1968; Modliński, 1988), ostracods, conodonts (Nehring, 1969; Bednarczyk, 1998), and *Hirnantia* fauna (Podhalańska, 1980, 1999, 2003b). The sediments are documented with graptolites of the *teretiusculus - persculptus* graptolite zones. Proposals of formal biostratigraphic division for the western part were presented partly after Podhalańska (1980, 1999) and Podhalańska and Modliński (2006), and for the eastern part after Bednarczyk (1999a).

The total thickness of the Upper Ordovician sediments in the Polish part of the East European Platform varies from

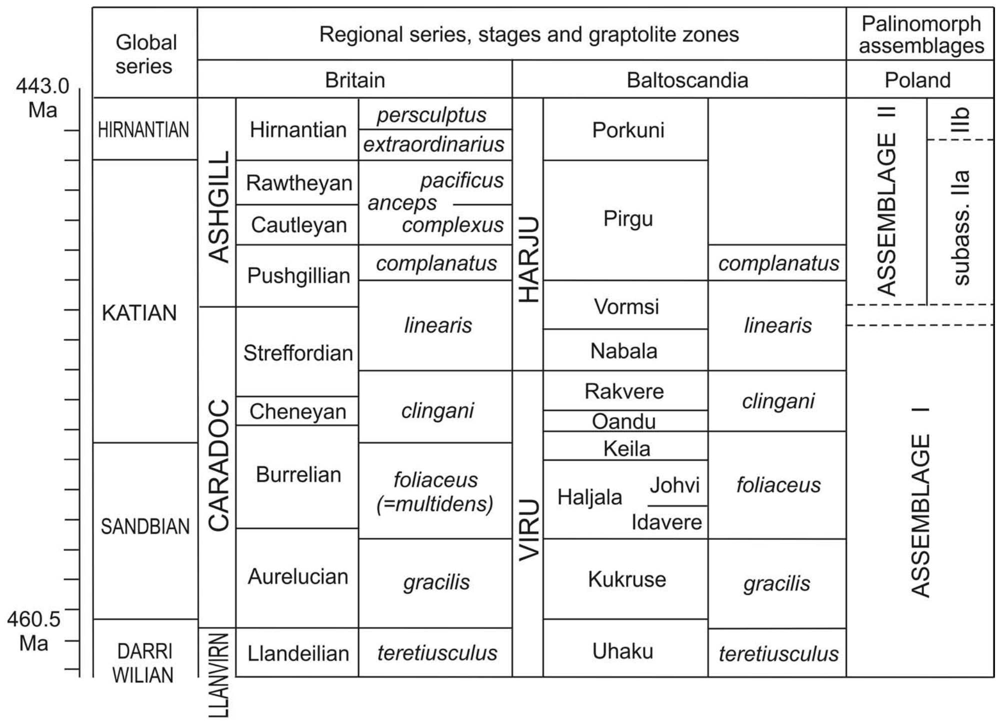


Fig. 3. Upper Ordovician global and regional series and stages, British and Baltoscandian graptolite zones (according to Cooper & Sadler, 2004; Webby *et al.*, 2004; Podhalańska & Modliński, 2006, and Modliński & Szymański, 2008)

12 to 1,200 m. A palaeothickness map of the Middle-Upper Ordovician deposits is shown in Modliński *et al.* (1999).

Two parallel bio- and chronostratigraphic schemes are used for the Upper Ordovician sequences of the Baltic Basin, because of the facies variation (graptolite claystone facies in the western part of the East European Platform and mainly carbonate facies in the eastern part of the platform). These are the classic British scheme, based on succession of planktonic graptolites, and the Baltoscandian scheme based on succession of trilobites and brachiopods in the sections of Estonia and central Sweden (*e.g.*, Männil, 1966). Correlation with the global scheme is shown in Fig. 3.

Holy Cross Mountains

The division of the Holy Cross Mountains into two regions with different geological history (the northern one – Łysogóry Fold Zone and the southern region – Kielce Fold Zone) had already been introduced by Czarnocki (1919, 1928, 1950) and Tomczyk and Turnau-Morawska (1967). Authors of more recent works on the Upper Ordovician strata (Bednarczyk, 1981; Lewandowski, 1993; Dzik & Pisera, 1994; Modliński & Szymański, 2001; Narkiewicz, 2001; Trela, 2006a) also use a two-fold division (Fig. 8) into a fairly uniform northern region (Łysogóry Fold Zone) and a more differentiated southern region (Kielce Fold Zone). The southern region (Kielce Fold Zone) constitutes a part of the Małopolska Block (Pożaryski, 1991).

Various divisions, often traditional, are still used for the Ordovician of the Holy Cross Mountains. They often do not fully conform to the rules adopted in the *Rules of Polish Stratigraphical Classification, Terminology and Nomenclature* (Alexandrowicz *et al.*, 1975) and the Polish Stratigraphical Code (Racki & Narkiewicz, 2006).

Holy Cross Mountains–Łysogóry Fold Zone (Łysogóry Region)

The Ordovician sediments in the Łysogóry Fold Zone have been reached by boreholes and by outcrops. The Upper Ordovician deposits in this region are developed mainly as limestones, marly limestones, marls, grey and dark-grey claystones, siltstones, grey-green marly mudstones and sandstones (Fig. 9). Proposals of formal division were presented among others by Bednarczyk (1996b) and Trela (2006a).

Some of these rocks yielded abundant marine faunas, such as graptolites (*e.g.*, Tomczyk, 1957; Tomczykowa, 1968), inarticulate brachiopods (Bednarczyk, 1981) and trilobites (Tomczykowa, 1968; Tomczykowa & Tomczyk, 2000).

The Ordovician sediments from the Łysogóry region are documented with graptolites of the *teretiusculus, gracilis* and *multidens* + *clingani* graptolite zones. Proposals of formal biostratigraphic division were presented by Bednarczyk (1971b).

Małopolska Block

The Małopolska Block lies between the East European Platform, Carpathian Foredeep, and the Kraków–Silesia Monocline. Palynological material derived from the Małopolska Block comes from the Holy Cross Mountains (Kielce Fold Zone; Kielce Region) and from the Nida region). Tectonic position and evolution of the Małopolska

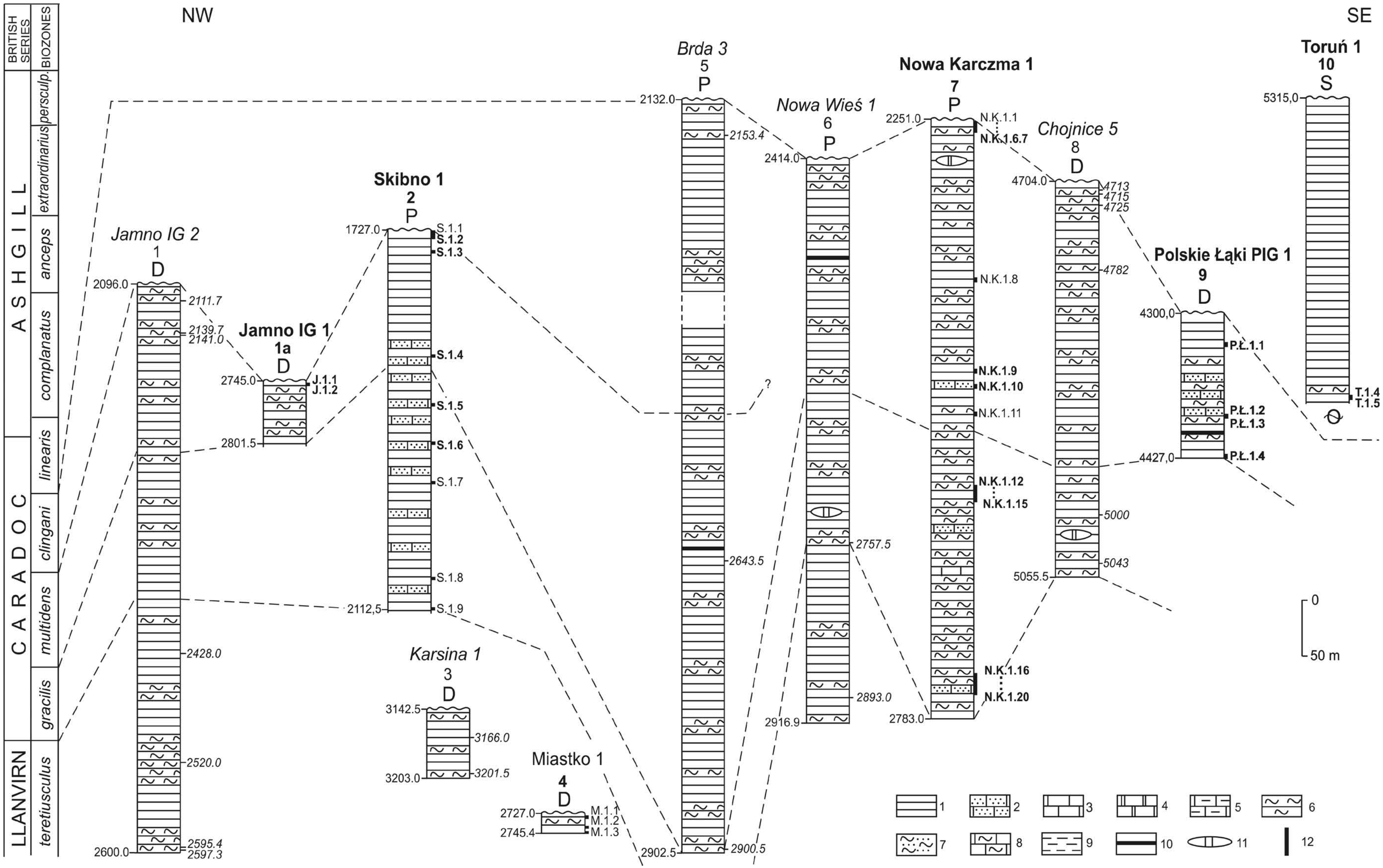


Fig. 4. Simplified lithostratigraphic sections and correlation scheme of the Upper Ordovician sediments from the epi-Caledonian Platform (Koszalin–Chojnice Zone). The British stratigraphic division after Fortey *et al.*, 1995; biostratigraphy partly after Bednarczyk (1974), modified and supplemented by Podhalańska and Modliński (2006). The samples from sections studied by the author are marked with symbols in individual figures, *e.g.*, S.1.3 (written in bold if sample is positive). In the other sections (samples studied by Górka, 1969, 1979, 1980, 1990 and Szczepanik, 2000), the sample locations are marked by the depth value of each location, written in italics, *e.g.*, *3166.5*. *1* – claystones, *2* – sandstones, *3* – limestones, *4* – dolomites, *5* – marly limestones, *6* – mudstones, *7* – sandy mudstones, *8* – marly mudstones, *9* – marly claystones, *10* – bentonites, *11* – sideritic-dolomitic lenses, *12* – sampled interwal, ε – Cambrian, θ – Ordovician, S – Silurian, D – Devonian, P – Permian, Q – Quaternary Period. The positive samples described by the author are marked by bold letters

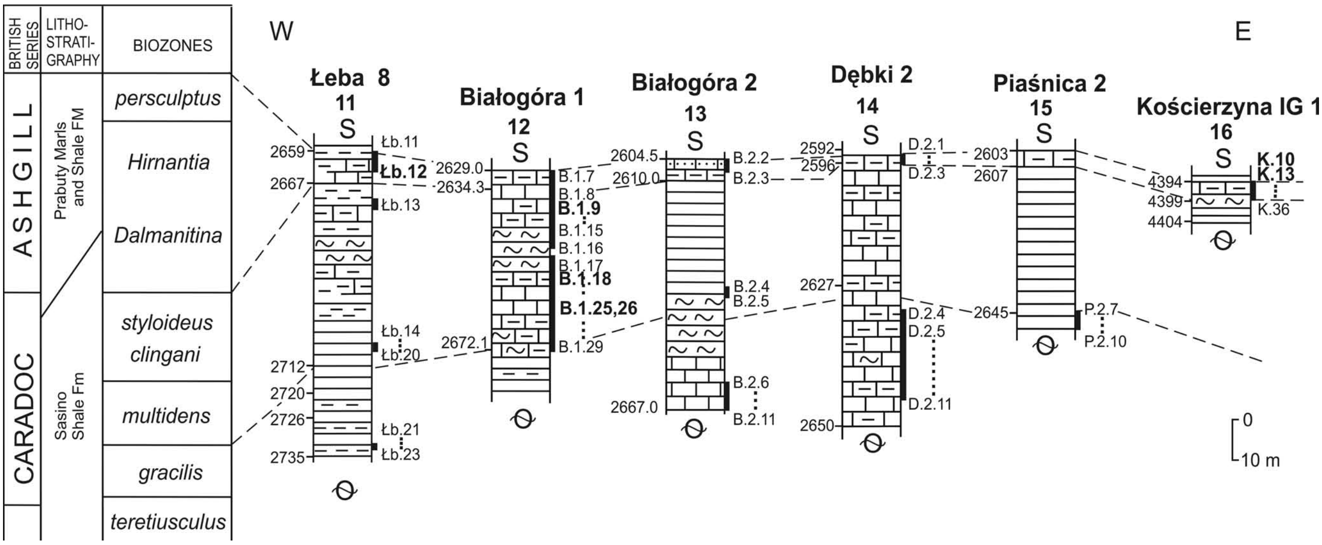


Fig. 5. Simplified lithostratigraphic sections and correlation scheme of the Upper Ordovician sediments from the western part of the Peribaltic Syneclise (Łeba area). Biostratigraphy partly after Podhalańska (1980, 1999). Lithostratigraphy after Modliński & Szymański (1997), biostratigraphy after Bednarczyk (1998, 1999a) and Podhalańska (1999). For explanations of lithostratigraphic symbols – see Fig. 4

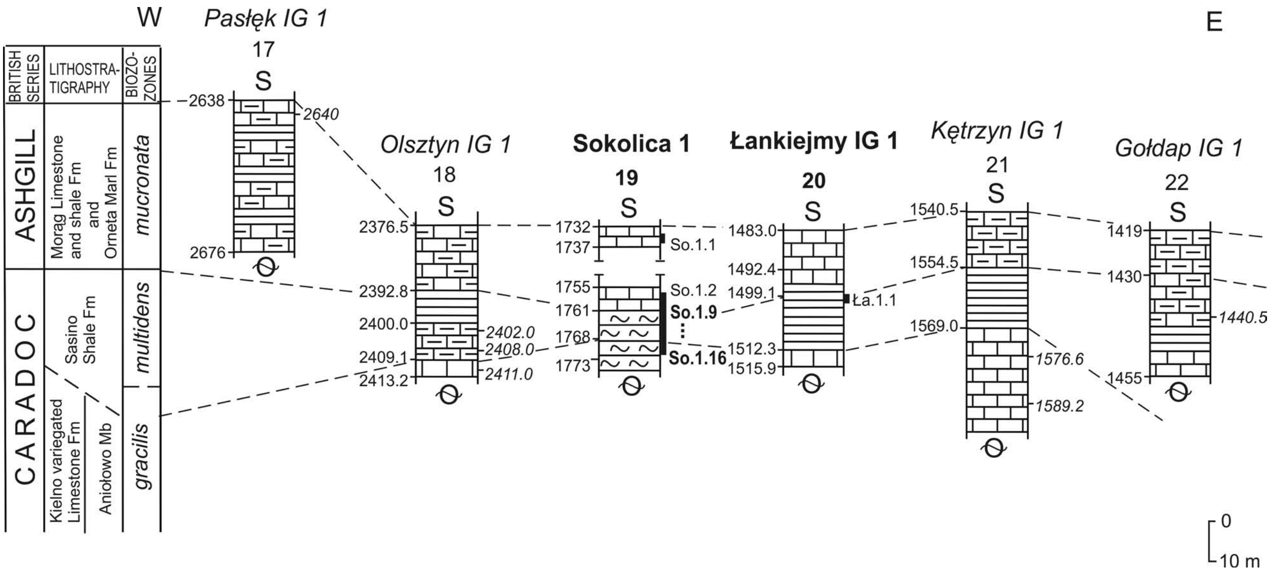


Fig. 6. Simplified lithostratigraphic sections and correlation scheme of the Upper Ordovician sediments from the eastern part of the Peribaltic Syneclise after Modliński and Szymański (1997) and Bednarczyk (1999b), biostratigraphy according to Bednarczyk (1999a). For explanations of lithostratigraphic symbols – see Fig. 4

Block with the Kielce Fold Zone were presented by Lewandowski (1993), Stupnicka *et al.*(1998), Dadlez *et al.* (1994), and Cocks and Torsvik (2005).

Holy Cross Mountains–Kielce Fold Zone (Kielce Region)

The Kielce Fold Zone is usually divided into three areas because of the facies variability: the western (Zbrza Anticline, Brzeziny, Mójcza), central (Bardo Syncline) and eastern (Międzygórz, Lenarczyce) areas. The facies contrasts in the Kielce Region, related to tectonic activity and variable subsidence rate, were presented in detail by Trela (2005a, b).

The Upper Ordovician from the western area – the Zbrza Anticline – begins with graptolite shales and claystones that directly overlie the Cambrian strata (Deczkowski & Tomczyk, 1969). The claystones are overlain by Ashgill greyish-yellow calcareous mudstones. The Silurian deposits overlie these sediments (Trela *et al.*, 2006).

In the central area, the Upper Ordovician (Ashgill) strata are developed as marly shales with bentonites (Chlebowski, 1971; Przybyłowicz & Stupnicka, 1991) and very fine-grained sandstones and claystones (Bednarczyk, 1981; Masiak et *al.*, 2003; Trela, 2005a; Trela & Szczepanik, 2009).

The sediments are documented with graptolites of the *gracilis - multidens + clingani* graptolite zones (Tomczyk & Turnau-Morawska, 1964; Deczkowski & Tomczyk, 1969; Trela, 2005a) and by graptolites of genera *Normalograptus* and *Glyptograptus* (Kremer, 2001). Trilobites (Kie-

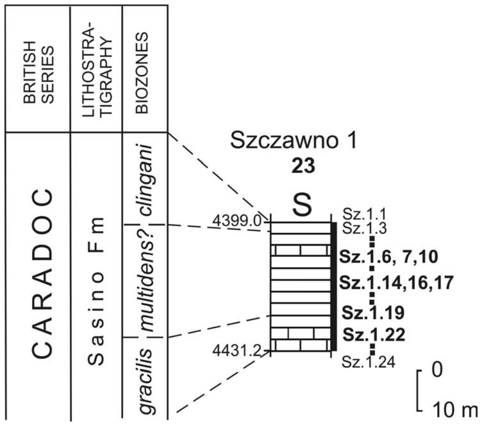


Fig. 7. Simplified lithostratigraphic section from the Płock – Warsaw Trough (borehole Szczawno 1). Lithostratigraphy after Modliński and Szymański (2008). Biostratigraphy according to Bednarczyk (1971c). For explanations of lithostratigraphic symbols – see Fig. 4

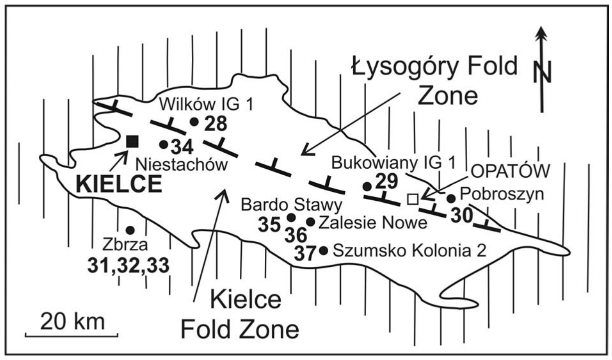


Fig. 8. Division of the Holy Cross Mts. and location of boreholes and outcrops with the Upper Ordovician deposits

lan, 1956, 1960), conodonts (Dzik, 1999) and brachiopod fauna of *Hirnantia* type (Temple, 1965; Bednarczyk, 1981) were found in the Bardo Syncline, in the so-called *Dalmanitina* beds. Proposals of formal biostratigraphic division were presented by Deczkowski and Tomczyk (1969; Fig. 10).

