# Acritarch biostratigraphy of the Lower Cambrian and the Precambrian–Cambrian boundary in southeastern Poland

Małgorzata Moczydłowska

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# Acritarch biostratigraphy of the Lower Cambrian and the Precambrian–Cambrian boundary in southeastern Poland

MAŁGORZATA MOCZYDŁOWSKA

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Acritarchs in the sedimentologically continuous, shallow-marine, Upper Vendian – Lower Cambrian subsurface sequence of the Lublin Slope, East European Platform (EEP), Poland are abundant and well-preserved. Forty-five form-species were recovered, and their taxonomic status is revised. Three new form-genera are erected. *Asteridium* n.gen. and *Heliosphaeridium* n.gen. include species with solid and hollow processes, respectively, previously referred to *Micrhystridium* Deflandre. *Globosphaeridium* n.gen. includes acritarchs with solid processes formerly attributed to *Baltisphaeridium* Eisenack. The genus *Skiagia* is emended. Microfossil preservation yields information on the thermal history of the Lublin basin. The acritarch succession in the Lublin Slope forms the basis for a new Lower Cambrian zonation, in ascending order the *Asteridium tornatum – Comasphaeridium velvetum, Skiagia ornata – Fimbriaglomerella membranacea, Heliosphaeridium dissimilare – Skiagia ciliosa*, and *Volkovia dentifera – Liepaina plana* Assemblage-zones. A significant radiation at the upper part of the Włodawa Formation and within the Mazowsze Formation involves taxa of the *Asteridium tornatum – Comasphaeridium velvetum* assemblage taken to mark the Precambrian–Cambrian boundary. The Kaplonosy IG-1 drillcore is proposed as reference section for the boundary. The Upper Vendian – Lower Cambrian biostratigraphy in Poland is revised. The *Sabellidites–Vendotaenia* Interval-zone is proposed, the range of the *Platysolenites antiquissimus* Zone is revised, and the *Holmia kjerulfi* Assemblage-zone is recognized. The *Protolenus* zone remains as an informal zone. Parts of the investigated sequence are correlated with the *Schmidtiellus mickwitzi* Zone elsewhere. The early Cambrian *Mobergella* Zone and the Klimontovian Stage are rejected. The Precambrian–Cambrian boundary is discussed in light of acritarch evidence from sequences in the East European, Baltoscandian, Siberian, South China and Avalon Platforms. The acritarch zone contemporaneous with the earliest trilobite zone in the Baltoscandian Platform and the EEP embraces part of the Tommotian and Meishucunian strata in Siberia and China. Units underlying the Tommotian in Siberia may be Cambrian. Lower Cambrian rocks of the EEP, the Baltoscandian Platform, and the Scandinavian Caledonides, are correlated on the basis of acritarchs. ☐*Acritarchs, cyanobacteria, microfossils, micropalaeontology, biostratigraphy, thermal alteration, organic matter, Precambrian–Cambrian boundary, Upper Proterozoic, Lower Cambrian, Poland, Lublin Slope, East European Platform.*

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# Introduction

The biotic changes near the Proterozoic–Cambrian boundary attracted the early inquiry of palaeontologists and geologists (Darwin 1859; Linnarsson 1871, 1876; Walcott 1890; Lapworth 1891; Matthew 1899). The observed changes are particularly concerned with the abrupt appearance of fully developed skeletons in sponges and most coelomate phyla. The last two decades of research have generated new insight into the complexity of the basic questions to be asked regarding this momentous event in the evolution and diversification of life on the planet (Towe 1970, 1981; Stanley 1976; Brasier 1979, 1982; Sepkoski 1979; Valentine 1980; Lowenstam 1980; Lowenstam & Margulis 1980; Runnegar 1982; Lovelock & Whitfield 1982; Glaessner 1983, 1984; Seilacher 1984; Valentine & Erwin 1987; Bergström 1989). However, the answers to these questions are totally dependent on a reliable timing of the events concerned.

Micropalaeontology has undergone intensive development since the late fifties and new techniques have become available that are applicable to the investigation of early life. Studies of marine phytoplankton pioneered by Eisenack (1931, 1932, 1934, 1937, 1938), O. Wetzel (1933) and Deflandre (1935, 1937) were applied by Naumova (1949, 1956, 1960) and Timofeev (1956, 1959, 1966, 1969, 1973) to the study of Proterozoic and early Cambrian strata in the East European Platform. The early results revealed a wealth of microbial fossils and paved the path to be followed by subsequent studies (Volkova 1962, 1964, 1965, 1968, 1969a, b, 1974a, b, c, 1976, 1985; Jagielska 1966a; Ważyńska 1967; Kirjanov 1968, 1969, 1974; Fridrichsone 1971; Umnova & Vanderflit 1971; Jankauskas 1972, 1974, 1975, 1976; Jankauskas & Posti 1976; Volkova *et al.* 1979, 1983).

The cysts, walls, and/or envelopes of prokaryotic and eukaryotic phytoplankton are abundant and widely distributed in Proterozoic and early Palaeozoic marine sedimentary rocks. Under certain conditions they accumulated in enormous numbers in sediments that formed in a wide range of depositional environments. The palaeobiology of these most abundant fossils is at an initial stage of understanding. It is, however, clear that they formed the basic link of increasingly complex trophic chains near the Proterozoic–Palaeozoic boundary. The basically poor understanding of the taxonomic affinity of the early fossil phytoplankton is reflected in its treatment under a provisional taxonomic category: the Group Acritarcha (Evitt, 1963).

During the last three decades or so an increasing number of studies have resulted in a considerably improved knowledge of the stratigraphic and palaeoenvironmental distribution of these microfossils (Downie 1960, 1973, 1974, 1982; Downie *et al.* 1961, 1963; Downie & Sarjeant 1963; Staplin *et al.* 1965; Sarjeant 1967; Vanguestaine 1967, 1974, 1978; Jux 1968, 1969a, b, 1971; Kjellström 1968, 1971; Górka 1969; Loeblich & Tappan 1969, 1976, 1978; Loeblich 1970; Tappan 1971, 1980, 1986; Tappan & Loeblich 1971a, b, 1973; Martin 1972, 1975, 1982, 1984; Eisenack *et al.* 1973, 1976, 1979a, b; Konzalová 1974b; Vavrdová 1974; 1982; Vidal 1974, 1976b, 1979b, 1981a, b, c, 1983a, b, 1985, 1990; Rauscher 1974; Wicander 1974, 1983, 1986; Wicander & Loeblich 1977; Fombella 1978, 1986, 1987; Martin & Dean 1981, 1983, 1984, 1988; Knoll 1981, 1982a, b, 1984, 1985; Knoll *et al.* 1981; Playford 1981; Colbath 1983; Playford & Martin 1984; Knoll & Swett 1985, 1987; Welsch 1986).

Numerous drillcores documented the continuous character of the siliciclastic sequence underlying the Lublin Slope of the EEP, motivating the present study. Furthermore, from the drillhole documentations and available publications it was evident that the existing combination of lithofacies was suitable for the preservation of organic-walled microfossils. Hence, it was expected that a rather complete record of planktic plant protists could be recovered across the critical interval of the Precambrian–Cambrian transition.

Studies of late Proterozoic and early Cambrian organic-walled microfossils in the southwestern sector of the EEP in Poland were initiated by Jagielska (1966a, b,) and Volkova (1969a, b, 1972, 1973). They reported acritarchs at a number of levels in the Lower Cambrian of the Kaplonosy IG-1 and Radzyń IG-1 drillholes. The present investigation has demonstrated that acritarchs are abundant in sequences of the Terebiń IG-5, Łopiennik IG-1 and Parczew IG-10 drill-