Nida Region

The basement of the Mesozoic rocks of the central part of the Nida region is known from twelve deep boreholes drilled by the Polish Geological Institute and Enterprise for Petroleum Prospection, Kraków, in years 1965–1970. Only three boreholes did reach Ordovician strata. The total thickness of the Ordovician deposits equals *ca.* 140 m. These sediments are mostly sandstones, limestones and mudstones (Jurkiewicz, 1975, 1991; Modliński & Szymański, 2001)

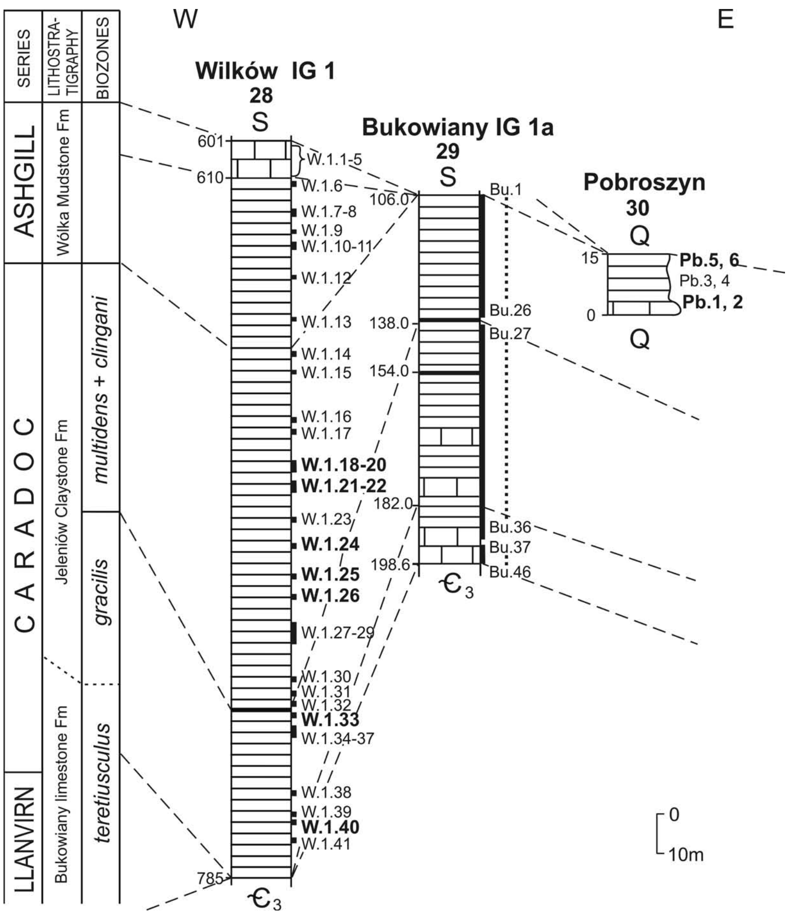


Fig. 9. Simplified lithostratigraphic sections and correlation scheme of the Upper Ordovician from the Holy Cross Mts. (Łysogóry Fold Zone). Lithostratigraphy after Trela (2006a), biostratigraphy after Bednarczyk (1971b). For explanations of lithostratigraphic symbols – see Fig. 4

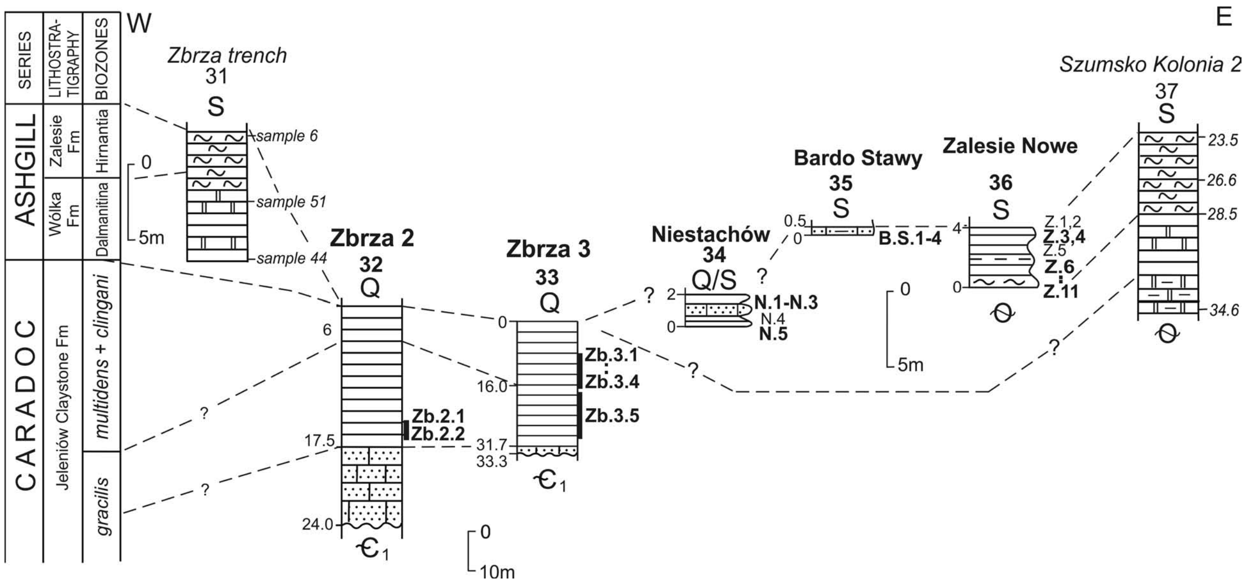


Fig. 10. Simplified lithostratigraphic sections and correlation scheme of the Upper Ordovician from the Holy Cross Mts. (Kielce Fold Zone). Lithostratigraphy and biostratigraphy after Deczkowski and Tomczyk (1969), Trela (2006a) and Trela and Szczepanik (2009). For explanations of lithostratigraphic symbols – see Fig. 4

with predominance of limestones in borehole Strożyska 5 (Fig. 11). The lithological descriptions of this borehole section are to be found in Tomczyk (1963), Bednarczyk *et al.* (1968), and Modliński and Szymański (2001). Ordovician strata in this region are covered with Palaeozoic and Mesozoic sediments.

The limestones penetrated in borehole Strożyska 5 provided numerous brachiopods (*Hirnantia* fauna) and conodonts. Proposals of division were presented by Bednarczyk *et al.* (1968).

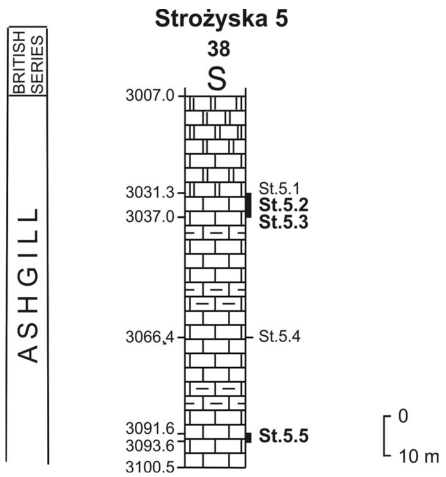


Fig. 11. Simplified lithostratigraphic section from the Nida Region (borehole Strożyska 5). Lithostratigraphy and biostratigraphy after Bednarczyk *et al.* (1968). For explanations of lithostratigraphic symbols – see Fig. 4

PALYNOLOGICAL CHARACTERISTIC OF OBTAINED MATERIAL

Epi-Caledonian Platform

Jamno IG 1

Two samples from borehole Jamno IG 1 (J.1.1 and J.1.2) were taken for palynological studies (Fig. 4). Both display similar species composition and belong to *multidens* graptolite Zone. Long-ranging small forms, up to 40 µm in diameter, in type of *Goniosphaeridium*, *Micrhystridium*, *Multiplicisphaeridium*, *Polygonium*, and *Veryhachium*, prevail among the identified specimens. They are accompanied by much less numerous various baltisphaerids and orthosphaerids with vesiculum diameters of *ca.* 50–70 µm and large appendages, broad at base (Table 1). The highest frequency, up to one hundred identifiable specimens per slide, was recorded in sample J.1.2 (Fig. 12).

The described palynomorph assemblage is usually well preserved and diversified.

Skibno 1

Nine samples were taken for palynological studies from borehole Skibno 1, (Wrona *et al.*, 2001). Five of them proved palynologically positive (Fig. 4).

Samples S.1.3–S.1.6 provided a poor assemblage of damaged long-ranging palynomorphs. They include only single goniosphaerids, multiplicisphaerids, micrhystrids, solisphaerids and veryhachiids, as well as sporadic baltisphaerids.

A rich, well preserved assemblage was found in only one sample – S.1.2. (*multidens* zone; Wrona *et al.*, 2001: see fig. 2, pl. 5, 6). The identified palynomorphs included quite numerous long-ranging small acanthomorphs, up to *ca.* 35 µm in diameter, from genera *Goniosphaeridium*, *Gorgoniosphaeridium*, *Multiplicisphaeridium*, *Micrhystridium*, *Solisphaeridium*, and *Veryhachium*. They are accompanied by an admixture of forms from genera *Baltisphaeridium*, *Ordovicidium*, *Peteinosphaeridium* with diameters *ca.* 65 µm and large thick appendages, and by single, possibly re-

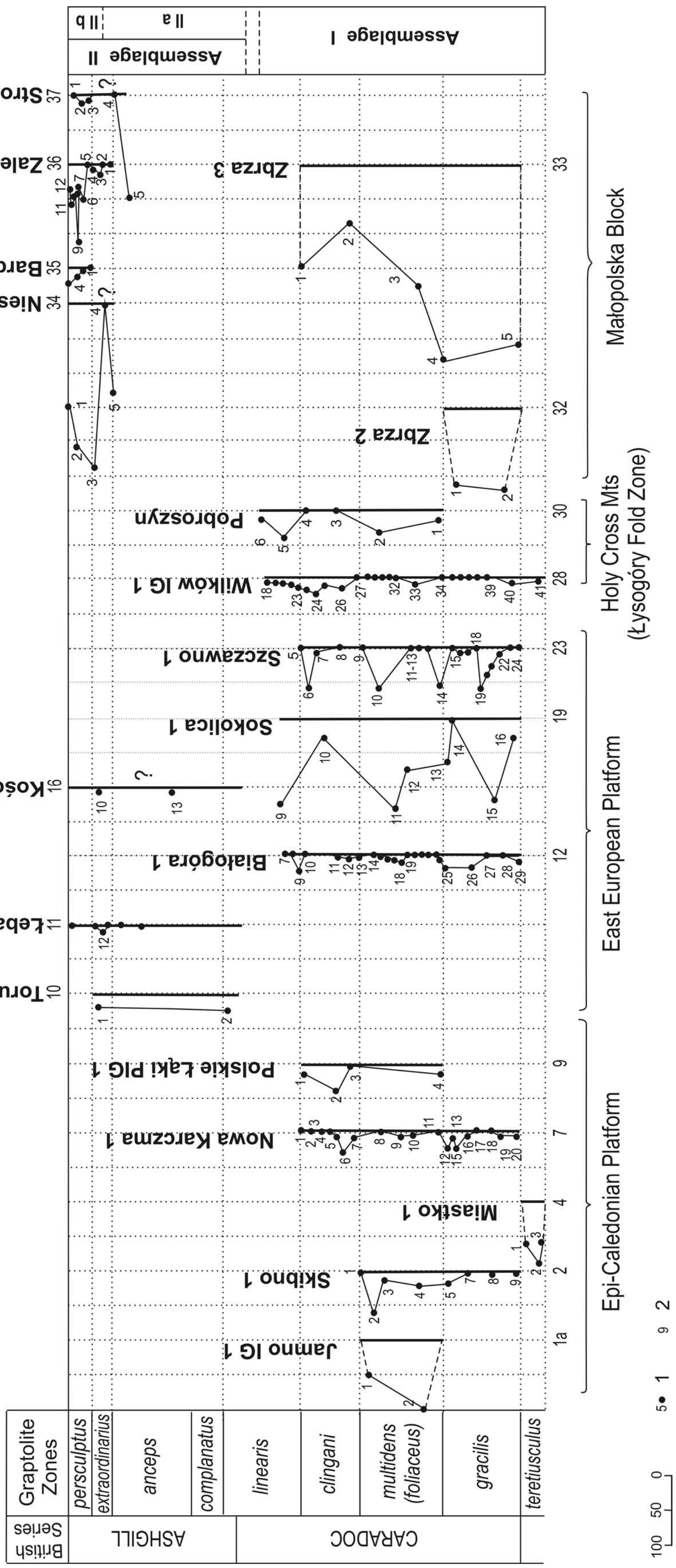


Fig. 12. Simplified palynomorph frequencies in the studied boreholes. *1* – number of the palynomorphs in sample, *2* – number of sample

Table 1

Palynomorphs from the epi-Caledonian Platform

	Miastko 1			Jamno IG 1	
Sample No / depth (m)	M.1.1 2730.0	M.1.2 2733.0	M.1.3 2740.0	J.1.1 2746.0	J.1.2 2747.0
Graptolite zone	*teretiusculus*			*multidens*	
Phytoplankton Assemblage	Assemblages I				
Baltisphaeridium calcispinae	+	+		+	+
Baltisphaeridium lancetispinae			+	+	+
Baltisphaeridium dasos				+	
Baltisphaeridium longispinosum				+	
Baltisphaeridium plicatispinae				+	+
Baltisphaeridium cf. *calcispinae*					+
Baltisphaeridium sp.	+	+	+	+	+
Dorsenidium cf. *undosum*		+			
?Frankea cf. *sartbernardensis*		+			
Goniosphaeridium connectum	+	+	+		+
Goniosphaeridium sp.	+	+	+	+	+
Kryptospory		+		+	
Leiofusa cf. fusiformis		+			
Leiosphaeridia	+	+	+	+	+
Liliosphaeridium cf. *kaljoi*		+			
Lophoshaeridium sylvanium		+			
Multiplicisphaeridium bifurcatum	+	+			+
Multiplicisphaeridium cf. *irregulare*	+	+	+	+	
Multiplicisphaeridium sp.	+	+	+	+	+
Micrhystridium stellatum		+	+		
Micrhystridium sp.		+	+		+
Navifusa sp.	+	+	+		
Ordovicidium elegantulum	+	+			
Ordovicidium nudum		+			
Ordovicidium sp.	+	+		+	
Orthosphaeridium cf. *insculptum*			+	+	+
Orthosphaeridium sp.					+
Peteinosphaeridium velatum		+			
Peteinosphaeridium cf. *trifurcatum*					+
Polygonium gracile	+	+	+	+	+
Polygonium cf. *gracile*				+	+
Polygonium sp.	+	+			+
Solisphaeridium sp.	+	+			
Veryhachium europeanum	+		+	+	+
Veryhachium lairdi	+	+			+
Veryhachium trispinosum	+	+	+	+	+
Villosacapsula cf. *irrorata*		+			
Villosacapsula sp.				+	+

Table 2

Palynomorphs from the epi-Caledonian Platform

	Skibno 1				
	S.1.2 1727.5	S.1.3 1732.0	S.1.4 1746.0	S.1.5 1839.4	S.1.6 1913.0
Graptolite zone	*multidens*			*gracilis*	
Phytoplankton Assemblage	Assemblage I				
Actinotodissus crassus	+				
Baltisphaeridium cf. *calcispinae*	+	+	+		
Baltisphaeridium sp.	+	+	+		
Goniosphaeridium splendens	+		+		
Goniosphaeridium sp.	+	+	+		+
Leiosphaeridia	+	+		+	
Multiplicisphaeridium cf. *bifurcatum*	+		+		
Multiplicisphaeridium cf. *irregulare*	+	+			
Multiplicisphaeridium sp.	+			+	+
Micrhystridium cf. *stellatum*	+	+	+		
Micrhystridium sp.	+	+	+	+	+
Ordovicidium elegantulum	+				
Ordovicidium heteromorphicum	+				
Ordovicidium nanofurcatum	+				
Ordovicidium nudum	+				
Ordovicidium sp.	+	+		+	+
Solisphaeridium sp.	+		+		+
Veryhachium reductum	+				
Veryhachium europeanum	+		+		
Veryhachium lairdi	+				
Veryhachium trispinosum	+	+		+	+
Veryhachium sp.	+	+	+		+

deposited, specimens of genus *Actinotodissus* (Table 2). This sample also featured the highest frequency of 60 identifiable specimens per slide (Fig. 12) and no diversity. Most specimens are fairly well preserved.

Miastko 1

Three samples for palynological investigation were taken from borehole Miastko1 (M.1.1–M.1.3; Fig. 4). All the samples proved palynologically positive and they include the same palynomorph assemblage. Mainly long-ranging small forms (diameters oscillate between 15 and 45 µm) of genera *Goniosphaeridium*, *Micrhystridium*, *Polygonium* and *Veryhachium* have been identified (Table 1), single index forms, with large diameters (60–80 µm) and equally large appendages, belonging to genera *Baltisphaeridium*, *Ordovicidium* and *Orthosphaeridium* (Stempień-Sałek, 2006). Frequency in sample M.1.1 and M.1.3 equals 60 identifiable forms per slide; in sample M.1.2 it attains 80 (Fig. 12).

Table 3

Palynomorphs from the epi-Caledonian Platform

	Nowa Karczma 1								
Sample No / depth (m)	NK.1.5 2260.0	NK.1.6 2262.0	NK.1.7 2263.0	NK.1.9 2475.5	NK.1.10 2488.0	NK.1.12 NK.1.1 32576.0 - 2578.0	NK.1.14 NK.1.15 2578.0 - 2589.0	NK.1.16 NK.1.19 2742.0 2755.0	NK.1.20 2761.7
Graptolite zone	*multidens + clingani*					*gracilis*			
Phytoplankton Assemblage	Assemblage I								
Baltisphaeridium cf. *calicispinae*				+					
Baltisphaeridium cf. *plicatispinae*			+						
Baltisphaeridium sp.			+	+					+
Cryptospores				+	+	+			
Goniosphaeridium cf. *polygonale*			+						
Goniosphaeridium sp.		+	+			+			
Micrhystridium stellatum	+	+				+	+		
Micrhystridium sp.		+				+		+	+
Multiplicisphaeridium bifurcatum	+	+	+	+		+			
Multiplicisphaeridium cf. *irregulare*		+				+			
Multiplicisphaeridium sp.		+	+	+		+		+	+
Leiosphaeridia	+	+		+			+	+	
Ordovicidium cf. *elegantulum*				+					
Ordovicidium cf. *nudum*				+					
Ordovicidium sp.				+					
Peteinosphaeridium sp.				+					
Polygonium gracilis		+				+			
Veryhachium lairdi		+		+					
Veryhachium trispinosum				+				+	
Veryhachium sp.	+						+		+

Nowa Karczma 1

Twenty samples were taken for palynological studies from borehole Nowa Karczma 1 (NK.1.1–NK.1.20; Fig. 4). Twelve of them proved palynologically positive. Only few of the positive samples (NK.1.9, NK.1.12, NK.1.13, NK.1.15) contain multispecific palynomorph assemblages (Table 3). Assemblages in all samples are similar in composition and they include representatives of the following groups present in greater numbers: micrhystrids, multiplicisphaerids, veryhachiids (15–45 μm) leiosphaerids and ordovicids (*ca.* 60 μm). Baltisphaerids occur only sporadically. Additionally, samples NK.1.10, NK.1.12, NK.1.13 and NK.15 include single brown cryptospores. The frequency of specimens is low (Fig. 12), from 3 (samples NK.1.5 and NK.1.7) to about 30 specimens per slide (samples NK.1.6, NK.1.12 and NK.1.15).

Polskie Łąki PIG 1

The material for palynological studies from borehole Polskie Łąki PIG 1 comes from four samples (Fig. 4). All samples proved palynologically positive, though palynological material in the slides is poor, both in quantity and quality (Stempień-Sałek, 2007; fig. 4). All samples include the same palynomorph assemblage, best represented in sample P.Ł.1.2. The assemblage consists mainly of small form (diameters up to *ca.* 40 μm) belonging to genera *Goniosphaeridim*, *Micrhystridium*, *Multiplcisphaeridium*, *Solisphaeridium*, and greater ones (diameters *ca.* 60 μm), belonging to baltisphaerids, ordovicids and leiosphaerids (Table 4). Sample P.Ł.1.2 has the greatest frequency of palynomorphs, up to 40 specimens per slide.