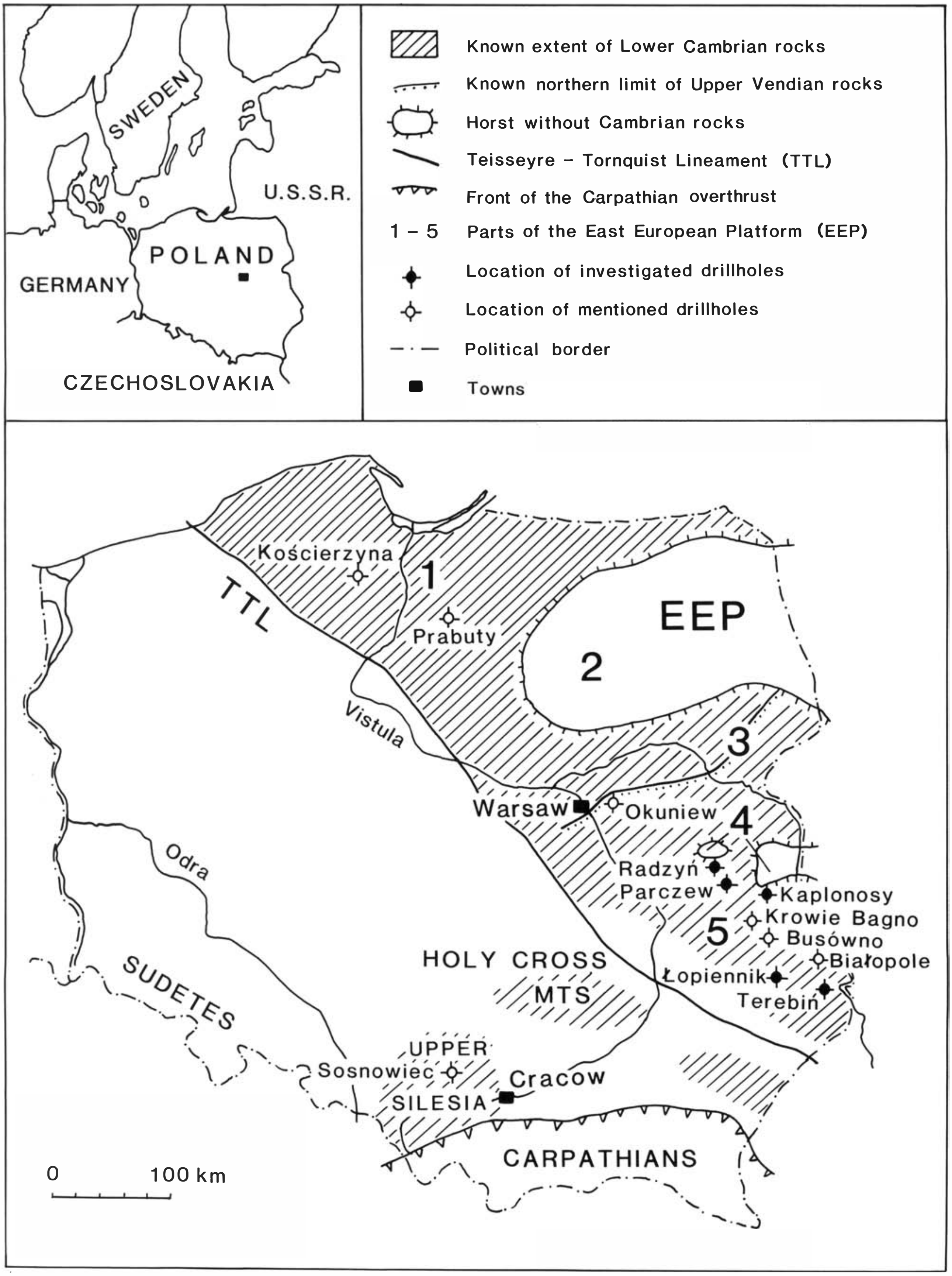

*Fig. 1.* Geological sketch-map of Poland showing the extent of Lower Cambrian deposits (subsurface and outcrop). EEP stands for the East European Platform and its tectonic units: 1 Baltic Syneclise, 2 Mazury–Byelorussia Anteclise, 3 Podlasie Depression, 4 Łuków–Wisznice Horst, 5 Lublin Slope. Modified after Pożaryski *et al.* 1981, Lendzion 1983a, Kowalczewski *et al.* 1984.

holes. The presence of acritarchs was also demonstrated in the Kaplonosy IG-1 and Radzyń IG-1 drillcores at depths previously not investigated by Jagielska and Volkova. Their taxonomic diversification and stratigraphic distribution made possible the acritarch-based subdivision of the Lower Cambrian strata and recognition of the Precambrian–Cambrian boundary in this area.

# Geological setting

## General geology

The Lublin Slope is part of the western margin of the East European Platform (Fig. 1) and is limited to the southwest by the Teisseyre–Tornquist Lineament (TTL) (Żelichowski 1972; Guterch 1977; Pożaryski 1977a, c; Pożaryski *et al.* 1982; Znosko 1979, 1984). Its northern and eastern limits are defined by the Łuków–Wisznice Horst and the Ukrainian Shield (Areń 1974, 1978; Areń *et al.* 1979b). The crystalline basement of the platform was consolidated during the Svecofennokarelian (Svecofennian) and Gothian orogenies (Ryka 1970, 1984; Kubicki *et al.* 1972; Znosko 1979, 1984; but concerning the Svecofennian and Gothian orogenies see Lundqvist 1979; Gorbatschev 1980; Gaál & Gorbatschev 1987). In the Lublin Slope region, peneplained crystalline basement is overlain by a sedimentary cover attaining a maximum thickness of more than 5600 m (Ryka 1970, 1984; Juskowiakowa 1974; Kubicki & Ryka 1982; Żelichowski 1976).

The sedimentary cover comprises deposits ranging in age from late Proterozoic (late Riphean) to Quaternary and contains numerous sedimentation breaks (Znosko 1972a, 1974, 1984; Żelichowski 1972; Juskowiakowa 1974; Areń 1974, 1978; Łaszkiewicz 1974). Rocks of the sedimentary cover are flat-lying and have escaped substantial metamorphism (Lendzion 1968a, 1970a, 1983a; Żelichowski 1972; Juskowiakowa 1974, 1978; Areń & Lendzion 1978; Jaworowski 1978). They are dissected by faults striking in directions generally perpendicular and parallel to the TTL, and the resulting step-wise down-faulted blocks plunge towards the TTL.

The Lublin Slope constitutes the distal part of the Volhynian aulacogen (Pożaryski 1963, 1977a; Pożaryski & Kotański 1979; Znosko 1966, 1979, 1984; Ryka 1970, 1984; Kubicki *et al.* 1972; Areń 1974, 1978; Areń *et al.* 1979b) and has been alternatively regarded as an aborted rift (Guterch 1977; Moczydłowska 1988b). The Volhynian aulacogen is part of the extensive system of subsiding basins developed over the total extension of the EEP during late Riphean and Vendian times (Aksenov *et al.* 1978).

Subsidence within the Lublin Slope established a marine basin during late Vendian and early Cambrian times which accumulated detrital deposits attaining a thickness exceeding 800 m (Pożaryski 1977a; Areń & Lendzion 1978; Jaworowski 1978, 1980; Juskowiakowa 1978; Areń *et al.* 1979b; Lendzion 1983a; Znosko 1984). The lowermost part of the sedimentary cover overlying the Proterozoic crystalline basement consists of terrigenous and volcanogenic deposits belonging to the Upper Riphean, Vendian, and Lower–Middle Cambrian (Lendzion 1962, 1968a, b, 1983a; Juskowiakowa 1971, 1974, 1978; Rydzewska 1974; Areń & Lendzion 1978; Jaworowski 1978; Wichrowska 1978).

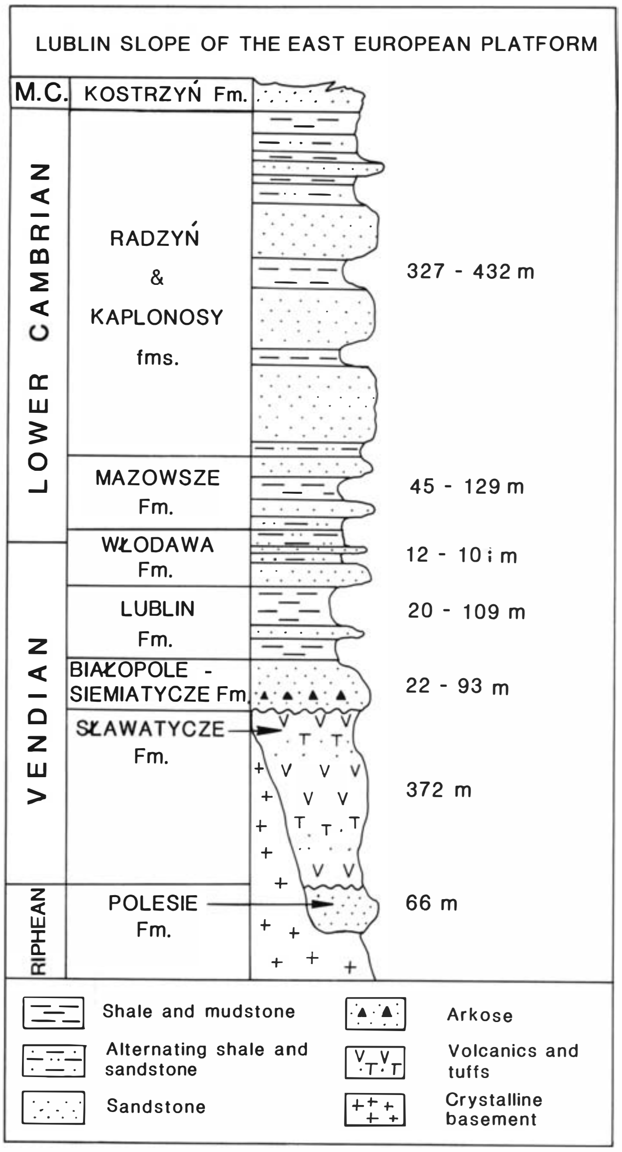

*Fig. 2.* Generalized lithostratigraphic section of the Riphean – Lower Cambrian sequence in the Lublin Slope. Modified after Juskowiakowa 1974 and Lendzion 1983a.

## Lithostratigraphy

In stratigraphic ascending order, the lowermost part of the sedimentary cover underlying the Lublin Slope comprises the Polesie, Sławatycze, Siemiatycze or Białopole (probably coeval formations), Lublin, Włodawa, Mazowsze, Kaplonosy, Radzyń and Kostrzyń Formations (Lendzion 1962, 1968a, b, 1983a, b, 1986; Areń & Lendzion 1974a, 1978; Mens *et al.* 1987, 1990; Fig. 2). The oldest deposits attain a thickness of 66 m and belong to the Polesie Formation which consists of fine-grained, equigranular sandstones and interbedded mudstones. On the basis of sedimentological evidence, rocks of the Polesie Formation were regarded as continental or continental–lagoonal deposits (Lendzion 1968a; Areń 1974; Juskowiakowa 1974). The

Polesie Formation rests with profound unconformity on the Proterozoic crystalline basement and has a very limited distribution in the Lublin Slope (drillcores Kaplonosy IG-1 and Busówno IG-1; Lendzion 1968a; Juskowiakowa 1974; Areń & Lendzion 1978). This unit appears to have accumulated in depressions on the crystalline basement during the initial opening of the Volhynian aulacogen (Areń 1974; Pożaryski 1977a; Znosko 1984) or aborted rift (Moczydłowska 1988b). A late Riphean age has been attributed to the Polesie Formation (Areń & Lendzion 1978). However, age data on this unit appear inconclusive, as isotopic dating of the extrusive lavas and tuffs in the overlying Sławatycze Formation and its correlatives in the U.S.S.R. is not definitely established.

The immediately overlying Sławatycze Formation is a complex unit consisting of basalts, tuffs and agglomerates, and it contains sandstones and conglomerates at the base. The unit has a maximum thickness of 372 m (Juskowiakowa 1971, 1974; Areń & Lendzion 1978). The Sławatycze Formation occupies a substantial area of the Lublin Slope. Volcanogenic rocks were penetrated only in the drillings Kaplonosy IG-1 and Busówno IG-1 (Fig. 1), where they rest disconformably on rocks of the Polesie Formation. At the sites of the Parczew IG-10 and Radzyń IG-1 drillholes, the Sławatycze Formation is missing and the crystalline basement is overlain by the immediately younger Siemiatycze Formation (Areń & Lendzion 1978). On uncertain grounds, mostly lithostratigraphic correlation with probably coeval units in the U.S.S.R., an early Vendian age has been attributed to the Sławatycze Formation (Areń & Lendzion 1978).

Younger units overlie either the crystalline basement (Parczew IG-10 and Radzyń IG-1 drillholes), or the volcanogenic rocks of the Sławatycze Formation. They comprise in ascending order the Siemiatycze or Białopole Formations, and the Lublin, Włodawa, Mazowsze, Kaplonosy and Radzyń Formations. These formations are regarded as Upper Vendian and Lower Cambrian (Areń 1978, 1982; Areń & Lendzion 1978; Lendzion 1983a, b). The Siemiatycze Formation consists of rocks that formed under continental depositional conditions and is transitionally succeeded by rocks formed under shallow-marine depositional conditions (Lendzion 1968a, b, 1983a; Juskowiakowa 1974; Areń 1978; Jaworowski 1978). A hiatus, attributed to possible epeirogenic uplift (Lendzion 1983a, b), was reported at the junction between the Lower Cambrian Mazowsze and Kaplonosy Formations (Lendzion *in* Areń & Lendzion 1978; Lendzion 1983a, b; Lendzion *in* Mens *et al.* 1987, 1990). The proposed hiatus is in disagreement with sedimentological data by Jaworowski (1978, 1980), who demonstrated continuous sedimentation during Białopole to Radzyń deposition times (Fig. 2). The Siemiatycze, Białopole and Lublin Formations were formerly regarded as late Vendian in age, whereas the overlying Włodawa, Mazowsze, Kaplonosy and Radzyń Formations were considered as early Cambrian (Lendzion 1968a, b, 1983a, b; Areń & Lendzion 1974b, 1978). More recently, however, micropalaeontological investigations have demonstrated that most of the Włodawa Formation is late Vendian in age. The Precambrian–Cambrian boundary was suggested at the base of the Mazowsze Formation (Moczydłowska & Vidal 1986, 1988a; Moczydłowska, 1988b) and subsequently adjusted to fall within the upper part of the Włodawa Formation (Moczydłowska 1988a, 1989).

The deposits of the Siemiatycze and Białopole Formations are regarded as laterally equivalent and thus probably contemporaneous (Areń 1978, 1982; Areń & Lendzion, 1978; Areń *et al.* 1979b; Lendzion 1983a). The Siemiatycze Formation occupies the northern part of the Lublin region and is represented in the Kaplonosy IG-1, Radzyń IG-1 and Parczew IG-10 drillcores, whereas deposits of the Białopole Formation occur in the southern part of the region and have been penetrated at the Krowie Bagno IG-1, Busówno IG-1, Białopole IG-1, Terebiń IG-5, and Łopiennik IG-1 drilling sites (Areń & Lendzion 1978; Areń 1982). In their respective areas of occurrence the units are widespread and generally rest on the volcanogenic rocks of the Sławatycze Formation. However, in drillholes Parczew IG-10 and Radzyń IG-1, the Siemiatycze Formation is found to rest on the crystalline basement (Areń & Lendzion 1978). The thickness of the Siemiatycze and Białopole Formations varies from 22 to 93 m (Juskowiakowa 1974; Areń & Lendzion 1978).

The Siemiatycze Formation consists of conglomerates, arkoses and feldspathic sandstones with intervening mudstones (Juskowiakowa 1974; Areń 1978, 1982; Areń & Lendzion 1978). The Białopole Formation consists of quartzitic sandstones (Areń 1978, 1982; Areń & Lendzion 1978). The feldspathic sandstones of the Siemiatycze Formation and the quartzitic arenites of the Białopole Formation were regarded to interdigitate laterally (Areń & Lendzion 1978; Areń 1982; Areń *et al.* 1979b; Lendzion 1983a). In the northern part of the Lublin Slope, sandstones of the Siemiatycze Formation are more feldspathic than in the southern part of the region. Moreover, the composition of sandstones of the Białopole Formation is more quartzitic in the southern part of the region, where rocks of this unit were shown to have a clayey matrix. Locally, the Białopole Formation contains intercalated mudstones and shales (Areń & Lendzion 1978; Areń 1982). In the Terebiń IG-5 drillhole (Appendix 9), however, the basal part of the unit consists of shales and mudstones. Deposits of the Siemiatycze Formation were interpreted as continental, alluvial and nearshore marine (Lendzion 1968a, 1983a; Juskowiakowa 1974; Areń 1978, 1982; Jaworowski 1978; Areń *et al.* 1979b; Wichrowska 1982). Deposits of the Białopole Formation were regarded as marine (Lendzion 1968a, 1983a; Areń 1978, 1982; Areń & Lendzion 1978; Jaworowski 1978; Wichrowska 1982). In the investigated sequence of the Lublin Slope, the Białopole Formation yielded the earliest recorded organic-walled microfossils consisting of cyanobacteria and acritarchs (Moczydłowska & Vidal 1986; Moczydłowska 1988b, 1989).

The immediately overlying Lublin Formation consists of shales, mudstones and sandstones attaining a thickness of 20–109 m. The dominant components of the unit are thinly laminated shales with intercalated thinly bedded mudstones and light-coloured quartzitic sandstones. The sandstones attain a greater thickness in the Parczew IG-10 drillcore (Areń & Lendzion 1978; Areń 1982). Vendotaenids are the only common fossils in rocks of the Lublin Formation (Areń & Lendzion 1978; Gnilovskaya 1979b, 1983; Lendzion 1983a, b) and form the basis for defining the *Vendotaenia* Zone (Lendzion 1983b). Furthermore, the Lublin Formation yielded the oldest known ichnofauna in the Lublin Slope, consisting of morphologically simple ichnofossils (Paczesna 1985, 1986). Fossil phytoplankton from this unit consists of cyanobacteria and simple spheromorphic acritarchs (Moczydłowska & Vidal 1986; Moczydłowska 1988b, 1989).

The transgressively overlying Włodawa Formation (Włodawa Member according to Lendzion 1983a, 1986, and Mens *et al.* 1987, 1990) consists of bimodal, occasionally glauconitic quartz sandstones which contain scattered phosphatic conglomerates, shales and micaceous mudstones. The thickness of the unit is variable over a range of 12–101 m (Areń & Lendzion 1978; Areń 1982). Here, the name Włodawa Formation is used for the part of the sequence identified as the Włodawa Formation by Areń & Lendzion (1978). The status of the unit was modified by Lendzion (Lendzion 1983a, 1986; *in* Mens *et al.* 1987, 1990). The name Włodawa Member was used for deposits underlying the Mazowsze Formation (Lendzion 1983a). However, the depth intervals in the selected drillhole sections were not specified, and Lendzion (1983a) did not indicate which formation the Włodawa Member was referred to. Later, the Włodawa Member was referred to the lower part of the Mazowsze Formation in the section of the Łopiennik IG-1 drillhole, although no information was provided regarding the depth interval comprising the unit in the drillhole (Lendzion 1986). More recently, a stratotype was proposed for the Włodawa Member or Włodawa Subformation (sic! Lendzion *in* Mens *et al.* 1987, p. 40, and chart; Mens *et al.* 1990) which was also regarded as equivalent to the Włodawa Formation (*sensu* Areń & Lendzion 1978). Thus, without further motivation the status of the unit was modified to become part of the Mazowsze Formation. Furthermore, Lendzion *in* Mens *et al.* (1987, 1990) erroneously attributed this change of status to Lendzion 1983 (1983a? b?).

Rocks of the Włodawa Formation have yielded vendotaenids, organic-walled tubular fossils attributed to *Sabellidites*, and – in the uppermost part – the first recorded skeletal fossils attributed to *Platysolenites*, *Onuphionella*, *Aldanella* and *Anabarella* (Lendzion 1977, 1983a, b, c; Areń & Lendzion 1978). Rocks of the Włodawa Formation were referred to the *Sabellidites* Zone, taken as the earliest zone of the Cambrian Period (Areń & Lendzion 1978; Lendzion 1983a, b). Alternatively, the Włodawa Formation was regarded as Vendian (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, b, 1989). The Włodawa Formation yielded a depauperate assemblage of trace fossils including *Planolites* (Paczesna 1986). A phytoplankton assemblage recovered from this unit does not differ from the taxonomically simple assemblage recorded in the Proterozoic Lublin Formation (Volkova 1969a, 1973; Moczydłowska & Vidal 1986; Moczydłowska 1989). However, in the drillcores Łopiennik IG-1, Parczew IG-10 and Kaplonosy IG-1, the uppermost part of the Włodawa Formation yielded the earliest recorded specimens of acritarch taxa characteristic of the basal Cambrian and found in the overlying Lower Cambrian Mazowsze Formation (Moczydłowska & Vidal 1986; Moczydłowska 1988a, 1989).

The conformably overlying Mazowsze Formation consists of shales and mudstones intercalated with glauconitic sandstones. Occasional phosphatic concretions occur in the lower part of the unit (Areń & Lendzion 1978). The total thickness of the formation ranges from 45 to 129 m (Areń & Lendzion 1978; Lendzion 1983a). The Mazowsze Formation yielded *Platysolenites*, *Onuphionella*, *Coleolella* and *Torellella* and has been referred to the *Platysolenites* Zone (Areń & Lendzion 1978; Lendzion 1983a, b). Trace fossils from the Mazowsze Formation are diverse and comprise numerous ichnospecies now considered to be diagnostic of the Lower Cambrian and higher levels (Paczesna 1986). Acritarchs from this formation were first recorded by Jagielska (1966a), who described exclusively spheromorphic, non-diagnostic forms. Later Volkova (1969a, b) recovered an assemblage comparable to a previously reported acritarch assemblage from the Lower Cambrian Lontova 'horizon' in Estonia (Volkova 1969b, 1973). Simple, spherical and tubular cyanobacteria and more lavishly ornamented acritarchs were reported by Moczydłowska & Vidal (1986) and Moczydłowska (1988a, 1989), who considered that the acritarchs represent a radiation of distinctive planktic protists. This conspicuous event was considered to mark the Precambrian–Cambrian boundary in the investigated area (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989).