Toruń 1

Two samples were taken for palynological studies from the Upper Ordovician strata in borehole Toruń 1 (T.1.4 and T.1.5; Fig. 4) from sediments with poor palaeontological evidence (Tomczyk, 1980; Podhalańska & Modliński, 2006). Both samples were positive, though material in them displays a high degradation and a low species diversity. Both have similar species composition and similar frequency of *ca.* 20 identifiable specimens per slide (Fig. 12). Prevailing are forms of *Goniosphaeridium*, *Multiplicisphaeridium*, and *Micrhystridium* types (Table 5), with vesiculum diameters up to 40 μm. Samples contain single specimens of *Baltisphaeridum* cf. *heizelin* and small *Baltisphaeridum* sp.

Table 4

Palynomorphs from the epi-Caledonian Platform

	Polskie Łąki PIG1			
Sample No / depth (m)	PŁ.1.1 4327.5	PŁ.1.2 4390.5	PŁ.1.3 4391.5	PŁ.1.4 4426.5
Graptolite zone	*clingani*			
Phytoplankton Assemblage	Assemblage I			
Baltisphaeridium cf. *calicispinae*		+		
Baltisphaeridium sp.	+	+	+	
Goniosphaeridium sp.		+	+	+
Multiplicisphaeridium cf. *bifurcatum*		+		
Multiplicisphaeridium sp.			+	
Navifusa sp.	+			
Micrhystridium cf. *stellatum*		+		
Micrhystridium sp.	+	+		+
Ordovicidium cf. *nannofurcatum*		+		
Ordovicidium sp.	+			
Orthosphaeridium sp.			+	
Leiosphaeridium sp.		+		+
Solisphaeridium sp.	+		+	+
Veryhachium sp.		+		
Vulcanisphaera sp.				+

Table 5

Palynomorphs from the epi-Caledonian Platform

	Toruń 1	
Sample No / depth (m)	T.1.4 5583.0	T.1.5 5584.0
	Ashgill	
Phytoplankton Assemblage	Assemblage IIa	
Baltisphaeridium cf. *heizelinii*	+	
Cymatiosphaera sp.	+	+
Goniosphaeridium sp.	+	+
Multiplicisphaeridium cf. *bifurcatum*	+	
Multiplicisphaeridium cf. *irregulare*	+	+
Multiplicisphaeridium sp.	+	+
Micrhystridium cf. *stellatum*		+
Micrhystridium sp.	+	+
Pachysphaeridium sp.	+	
Veryhachium sp.	+	+
Villosacapsula sp.	+	+

Table 6

Palynomorphs from the East European Platform

	Białogóra 1			Łeba 8	Koś-cie-rzyna IG 1
Sample No / depth (m)	B.1.9 2630.0	B.1.25 2664.7	B.1.26 2665.5	Ł.1.2 2660.0	K.10 4393.9 K.13 4394.2
Graptolite zone	*gracilis - clingani*			Ashgill	Ashgill
Phytoplankton Assemblage	Assemblage I			Ass. IIa	Ass. II
Baltisphaeridium sp.	+	+	+		+?
Goniosphaeridium sp.	+	+	+		
Leiosphaeridia	+	+	+		
Multiplicisphaeridium cf. *bifurcatum*	+				
Multiplicisphaeridium cf. *irregulare*	+				
Multiplicisphaeridium sp.	+		+		
Micrhystridium cf. *stellatum*	+				
Micrhystridium sp.	+	+	+	+	+
Ordovicidium sp.	+	+	+		
Orthosphaeridium sp.	+	+	+		
Polygonium cf. *gracile*	+				
Solisphaeridium sp.	+			+	+
Veryhachium trispinosum	+				
Veryhachium sp.	+			+	

East European Platform

Łeba 8

Thirteen samples have been collected for palynological studies from borehole Łeba 8, but only one of them (sample Ł.12 from the Ashgill) proved palynologically positive (Fig. 5). This sample is dated on the grounds of the *Hirnantia* fauna. It includes, however, damaged black acritarchs (up to six per slide). Some of them resemble in outline *Micrhystridium*, *Solisphaeridium* and *Veryhachium* forms.

Białogóra 1

Palynological study of borehole Białogóra 1 was done on 23 samples (Fig. 5). Three of them (B.1.9, B.1.25 and B.1.26; Table 6) proved palynologically fairly well documented (more than 5 palynomorphs per slide; Fig. 12). The other samples contain remains of single hardly identifiable palynomorphs (B.1.11, B.1.12, B.1.13, B.15–18, B.1.24 and B.1.29). Sample B.1.9 from the boundary zone between the Ashgill and Caradoc includes baltisphaerids, goniosphaerids, multiplicisphaerids (diameters 25–45 µm, *ca.* 60% of the palynomorph assemblage), and orthosphaerids (Table 6).

Veryhachiids occur only sporadically (only two specimens were identified). This is the best preserved phytoplankton assemblage in the whole section. The assemblage in samples B.1.25 and B.1.26 is similar in composition to that in sample B.1.9. The difference consists in slightly greater frequency of the forms of *Baltisphaeridium* and *Ordovicidium* types with large diameters (60–75 µm) and large appendages, as well as in the lower frequency of small acanthomorphs (diameters 18–35 µm), such as *Multiplicisphaeridium* and *Goniosphaeridium* in the samples from greater depth (*ca.* 40%). Frequency varies from 3 (samples B.1.11) to 25 (sample B.1.9) specimens (Fig. 12).

Table 7

Palynomorphs from the East European Platform

	Sokolica 1						
Sample No / depth (m)	So.1.9 1761.0-1762.0	So.1.10 1762.01763.0	So.1.11 1763.0-1764.0	So.1.12 1764.0-1765.0	So.1.13 1765.0-1766.0	So.1.15 1768.0-1769.0	So.1.16 1769.0-1770.0
Graptolite zone	*gracilis - multidens*					*gracilis*	
Phytoplankton Assemblage	Assemblage I						
Baltisphaeridium annelieae	+		+			+	
Baltisphaeridium multispinosum	+	+	+			+	+
Baltisphaeridium cf. *calicispinae*	+		+			+	
Baltisphaeridium cf. *plicatispinae*			+			+	
Baltisphaeridium cf. *nanninum*	+		+			+	
Baltisphaeridium cf. *trabeculaespinae*			+			+	
Domasia sp.	+	+	+			+	
Excultibrachium cf. *concinnum*			+	+			
Goniosphaeridium polygonale	+					+	
Goniosphaeridium sp.	+		+	+	+	+	
Multiplicisphaeridium bifurcatum				+	+	+	+
Multiplicisphaeridium cf. *irregulare*	+		+	+			
Multiplicisphaeridium sp.	+		+	+		+	+
Navifusa ancepsipuncta	+	+	+		+	+	+
Navifusa sp.	+	+	+		+	+	
Micrhystridium stellatum				+	+	+	+
Micrhystridium sp.	+	+		+	+		
Ordovicidium nudum						+	
Ordovicidium sp.	+	+	+			+	+
Orthosphaeridium vibrissiferum			+				
Orthosphaeridium sp.	+		+			+	
Peteinosphaeridium sp.			+				
Polygonium gracile	+		+			+	
Veryhachium lairdi					+	+	
Veryhachium trispinosum	+	+	+		+	+	+
Veryhachium sp.	+		+	+		+	

Białogóra 2

Ten samples from borehole Białogóra 2 were used for palynological studies. All samples proved palynologically barren (Fig. 5).

Dębki 2

Eleven samples were taken for palynological studies from borehole Dębki 2 (Fig. 5). All samples proved palynologically barren.

Piaśnica 2

Five samples were taken for palynological studies from borehole Piaśnica 2 (Fig. 5). All samples proved palynologically barren.

Kościerzyna IG 1

Twenty seven samples were palynologically studied from borehole Kościerzyna IG 1 (K.10–K.36). All were taken from the Ashgill sediments. Nearly all of them proved palynologically barren; only samples K.10 and K.13 contain fragments of small spiny palynomorphs (most likely *Micrhystridium* and *Veryhachium*). Distinguishing of assemblage was not possible, but the composition of palynomorphs (*e.g.*, lack of baltisphaerids) may suggests the presence of Assemblage II.

Sokolica 1

Sixteen samples (Fig. 6) were taken for palynological studies from borehole Sokolica 1. Seven of them contained determinable palynomorphs (S.9–S.13 and S.15, S.16).

Samples S.9–S.16 come from sediments dated on conodonts (*anserinus* - *superbus* zones; Bednarczyk, 1999a) at the Caradoc graptolite zones *gracilis* - *clingani*. The samples, except the barren one S.14, contain a quite rich and diversified palynological assemblage with well preserved specimens. They include numerous long-ranging small

Table 8

Palynomorphs from the East European Platform

	Szczawno 1									
Sample No / depth (m)	Sz.1.6 4406.0	Sz.1.7 4406.5	Sz.1.10 4411.0	Sz.1.14 4415.0	Sz.1.16 4416.3	Sz.1.17 4416.7	Sz.1.19 4418.3	Sz.1.20 4419.0	Sz.1.21 4420.5	Sz.1.22 4423.8
Graptolite zone	*multidens?*									*gracilis*
Phytoplankton Assemblage	Assemblage I									
Baltisphaeridium cf. *calicispinae*			+	+		+	+		+	
Baltisphaeridium sp.			+	+		+	+			+
Goniosphaeridium sp.	+	+	+	+		+	+	+	+	
Goniosphaeridium connectum	+					+			+	
Multiplicisphaeridium bifurcatum					+		+	+		+
Multiplicisphaeridium cornigerum	+		+	+	+			+		+
Multiplicisphaeridium cf. *bifurcatum*			+			+			+	
Multiplicisphaeridium cf. *irregulare*	+		+			+				
Multiplicisphaeridium sp.	+	+	+	+	+	+	+		+	+
Micrhystridium sp.	+		+	+	+	+	+		+	
Ordovicidium elegantulum	+	+	+	+		+		+	+	
Ordovicidium heteromorficum	+		+							
Ordovicidium nudum	+	+		+			+	+		+
Ordovicidium sp.	+		+	+	+	+	+		+	+
Orthosphaeridium sp.			+		+			+		
Peteinosphaeridium sp.				+			+	+		
Polygonium cf. *gracile*	+		+		+					
Polygonium sp.	+			+			+	+		+
Solispaeridium sp.		+	+	+			+	+	+	

acanthomorphs, up to *ca.* 40 µm in diameter, belonging to genera *Domasia*, *Goniosphaeridum*, *Micrhystridium*, *Multiplicisphaeridium*, *Navifusa*, *Polygonium*, and *Veryhachium*. They are accompanied by large Caradoc forms of genera *Baltisphaeridium* and *Ordovicidium* (diameters up to *ca.* 75 µm).

The compositions of assemblages in samples S.9–S.16 are all similar, in the list of species included in them (Table 7). They differ mainly in quantitative proportions of the species. Frequency of palynomorphs is the highest in samples S.9, S.11 and S.15 (up to 130 specimens per slide (Fig. 12) and the lowest in samples S.10 and S.16 (*ca.* 30 specimens per slide).

Taking into account the nearly identical qualitative composition and usually similar quantitative composition, it may be suggested that all the positive samples from borehole Sokolica 1 contain the same palynomorph assemblage, which corresponds probably to the characteristics of Assemblage I, though big admixture of Silurian forms as *Domasia* is doubtful.

Łankiejmy IG 1

One sample taken for palynological studies from borehole Łankiejmy IG 1 (Fig. 6) proved palynologically barren.

Szczawno 1

Twenty four samples were taken from borehole Szczawno 1 for palynological studies (Sz.1.1–Sz.1.24; Fig. 7). Ten of them (Sz.1.6–Sz.1.22 except of: Sz.1.8, Sz.1.9, Sz.1.11– Sz.1.13, Sz.1.15 and Sz.1.18) proved palynologically positive.

The compositions of assemblages in all samples are similar, quite rich in specimens and taxa. Long-ranging small forms, up to 40 µm, in type of *Goniosphaeridium*, *Micrhystridium*, *Multiplicisphaeridium*, predominate among the identified specimens. Only slightly less numerous are various baltisphaerids and ordovicids with vesiculum diameters of *ca.* 50–65 µm. No specimens from genus *Veryhachium* were found there (Table 8). The greatest frequency of palynomorphs, up to 60 specimens per slide, was found in samples Sz.1.6, Sz.1.10, Sz.1.14 and Sz.1.19, the lowest frequency (10 specimens per slide) – in samples Sz.1.7 and Sz.1.22 (Fig. 12). This species composition corresponds to the characteristics of Assemblage I.

Holy Cross Mountains–Łysogóry Fold Zone

Wilków IG 1

Palynological studies of borehole section Wilków IG 1 were made on 41 samples (Figs 8, 9). Twelve of them contained palynomorphs. Samples W.1.14–W.1.41 come from sediments palaeontologically proven to belong to the Caradoc. Only 12 of them (W.1.18–26, W.1.33, W.1.40, W.1.41) included palynomorphs. The single identified palynomorphs belong to acritarchs and leiospherids. Sample

Table 9

Palynomorphs from the Holy Cross Mountains

	Wilków IG 1		Pobroszyn
Sample No / depth (m)	W.1.24 704.2-705.5	W.1.26 711.5-713.0	
Graptolite zone	*multidens + clingani*		*multidens + clingani*
Phytoplankton Assemblage	Assemblage I		Assemblage I
Actinotodissus cf. *crassus*			+
Acanthodiacrodium sp.			+
Balltisphaeridum sp.			+
Cymatiogalea sp.			+
Goniosphaeridium sp.	+		+
Gorgonisphaeridium sp.			+
Leiosphaeridia	+	+	+
Multiplicisphaeridium cf. *ramusculosum*	+		
Multiplicisphaeridium cf. *raspa*			+
Multiplicisphaeridium sp.	+	+	+
Micrhystridium sp.		+	+
Polonosphaeridium cf. *francinae*			+
Polygonium cf. *gracile*			+
Tyllignasoma sp.			+
Veryhachium trispinosum			+
Veryhachium sp.	+	+	+
Vulcanisphera cf. *imparilis*			+

W.1.24 is richest in palynomorphs. This sample includes, besides some leiospherids, single spiny palynomorphs belonging to genera *Micrychstridium*, *Multiplicisphaeridium* and *Verychahium* (Table 9). The greatest frequency, in this sample amounts to *ca.* 15 determinable forms per slide (Fig. 12). The composition of palynomorph assemblage may suggests the presence of poor Assemblage I.

Bukowiany IG 1a

Fourty-nine palynological samples (Bu.1–Bu.49) were taken from borehole Bukowiany IG 1a (Figs 8, 9). The vertical separation between successive samples was 10–15 cm. Nearly all samples proved palynologically barren. Only samples Bu.15–Bu.18 and Bu.31 did provide several indeterminable palynomorphs each. No palynological conclusions may be based on them.

Pobroszyn

Six palynological samples (Figs 8, 9; samples P.1–P.6) were taken from the outcrop at Pobroszyn (Trela *et al.*, 2001: package E; Bednarczyk & Stempień-Sałek, 2010). Four of them contained palynomorphs. Palynomorphs in these samples represent one, little differentiated assemblage consisting of specimens that occur in approximately equal numbers (Table 9). The greatest frequency amounts to *ca.* 40 determinable specimens per slide in samples P.5 and P.6 (Fig. 12). This species composition corresponds to the characteristics of the Assemblage I.

Table 10

Palynomorphs from the Małopolska Block

	Zbrza 2	
Sample No / depth (m)	Z. 2.1 15.5	Z.2.2 16.0
Graptolite zone	*gracilis*	
Phytoplankton Assemblage	Assemblage I	
Baltisphaeridium bramkaense	+	
Baltisphaeridium longispinosum	+	+
Baltisphaeridium ritavae	+	
Baltisphaeridium lancettispinae		+
Baltisphaeridium plicatispinae	+	+
Baltisphaeridium pseudocalicispinum	+	+
Goniosphaeridium cf. *splendens*	+	
Goniosphaeridium polygonale	+	+
Multiplicisphaeridium bifurcatum	+	+
Micrhystridium stellatum		+
Micrhystridium sp.		+
Ordovicidium nudum	+	
Orthosphaeridium sp.		+
Peteinosphaeridium sp.		+
Polonosphaeridium francinae	+	
Polygonium gracile		+
Veryhachium spp.	+	

Małopolska Block

Zbrza 2

Two samples were taken (Z.2.1 and Z.2.2) from borehole Zbrza 2 (Figs 8, 10). The acritarchs in these samples display great species diversity. They are numerous and most of them are quite well preserved. Similar palynological assemblages are present in both samples. Small palynomorphs with diameters up to 40 µm, such as *Micrychstridium*, *Multiplicisphaeridium* or *Veryhachium*, are accompanied by baltisphaerids, ordovicids, orthosphaerids and peteinosphaerids (Table 10). Frequency in both samples is high and approaches 100 specimens per slide (Fig. 12). This species composition corresponds to the characteristics of Assemblage I.

Zbrza 3

Five palynological samples were studied from borehole Zbrza 3 (samples Zb.3.1–Zb.3.5). The deepest sample, Zb.3.5, comes from the *gracilis* Zone (Fig. 10). Only material from a broad depth interval 17.5–30 m was available for this sample. The depth of the sample provenance cannot be precisely determined. The sample contains a palynomorph assemblage that is exceptionally rich in species and specimens and includes the forms listed in Table 11.

Table 11

Palynomorphs from the Małopolska Block

	Zbrza 3				
Sample No / depth (m)	Zb.3.1 6.0-8.0	Zb.3.2 8.0-10.0	Zb.3.3 10.0-14.0	Zb.3.4 14.0-17.0	Zb.3.5 17.5-30.0
Graptolite zone	*gracilis, multidens + clingani*				
Phytoplankton Assemblage	Assemblage I				
Aremoricanium deflandrei					+
Aremoricanium cf. *rigaudiae*					+
Baltisphaeridium calicispinae	+		+		+
Baltisphaeridium lancettispinae	+			+	+
Baltisphaeridium plicatispinae	+	+		+	+
Baltisphaeridium podboroviscensis					+
Baltisphaeridium pseudocalicispinum				+	
Baltisphaeridium cf. *varsoviensis*					+
Dactylofusa cf. *ctenista*					+
Goniosphaeridium polygonale				+	+
Goniosphaeridium sp.	+	+	+	+	+
Kryptospory				+	+
Liliosphaeridium cf. *kaljoi*					+
Micrhystridium stellatum				+	
Micrhystridium sp.	+		+	+	+
Multiplicisphaeridium bifurcatum	+		+		+
Multiplicisphaeridium cf. *irregulare*			+		+
Navifusa sp.					+
Ordovicidium elegantulum	+		+		
Ordovicidium heteromorphicum				+	+
Ordovicidium nudum			+	+	+
Ordovicidium sp.	+		+	+	+
Orthosphaeridium sp.				+	+
Peteinosphaeridium cf. *micrthantum*			+	+	+
Polygonium gracile	+				+
Veryhachium lairdi	+		+	+	+
Veryhachium reductum	+				+
Veryhachium trispinosum	+	+	+	+	+
Veryhachium cf. *subglobosum*	+				+
Veryhachium sp.		+		+	
Villosacapsula cf. *setosapellicula*	+				

Fauna equally rich in well preserved forms is present in sample Z.3.4, coming from the boundary of graptolite zones *gracilis* and *multidens* (Fig. 9, Table 11). Noteworthy in the palynomorph assemblage is the presence of cryptospores in this sample.

Palynomorphs from samples Zb.3.1, Zb.3.2 and Zb.3.3 (shales belonging to graptolite zones *Diplograptus multidens*; Fig. 10), are somewhat less diversified. They all represent the same, one palynological assemblage, though the individual samples differ in species compositions and frequencies. The poorest palynological material is present in sample Zb.3.2 (Table 11).

A relation between the sample depth and the composition of the palynomorph assemblage was observed in the samples from this borehole (the most numerous amongst the borehole samples from Zbrza) with decreasing sample depth. The proportion of acritarchs with short appendages decreases, from 70/100 at the depth 17.5–30 m in sample Zb.3.5, to 35/100 at the depth 6–8 m in sample Zb.3.1. Frequency of palynomorphs is generally high, up to 150 specimens per slide. The greatest frequency in samples Zb.3.4 and Zb.3.5 amounts to *ca.* 300 determinable forms per slide, the lowest one (*ca.* 80) was noted in sample Zb.3.2 (Fig. 12). The palynomorph inventory indicates their attribution to Assemblage I.

Table 12

Palynomorphs from the Małopolska Block

Niestachów	N.1	N.2	N.3	N.4
	Redeposited ass., Ass. I?			
Acanthodiacrodium cf. *ubui*		+		+
Acanthodiacrodium sp.	+		+	+
Baltisphaeridium annelieae	+	+	+	+
Baltisphaeridium dubitum		+	+	+
Baltisphaeridium plicatispinae	+	+	+	+
Cymatiosphaera heloderma	+		+	
Dasydiacrodium sp.	+	+		+
Diexallophasis remota	+	+	+	+
Leiovalia scaberula		+		
Leiovalia tenuissima	+			+
Micrhystridium acerbum	+	+	+	+
Micrhystridium sp.				
Multiplicisphaeridium denticulatum	+	+	+	+
Multiplicisphaeridium ramusculosum	+	+	+	+
Multiplicisphaeridium rusticum			+	+
Ordovicidium nudum	+	+		+
Polygonium gracile		+	+	
Tylotopalla tappanae	+	+	+	+
Veryhachium europaeum	+	+		+
Veryhachium lairdi	+	+	+	+
Veryhachium reductum	+	+	+	+
Veryhachium trispinosum	+	+	+	+
Villosacapsula cf. *imparilis*				+

Table 13

Palynomorphs from the Małopolska Block

	Strożyska 5		
Sample No / depth (m)	St.5.2 3032.0-3033.0	St.5.3 3033.0-3034.0	St.5.5 3091.6-3093.6
	Ashgill		
Phytoplankton Assemblage	Ass. II b		Ass. IIa? / I ?
Baltisphaeridium cf. *annelieae*			+
Baltisphaeridium cf. *calcispinae*			+
Baltisphaeridium cf. *lancetispinae*			+
Baltisphaeridium sp.			+
Diexallophasis sp.	+		
Goniosphaeridium cf. *polygonium*			+
Goniosphaeridium cf. *christianii*			+
Goniosphaeridium sp.	+	+	+
Gorgonisphaeridium cf. *frequens*			+
Gyalorhethium sp.			+
Multiplicisphaeridium sp.		+	+
Micrhystridium stellatum			+
Micrhystridium sp.	+	+	+
Ordovicidium sp.		+?	+
Pachysphaeridium robustum			+
Peteinosphaeridium accinctulum			+
Peteinosphaeridium cf. *bergstroemii*			+
Peteinosphaeridium cf. *micranthum*			+
Peteinosphaeridium trifurcatum			+
Peteinosphaeridium cf. *velatum*			+
Peteinosphaeridium sp.			+
Polonosphaeridium francinae			+
Veryhachium lairdi			+
Veryhachium trispinosum			+
Veryhachium sp.	+	+	+
Villosacapsula sp.		+	

Niestachów

Five palynological samples were taken from clayey-muddy shales (Stempień, 1990; fig. 2, pl. 1, 2). Four of them include palynomorphs (Fig. 10, Table 12). The samples with palynomorphs differ in composition. All contain the same two separate acritarch assemblages. The first of them, most likely redeposited, includes typical Ordovician forms (*e.g.*, *Ordovicidium nudum*, Table 12). The second assemblage includes Silurian palynomorphs (*e.g.*, *Tylotopalla tappanae*). Frequency of palynomorphs amounts from *ca.* 40 (sample N.1) to 80 (sample N.2) determinable forms per slide (Fig. 12). Distinguishing of assemblage was not possible here.

Zalesie Nowe, Bardo Stawy

Material for palynological studies came from 12 positive samples from exposures at Zalesie Nowe and Bardo Stawy (Fig. 10). Long-ranging, little differentiated and cosmopolitan forms were identified from the exposure at Zalesie. They are accompanied by single *Acanthodiacrodium* sp., small *Baltisphaeridium* sp., *Ordovicidium* sp. and by Silurian forms, such as *Diexallophasis remota*, *Diexallophasis* sp. and *Navifusa* sp. Single *Acanthodiacrodium* sp., *Orthosphaeridium* sp. and *Diexallophasis* sp. and cosmopolitan forms have been determined from exposure Bardo Stawy. The numbers of determined specimens per slide vary in the Zalesie Nowe borehole from 15 to 110, and in Bardo Stawy – from 4 to 18 (Masiak *et al.*, 2003). The palynomorph inventory (Z.6 Z.12) indicates their attribution to Assemblage IIb.

Strożyska 5

Palynological studies in borehole Strożyska 5 were based on five samples (St.5.1–St.5.5; Fig. 11) taken from sediments, dated with brachiopods and conodonts at the Upper Ashgill (Bednarczyk *et al.*, 1968). Only one sample (St.5.5) includes a rich assemblage of well preserved palynomorphs (Table 13) with numerous small, long-ranging and cosmopolitan acanthomorphs with admixture (*ca.* 15%) of genera baltisphaerids, peteinosphaerids and ordovicids. They were determined as belonging to 9 genera and 12 species, including numerous baltisphaerids. This sample

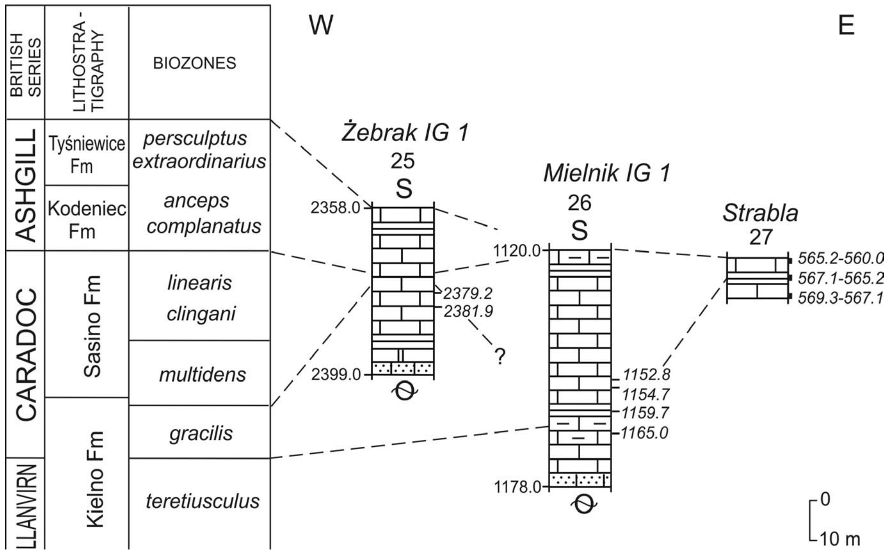


Fig. 13. Simplified lithostratigraphic sections and correlation scheme of the Upper Ordovician from the Podlasie Syneclise. Lithostratigraphy and biostratigraphy after Modliński and Szymański (2008). For explanations of lithostratigraphic symbols – see Fig. 4

also features the greatest frequency of palynomorphs, up to 150 specimens per slide (Fig. 12).

It is not possible to determine exactly the position of this assemblage. The palynomorph inventory indicates their attribution to Assemblage I, probably to the Caradok–Ashgill boundary interval.

Palynomorphs were also present (though scarce in specimens and taxa) in samples St.5.2 and St.5.3. These samples contain only single, small cosmopolitan acanthomorphs with single *Diexallophasis* sp. and *Ordovicidium* sp. The palynomorph inventory from samples St.5.2 and St.5.3 may indicate their attribution to Subassemblage IIb.

PALYNOSTRATIGRAPHY

Palynomorphs as a stratigraphical tool satisfy several criteria of guide fossils: are widespread geographically, are easy to identify, chemically and mechanically resistant, capable of stratigraphic condensation and redeposition, and are microscopic in size. However, in the Upper Ordovician sequences they do not present a rapid succession of species and they are abundant in some facies only. Consequently, they are not a sensitive stratigraphic tool, though in those sections that lack other guide fossils, they can be an important source of information. Indicative of age are whole palynomorph assemblages with characteristic forms of a short stratigraphical range.

Two palynological assemblages have been distinguished in the studied material (Fig. 2). A precise placing of the boundary between these assemblages was not possible, because of the relatively scarce palynological material in comparison to other regions and because of incomplete availability of drilling core. A correlation of these assemblages with the global, British and Baltoscandian stratigraphic divisions based on graptolites is presented in Fig. 3. A correlation of these assemblages with the palynostratigraphic division, proposed from the epi-Caledonian Platform by Szczepanik (2000) is presented in Fig. 14.

The assemblages introduced here are of assemblage character. They are not formally defined as the author feels that their number of samples and their diversity are not sufficient. In the following text, the units are described in ascending order.

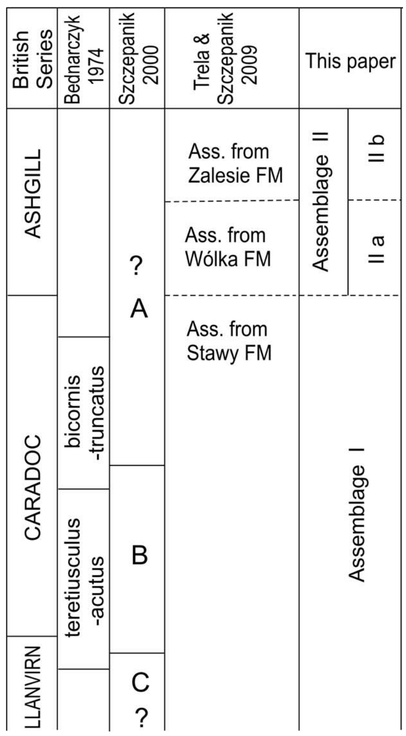


Fig. 14. Correlation scheme of the Upper Ordovician local palaeontological zones and palynological assemblages in the epi-Caledonian Platform and the Holy Cross Mountains

Assemblage I

The presence of Assemblage I was ascertained in 24 boreholes (Fig. 2). Twelve of them are described in this paper, 12 come from the material documented by Szczepanik (2000), Trela and Szczepanik (2009), and Górka (1969, 1979, 1980, 1990).

The lower boundary of the Assemblage I is not known. The Assemblage I (Tables 1–4, 6–11) contains mainly long-ranging, small and numerous acanthomorphs (*e.g.*, goniosphaerids, micrhystrids, veryhachiids) with diameters of *ca.* 30–35 µm (65–70% of population) and concurrent with them, but much less numerous, as an admixture of 15–20%, baltisphaerids characteristic of the Caradoc, with diameters of *ca.* 65 µm and large, broad at base, appendages (*e.g.*, *B. calicispinae*, *B. plicatispinae* or *B. longispinosum* and *B. lancetispinae*). They are accompanied by, often numerous, large peteinosphaerids, ordovicids and by single orthosphaerids (Figs 15, 16, 19–21). Single cryptospores were found in some boreholes, especially those situated in the SE part of the epi-Caledonian Platform (*e.g.*, Miastko 1, Nowa Karczma 1).

Palynomorphs are highly diversified (nearly 30 species), numerous and slightly degraded. Frequency of forms is usually high, some 60–80 specimens per slide (exceptionally more than 300 in Zbrza anticline; Fig. 12). In many cases, the admixture of the large forms of *"Baltisphaeridium*-type*"* is greater in sediments dated at the *teretiusculus*, *gracilis* and *multidens* zones than in *clingani* Zone; *e.g.*, in the sediments of the Nowa Karczma 1 borehole: 22% in the *gracilis* Zone (samples NK. 12, NK. 15) and 15% in the *clingani* Zone (samples NK. 5 and NK. 6). Similar proportions are preserved in the sediments from the borehole Szczawno 1 (samples Sz. 22 and Sz. 7). This is not, however, a rule, hence we cannot say that Assemblage I is divided into two subassemblages.

The upper boundary of the Assemblage I is marked by the disappearance of the forms of "large baltisphaerids" type with long appendages, broad at base.

The conodont and graptolite data (Bednarczyk, 1971, 1974; Podhalańska & Modliński, 2006; Trela, 2006b) indicate that the Assemblage I corresponds to the graptolite zones, from the upper *teretiusculus* Zone to *clingani* and partly *linearis* zones (Figs 2, 3); these are the uppermost Llanvirn and the entire Caradoc (Dariwillian to Katian).

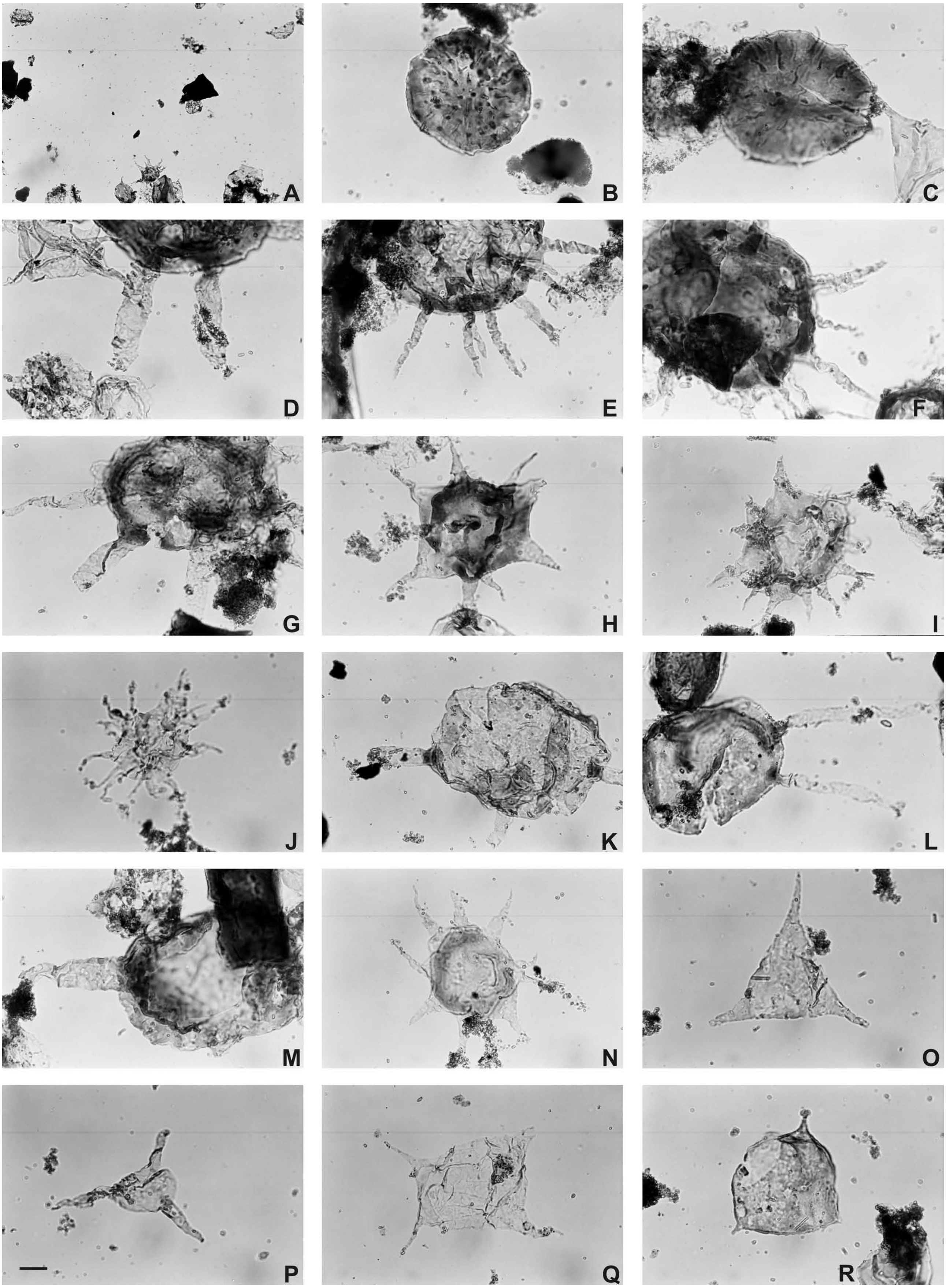
The palynomorph assemblages characteristic of the Assemblage I contain numerous species, which are also known from other regions and permit interregional correlations (Fig. 3).

The Assemblage I distinguished in the epi-Caledonian Platform is probably the equivalent of the part of the zone C, zone B, and a part of the zone A described by Szczepanik (2000; Fig. 14). Common palynomorphs are: the large forms of *"Baltisphaeridium"* type (*e.g.*, *B. calcispinae*, Fig. 16C, *B. plicatispinae*, Fig. 15G, *B. lancetispinae* Fig. 15D), *"Ordovicidium*-type*"* (*e.g.*, *O. nudum*, Fig. 16K) and forms of the *Peteinosphaeridium*, *Orthosphaeridium* and *Veryhachium* type. A more precise comparison and division inside the Assemblage I is not possible because the definition of zones A, B and C is based on a quantitative analysis of palynomorph assemblages rather than on the stratigraphical ranges of individual forms and because of too scarce author's palynological material. Additionally, the boundaries between the palynomorph assemblages A, B and C are not distinctively indicated.

The Assemblage I is similar, in due of both content and frequencies, to the described and documented by Trela and Szczepanik (2009) from the Stawy Formation in the Upper Caradoc strata of the Holy Cross Mountains, the Bardo Syncline (Fig. 14). Common palynomorphs are: the large forms of baltisphaerids (*e.g.*, *B. lancetispinae*, Fig. 15D), ordovicids (*e.g.*, *O. elegantulum*, Fig. 21F), peteinosphaerids (*e.g.*, *P. trifurcatum* Fig. 22L), orthosphaerids and small, long-ranging and cosmopolitan spiny acritarchs (*e.g.*, *Micrhistridium*, *Multiplicisphaeridium*, *Veryhachium*). Assemblage from Stawy Formation was correlated by Trela and Szczepanik (2009) with pre-glacial assemblage, described by Vecoli and Le Hérissé (2004), and Vecoli (2008).

A similar composition as in the Assemblage I (the large forms of baltisphaerids, ordovicids, peteinosphaerids, orthosphaerids and veryhachiids and small, long-ranging and cosmopolitan spiny acritarchs) is also characteristic for assemblages of the Upper and Middle Ordovician from other regions with common species, such as: *Baltisphaeridium longispinosum*, *Ordovicidium elegantulum* (Fig. 16K), *Peteinosphaeridum trifurcatum* (Fig. 22L), *Goniosphaeridium connectum* (Fig. 15H), *Navifusa ancepsipuncta* (England – Turner, 1984); *Baltisphaeridium annelieae*, *B. ritvae*, *Goniosphaeridium connectum* (Sweden – Kjellströem, 1971); *Baltisphaeridium dasos* (Fig. 15C), *Baltisphaeridium heinzelinii*, *B. nanninum* (Fig. 5D; East-European Platform – Uutela & Tynni, 1991); *Baltisphaeridium nanninum*, *Ordoviciunium elegantulum*, *Polygonium gracile* (Fig. 15N; Raevskaya *et al.*, 2004); *Baltisphaeridium pachyacanthum*, *B. longispinosum*, *Polygonium gracile* (northern Gondwana – Vecoli & Le Hérissé, 2004); *Dorsenidium undosum* Fig. 16D), *Ordoviciunium elegantulum*, and *Polygonium gracile* (northwestern China – Li *et al.*, 2006).