The Mazowsze Formation is conformably overlain by rocks attributed to the Kaplonosy formation. The latter is in turn conformably overlain by the Radzyń formation (Jaworowski 1978, 1980). The Kaplonosy and Radzyń formational concepts were first introduced by Lendzion (1962). However, no stratotypes were established and depth figures for the units were not indicated (cf. Lendzion 1962, 1968b; Areń & Lendzion 1978; Lendzion 1983a). The boundary between the Kaplonosy and Radzyń formations was indicated only in the drillcores Kaplonosy IG-1 and Radzyń IG-1, but discrepant depth figures were provided in papers by Lendzion (1969b, 1972a). Subsequently, the boundary between two units was either not mentioned or subjected to modifications (Areń & Lendzion 1978; Lendzion 1983a, b). More recently (Lendzion *in* Mens *et al.* 1987, 1990), stratotypes for the units were proposed in the Kaplonosy IG-1 and Radzyń IG-1 drillcores, making reference to Lendzion (1962). However, because the units had no previously defined lithologic boundaries they were evidently invalidly introduced by Lendzion (1962). Nevertheless, deposits underlying the 'Kaplonosy Formation' had not yet been drilled through at the time of publication of Lendzion's 1962 report and were therefore unknown at the time (cf. Lendzion 1962, Fig. 1). This circumstance evidently impeded establishing the base of the formation. Both formations (Kaplonosy and Radzyń) were defined on the basis of biostratigraphic evidence rather than on lithological criteria (Bednarczyk 1986). For this reason, possibly time equivalent deposits occurring in the Baltic Syneclise were included in a single unit, the Łeba Formation (Bednarczyk & Turnau-Morawska 1975; Bednarczyk 1986).

| Drillcore<br>Formation | TEREBIŃ IG-5 | ŁOPIENNIK IG-1 | PARCZEW IG-10 | KAPLONOSY IG-1 | RADZYŃ IG-1 | Number of samples within formation |
|---|---|---|---|---|---|---|
| RADZYŃ & KAPLONOSY | 8 +3 -5 | 26 +24 -2 | 16 +15 -1 | 12 +6 -6 | 13 +12 -1 | 75 +60 -15 |
| MAZOWSZE | 10 +6 -4 | 16 +12 -4 | 28 +18 -10 | 14 +13 -1 | 8 +8 0 | 76 +57 -19 |
| WŁODAWA | 3 +3 0 | 14 +14 0 | 8 +17 -1 | 5 +5 -0 | 3 +1 -2 | 33 +30 -3 |
| LUBLIN | 24 +7 -17 | 12 +11 -1 | 18 +7 -11 | 11 +10 -1 | 6 +5 -1 | 71 +40 -31 |
| BIAŁOPOLE | 12 0 -12 | 5 0 -5 | 0 | 0 | 0 | 17 0 -17 |
| Number of samples within drillcore | 57 +19 -38 | 73 +61 -12 | 70 +47 -23 | 42 +34 -8 | 30 +26 -4 | Total number 272 +187 -85 |

*Fig. 3.* Frequency table of fossiliferous samples in the investigated drillcores. Figure on the left side of each column indicates the total number of examined samples. The plus symbols indicate the number of acritarch productive samples; the minus symbols indicate barren samples and/or samples yielding only cyanobacterial microfossils.

Neither the top of the Kaplonosy formation nor the bottom of the Radzyń formation have been established in the drillcore sequences under discussion, other than Kaplonosy IG-1 and Radzyń IG-1 drillholes. Thus the units are poorly defined. Because of this confusing situation Moczydłowska & Vidal (1986, 1988a) referred the rock sequence embraced by the two units to a single composite unit (the Kaplonosy and Radzyń formation). However, double formation names are recommended only for laterally homogeneous lithostratigraphic units (Hedberg 1976), not to be applied to stratigraphically successive units. Accordingly, the lithologic units under discussion were lately treated as informal Kaplonosy formation and Radzyń formation (Moczydłowska 1989; Fig. 2).

Generally, the accumulated thickness of the two units ranges from 327 to 432 m. However, in the drillhole Podedwórze IG-2, located at the border of the Łuków–Wisznice Horst (Fig. 1), the two units attain a total thickness of only 5 m (Lendzion 1983a). The Kaplonosy formation consists of quartzitic sandstones interbedded with shales and mudstones, whereas the Radzyń formation is made up of alternating mudstones, shales and glauconitic sandstones (Areń & Lendzion 1978; Lendzion 1983a, b). In the Lublin area, both units yielded fossils referred to *Torellella*, *Hyolithellus*, *Volborthella*, *Lingulella* and *Westonia*, fossils that elsewhere are diagnostic of a Cambrian age. The most important index fossils are trilobites, which appear for the first time in the Kaplonosy formation (Areń & Lendzion 1978). The recorded trilobites belong to *Schmidtiellus*, *Holmia*, *Strenuaeva*, *Ellipsocephalus* and *Kingaspis* (Areń & Lendzion 1978; Lendzion 1983a, b, c). Rocks of the Kaplonosy and Radzyń formations were referred to the *Holmia* and *Protolenus* Zones (Areń & Lendzion 1978; Lendzion 1983a, b). Both zones were considered to occur in the Lublin Slope (Areń & Lendzion 1978; Lendzion 1983a, b), but their ranges were only indicated in the Kaplonosy IG-1 and Radzyń IG-1 drillcores (Lendzion 1969a, b, 1972a; Areń & Lendzion, 1978). However, even for these drillcores Lendzion (1969a, b, 1972a) and Areń & Lendzion (1978) provided discrepant or conflicting information concerning the depths of the strata embraced by the zones. Thus, these units are still to be considered as informal.

Acritarchs from the Kaplonosy and Radzyń formations form assemblages comparable to those recorded from the Talsy, Vergale and Rausve 'horizons' (acritarch bio-units) in the U.S.S.R. part of the EEP (Volkova 1969a, 1973; Volkova *et al.* 1979, 1983; Moczydłowska 1981, 1988a, 1989; see 'Acritarch-based correlation of the Lower Cambrian'; Fig. 10).

The above mentioned Lower Cambrian units are conformably overlain by the Kostrzyń Formation which consists of quartzitic sandstones. The formation is attributed to the Middle Cambrian *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones (Lendzion 1983a; Mens *et al.* 1987, 1990).

# Material and methods

The material dealt with in the present investigation consists of drillcore samples deriving from research and prospecting deep drillholes in the Lublin region in southeastern

Poland (Fig. 1). The cores most suitable for the preservation of acid-resistant microfossils and with the most complete core recovery (some of them 100%; see Appendices 6–10) were selected. Samples from major beds and intercalations of shales, mudstones and siltstones, generally amounting to about 500 g of rock, were collected (Appendices 6–10). The samples were not taken at pre-established intervals, and their number was only determined by the state of preservation and completeness of the drillcores. Strongly bioturbated and slumped intervals, which may result in mixed or reworked microfossil assemblages, were avoided during the course of the sampling. Samples were processed using conventional palynological techniques (cf. Gray 1965; Phipps & Playford 1984; Vidal 1988). After maceration in HCl and HF, repeated rinsing in distilled water, and ensuing decantation, microfossils were extracted by flotation in a solution of cadmium iodide and potassium iodide ($CdJ_2$+KJ). Centrifugation was applied in connection with flotation. Oxidizing agents ($HNO_3$ and Shultze solution) were used only after the colour of organic residues had been observed.

A total of 272 samples were examined, 187 of which yielded acritarchs (Fig. 3). Additional fossiliferous samples, containing presumably cyanobacterial microfossils, derive from the Białopole Formation and in particular the Lublin Formation (not accounted for in Fig. 3). The number of acritarch specimens in the discrete strew mounts varied from only a few to several hundred specimens. Occasionally, more than one thousand specimens were recorded on a single slide. More than 35 000 specimens of acritarchs were identified. Microfossils were inbedded in sealed semipermanent mounts using glycerol jelly as a mounting medium. A transmitted light microscope (Leitz Wetzlar Dialux 20) provided with an interference contrast attachment was routinely used. Micrographs were taken under interference contrast with a ×100 oil-immersion lens, using Leitz Vario Orthomat micrography equipment. The location of specimens in the microscopic slides were recorded using an England Finder. Figured specimens are kept in the collections of the Geology Department, University of Lund.

## Taphonomy, state of preservation and thermal history

The geologic history of sedimentary basins is reflected by (and may be partly inferred from) the state of preservation of buried organic matter. After burial, organic matter gets involved in complex organic–inorganic interactions that influence the diagenetic and geochemical processes which shape the diagenetic fate of sedimentary rocks (Gautier 1986). The amount of organic matter preserved in sediments depends on the organic productivity and preservation potential of organic matter in a sedimentary basin. Anoxic environments are favourable for the preservation of organic matter in sediments (Tissot 1977; Tissot & Welte 1978; Brooks 1981; Selley 1985).

Late Proterozoic and early Cambrian marine ecosystems were taxonomically substantially impoverished in comparison with more diverse modern ecosystems. However, during the late Proterozoic and early Cambrian the area covered by continental shelves was enlarged through the breakup of the late Proterozoic supercontinent (Piper 1985; Kumpulainen & Nystuen 1985), thus resulting in expanded global productivity in the oceans (Knoll 1982c). The ensuing transgressive event(s) during early Cambrian times (Brasier 1982, 1985) might have resulted in an increase of the area and volume of the shallow epicontinental sea habitats (Riding 1982; Surlyk 1980), thus resulting in further increased productivity.

Extrapolating actualistic models back in time meets difficulties particularly concerning the interpretation and reconstruction of ancient basins. However, studies of phytoplankton may be very useful for any estimation of biological productivity even for very early segments of Earth history (Tappan 1968, 1986; Tappan & Loeblich 1970, 1971a, 1982; Hofmann 1976; Tappan 1976; Vidal 1976a, 1983a; Horodyski 1980; Knoll 1981, 1982c, 1985; Jankauskas 1982, 1989; Vidal & Knoll 1983; Selley 1985).

Organic-walled phytoplanktic microfossils from the Upper Vendian and Lower Cambrian deposits in the Lublin region are referred to the acritarchs and generally display a good state of preservation. Their processes, outer membranes, and additional wall sculpture elements are usually well preserved. Part of the recovered microfossils are corroded or may display impressions and pyrite framboids and pseudomorphs (cf. Neves & Sullivan 1964; Volkova 1964; Vidal 1974). The effects of corrosion are clearly visible on the surfaces of spheromorphs attributed to *Leiosphaeridia* sp. (Pls 12A, B, C, E; 13A, B). They are particularly evident on microfossils from deposits underlying the Kaplonosy formation (Fig. 2). Imprints of pyrite pseudomorphs are observed on the walls of acritarchs and on unidentifiable fragments of organic matter (Pls 13H; 15H) deriving from sandstone, mudstone and shale lithofacies from all investigated stratigraphic units.

In certain samples, specimens of acritarchs showing different stages of degradation were observed to co-occur. In numerous instances wall ornamentation and processes were preserved despite partial wall corrosion. These features, taken together, may indicate that the variable stages of preservation could be ascribed to pre-burial conditions. However, palynological samples are bulk samples that may comprise repeated generations of cyst production accumulating under substantially variable environmental and burial conditions. This may also explain the mixed states of preservation observed on acritarchs from the same sample.

Similar conditions of preservation of organic-walled microfossils were attributed by Vidal & Siedlecka (1983) to redeposition in a tidal flat environment. This interpretation may be applicable to the present material as well, since corroded and well-preserved specimens co-occur in various parts of the Mazowsze Formation in the Kaplonosy IG-1 and Radzyń IG-1 drillholes. Further evidence derives from sedimentological data indicating that the Lublin Slope was a shallow epicontinental basin, possibly even occupying the

| DRILLHOLE / FORMATION | O.M. COLOUR | T.A.I. | PALAEO-TEMPERATURE | LITHO-GENESIS | T. P. B. | DEPTH [m] |
|---|---|---|---|---|---|---|
| **TEREBIŃ IG-5** | | | | | | |
| KAPLONOSY & RADZYŃ | YELLOW-ORANGE | 2 | 50° – 100° | PK | 80° - 90° | 3209.5 – 3583.0 |
| MAZOWSZE | ORANGE - BROWN | 2-3 | 50° – 150° | PK | 90° - 91° | 3583.0 - 3660.0 |
| WŁODAWA | BROWN | 3 | 100°- 150° | PK | 91° - 92° | 3660.0 - 3671.8 |
| LUBLIN | BROWN | 3 | 100°- 150° | PK | 92° - 94° | 3671.8 – 3781.0 |
| SIEMIATYCZE-BIAŁOPOLE | BROWN | 3 | 100°- 150° | PK | 94° - 95° | 3781.0 – 3832.5 |
| **ŁOPIENNIK IG-1** | | | | | | |
| KAPLONOSY & RADZYŃ | ORANGE -BROWN | 2 - 3 | 50°-150° | PK | 118°-130° | 4742.0-5192.0 |
| MAZOWSZE | ORANGE -BROWN | 2 - 3 | 50°-150° | PK | 130°-132° | 5192.0 -5302.0 |
| WŁODAWA | BROWN - DARK BROWN | 3 - 4 | 100°- 200° | MK | 132°-135° | 5302.0 - 5403.0 |
| LUBLIN | DARK BROWN | 4 | 150°- 200° | MK | 135°-137° | 5403.0 - 5474.4 |
| SIEMIATYCZE - BIAŁOPOLE | DARK BROWN | 4 | 150°- 200° | MK | 137°-140° | 5474.4 – 5567.3 |
| **PARCZEW IG-10** | | | | | | |
| KAPLONOSY & RADZYŃ | YELLOW | 1 | 0° - 50° | DG | 42°-51° | 1670.0 -2062.4 |
| MAZOWSZE | YELLOW-ORANGE | 1 - 2 | 30°- 100° | DG - PK | 51°- 54° | 2062.4-2175.7 |
| WŁODAWA | ORANGE - BROWN | 2 - 3 | 50°- 150° | PK | 54°- 56° | 2175.7 -2239.8 |
| LUBLIN | BROWN | 3 | 100°- 150° | PK | 56°-57° | 2239.8 - 2280.7 |
| SIEMIATYCZE-BIAŁOPOLE | — | — | — | — | — | 2280.7 - 2302.3 |
| **RADZYŃ IG-1** | | | | | | |
| KAPLONOSY & RADZYŃ | YELLOW | 1 | 0° - 50° | DG | 26°- 36° | 1067.8 - 1464.3 |
| MAZOWSZE | YELLOW-ORANGE | 1 - 2 | 30° - 100° | DG - PK | 36°- 40° | 1464.3 - 1593.7 |
| WŁODAWA | YELLOW-ORANGE | 1 - 2 | 30°- 100° | DG - PK | 40°- 41° | 1593.7 - 1625.4 |
| LUBLIN | YELLOW-ORANGE | 1 - 2 | 30°-100° | DG - PK | ~ 41° | 1625.4 - 1646.2 |
| SIEMIATYCZE - BIAŁOPOLE | — | — | — | — | — | 1646.2 - 1669.5 |
| **KAPLONOSY IG-1** | | | | | | |
| KAPLONOSY & RADZYŃ | YELLOW | 1 | 0° - 50° | DG | 22°- 30° | 888.2 -1215.6 |
| MAZOWSZE | YELLOW-ORANGE | 1 - 2 | 30°-100° | DG - PK | 30°- 34° | 1215.6 –1339.3 |
| WŁODAWA | YELLOW-ORANGE | 1 – 2 | 30°- 100° | DG - PK | ~ 34° | 1339.3 - 1352.8 |
| LUBLIN | YELLOW-ORANGE | 1 - 2 | 30°- 100° | DG - PK | 34° - 35° | 1352.8 - 1401.4 |
| SIEMIATYCZE-BIAŁOPOLE | — | — | — | — | — | 1401.4 -1439.3 |

*Fig. 4.* Observations on the thermal alteration of organic matter and inferred stages of lithogenesis in the transitional Upper Vendian – Lower Cambrian deposits in the Lublin Slope (after Moczydłowska 1988b). O.M. – organic matter; T.A.I. – thermal alteration index; T.P.B. – temperature of present burial. Lithogenesis according to Rovnina (1981): DG – diagenesis; PK – protokatagenesis; MK – mesokatagenesis. T.A.I. and palaeotemperature (°C) according to Hayes *et al.* (1983). T.P.B. – 2.5°C/100 m, according to Majorowicz (1982b).

tidal zone during Vendian and earliest Cambrian times (Jaworowski 1978).

Pyrite in association with microfossils commonly occurs in connection with substantial accumulation of organic matter. In the Lublin basin, mass accumulation of organic matter is associated with palynofacies with rich occurrences of cyanobacterial fragments, particulate organic matter, sapropel and acritarchs forming an organic 'mosaic' (Pl. 15G). The fragments of organic matter reach dimensions of several hundred micrometers. The mass occurrence of organic matter is stratigraphically well defined and particularly related to the Lublin Formation. However, minor levels of enrichment of particulate organic matter also occur in other investigated formations. Substantially reduced levels of bioturbation by detrital feeders in Lublin time can be inferred from the trace fossil record (Pacześna 1986). The absence or low level of bioturbation associated with this unit could be an additional parameter to be taken into consideration in terms of the preservation and final burial of organic matter. Indirectly, accumulation of organic matter was probably a result of mass blooms of algal protists, cyanobacteria and/or bacteria. After burial these underwent bacterial degradation and helped create reducing conditions in the oxygen minimum zone in the shallow-marine Lublin basin. Probably, in such environments, hydrogen sulphide ($H_2S$) generated by anaerobic sulphate-reducing bacteria recombined with iron ions to form pyrite (e.g. Schidlowski *et al.* 1983; Berner 1984; Selley 1985).

Besides diagenetic, purely mechanical and biochemical changes, the state of preservation of palynomorphs was also affected by the thermal development of the Lublin basin. The effect of thermal alteration on organic matter is reflected by irreversible colour changes. Thus, as condensation reactions proceed during the process of diagenesis, katagenesis or metagenesis (Tissot 1977), the colour of organic matter becomes increasingly darker. The 'maturation' of organic matter caused by thermal alteration depends on increasing depth of burial which is obviously closely related to increased pressure (Brooks 1981; Selley 1985) and to diastrophic processes.

The colour of acritarchs from the Upper Proterozoic and the Lower Cambrian formations varies from yellow to dark brown and displays certain differences between discrete formations (Moczydłowska & Vidal 1986; Moczydłowska 1988b; Fig. 4). Colour changes observed in particulate organic matter can be related to values of the thermal alteration index (TAI), ranging from 1 to 4 (according to the scale of Hayes *et al.* 1983). These TAI values correspond to the diagenesis, protokatagenesis and mesokatagenesis stages of lithogenesis (Rovnina 1981).

The recorded higher thermal alteration of organic matter in the Upper Proterozoic (Vendian) deposits (e.g. Białopole, Lublin and Włodawa Formations) in the Lublin region is probably the result of increased heat flow to the upper crust due to the opening of the aborted rift (Moczydłowska 1988b). The degree of maturation of organic matter is regarded as a direct indicator of the possibility for the occurrence and migration of hydrocarbons (Brooks 1981). The early stage of katagenesis which has affected the organic matter in the investigated deposits excludes the possibility for any significant amounts of hydrocarbons in Vendian and Lower Cambrian strata in the investigated sector of the Lublin Slope in the EEP (Majorowicz 1978b; Depowski & Majorowicz 1979; Majorowicz *et al.* 1983, 1984; Moczydłowska 1988b).

# Micropalaeontologic results

Detailed lists of microfossil species occurring in the investigated samples are shown in Appendices 1–5.