Fig. 15. Caradocian phytoplankton (Assemblage I), borehole Jamno IG 1, sample J.1.2; **A.** general view, magnification ×100, **B.** *Baltisphaeridium dasos*, **C.** *Baltisphaeridium* cf. *dasos*, **D.** *Baltisphaeridium lancettispinae*, **E.** *Baltisphaeridium* cf. *calcispinae*, **F, G.** *Baltisphaeridium* cf. *plicatispinae*, **H.** *Goniosphaeridium* cf. *connectum*, **I.** *Goniosphaeridium* sp., **J.** *Micrhystridium* sp., **K, L.** *Orthosphaeridium* cf. *insculptum*, **M.** *Orthosphaeridium* sp., **N.** *Polygonium* cf. *gracile*, **O.** *Veryhachium trispinosum*, **P.** *Veryhachium* sp., **Q.** *Veryhachium* cf. *lairdi* **R.** *Villosacapsula* sp. Length of scale bar is 10 µm and it refers to all pictures except for A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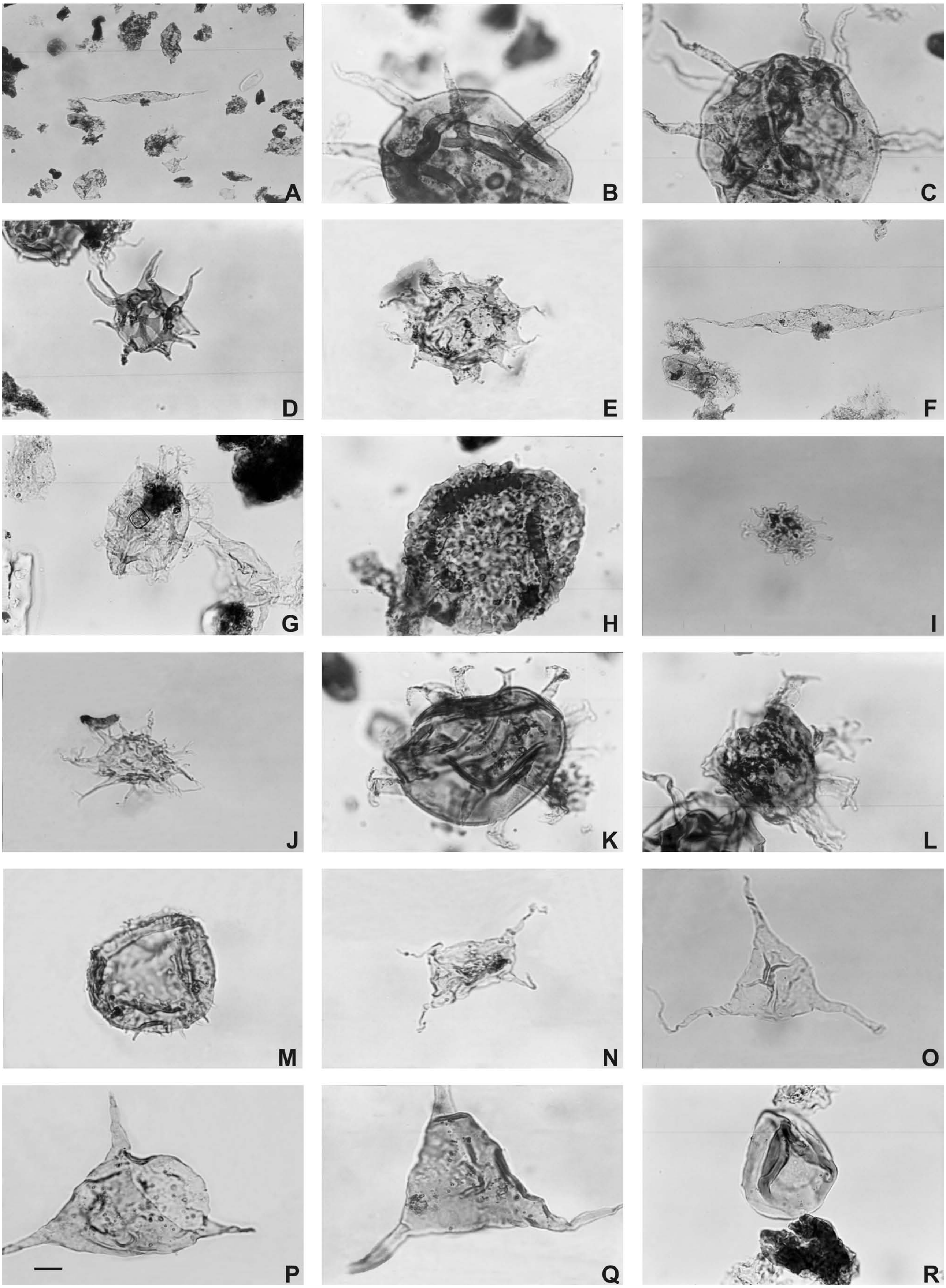
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Fig. 16. Caradocian phytoplankton (Assemblage I), borehole Miastko 1, sample M.1.2; **A.** general view, magnification ×100, **B, C.** *Baltisphaeridium calcispinae*, **D.** *Dorsenidium undosum*, **E.** *Goniosphaeridium* sp., **F.** *Navifusa* sp., **G.** *Liliosphaeridium* cf. *kaljoi*, **H.** *Lophosphaeridium sylvanium*, **I.** *Multiplicisphaeridium bifurcatum*, **J.** *Multiplicisphaeridium irregulare*, **K.** *Ordovicidium nudum*, **L.** *Peteinosphaeridium velatum*, **M.** *Solisphaeridium* sp., **N.** *Veryhachium lairdi*, **O, P.** *Veryhachium trispinosum*, **Q.** *Veryhachium* sp., **P.** cryptospore. Length of scale bar is 10 µm and it refers to all pictures except for A

Assemblage II

The younger assemblage II (Figs 2, 17, 22, Tables 5, 6, 11, 13,) is more difficult to identify, though two sub-assemblages in some of the samples can be distinguished within it: IIa and IIb.

Assemblage II was distinguished in the Toruń 1, Łeba 8, Kościerzyna IG 1, Strożyska 5 boreholes, and in the Bardo Stawy and Zalesie Nowe outcrops.

Subassemblage IIa

Assemblage IIa was distinguished in Toruń 1 and Łeba 8 boreholes, and probably palynomorphs from St.5.2 and St.5. 3 in Strożyska 5 borehole may also belong to its (Figs 2, 17, 22). The lower boundary of Sub-assemblage IIa is defined by the appearance of forms of the "small baltisphaerids-type" in place of the "large baltisphaeridium-type".

Only small, long-ranging and cosmopolitan, spiny acritarchs (diameter *ca.* 30 µm, *e.g.*, *Multiplicisphaeridium* cf.

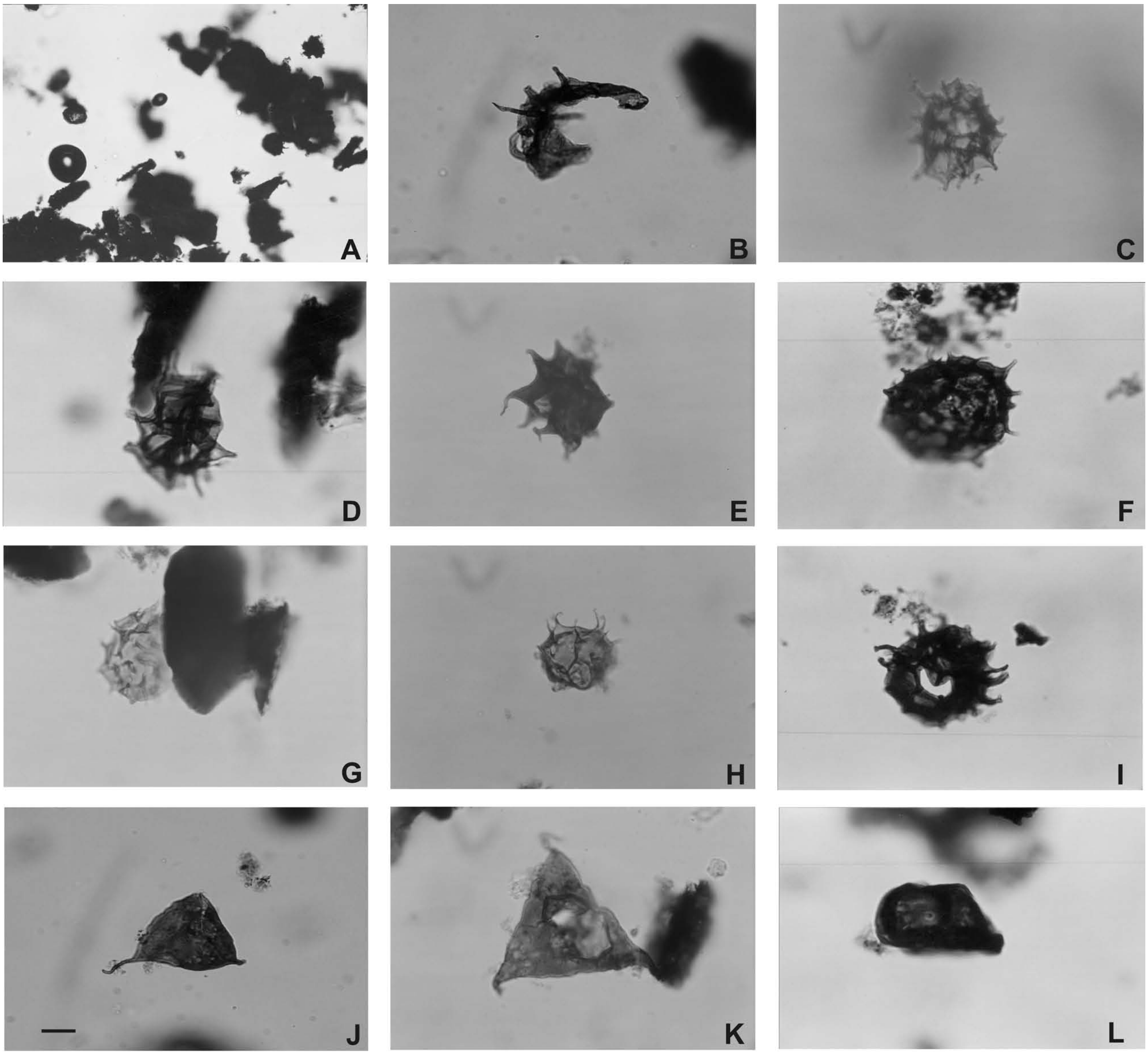


Fig. 17. Ashgillian phytoplankton (Assemblage II), borehole Toruń 1, sample T.1.4; **A.** general view, magnification ×100, **B.** *Baltisphaeridium heizelinni*, **C, D.** *Cymatiosphaera* sp., **E, F.** *Goniosphaeridium* sp., **G, H.** *Micrhystridium* sp., **I.** *Pachysphaeridium* sp., **J, K.** *Veryhachium* sp., **L.** cryptospore. Length of scale bar is 10 µm and it refers to all pictures except for A

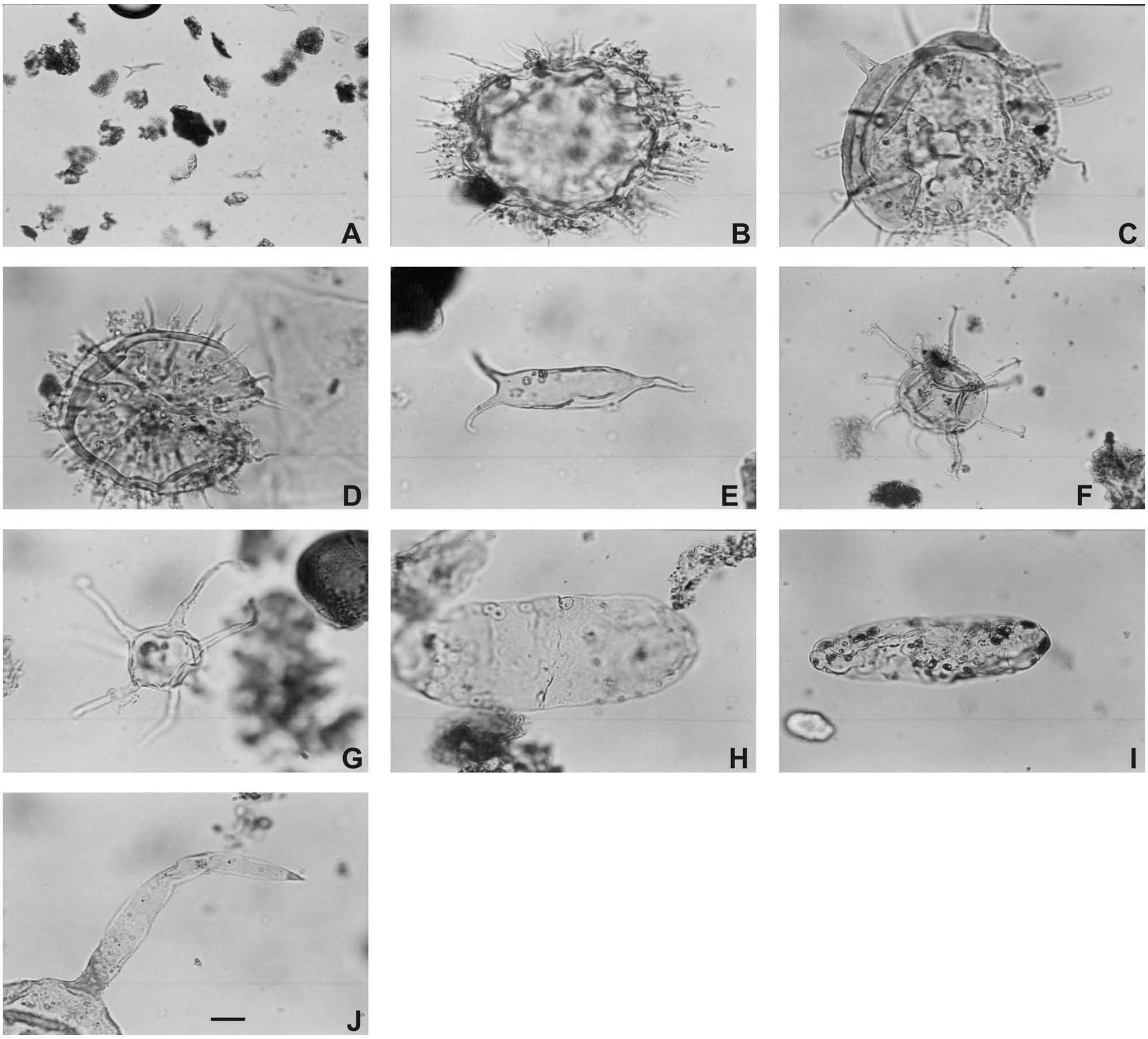
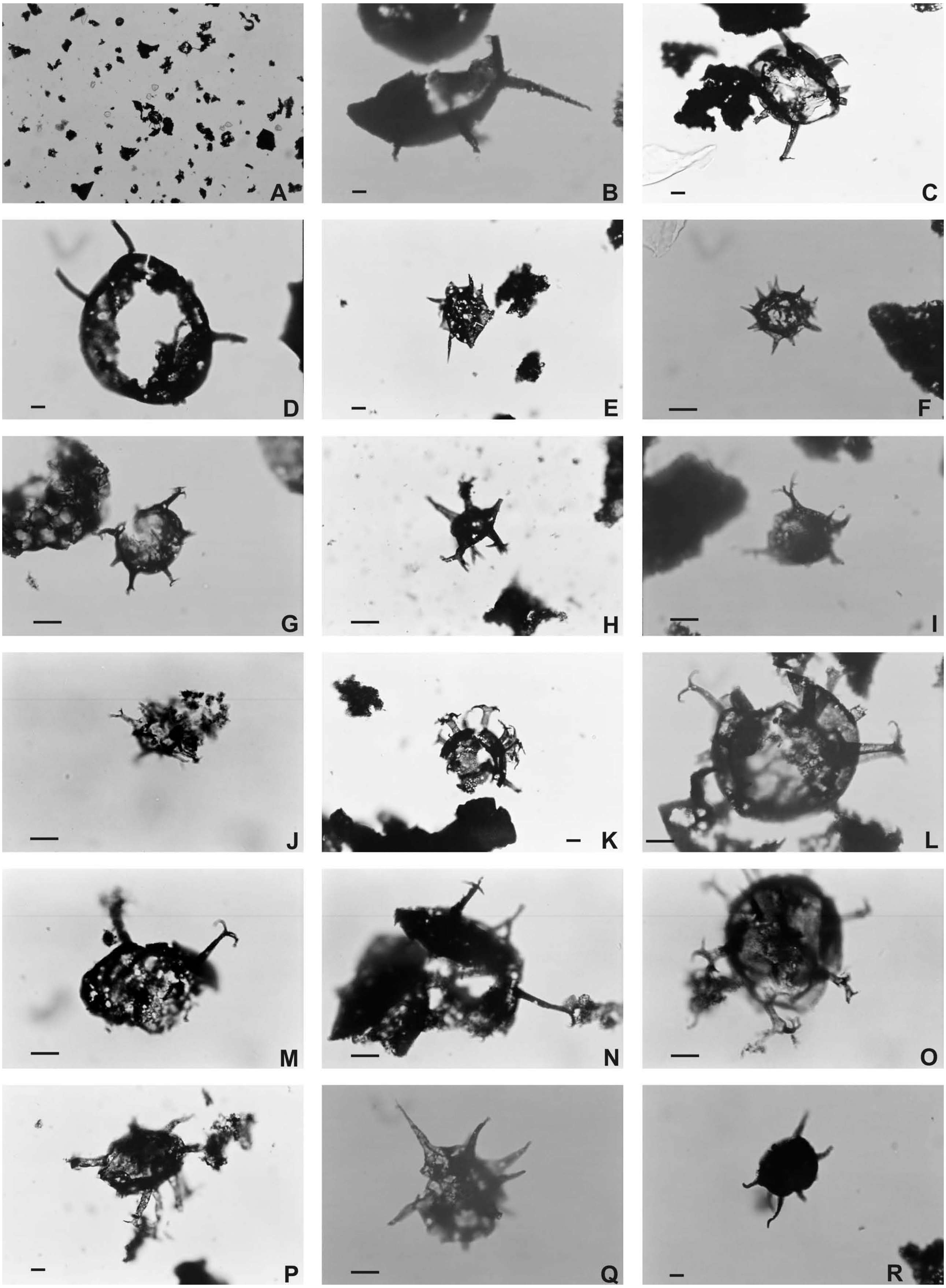


Fig. 18. Caradocian phytoplankton (Assemblage I), borehole Sokolica 1, Figs A and G from sample So.1.12, the others – from sample So.1.11; all magnification ×600, except when indicated: **A.** general view, magnification ×100, **B.** *Baltisphaeridium multispinosum*, **C.** *Baltisphaeridium* cf. *trabeculaespinae*, **D.** *Baltisphaeridium* cf. *nanninum*, **E.** *Domasia* sp., **F.** *Excultibrachium* cf. *concinnum*, **G.** *Micrhystridium* sp., **H.** *Navifusa ancepsipuncta*, **I.** *Navifusa* sp., **J.** *Orthosphaeridium vibrissiferum*. Length of scale bar is 10 µm and it refers to all pictures except for A

bifurcatum, *Micrhystridium* cf. *stellatum*, *Micrhystridium* sp., *Goniosphaeridium* sp., *Veryhachium* sp.) are characteristic for this assemblage. Additionally, there occurs a small admixture (*ca.* 15%) of forms of the “small baltisphaerids” type with diameters 40–50 µm and narrow, spiny appendages (*e.g.*, *Baltispaeridium* cf. *annelieae*: Table 13, Fig. 22 B; *B.* cf. *heizelinii*: Table 4, Fig.17B and *Baltisphaeridium* sp.; Table 13). The number and diversity of the palynomorphs are usually smaller than 50 specimens per slide (Fig. 12).