Seventeen samples from the Białopole Formation in the Terebiń IG-5 and Łopiennik IG-1 drillcores were examined (Fig. 3). Coeval deposits of the Siemiatycze Formation (Lendzion 1983a) from the Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1 drilling sites were not sampled because these rocks contain few shale and mudstone interbeds promising for the extraction of organic-walled fossils. Furthermore, the red sandstones of the Siemiatycze Formation do not reflect conditions suitable for the accumulation and preservation of acritarchs. Acritarchs were not recovered from the Białopole Formation, although there is an abundance of presumably cyanobacterial microfossils, irregular fragments of organic matter, and unidentifiable finely particulate organic matter. Possible cyanobacterial remains occur as simple, smooth, filamentous sheaths (Pl. 14I–J), unicellular spherical envelopes with smooth walls (Pl. 15F), and clusters (diameter 20 µm) of colonial spherical vesicles. The latter, chroococcalean-like (Mansuy & Vidal 1983; Moczydłowska & Vidal 1986; Vidal & Nystuen 1990) or pleurocapsalean-like (Knoll *et al.* 1981; Knoll & Swett 1985, 1987; Allison 1988) vesicles are referred to *Sphaerocongregus variabilis* Moorman (Pl. 15I). Microfossils of this species have been attributed to *Bavlinella faveolata* Shepeleva emend. Vidal (Shepeleva 1962; Vidal 1976a, 1979b; Knoll *et al.* 1981; Mansuy & Vidal 1983; Knoll & Swett 1985, 1987; Moczydłowska & Vidal 1986; Palacios Medrano 1989) or to two discrete species, *S. variabilis* and *B. faveolata* (Allison 1988). Recently, however, the name *Sphaerocongregus variabilis* Moorman, being a formally valid name for the species (Moorman 1974) was restored (Vidal & Nystuen 1990).

Seventy-one samples from the Lublin Formation were investigated, and 40 of them provided more than 1300 specimens of *Leiosphaeridia* sp. (Fig. 3; Pl. 12A–D). They were accompanied by very abundant vendotaenid filaments (group Vendotaenides Gnilovskaya 1971), colonial spheroidal cyanobacterial remains (*S. variabilis* Moorman), simple cylindrical sheaths and ornamented sheaths, and irregular fragments of organic matter (Pl. 15G). The ornamentation of the cyanobacterial sheaths consists of thickened ridges and annular surface structures (Moczydłowska & Vidal 1986; Pl. 14G–H).

Vendotaenids were generally regarded as multicellular algae, probably brown algae (Gnilovskaya 1971, 1974, 1975, 1976, 1979a, b, 1983). Because of their large dimensions and mass occurrence in the Upper Vendian deposits, vendotaenids have attracted special attention. Their supposed relation to metaphytic algae was mainly based on their macroscopic dimensions and the presence of structures thought to be reproductive (Gnilovskaya 1971, 1974, 1975, 1976, 1979a, b, 1983). The multicellular thallophytic organization was never satisfactorily demonstrated (cf. Gnilovskaya 1971, 1975, 1979a, b, 1983), however, and vendotaenids have recently been reinterpreted as abandoned giant cyanobacterial sheaths (Vidal *in* Germs *et al.* 1986) or alternatively as sheaths of beggiatoacean white bacteria resembling *Thioploca* (Vidal 1989).

Thirty-three samples from the Włodawa Formation were investigated and only three were found barren (Fig. 3). The productive samples yielded more than 2300 specimens of *Leiosphaeridia* sp. The first specimens of ornamented acritarchs referred to *Granomarginata squamacea* Volkova, *Lophosphaeridium tentativum* Volkova, *Comasphaeridium agglutinatum* Moczydłowska, and *Asteridium* sp. appear in the uppermost part of the formation and are recorded in the drillcores Łopiennik IG-1 (5302.0–5305.8 m), Parczew IG-10 (2175.7–2181.0 m) and Kaplonosy IG-1 (1339.3–1342.5 m) (Appendices 10, 7 and 6, respectively). These species characterize the overlying Mazowsze Formation where they are more frequent. The Włodawa Formation yielded numerous sheaths of vendotaenids, filamentous cyanobacteria and irregularly shaped organic remains. Except for the ornamented acritarchs, the assemblage of microfossils and associated unidentified organic remains is similar in composition and state of preservation to that of the underlying Lublin Formation.

Fifty-seven out of 76 processed rock samples from the Mazowsze Formation yielded abundant acritarchs (Fig. 3) accompanied by cyanobacterial filamentous and tubular sheaths (Pl. 15A–B) and organic fragments. The cyanobacterial remains are less abundant than in the underlying units. Additionally, a few specimens of the problematic microfossil *Ceratophyton vernicosum* Kirjanov were recovered (Pl. 15E). *C. vernicosum* was originally described as plant remains of unknown systematic affiliation (Kirjanov 1968, and *in* Volkova *et al.* 1979). The species is known to occur in the Rovno and Lontova horizons in the EEP of the U.S.S.R. (Volkova *et al.* 1979, 1983). In the Lublin Slope *C. vernicosum* is recorded in the drillcores Łopiennik IG-1 (5210.0 m and 5197.2 m) and Kaplonosy IG-1 (1314.0 m and 1293.0 m). A single, presumably chitinous arthropod fragment was recovered from a sample at the depth of 1302.0 m in the Kaplonosy IG-1 drillcore (Pl. 15D).

The acritarch assemblage from the Mazowsze Formation is taxonomically rich (Appendices 1–10) and contains lavishly ornamented taxa exhibiting processes, spines, ridges, muri, membranes and pores. However, most frequent are smooth and undiagnostic spheromorphs attributed to *Leiosphaeridia* sp., amounting to more than 8600 specimens. The diagnostically ornamented acritarchs are less numerous (about 1600 specimens). In all, the assemblage comprises 17 taxa (Moczydłowska & Vidal 1986; Moczydłowska 1988a, 1989; Appendices 1–10). Four of them, *Comasphaeridium agglutinatum* Moczydłowska, *C. formosum* Moczydłowska, *C. velvetum* Moczydłowska, and *Pterospermella velata* Moczydłowska, are so far known only from the Mazowsze Formation in the Lublin Slope. The remaining species occur frequently in the Lower Cambrian deposits of the EEP, Scandinavia, Greenland, Svalbard, Scotland and Canada (Volkova 1968, 1969a, b, 1973; Volkova *et al.* 1979, 1983; Downie 1974, 1982; Vidal 1979b, 1981a, b, c; Moczydłowska 1981, 1989; Moczydłowska & Vidal 1986; Knoll & Swett 1987). Only one species, *Asteridium tornatum* (Volkova) comb.nov. (=*Micrhystridium tornatum* Volkova), was previously reported from the Upper Proterozoic Kotlin Formation in the EEP of the U.S.S.R. (Volkova 1968, 1969b, 1973; Volkova *et al.* 1979, 1983) and in the Lublin and Włodawa Formations of the Lublin Slope (Radzyń IG-1 drillhole; Volkova 1969a, b). Unfortunately, the occurrence of the species in the Kotlin Formation is poorly documented (see 'Acritarch-based correlation of the Precambrian–Cambrian boundary', The EEP), and the present study could not confirm it from the Lublin and Włodawa Formations. The acritarch assemblage recovered from the Mazowsze Formation is here regarded as defining the oldest microfossil zone of the Cambrian in the Lublin Slope (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989; Figs. 5, 6).

Seventy-five samples deriving from the Kaplonosy and Radzyń formations were studied, and 62 of them yielded abundant acritarchs (Fig. 3). The microfossils recorded from this part of the Lower Cambrian sequence in the Lublin Slope can be attributed to 50 acritarch taxa (Moczydłowska 1989; Figs. 5, 8). This taxonomically diverse assemblage is here taken to represent a major speciation event. More than 20 000 specimens were examined, and about 5000 can be referred to short-ranging and biostratigraphically significant species (Fig. 5). Two species are presently known exclusively from the Lublin region, i.e. *Heliosphaeridium longum* (Moczydłowska) comb. nov. and *Skiagia pura* Moczydłowska (Moczydłowska 1988a). The remaining species are also known from the Lower Cambrian deposits in other parts of the EEP, Scandinavia, Greenland, Svalbard, Scotland and Canada (Tynni 1978, 1982a; Volkova *et al.* 1979, 1983; Vidal 1979b, 1981a, b, c; Moczydłowska 1981, 1989; Downie 1982, 1984; Moczydłowska & Vidal 1986; Knoll & Swett 1987; Hagenfeldt 1988, 1989a; Eklund 1990).

The acritarchs from the Kaplonosy and Radzyń formations allow the discrimination of three assemblages (Figs. 5, 8). They are accompanied by cyanobacterial sheaths (single vesicles and filaments), specimens of *Ceratophyton vernicosum* Kirjanov and vendotaenid filaments. All these accessory microfossils are rare in the lower part of the Kaplonosy and Radzyń formations and disappear in the upper part of the sequence.

## Microfossil assemblages – acritarch zones

Several drillcores through the Upper Vendian and Lower Cambrian deposits in the Lublin Slope of the EEP have a continuous succession of acritarch and cyanobacterial assemblages. These are taxonomically distinctive and consist of species with limited stratigraphic ranges. The observed variations in the specific composition of discrete phytoplankton assemblages is here interpreted to indicate stepwise development of the microbiotas through time, apparently independent of palaeoenvironmental conditions and facies changes. Appendices 1–5 show graphic abundances of acritarch species from all investigated drillcores.

The investigated Upper Vendian and Lower Cambrian lithological sequences are displayed in Appendices 6–10 together with the stratigraphic distribution of discrete acritarch assemblages. Six microbial assemblages numbered 1 to 6 in ascending order (Appendices 1–5; Fig. 5) are established on the basis of the earliest appearances of microfossil taxa. Four of them (assemblages 3–6) determine the proposed formal acritarch Assemblage-zones (Appendices 6–10; Fig. 5). The assemblages and the concurrent zones defined by them allow correlation of the deposits irrespective of lithofacies development and presence or absence of macrofauna. Biozones are delimited by the first appearance of new species (their lower boundary), by index taxa having stratigraphic ranges limited to this zone, and by the base of the range of the next appearing species that define the immediately succeeding zone (and the top limit of the zone). Acritarch zones (Appendices 6–10; Fig. 5) are established for the Lower Cambrian, excluding the bulk of the Włodawa Formation, which is regarded as Vendian in age (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, b, 1989).

The microfossils in Vendian deposits (e.g. cyanobacteria and leiosphaerids) have comprehensive stratigraphic ranges and are not biostratigraphically significant. In the investigated region, the oldest organic remains form Assemblage 1 (Fig. 5) which consists of filamentous sheaths and spheroidal envelopes of cyanobacteria. Assemblage 1 occurs within the Białopole Formation in the Terebiń IG-5 and Łopiennik IG-1 drillcores (Appendices 9 and 10, respectively).

The second microbial assemblage (Fig. 5) is composed of acritarchs appearing for the first time in the Lublin basin, and of cyanobacteria and/or bacteria, including vendotaenids. Some of the cyanobacterial microfossils are identical to those recovered from the underlying rocks. However, some forms are new and morphologically more complex. The presumable cyanobacterial remains occurring in the assemblage are unicellular vesicles, colonial spheroids referred to *Sphaerocongregus variabilis* Moorman (Pl. 15I), simple and smooth filamentous sheaths (Pl. 14I–J), and sheaths with annular thickenings (Pl. 14G–H). Vendotaenids have mass occurrences, while acritarchs of the genus *Leiosphaeridia* are very abundant (Pl. 12A–H). Differences among the leiosphaerid populations concern the diameter of vesicles and wall thickness, which could perhaps be dependent on environmental conditions and thus be of limited stratigraphic significance (Lindgren 1981, 1982b). The microfossils are accompanied by abundant particulate organic matter. The above mentioned microbial assemblage is known to occur in all the investigated sections through the Lublin and Włodawa Formations (Appendices 6–10).

The third microbial assemblage (Fig. 5) is significant in representing the first early Cambrian acritarch radiation which resulted in a rise of numerous new species (Moczydłowska & Vidal 1986; Moczydłowska 1988a, 1989). This acritarch assemblage is comparatively diverse compared to preceding assemblages. In the investigated sequence in the Lublin basin, fifteen acritarch species have their earliest recorded appearance in this assemblage (Fig. 5). Most of them were previously known from the Lower Cambrian platform sequences in the Polish and U.S.S.R. sectors of the EEP, from Baltoscandia, and the platform and turbiditic sequences in Scotland, Greenland, Svalbard and Canada (Volkova *et al.* 1979; Vidal 1979b, 1981b; Downie 1982; Moczydłowska & Vidal 1986; Knoll & Swett 1987; Baudet *et al.* 1989). Four species are unique to Assemblage 3 and define an assemblage-zone (Fig. 5). The index taxa comprise *Comasphaeridium agglutinatum* Moczydłowska, *C. formosum* Moczydłowska, *C. velvetum* Moczydłowska and *Pterospermella velata* Moczydłowska. With the exception of *C. formosum*, the species are abundant in samples from all investigated sections in the Lublin basin. In addition to acritarchs, there are rare vendotaenids, abundant fragments of organic matter, cyanobacterial remains (Pl. 15A, B, F) comparable to those reported from older assemblages, and the problematic microfossil *Ceratophyton vernicosum* Kirjanov (Pl. 15E).

The third acritarch assemblage constitutes the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone (Fig. 5). The name of the zone refers to the abundant occurrence of *Asteridium tornatum* (Volkova) comb. nov. and the dominance of *Comasphaeridium velvetum* Moczydłowska among the index taxa of this zone. The zone embraces the Mazowsze Formation (which Areń & Lendzion 1978 and Lendzion 1983a, b refer to the *Platysolenites* Zone) and the uppermost part of the Włodawa Formation (referred to the *Sabellidites* Zone by Areń & Lendzion 1978 and Lendzion 1983a, b) in the rock sequences penetrated by the drillholes Łopiennik IG-1 (at the depth 5302.0–5305.8 m), Parczew IG-10 (at the depth 2157.7–2181.0 m) and Kaplonosy IG-1 (at the depth 1339.3–1342.5 m) (see Appendices 10, 7 and 6).

The next succeeding microbial assemblage (Assemblage 4) shows high taxonomic diversity (Fig. 5). Numerous new species that display more complex diagnostic morphologic features also appear. The taxa composing this assemblage are both diagnostic and widely distributed, and they are accompanied by cyanobacterial remains extending from underlying strata. The fourth assemblage constitutes the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone (Fig. 5). Most species of the fourth assemblage have their first recorded appearances in this zone but have extended ranges into the succeeding zones. *Asteridium pallidum* (Volkova) comb. nov., and *Skiagia pura* Moczydłowska are the index taxa of the zone. However, these species are very rare, and particularly *Skiagia pura* is known only from the Lublin Slope.

The genus *Skiagia* accounts for most of the taxa recorded in the fourth assemblage. Most numerous are microfossils attributed to *Skiagia ornata* (Volkova) Downie, *S. orbiculare* (Volkova) Downie and *S. compressa* (Volkova) Downie. The assemblage also includes the acritarchs *Fimbriaglomerella membranacea* (Kirjanov) Moczydłowska & Vidal, *F. minuta* (Jankauskas) Moczydłowska & Vidal, *Comasphaeridium molliculum* Moczydłowska & Vidal, and *C. brachyspinosum* (Kirjanov) Moczydłowska & Vidal. These taxa are previously known from numerous occurrences elsewhere (Moczy-

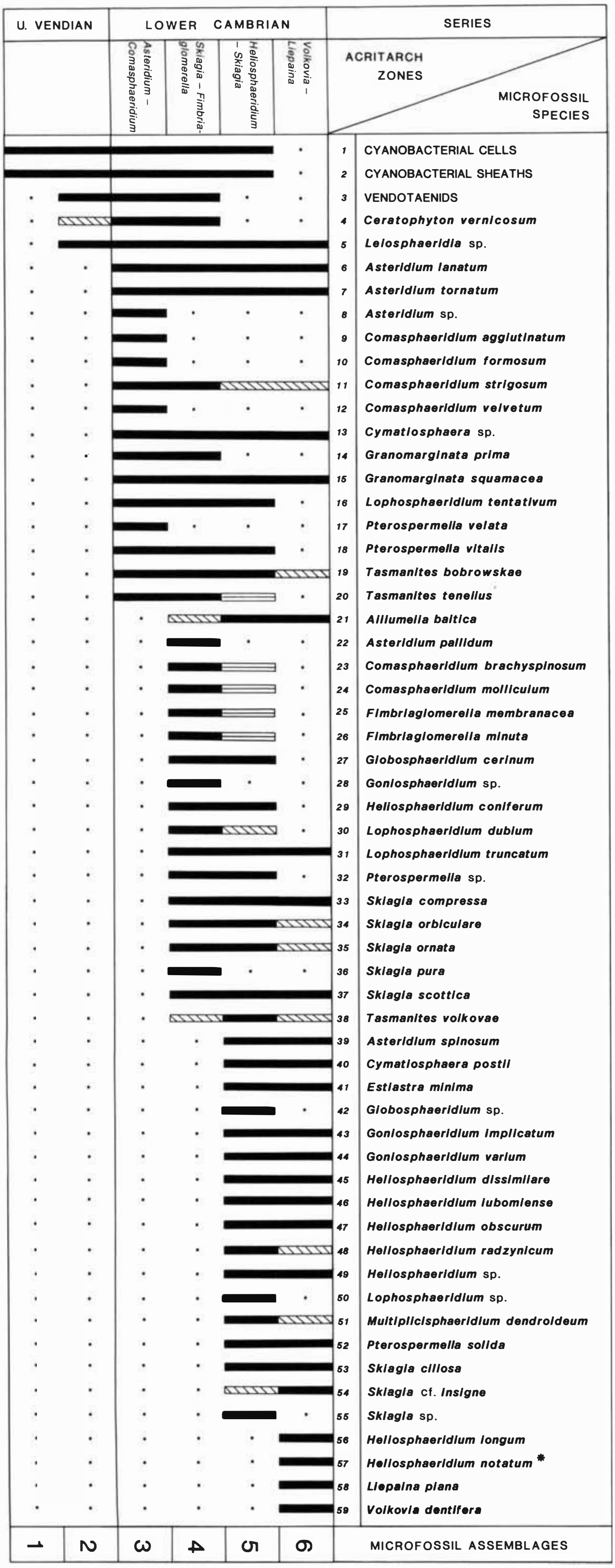

*Fig. 5.* Succession of microfossil assemblages across the Upper Vendian and Lower Cambrian in the Lublin Slope, southeastern Poland, and proposed zonal subdivision according to recognized acritarch assemblages. Additional occurrences in time equivalent zones are indicated by a dashed-line bar for the U.S.S.R., and a vertical-line bar for Scandinavia (after Volkova *et al.* 1979; Vidal 1981c; Eklund 1990). Asterisk indicates occurrence of species in the Lublin Slope according to Volkova 1969a.

dłowska & Vidal 1988b). A mass occurrence of *Tasmanites bobrowskae* Ważyńska is recorded in rocks embraced by this zone. Presumable cyanobacterial remains and unidentifiable fragments of organic matter are decidedly less common than in the preceding zones. *Ceratophyton vernicosum* Kirjanov and rare vendotaenid fragments ranging from the older zones are also present.

The *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone embraces the lower part of the Kaplonosy and Radzyń formations (Appendices 6–10). Additionally, the uppermost part of the Mazowsze Formation in the Łopiennik IG-1 (at 5192.0–5198.0 m) and Parczew IG-10 (at 2062.4–2065.0 m) drillcores is referred to this zone (Appendices 10 and 7, respectively). *Comasphaeridium molliculum* occurs at the discussed interval in the Łopiennik IG-1 drillcore (Appendices 5, 10). This species is regarded to have its first appearance in the fourth assemblage, recognized over the whole Lublin Slope. Thus the uppermost part of the Mazowsze Formation in Łopiennik IG-1 belongs to the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone. An analogous situation is found in coeval strata in the Parczew IG-10 drillcore, where *Fimbriaglomerella minuta* occurs at a depth of 2065.0 m (Appendices 2, 7).

The fifth microbial assemblage in the Lublin region (Appendices 1–5; Fig. 5) is the taxonomically most diverse. The number of new taxa compares with that in the preceding assemblage. However, none of the taxa are restricted to this assemblage. The acritarchs are accompanied by rare unicellular and filamentous cyanobacterial microfossils and particulate organic matter. This assemblage defines the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone (Appendices 6–10; Fig. 5). There are twelve acritarch species that first appear at this level: *Heliosphaeridium dissimilare* (Volkova) comb. nov., *H. lubomlense* (Kirjanov) comb. nov., *H. obscurum* (Volkova) comb. nov., *H. radzynicum* (Volkova) comb. nov., *Asteridium spinosum* (Volkova) comb. nov., *Skiagia ciliosa* (Volkova) Downie, *Estiastra minima* Volkova, *Goniosphaeridium varium* (Volkova) Downie, *G. implicatum* (Fridrichsone) Downie, *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas & Kirjanov, *Pterospermella solida* (Volkova) Volkova, and *Cymatiosphaera postii* (Jankauskas) Jankauskas. *Heliosphaeridium dissimilare* and *Skiagia ciliosa* dominate the assemblage and are widely distributed. Additionally, the most common species are *S. ornata*, *S. scottica* and *Estiastra minima*. This zone displays the greatest taxonomic diversity and yields the largest recorded number of acritarchs. This seems to coincide with the maximum level in the early Cambrian transgression on the EEP (Brangulis *et al.* 1981; Lendzion 1983a). The *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone embraces the middle part of the Kaplonosy and Radzyń formations (Appendices 6–10).