The upper boundary of Assemblage IIa is marked by the disappearance of forms of the ”small baltisphaerids” type and the appearance of the first, single Silurian forms, as *e.g.*, *Diexallophasis.*

Fig. 19. Caradocian phytoplankton (Assemblage I), borehole Szczawno 1, sample Sz.1.6; **A.** general view (×100), **B.** *Baltisphaeridium* cf. *calcispinae*, **C, D.** *Baltisphaeridium* sp., **E.** *Goniosphaeridium* cf. *connectum*, **F.** *Micrhystridium* sp., **G.** *Multiplicisphaeridium* cf. *cornigerum*, **H.** *Multiplicisphaeridium irregulare*, **I.** *Multiplicisphaeridium* cf. *irregulare*, **J.** *Multiplicisphaeridium* cf. *bifurcatum*, **K.** *Ordovicidium elegantulum*, **L, M.** *Ordovicidium* cf. *elegantulum*, **N.** *Ordovicidium* cf. *heteromorphicum*, **O.** *Ordovicidium nudum*, **P.** *Ordovicidium* sp., **Q.** *Polygonium* cf. *gracile*, **R.** *Solisphaeridium* sp. Length of scale bar is 10 µm and it refers to all pictures except for A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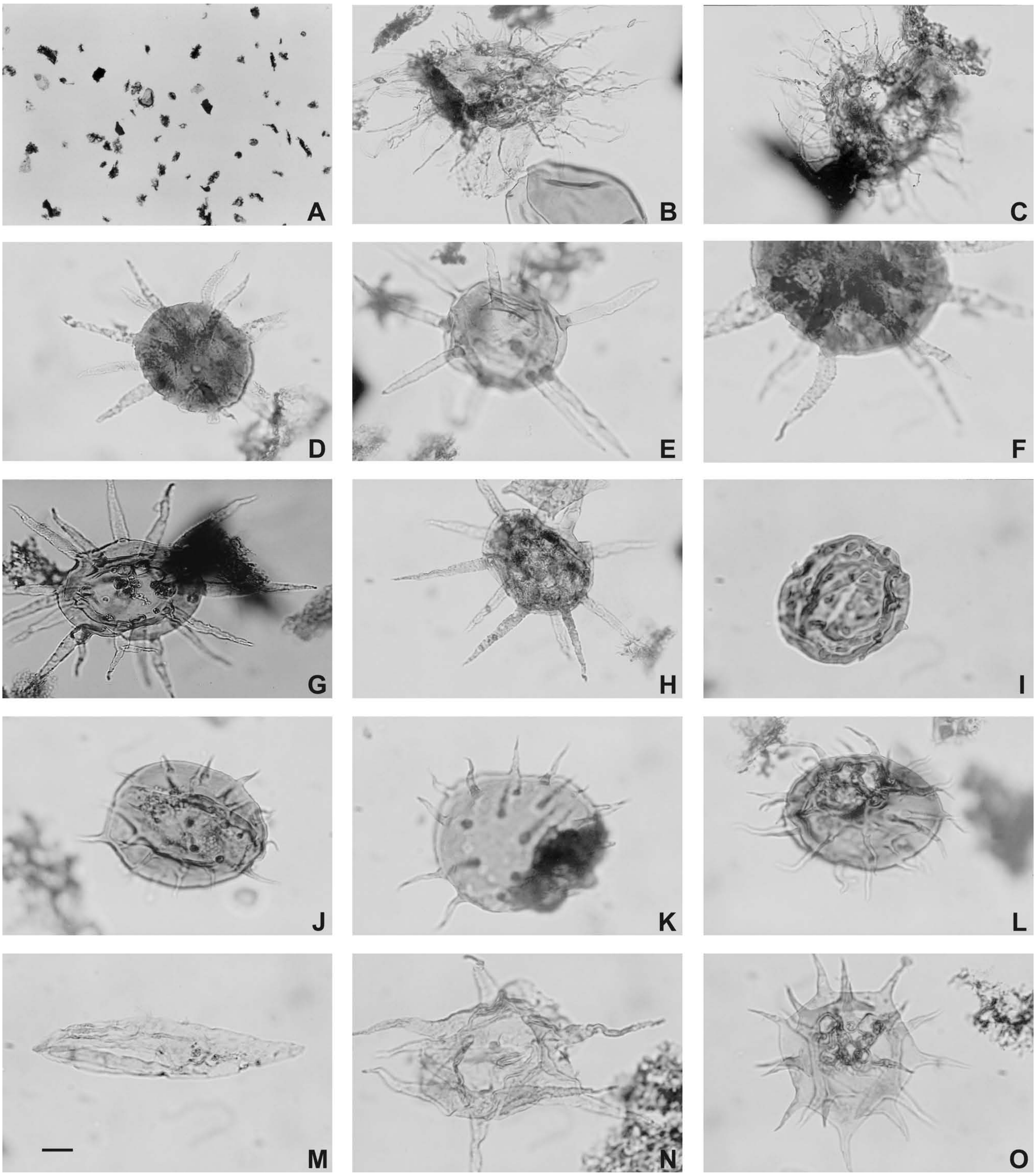

Fig. 20. Caradocian phytoplankton (Assemblage I), borehole Zbrza 3, sample Z.3.5; **A.** general view, magnification ×100, **B, C.** *Aremoricanium deflandrei*, **D–F.** *Baltisphaeridium calcispinae*, **G, H.** *Baltisphaeridium plicatispinae*, **I.** *Baltisphaeridium podboroviscensis*, **J, K.** *Baltisphaeridium* cf. *varsoviensis*, **L.** *Baltisphaeridium* sp., **M.** *Dactylofusa* cf. *ctenista*, **N, O.** *Goniosphaeridium* sp. Length of scale bar is 10 µm and it refers to all pictures except for A

The conodont and other faunal data (Bednarczyk, 1971a, 1974; Podhalańska & Modliński, 2006; Trela, 2006b) indicate that the Assemblage IIa corresponds to graptolite zones from *complanatus* to lower part of *extraordinarius* and, in the upper part, to the *Dalmanitina* beds and the lower Hirnantian fauna. It represents the lower part of the Ashgill (Figs 2, 3).

The composition of the Assemblage IIa appears to be similar to that from the Wólka Formation in the Zbrza trench in the Holy Cross Mountains (Kielce Region), described from Ashgill by Trela and Szczepanik (2009; Fig. 14). Common palynomorphs are "small baltisphaerids-type" (*Baltisphaeridium* sp., Fig. 22C) and small, cosmopolitan spiny acritarchs (*e.g.*, *Pachysphaeridium* sp., Fig.

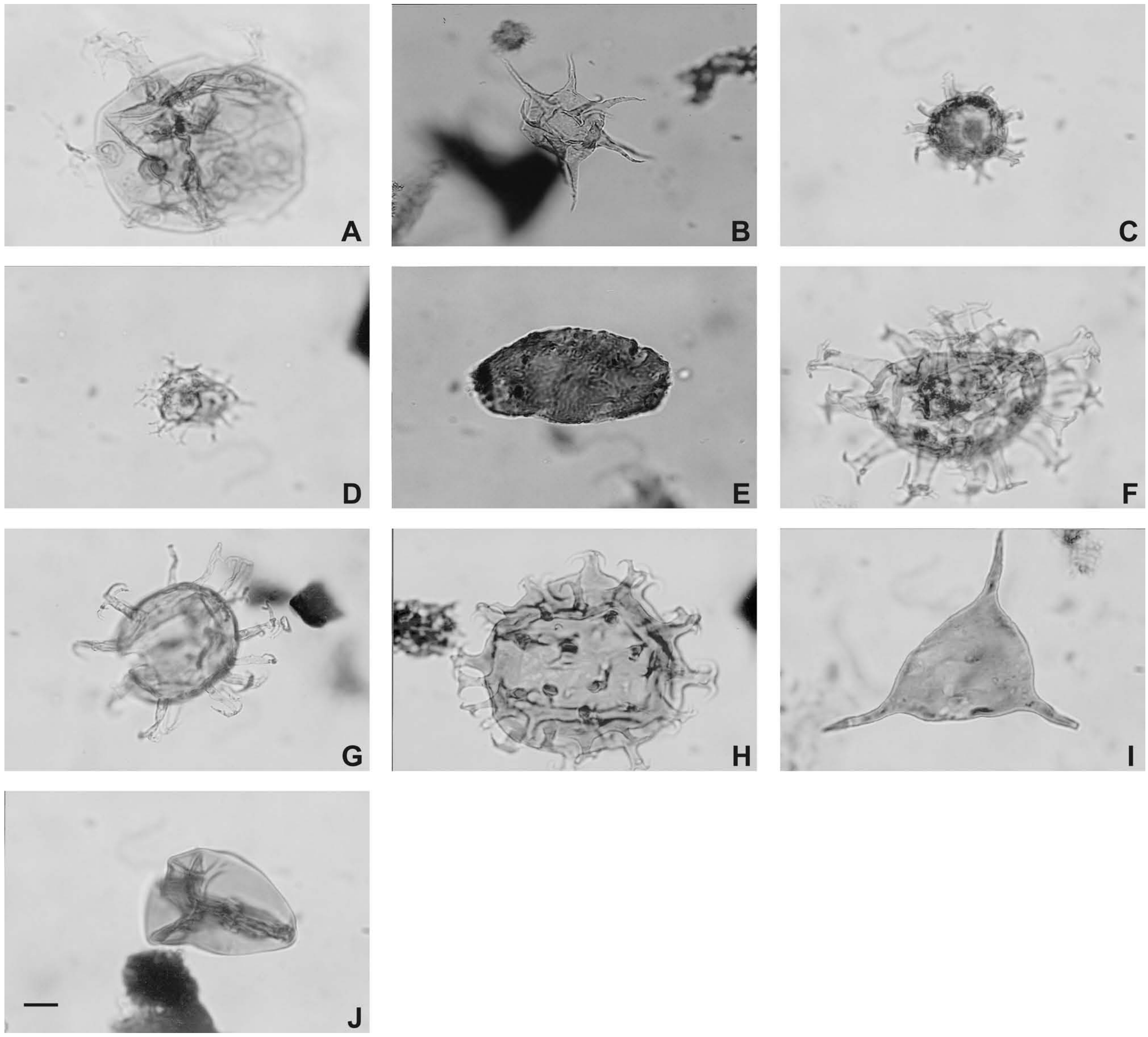

Fig. 21. Caradocian phytoplankton (Assemblage I), borehole Zbrza 3, sample Z.3.5; **A.** *Liliosphaeridium* cf. *kaljoi*, **B.** *Micrhystridium* sp., **C.** *Multiplicisphaeridium irregulare*, **D.** *Multiplicisphaeridium* cf. *bifurcatum*, **E.** *Navifusa* sp., **F.** *Ordovicidium elegantulum*, **G.** *Ordovicidium heteromorphicum*, **H.** *Ordovicidium* sp., **I.** *Veryhachium trispinosum*, **J.** cryptospore. Length of scale bar is 10 µm and it refers to all pictures

17I, *Veryhachium* sp.). Assemblages from the Wólka Formation is correlated by Trela and Szczepanik (2009) with the passage between pre-glacial and glacial assemblages described by Vecoli and Le Hérissé (2004), and Vecoli (2008).

Sub-assemblage IIb

Sub-assemblage IIb was distinguished in the sediments of the Małoplska Block, including Zalesie Nowe and Bardo Stawy outcrops, and in the Strożyska 5 borehole (samples St.5.2 and St.5.3 Fig. 2, Table 13; see also Masiak *et al.*, 2003). The lower boundary of the Sub-assemblage IIb is defined by the appearance of the first, single Silurian forms, as *e.g.*, *Diexallophasis*.

This sub-assemblage contains mainly long-ranging, small and numerous acanthomorphs (*e.g.*, goniosphaerids, micrhystrids, veryhachiids) with diameters of *ca.* 30–35 µm, concurrent with the Silurian precursors such as *Diexallophasis* (Zalesie Nowe, fig. 10 in Masiak *et al.*, 2003; Bardo Stawy, Strożyska 5, Table 13). Forms of the "small baltisphaerids-type" nearly completely disappear here.

The frequency of forms is usually low, but variable (Fig. 12). In the outcrop Bardo Stawy, it does not exceed 15 palynomorphs in the richest slide; only three samples from outcrop Zalesie Nowe exceed 20 palynomorphs per slide (Z.6, Z.9, Z and Z.11), but in the richest sample Z.9 from the *mucronata* Biozone (Masiak *et al.*, 2003) it attains 110 forms per slide.

The upper boundary of the Sub-assemblage IIb, an equivalent to the lower boundary of the Silurian, is already not visible in the studied material, but it is marked by the mass appearance of numerous species of *Diexallophasis*,

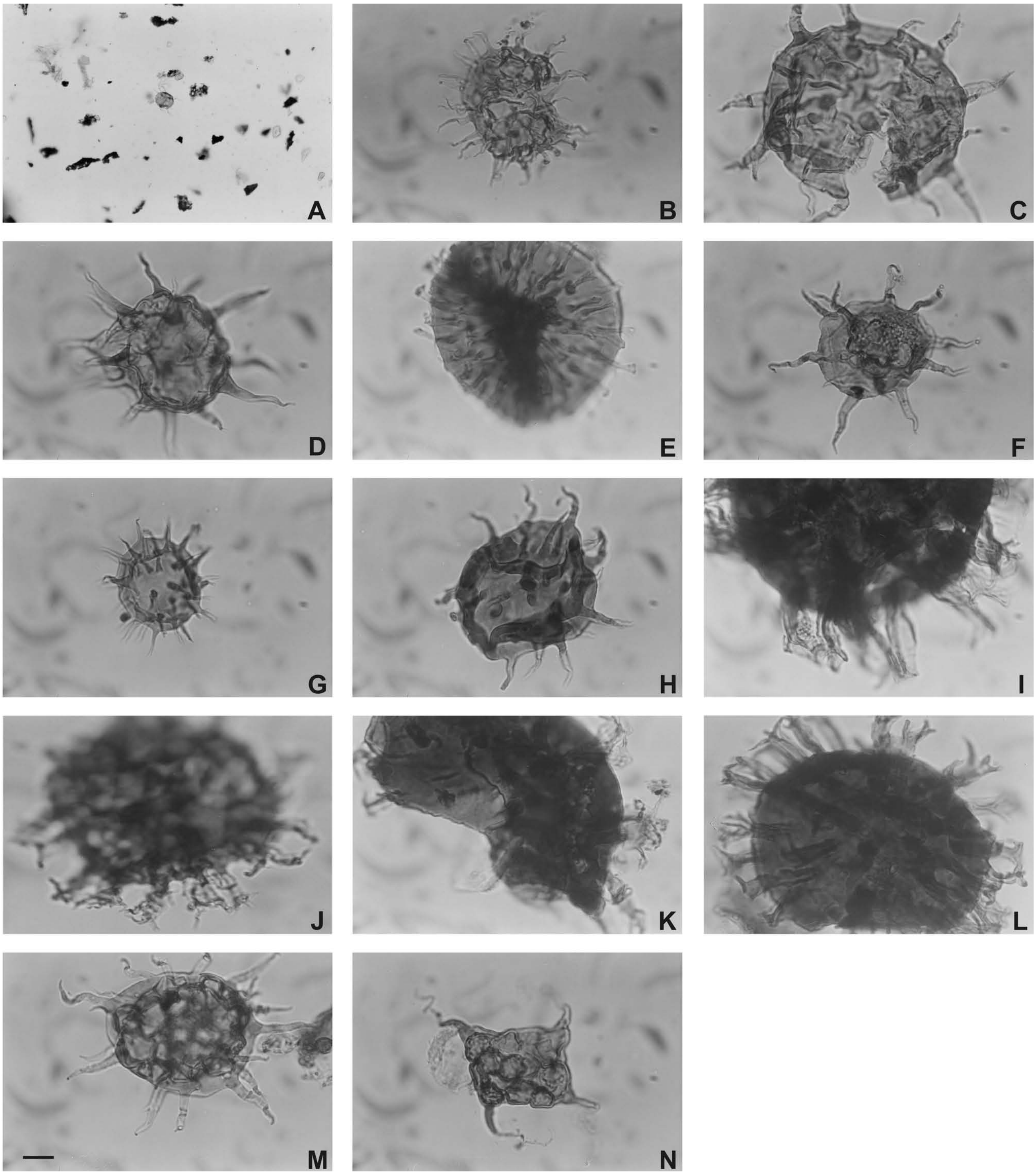

Fig. 22. Ashgillian phytoplankton (Assemblage II), borehole Strożyska 5, sample St.5.5; **A.** general view, magnification ×100, **B.** *Baltisphaeridium* cf. *annelieae*, **C.** *Baltisphaeridium* sp., **D.** *Goniosphaeridium* cf. *christianii*, **E.** *Gorgonisphaeridium* cf. *frequens*, **F.** *Gyalorhethium* sp., **G.** *Micrhystridium* sp., **H.** *Pachysphaeridium robustum*, **I.** *Peteinosphaeridium accinctulum*, **J.** *Peteinosphaeridium* cf. *accinctulum*, **K.** *Peteinosphaeridium* cf. *bergstroemii*, **L.** *Peteinosphaeridium trifurcatum*, **M.** *Polonosphaeridium francinae*, **N.** *Veryhachium lairdi*. Length of scale bar is 10 μm and it refers to all pictures except for A

Domasia, *Multiplicisphaeridium*, *Opilatalla* and *Tylotopalla* and by much greater frequency of palynomorphs, up to several hundred or more specimens per slide (Masiak *et al.*, 2003).

The faunal and microfaunal data (Bednarczyk, 1971a, 1974, 1981; Podhalańska & Modliński, 2006; Trela, 2006b) indicate that the Sub-assemblage IIb corresponds to graptolite zones from the upper *extraordinarius* Zone to *persculptus* Zone (Figs 2, 3), that is the uppermost Ashgill (Hirnantian without its lower part).

Sub-assemblage IIb seems to be the equivalent of the assemblage described by Trela and Szczepanik (2009) from the Zalesie Formation (Zbrza trench and borehole Szumsko Kolonia 2, Holy Cross Mountains, Kielce Region, Fig. 14). Common palynomorphs are *Multiplicisphaeridium*, *Polygonium*, *Verychachium* and *Diexallophasis*. The Sub-assemblage IIb differs from the assemblage from the Zalesie Fm. in frequency of palynomorphs, which is many times higher. Assemblages from the Zalesie Fm. were correlated by Trela and Szczepanik (2009) with glacial assemblage described by Vecoli and Le Hérissé (2004) and Vecoli (2008).

A similar composition as in the Sub-assemblage IIb, long-ranging, small and numerous acanthomorphs concurrent with the Silurian precursors, such as *Diexallophasis*, *Domasia*, and *Tylotopalla* (Niestachów and Szumsko Kolonia 2 borehole), is also characteristic for assemblages of the Upper Ordovician strata from other regions (*e.g.*, Prague Basin, Kosov Formation, Dufka & Fatka, 1993; southern Appalachians, Assemblage A, Colbath, 1986; northeast Libya, Hill & Molyneux, 1988; Vecoli & Le Hérissé, 2004; Vecoli, 2008). They have been also noted in the Upper Asghill by Fensome *et al.* (1990) and Paris *et al.* (2000).

Summing up, though precision of palynomorphs as stratigraphic tools is limited, the acritarchs from Assemblage I and Assemblage II in all of the mentioned regions are generally undoubtedly a useful stratigraphic marker for the Caradoc and Ashgill calcareous-clayey facies.

More diverse and problematic is the palynological material from the Nida region in the Małopolska Block (borehole Strożyska 5). It was taken from strata palaeontologically proven as of Ashgillian age. However, the lowermost sample (St.5.5; Fig. 11) includes, besides small spiny long-ranging palynomorphs of limited stratigraphical value (mostly *Goniosphaerids*), a marked admixture of somewhat larger (45–60 μm) forms of *Baltisphaeridium* and *Peteinosphaeridium* types (up to *ca.* 15%). Such a composition, coupled with the high frequency (up to 150 specimens per slide; Fig. 12) may suggest the attribution of the palynomorphs to Assemblage I (or boundary zone between assemblages I and II), which is present in the Caradoc strata in all other regions. The degree of degradation of both small and larger forms is similar and no other characteristics suggested redeposition of the material, though such possibility cannot be completely ruled out. An assemblage from the sample St.5.5 seems to be the equivalent of the assemblage described by Trela and Szczepanik (2009) from the Stawy Formation (Kielce Region, Holy Cross Mountains), palaentologically dated as the upper Caradoc. Common palynomorphs are, among others, *Peteinosphaeridium trifurcatum* (Table 13, Fig. 22L) and *Baltisphaeridium lancetispinae* (Table 13).

The higher samples (St.5.3 and 5.2) are much poorer and do not include the admixture of "large" and "small" *Baltisphaeridium*. They represent the Subassemblage IIb.

In borehole Strożyska 5 there are two palynological assemblages: an older one, transitional, from the boundary between the Caradoc and Ashgill (identified in sample St.5.5), and the younger, definitely Ashgill, Sub-assemblage IIb (present in samples St.5.3 and St.5.2). Thus, the sediments in sample St. 5.5, hitherto regarded as the Upper Ashgill (Bednarczyk *et al.*, 1968), should be accepted as somewhat older, at least the Lower Ashgill. However, palaeontological evidence from the same depth interval of 3,091.6–3,093.6 m (*Orbiculoidea radiata*, *Lingulella* sp., *Nicolella* sp. and *Eostropheodonta hirnantiensis*) unequivocally demonstrates the Upper Ashgill age.

Less problematic is also material from the Sokolica 1 borehole including a big admixture of *Domasia* and *Navifusa*. Genus *Domasia* constitutes probably a contamination from the overlying Silurian or uppermost Ashgill strata.

Somewhat different is the situation in exposure Niestachów. Material for palynological studies was collected from claystone-mudstone intercalations between the layers of the Upper Silurian sandstones (Tomczyk, 1956; Filonowicz, 1971) and it was redeposited from the Ordovician claystone-mudstone sediments (Stempień, 1990). The place of original deposition could not be identified.

PALAEOBIOGEOGRAPHY

The studies using Ordovician palynomorphs for palaeobiogeographical purposes began in the 1970s (Cramer & Diez, 1972, 1974, 1977; Vavrdova, 1974; Martin, 1982). Two provinces were then distinguished: a cold Mediterranean Province at high latitudes of the Southern Hemisphere, with predominance of diacromorph acritarchs, and the warmer Baltic Province at low latitudes, in the belt between the tropics, with predominance of acanthomorph acritarchs. This division, which is distinct for sediments from Arenig to Llanvirn, is still used (Servais *et al.*, 2003, 2004, 2005; Servais & Wellman, 2004), though with small modifications (extension of the Mediterranean Province to the peri-Gondwanan Province). The maximum separation of continents was probably attained at that time (Cocks, 2001; Scotese, 2001; Cocks & Torsvik, 2002, 2006).

In Late Ordovician time, a real separation of continents was much smaller than in the Middle Ordovician (Fig. 23). However, in the Late Ordovician (from Late Llanvirn/Early Caradoc to Ashgill) the differences between provinces began to diminish (Hill & Molyneux, 1988; Martin, 1968, 1974, 1980, 1988; Li & Servais, 2002; Le Hérissé & Vecoli, 2003; Vecoli & Le Hérissé, 2004, Yin & He, 2000; Li *et al.*, 2006), and cosmopolitan, small and long-ranging species are present (Dufka & Fatka, 1993; Molyneux & Paris, 1985; Vecoli, 1999; Xiang & Fang, 1999; Li *et al.*, 2006). Practically, no species are found that would be unequivocally limited to low or high latitudes. Many of these species appear in many geographical locations. For example, *Multiplicisphaeridium bifurcatum* and *M. irregulare* noted in Poland in the epi-Caledonian Platform are ubiquitous (*e.g.*, Poland, Upper Silesian Block: Jachowicz, 2005; Estonia – Uutela & Tynni, 1991; North America and Europe – Wicander *et al.*, 1999, Playford & Wicander, 2006; Tarim Basin, China – Li *et al.*, 2006). *Ordovicidium elegantulum*, which is present in the epi-Caledonian Platform and in the Kielce Region of the Holy Cross Mountains, is also noted in many areas worldwide (*e.g.*, Oklahoma – Tappan & Löeblich, 1971; England – Turner, 1984; Estonia – Uutela & Tynni, 1991; Gotland – Eiserhard, 1992; Tarim Basin – Li *et al.*, 2006). *Polygonium gracile*, noted in most Polish Upper Ordovician assem-

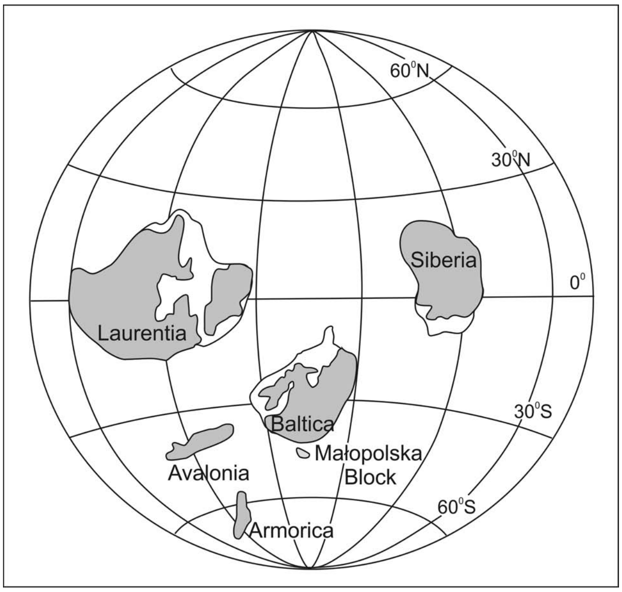

Fig. 23. Late Ordovician palaeogeographic reconstruction after Scotese and Mc Kerrow (1999) and Li and Powell (2001)

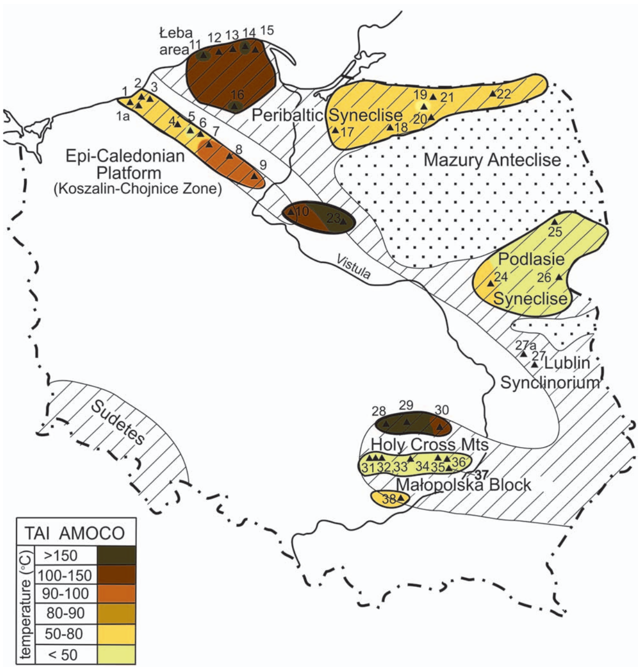

Fig. 24. Map of palaeotemperatures in palynological record. For names of boreholes and outcrops see Fig. 1

blages, is common worldwide (*e.g.*, in Europe – Vavrdova, 1966; Sarjeant & Stancliffe, 1994; in China, Tarim Basin – Li *et al.*, 2006).

Nevertheless, a small variation is present in the Polish Upper Ordovician sections from various regions. So, no diacromorph acritarchs (or single, uncertain only; Szczepanik, 2000, borehole Chojnice 5) were found in the epi-Caledonian Platform and in the East European Platform, while acanthomorph acritarchs are numerous.

Single diacromorph acritarchs were found in the Holy Cross Mountains, in both the northern region (outcrop Pobroszyn: *Acanthodiacrodium* sp., *Actinotodissus* cf. *crassus*), and the Kielce Region (outcrop Bardo Stawy and Zalesie Nowe: *Acanthodiacrodium* sp., Niestachów: *Dasydiacrodium* sp. and *Acanthodiacrodium* cf. *ubui*). However, the numbers of diacromorph acritarchs are small in both cases (13 specimens in total). Diacromorph acritarch (*e.g.*, *Acanthodiacrodium angustum*, *Acanthodiacrodium* sp., *Actinotodissus formosus)* were also found in the Zbrza trench and the Szumsko Kolonia 2 borehole (Trela & Szczepanik, 2009), too. A lot of diacromorph acritarchs (various *Acanthodiacrodium*) were found in the Upper Silesian Block in Lanvirn and Caradoc strata (Jachowicz, 2005). Diacromorph acritarchs (*Actinodissus crassus*) were also found in the Upper Ordovician strata from the Southern Appalachians (Colbath, 1986).

The presence of representatives of the genera *Acanthodiacrodium* (typically Middle Ordovician forms, and not recorded in the post-Llanvirn strata) strongly suggests sediment reworking in the Upper Ordovician in the Holy Cross Mountains.

The scarce data are not sufficient for any general palaeogeographic conclusions. It may be only concluded that the uppermost Ordovician material from the Holy Cross Mountains includes diacromorph acritarchs, characteristic of the Mediterranean and Peri-Gondwanan Provinces that is for high latitudes and cold climate, at that time.

PALAEOTEMPERATURES IN PALYNOLOGICAL RECORD

Observations of palynomorphs in different four units reveal a large variation in colour of the specimens, from bright-yellow through dark-yellow, brown and dark-grey to black, depending on the degree of heating. Temperatures, to which sediments with palynomorphs were heated, are determined using the method of Thermal Alteration Index (TAI). The method consists in the comparison of palynomorph colour with one of standard colour scales. A six-grade scale TAI AMOCO, modified by Engelhardt *et al.* (1992), was used in this study (Fig. 24).

Transformations of organic matter and the degree of its maturity are also indicated by the Vitrinite Reflectance Index R_o, obtained by measurements of reflectance (Robert, 1985) and by CAI – Conodont Alteration Index (Narkiewicz & Nehring-Lefeld, 1993).

Palaeotemperatures in epi-Caledonian Platform (Koszalin–Chojnice Zone)

The studied samples reveal marked variations in colour of palynomorphs (Figs 15, 25, Table 14). Colour of identifiable specimens from various boreholes, taken from similar depths, varies from bright-yellow in borehole Brda 3 (Szczepanik, 2000) to brown in boreholes Nowa Karczma 1, and Polskie Łąki PIG 1 (Table 14).

This change in colour, hence also in the temperature of heating, shows a regular trend. The palynological material in the boreholes situated in the NW part of the region (*e.g.*,

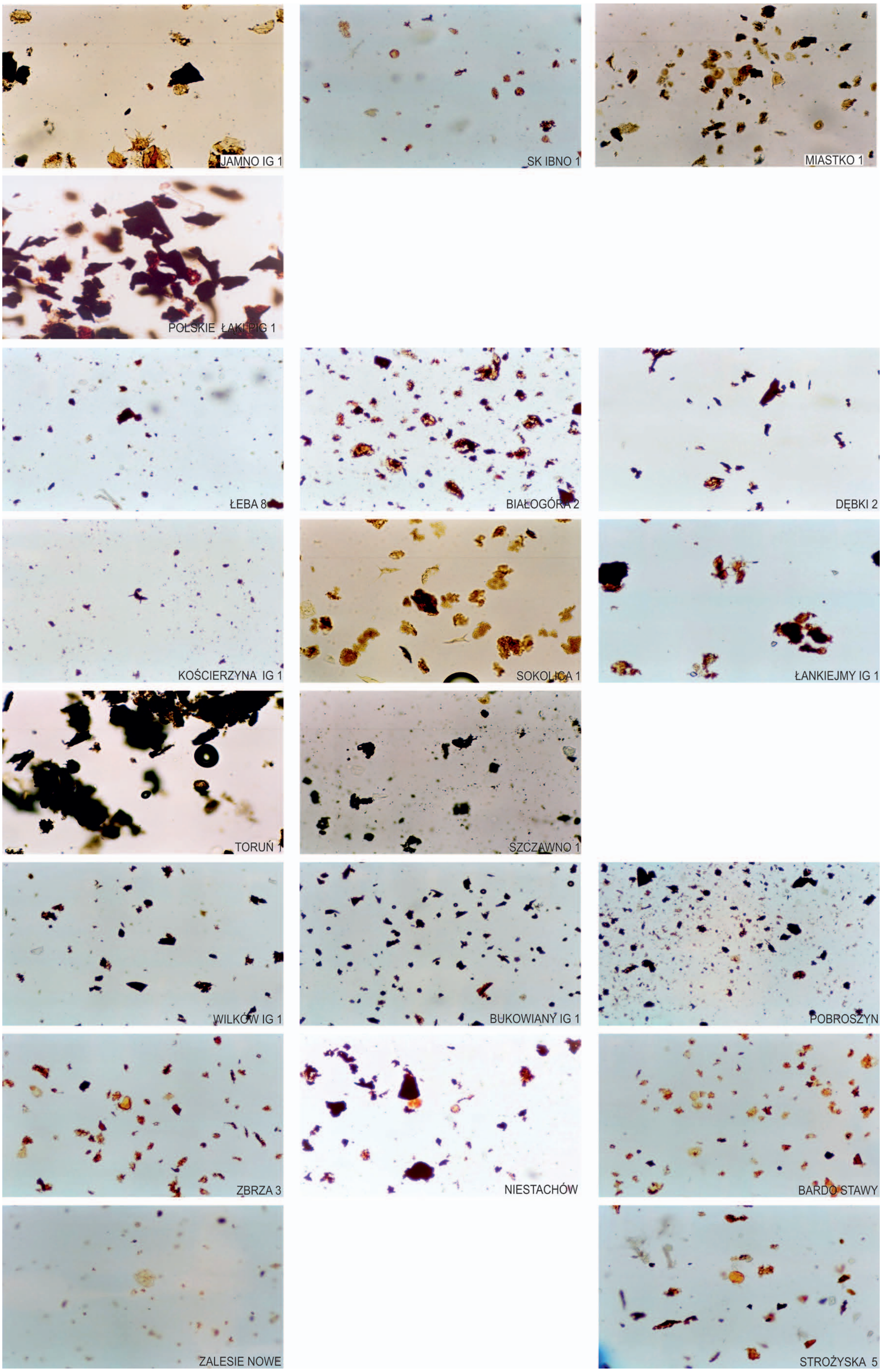

Fig. 25. Thermal Alteration Index (TAI) in the examined boreholes

Table 14

Palaeotemperatures in the epi-Caledonian Platform

Epi-Caledonian Platform (Koszalin-Chojnice Zone)												
TAI AMOCO		borehole	Jamno IG 1	Jamno IG 2	Skibno 1	Karsina 1	Miastko 1	Brda 3	Nowa Wieś 1	N. Karczma 1	Chojnice 5	P. Łąki PIG 1
temperature	>150°C overmature											
	100 - 1500°C gas window										+	
	90 - 1000°C condensate window									+	+	+
	80 - 900°C oil window					+						+
	50 - 800°C early oil window		+	+	+	+	+		+			
	< 500°C							+				

Table 15

Palaeotemperatures in the East European Platform

East European Platform																			
TAI AMOCO		borehole	Łeba 8	Białogóra 1	Białogóra 2	Piaśnica 2	Dębki 2	Kościerzyna IG1	Toruń 1	Szczawno 1	Pasłęk IG1	Olsztyn 1	Sokolica 1	Kętrzyn IG 1	Łankiejmy IG 1	Gołdap IG 1	Żebrak IG1	Strabla	Mielnik IG1
temperature	>150°C overmature		+					+?		+									
	100 - 150°C gas window			+	+	+			+										
	90 - 100°C condensate window																		
	80 - 90°C oil window																		
	50 - 80°C early oil window										+	+		+	+	+	+		
	< 50°C												+					+	+

boreholes Jamno IG 1, Skibno 1, Miastko 1) shows heating to temperatures of *ca.* 50–80°C (early oil window), while in the SE of the region (*e.g.*, boreholes Nowa Karczma 1, Chojnice 5) palaeotemperatures attained about 100°C (condensate window). However, it should be noted that the darkest palynomorphs come from boreholes Chojnice 5 and Polskie Łąki PIG 1, which not only lie farthest to the east, but also the palynomorphs reached there the greatest depths. The samples from both boreholes were taken from depths greater by 2,000 m than in the neighbouring boreholes. The much darker colour may be thus related also to the higher geothermal gradient, which changes in this area (at the margin of the East European Platform) to the values of *ca.* 2–2.5°C per 100 m (Majorowicz, 1982). Nevertheless, a greater thermal engagement of the SE part of the Koszalin–Chojnice Zone seems to be corroborated by the fact of elevated value of sediment heating, to *ca.* 100°C (condensate window), shown by palynomorphs from the neighbouring, shallower borehole Nowa Karczma 1.

Thus, it seems likely that the sediments from which palynological samples were taken in the NW part of the region were much less heated than the sediments from the SE part. The difference in palaeotemperatures determined using the TAI AMOCO scale amounts to *ca.* 50°C.

The Vitrinite Reflectance Index R_O, obtained from reflectance measurement values for the NE part of the Koszalin–Chojnice Zone, varies from 0.73 to 0.91%, demonstrating that maturity of the organic matter corresponds to the main phase of oil generation (palaeotemperatures 50–100°C). The values for the SE part of the discussed area equal 1.78–1.8%, thus they correspond to palaeotemperatures varying within the range 70–170°C, the main phase of gas generation (Grotek, 1999).

East European Platform

Two zones with different lithology of Upper Ordovician sediments differ also in palaeotemperature record (Fig. 23).

Western part of the Peribaltic Syneclise

The palynological record in the Łeba area is quite different from that in the neighbouring areas. They are dark in colour (black or grey); palaeotemperatures had to exceed locally 150°C (Fig. 23). Such conditions did not favour palynomorph preservation.

Similar determinations of the degree of organic matter heating were obtained for the Łeba area using the Vitrinite Reflectance Index R_O (reflectance measurements, Grotek, 1999). The R_O values vary in this area from 1.12 to 2.30%, pointing to organic matter maturity corresponding to the early to late phase of gas generation and maximum temperatures of 70–180°C. The CAI for the Łeba area equals 3 and thus corresponds to the phase of condensate generation and palaeotemperatures of 110–200°C (Nehring-Lefeld *et al.*, 1997).

Eastern part of the Peribaltic Syneclise

Palynomorphs from the boreholes Sokolica 1 (Fig. 1), Olsztyn IG 1 and Gołdap IG 1 (Górka's collection, Fig. 6) feature bright colours. With the overburden thickness similar in all boreholes, the palynomorphs are from bright do dark-yellow, indicating a low degree of heating of the studied sediments. The lowest palaeotemperatures are indicated by sediments from borehole Sokolica 1 (not exceeding 50°C, immature stage). The degree of thermal maturity in other boreholes of the area indicates an interval of 50–80°C (early oil window; Fig. 23, Table 15).

Similar values of temperature are indicated by coefficient R_O, whose value for the sediments of borehole Olsztyn equals 0.5%, corresponding to thermally immature organic matter and temperatures approaching 50°C, and the CAI coefficient equal 2, pointing to temperatures of 60–140°C (Nehring-Lefeld *et al.*, 1997).

Therefore, the palaeothermal histories of the eastern and western parts of the Peribaltic Syneclise were clearly different, as is shown by the evidence of palaeotemperature difference of more than 100°C.

Western slope of the Mazury Anteclise (Płock–Warszawa Trough)

The borehole Szczawno 1 is situated in the Płock– Warszawa Through. The borehole Toruń 1, is situated *ca.* 70 NE from it, in a SE prolongation of the Koszalin–Chojnice Zone. Both boreholes are similarly distant from the platform margin; the borehole Toruń 1 on the SW side of the Teisseyre–Tornquist Zone (TTZ), the borehole Szczawno 1 on its NE side. Results of palynological analyses were similar in both boreholes. They are discussed here jointly because of some palynological similarities and interfingering of the mentioned units.

The colour of palynomorphs changes from dark-brown to black in borehole Toruń 1, indicative of heating to *ca.* 100–150°C (gas window, Figs 23, 25, Tab. 15). Palynomorphs from borehole Szczawno 1 are still darker. They feature dark colour and display characteristic, brittle structure that suggests palaeotemperatures of at least 150°C (transition between gas window and overmature). Overburden thickness in both boreholes is great (above 4,000 m) but similar, hence, it does not disturb comparison.

The R_O index for the area of borehole Szczawno 1 equals 3%, that is corresponds to the phase of condensate generation and temperatures 190–300°C. The CAI index attains the value of 5 and it corresponds to temperatures 300–400°C (Nehring-Lefeld *et al.*, 1997).

The palaeotemperatures obtained using the R_O and CAI indices are much higher than those at which palynomorphs are preserved and much higher than those indicated by the TAI scale. So, the results obtained for borehole Szczawno 1 using the three methods are different. The difference may be caused by the fact that the TAI method was used just for sediments from borehole Szczawno 1, while the R_O and CAI data come from borehole Polik IG 1 distant by 15 km, even if both boreholes lie within the same interval of the R_O and CAI values (Nehring-Lefeld *et al.*, 1997).

A comparison of material from both boreholes is hampered by different ages of the palynomorphs and different depths from which the samples were taken. Samples from the studied interval of borehole Toruń 1 are most likely Ashgill in age and they come from a depth greater than 5,300 m. Samples from borehole Szczawno1 are Caradoc in age and they come from a depth greater than 4,300 m. However, taking into account that conditions at both sites were similarly favourable for acritarch preservation and that the degree of sediment heating was similar at both sides of the TT Zone in the Koszalin–Chojnice Zone (Szczepanik, 2000), it may be accepted that determination of similar palaeotemperatures in boreholes Toruń 1 and Szczawno 1 is not erroneous.

Podlasie Syneclise

Palynological material comes from boreholes Żebrak IG 1, Mielnik IG 1 and Strabla (Górka's collection of the acritarchs, Fig. 13). Palynomorphs from individual boreholes differ only slightly in colour, which is a proxy for sediment heating (Figs 12, 23; Table 15).

The data on heating indicate that sediments in borehole Żebrak IG 1 were subject to slightly higher temperatures (50–80°C, early oil window) than those in boreholes Strabla and Mielnik IG 1 (less than 50°C, immature stage).

Table 16

Palaeotemperatures in the Holy Cross Mountains and in the Małopolska Block

		HCM Łysogóry Region				Małopolska Block HCM Kielce Region						Nida Region
TAI AMOCO		borehole	Wilków IG1	Bukowiany IG1	Pobroszyn	Zbrza 1	Zbrza 2	Zbrza 3	Niestachów	Bardo Stawy	Zalesie	Strożyska 5
temperature	>150°C overmature		+	+								
	100 - 150°C gas window											
	90 - 100°C condensate window				+							
	80 - 90°C oil window				+							
	50 - 80°C early oil window											+
	< 50°C					+	+	+		+	+	

The index R_O for the whole area of Podlasie is lower than 1, corresponding to immature organic matter and temperatures of 50–80°C. The value of CAI index attains 3 for borehole Żebrak IG 1 (temperatures 110–200°C, phase of condensate generation) and 1 for boreholes Strabla and Mielnik IG 1 (Nehring-Lefeld *et al.*, 1997), corresponding to temperaturesof 50–80°C and immature organic matter.

Palaeotemperature values obtained for borehole Żebrak IG 1 using the CAI method are higher than those obtained using the TAI method for the same borehole by at least *ca.* 30°C.

Thus, a similar phenomenon is present in the Podlasie area as in the Peribaltic Syneclise. The farther east from the platform margin, the lower is the degree of sediment heating. It should be noted, however, that overburden thickness in borehole Żebrak IG 1 is greater by 1,000 m than in borehole Mielnik IG 1, and this certainly caused the darker colour of the studied material.

Holy Cross Mountains (Łysogóry Fold Zone)

The palynomorphs found in the Łysogóry Region are destroyed, usually dark-grey brown to black in colour, indicative of heating of sediments to temperatures up to 150°C – transition between the gas window and overmature (Figs 23, 25, Table 16). The degree of heating decreases eastward and near Opatów (Pobroszyn outcrop) it does not exceed 100°C (condensate window – 90–100°C, bright-grey brown colour). The overburden thickness in both boreholes does not exceed few hundred metres. Similar palaeotemperature values, indicative of overheating (overmature window), are marked in material from borehole Janowice IG 1 (Szczepanik, 2007).

The easternmost outcrop, Pobroszyn, situated at a similar distance from the line of the Holy Cross Overthrust as boreholes Wilków IG 1 and Bukowiany IG 1, features the lowest degree of heating and the highest content of rela-

Table 17

The species compositions in Avalonia, Baltica and Małopolska Block

Palynomorphs	Avalonia			Baltica			Małopolska Block
	Rügen Servais,1994	England Turner,1984	Poland K-Ch area, this paper	Gotlandia Górka,1978	Estonia Uutela & Tynni,1991	Poland this paper	Poland this paper
Baltisphaeridium longispinosum	+	+	+	+	+	+	+
Baltisphaeridium plicatispinae			+	+		+	+
Goniosphaeridium polygonale	+	+	+	+		+	+
Multiplicisphaeridium irregulare	+	+	+		+	+	+
Ordovicidium elegantulum	+ sp.	+	+	+	+	+	+
Ordovicidium heteromorphicum		+	+	+	+	+	
Ordovicidium nudum	+	+	+	+	+	+	+
Orthosphaeridium vibrissiferum		+ sp.		+	+	+	+ sp.
Peteinosphaeridium brevispinosum		+		+	+		
Polygonium gracile		+	+		+	+	+

tively slightly damaged palynomorphs among the whole material from the Łysogóry region.

Małopolska Block

Kielce Fold Zone (Kielce region)

Boreholes Zbrza 2 and 3, situated in the western part of the region, feature the presence of bright-yellow material and palaeotemperatures lower than 50°C (immature stage; Fig. 23, Table 16). Similarly pale-yellow are palynomorphs from the central (Niestachów) and eastern (Zalesie Nowe, Bardo Stawy) parts of the region; hence, their degree of heating was similar (Fig. 25). Palynological material from boreholes Ublinek 1 and Włostów 1 (Szczepanik, 2007), and from Zalesie and Szumsko Kolonia 2 boreholes (Trela & Szczepanik, 2009) also represents the eastern part of the region and displays yellow colour of palynomorphs.

Palynomorph colouring indicates thus that the whole southern region was subject to very slight heating, not exceeding 50°C .

In summary, palynological characteristics of the Holy Cross Mountains show marked differences between the northern (Łysogóry Fold Zone) and southern (Kielce Fold Zone) regions (Fig. 23). The degree of heating in the north is at least 100°C greater than in the south. It varies also within the region, decreasing from more than 150°C in the west (Wilków IG 1) to *ca.* 100°C in the east (Pobroszyn). In the southern region, the degree of heating seems to be uniform over the whole area; palaeotemperatures do not exceed 50°C (immature stage) in all the studied boreholes. Specimen colours demonstrate different geological histories of both regions of the Holy Cross Mountains.

Similar conclusions can be drawn by comparison of vitrinite reflectance coefficient R_o in the northern (Wilków IG 1 and Pobroszyn) and southern (Zalesie Nowe) regions. The value of coefficient R_o for borehole Wilków IG 1, depth 768.5 m, is 3.53%, and for the outcrop Pobroszyn – 3.2%, indicative of palaeotemperatures greater than 200°C; data from Zalesie Nowe, where R_o=1.0 (Grotek, 2005), indicate palaeotemperatures slightly above 60°C.

Nida region

Material from the Nida region (borehole Strożyska 5, Figs 23, 25, Table 16) features a similar colour of specimens in all samples, yellow and dark-yellow, indicative of sediment heating to temperatures not exceeding 80°C (early oil window).

In the central part of the Nida region, geothermal degree and gradient were measured. The mean values of geothermal gradients for the whole measurement zones vary from 1.72°C/100 m to 2.96°C/100 m (Jurkiewicz & Szczerba, 1976). No data on the CAI and R_o coefficients for borehole Strożyska 5 have been published.

In summary, the highest temperature values received with TAI method (150°C approximately and more) appear in the region of the TESZ Zone (Fig. 23). It is the result of tectonic activity during the Caledonian orogenesis. Similar temperatures are registered from the Łysogóry Fold Zone (northern part of the Holy Cross Mountains); concerning the temperatures in the Łysogóry Fold Zone these are related to the TESZ zone and the western part of Baltica.

The lowest palaeotemperatures (lower than 50°C) are registered within the Polish part of the East European Platform, in the area, which has not been affected by transformations of Caledonian orogenesis. Palaeotemperatures lower than 50°C are also registered from the Kielce Fold Zone.

The Kielce Fold Zone with palaeotemperatures lower than 50°C and the Nida region with palaeotemperatures indicating warming of 50–80°C are showing individual character of the Małopolska Block in comparison with the northern part of the Holy Cross Mountains and the south-eastern edge of the East European Platform.

AREAS OF AVALONIA, BALTICA AND MAŁOPOLSKA BLOCK IN THE LIGHT OF OBTAINED PALYNOLOGICAL DATA

The areas of Avalonia, Baltica and the Małopolska Block were placed close to one another during the Late Ordovician time (Fig. 24), at similar latitude and in the same climate zone. Consequently, the palynomorph assemblages from these three areas have similar species compositions (Table 17).

More distinct are differences related to the degree of thermal maturation (Fig. 23). Within the epi-Caledonian Platform, Ordovician sediments are related to an early Palaeozoic terrane of Gondwanan origin, known as Eastern Avalonia (Tait *et al.*, 1997; Pharaoh, 1999; Jaworowski, 2000; Samuelsson *et al.*, 2002). The palynological assemblage present over the whole area displays similar degrees of heating, about 50–100°C.

Within the East European Platform (Baltica), palynological material indicates marked differences. The highest palaeotemperatures are indicated in material from the Łeba area and the Warsaw–Płock Trough (above 150°C). The degree of heating decreases eastward from the margin of the Baltica palaeocontinent, hardly attaining 50°C.

The area described as the Małopolska Block is also complex in the geological and palynological sense. It includes the southern (Kielce) region of the Holy Cross Mountains and the Nida region. The degree of heating is similar in both regions – *ca.* 50°C.

A marked difference related to the frequency of palynomorphs is shown between the Avalonia, Baltica and the Małopolska Block. Generally, assemblages from the Avalonia and the Baltica are palynologically poor, their frequency is low (*ca.* 10–50 forms per slide), while the frequency from the Małopolska Block (in the same, richest graptolite Zones *gracilis - multidens*) varies from 45 to 320 identified specimens per slide (Fig. 12).

The diversity of palynomorphs in a one sample within the graptolite Zones *gracilis - multidens* is also highest in material from the Małopolska Block (13–25 identified species). In other regions, the diversity fluctuates between 3 and 13 identified species. The compositions of the studied palynological assemblages from the Małopolska Block is similar to the compositions of the Llanvirn – Caradoc palynological assemblages from the Upper Silesian Block (Gładysz *et al.*, 1999; Jachowicz, 2005).

In summary, the Małopolska Block is palynologically different from the epi-Caledonian Platform and from the Baltica in the degree of thermal maturation (the same, *ca.* 50°C in the whole region), palynomorph frequency, and in the higher diversity of palynomorphs.

CONCLUSIONS

1. Palynological analysis of the Upper Ordovician material from the studied regions proved that palynomorphs are useful for palynostratigraphical studies of the strata within this age interval. Though they do not display rapid succession and are not present in all facies, they enable unquestionable division into two assemblages of different age: the Caradoc Assemblage I and the Ashgill Assemblage II. Additionally, two groups of palynomorphs in some cases, when frequency is high, allow one to distinguish two subassemblages – IIa and IIb. Well expressed is also a difference in composition of the assemblages from the Ordovician and Silurian boundary zone. A distinction of the Upper Ordovician from the Lower Silurian sediments on this ground should be easy.

2. Transformations in coalification of organic matter and the degree of its thermal maturity indicate temperature to which sediment was heated and thus allow to restore thermal history of the basin. The results obtained in all the studied regions using the TAI method are similar to the results obtained using the Vitrinite Reflectance Index R_O and index of conodont colour alteration CAI. Palaeotemperature characteristics of the Holy Cross Mountains show marked differences between the northern (Łysogóry Fold Zone) and southern (Kielce Fold Zone) regions. The palaeotemperatures show individual character of the Małopolska Block (the same, *ca.* 50°C in the whole region) in comparison with the northern part of the Holy Cross Mountains, SE margin of the East European Platform, and the epi-Caledonian Platform.

3. A comparison of palynomorph frequencies in coeval sediments does not reveal big systematic pattern within individual geological regions and between them. A marked difference between them is discernible: *A* – between the material from the Caradoc and Ashgill. Generally, the Caradoc material is many times richer (both in quality and quantity) than the Ashgill material. Many Ashgill samples were palynologically barren. The lower frequencies in the Ashgill sediments may be also attributed to the appearance of ice-sheets in the Southern Hemisphere during Late Ordovician time; *B* – between the material from the Małopolska Block and from the East European Platform and the epi-Caledonian Platform. The palynomorph frequencies in the Małopolska Block are much higher than those in the others regions. Higher is also the diversity of palynomorphs in the Małopolska Block.

4. The areas of the Avalonia, Baltica and the Małopolska Block were situated on the same latitude and in the similar climatic zone during the Late Ordovician. As a result, the palynomorphs, which have been found in those areas, do not show any essential differences regarding species composition. Practically, no species have been found in sediments of this age whose occurrence would indicate low or high latitudes. Most species are cosmopolitan. Information obtained from the analysis of assemblage composition do not allow to draw palaeobiological conclusions based on them.

5. No diacromorph acritarchs (*e.g.*, *Acanthodiacrodium*) were found in the epi-Caledonian Platform and in the East European Platform, while acanthomorph acritarchs are numerous. The presence of representatives of the genera *Acanthodiacrodium* (typical Middle Ordovician forms, and not recorded in post-Llanvirn strata) in the Upper Ordovician in the Holy Cross Mountains strongly suggests sediment reworking and connection with a cold Mediterranean

Province at high latitudes of the Southern Hemisphere, with predominance of diacromorph acritarchs.

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Appendix
List of identified taxa

The identified acritarch taxa are reported in the following list (in alphabetical order). Taxa marked with an asterisk (*) are shown in Figs 15–22.

Actinotodissus cf. *crassus* Löeblich *et* Tappan, 1978
Acanthodiacrodium sp.
Aremoricanium rigauae Deunff, 1955
Aremoricanium deflandrei Henry, 1969*
Baltisphaeridium annelieae (Kjellström) Bockelie *et* Kjellström, 1979 *Baltisphaeridium bramkaense* Górka, 1979
Baltisphaeridum calicispinae Górka, 1969*
Baltisphaeridium dasos Colbath, 1979*
Baltisphaeridium microspinosum Eisenack, 1954
Baltisphaeridium multispinosum (Eisenack) Eisenack, 1969*
*Baltisphaeridium lancettispinae*Górka, 1969*
Baltisphaeridum longispinosum (Eisenack), Staplin *et al.*, 1965
Baltisphaeridum pachyacanthum Eisenack, 1965
Baltisphaeridum plicatispinae Górka, 1969*
Baltisphaeridum podboroviscensis Górka, 1969*
Baltisphaeridium pseudocalcispinum Górka, 1980
Baltisphaeridium ritvae Kjellström, 1971
Baltisphaeridium cf. *heizelinii* Stckmans et Williere, 1969*
Baltisphaeridium cf. *nanninum* Eisenack, 1965*
Baltisphaeridum cf. *varsoviensis* Górka, 1969*
Baltisphaeridium cf. *trabeculaespinae* Górka, 1969*
Baltisphaeridum sp.*
Cymatiosphaera cf. *canadensis* Deunff, 1954
Cymatiosphaera sp.*
Cymatiogalea sp.
Dactylophusa cf. *ctenista* (Löeblich) Sarjeant *et* Stancliffe, 1994*
Diexallophasis remota (Deunff) Playford, 1977
Domasia sp.*
Dorsenidium cf. *undosum* Wicander *et al.*, 1999*
Exculibrachium cf. *concinnum* Löeblich *et* Tappan, 1978*
?Frankea cf. *sartbernardensis* (Martin) Colbath, 1986
Goniosphaeridium connectum Kjellström, 1971
*Goniosphaeridium gracile*Vavrdova, 1966*
Goniosphaeridium mochtiense (Górka) Kjellström, 1971
Goniosphaeridium cf. *christianii* Kjellström, 1976*
Goniosphaeridium sp.*
Gorgonisphaeridium cf. *frequens*Górka, 1987*
Gorgonisphaeridium sp.
Gyalorhetium sp.*
Leiosphaerids
Leiofusa cf. *fusiformis* (Eisenack) Eisenack, 1938
Liliosphaeridium cf. *kaljoi* Uutela *et* Tynni, 1991*
Lophosphaeridium sylvanium Playford et Wicander, 2006*
Micrhystridium stellatum Deflandre, 1945
Micrhystridium sp.*
Multiplicisphaeridium bifurcatum Staplin *et al.*, 1965*
Multiplicisphaeridium irregulare Staplin *et al.*, 1965*
Multiplicisphaeridium cf. *cornigerum* Uutela *et* Tynni, 1991*
Multiplicisphaeridium cf. *raspa* (Cramer) Eisenack *et al.*, 1973
Multiplicisphaeridium cf. *ramusculosum* (Deflandre) Lister, 1970
Multiplicisphaeridium sp.
Micrhystridium sp.*
Navifusa ancepsipuncta Löeblich, 1970*
Navifusa cf. *punctata* Löeblich *et* Tappan, 1978
Navifusa sp.*
Ordovicidium elegantulum Tappan *et* Löeblich, 1971*
Ordovicidium heteromorphicum (Kjellström) Löeblich *et* Tappan, 1978*
Ordovicidum nudum (Eisenack) Löeblich *et* Tappan, 1978*
Ordovicidium cf. *nanofurcatum* (Kjellstrom) Uutela *et* Tynni, 1991
Ordovicidium sp.*
Orthosphaeridum vibrissiferum Löeblich *et* Tappan, 1978*
Orthosphaeridum cf. *insculptum* Löeblich, 1970*
Orthosphaeridum cf. *rectangulare* Eisenack, 1963
Orthosphaeridium sp.*
Pachysphaeridium robustum (Eisenack) Fensome *et al.*, 1990*
Pachysphaeridium sp.*
Peteinosphaeridium accinctulum Wicander *et al.*, 1999*
Peteinosphaeridium trifurcatum (Eisenack) Staplin *et al.*,1965*
Peteinosphaeridium velatum Kjellström, 1971*
Peteinosphaeridium cf. *bergstroemii* Staplin *et al.*, 1965*
Peteinosphaeridium cf. *micranthum* (Eisenack) Eisenack *et al.*, 1973
Peteinosphaeridium sp.
Polonosphaeridium francinae (Górka) Górka,1987*
Polygonium gracile (Vavrdova) Sarjeant *et* Stancliffe, 1994*
Polygonium cf. *polyacanthum* (Eisenack) Sarjeant *et* Stancliffe, 1994
Polygonium sp.
Pterotoshaerula sp.
Solisphaeridium sp.*
Tyllignasoma sp.
Veryhachium lairdi (Deflandre) Deunff 1954 ex. Löeblich, 1970
Veryhachium reductum (Deunff) Downie *et* Sarjeant, 1965
Veryhachium trispinosum (Eisenack) Stockmans *et* Willičre, 1962 group
Veryhachium cf. *augustum* Deunff, 1977
Veryhachium cf. *hamii* Loeblich, 1970
Veryhachium cf. *oklahomense* Löeblich, 1970
Veryhachium cf. *subglobosum* Jardinié *et al.*, 1974
Veryhachium sp.*
Villosacapsula irrorata (Löeblich *et* Tappan) Fensome *et al.*, 1990
Villosacapsula sp.*
Vulcanisphaera cf. *imparilis* Rasul, 1976
Vulcanisphaera sp.

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