The youngest Lower Cambrian microbial assemblage (Assemblage 6; Appendices 1–5; Fig. 5) includes numerous species with ranges extending from the older zones. New species in the assemblage are *Liepaina plana* Jankauskas & Volkova and *Heliosphaeridium notatum* (Volkova) comb. nov., species known to range into the Middle Cambrian (Volkova *et al.* 1979, 1983), and *Volkovia dentifera* (Volkova) Downie and *Heliosphaeridium longum* (Moczydłowska) comb. nov., which are the index taxa of this assemblage (Fig. 5). In addition, the assemblage contains all the taxa from the immediately preceding assemblage. This makes its identification difficult, particularly since *Volkovia dentifera*, *Heliosphaeridium longum* and *H. notatum* are generally rare. Only a few specimens of *V. dentifera* and *H. longum* were recovered from the investigated samples. *H. notatum* was reported by Volkova (1969a, 1972, 1973, *in* Volkova *et al.* 1979, 1983) from the Radzyń IG-1 drillcore, but was not found in the present material. However, the species was also recorded in coeval subsurface strata in Upper Silesia penetrated at drillhole Sosnowiec IG-1 (Kowalczewski *et al.* 1984).

The sixth assemblage constitutes the *Volkovia dentifera – Liepaina plana* Assemblage-zone, embracing the upper part of the Kaplonosy and Radzyń formations. Volkova (1972, 1973) regarded this part of the Lower Cambrian sequence in the Radzyń IG-1 drillcore as time equivalent to the *Protolenus* zone.

# The Precambrian–Cambrian boundary in the Lublin Slope

## General aspects

The present investigation comprises numerous fossiliferous samples from across the Precambrian–Cambrian boundary retrieved at five drilling sites in the Lublin Slope (Fig. 3). The recorded frequency of acritarchs is generally high (Appendices 1–5). It seems therefore safe to conclude that the obtained microbiotas can be regarded as representative of the Vendian and Lower Cambrian deposits in the investigated area.

The appearance of a rich acritarch assemblage defining the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone seems independent of lithofacies changes within the sampled interval. This is suggested by the fact that the assemblage is recorded in several drillcores irrespective of lithofacies variations (Appendices 6–10). The *Leiosphaeridia*-dominated assemblage is replaced by the *Asteridium tornatum – Comasphaeridium velvetum* assemblage over a sequence of alternating clayey, silty and sandy rocks (Moczydłowska & Vidal 1986; Moczydłowska 1988a). Although the presence of a minor break in sedimentation cannot be excluded, the lithologically monotonous rock sequence bracketing the stepwise radiation of acritarchs occurs in what might have been a mono- or polysequential stratigraphic horizon embracing the Upper Włodawa and Mazowsze Formations. Hence the radiation is always initiated with the appearance of a few innovative taxa at the top of the Włodawa Formation, and it continues within the Mazowsze Formation where the full spectrum of the *Asteridium tornatum – Comasphaeridium velvetum* assemblage is present.

The vertical ranges of acritarch species in the investigated drillcores coincide, and within the limits of resolution the first appearances of discrete taxa are at the same stratigraphic levels. This could be alternatively interpreted

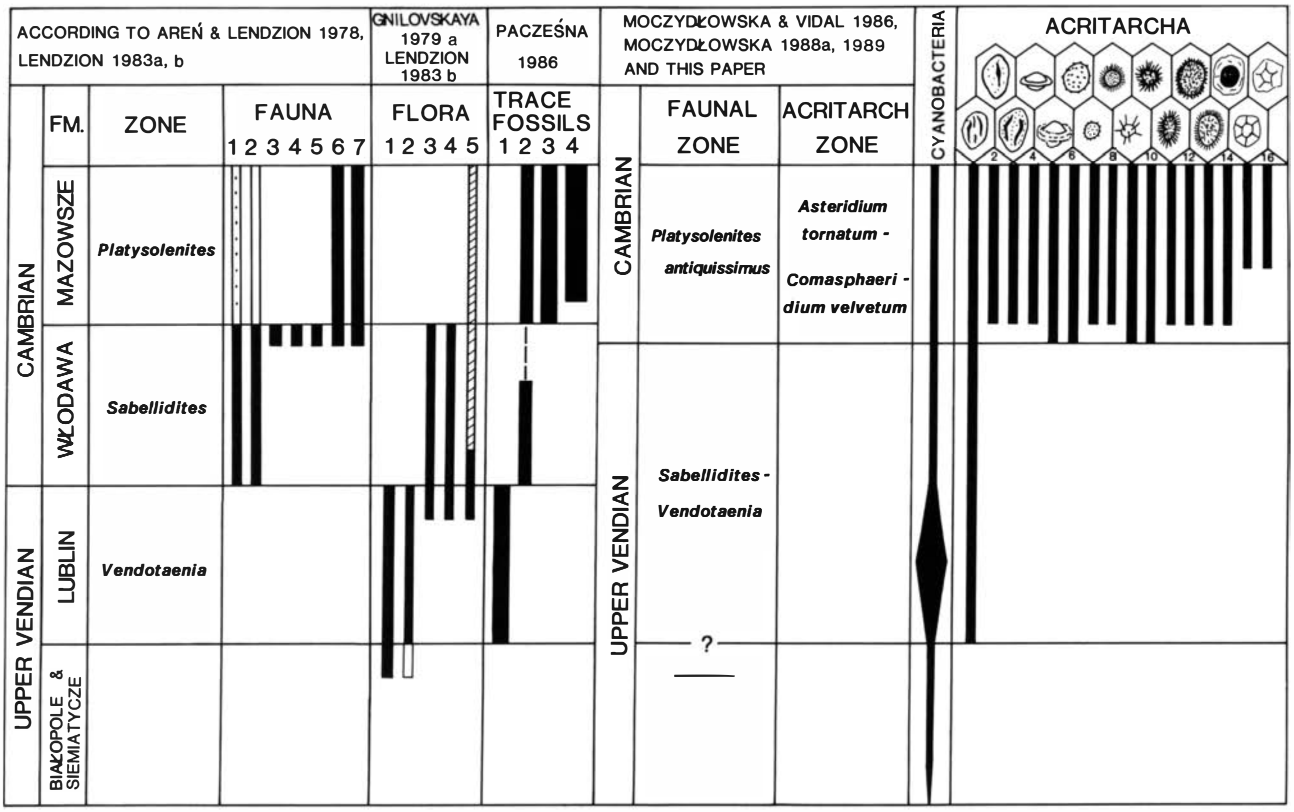

*Fig. 6.* The Precambrian–Cambrian boundary in the Lublin Slope of the East European Platform in Poland. Fauna: 1 – *Sabellidites cambriensis.* 2 – *Sabellidites* sp. 3 – *Aldanella polonica* = *A. attleborensis* (Landing 1988b). 4 – *Anabarella* sp. 5 – *Platysolenites* sp. 6 – *Platysolenites antiquissimus.* 7 – *Onuphionella agglutinata.* Flora: 1 – *Vendotaenia antiqua.* 2 – *Vendotaenia* sp. 3 – *Tyrasotaenia podolica.* 4 – *Tyrasotaenia tungusica.* 5 – *Tyrasotaenia* sp. Trace-fossils: 1 – *Gordia, Paleopascichnus, Torrowangea.* 2 – *Planolites.* 3 – *Phycodes, Monocraterion.* 4 – *Bergaueria, Gyrolithes, Neonereites, Treptichnus, Teichichnus, Bilinichnus, Mammilichnis.* Cyanobacteria: coccoidal and filamentous cyanobacteria, including vendotaenids. Acritarcha: 1 – *Leiosphaeridia* sp. 2 – *Tasmanites tenellus.* 3 – *T. bobrowskae.* 4 – *Granomarginata prima.* 5 – *G. squamacea.* 6 – *Lophosphaeridium tentativum.* 7 – *Asteridium tornatum.* 8 – *A. lanatum.* 9 – *Asteridium* sp. 10 – *Comasphaeridium agglutinatum.* 11 – *C. formosum.* 12 – *C. velvetum.* 13 – *C. strigosum.* 14 – *Pterospermella velata.* 15 – *P. vitalis.* 16 – *Cymatiosphaera* sp. Dotted part of range bar for 1 under Fauna refers to time equivalent zone in the U.S.S.R., according to Keller & Rozanov 1979b. Open part of range bar for 2 under Fauna and Flora applies to other parts of the East European Platform in Poland according to Areń *et al.* 1979b. Striped portion of range bar for 5 under Flora refers to time equivalent zones in the Orsha Depression in the U.S.S.R., according to Bessonova & Chumakov 1979.

as a true and significant radiation event or as a sudden influx of eukaryotic plankters in an open-marine environment. The conspicuous change involved in the appearance of the acritarch taxa defining the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone occurs over a stratigraphic interval of variable thickness in the investigated drillcores. This reflects variable rates of sedimentation at discrete locations in areas of the shelf on a passive platform edge (Guterch 1977; Pożaryski 1977c; Jaworowski 1978; Areń *et al.* 1979b; Znosko 1984). In general terms, at all investigated drilling sites sediment types and sedimentary structures are in agreement with normal relatively shallow-marine depositional conditions. Therefore it can be inferred that at all locations the biotic changes observed through the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone occurred over a short time span.

In terms of geologic time, the *A. tornatum – C. velvetum* Zone follows a long period dominated by diverse microbiotas characterizing the Riphean and Vendian (Volkova 1962, 1968, 1973, 1976, 1981c, 1985; Volkova *et al.* 1979, 1980, 1983; Rudavskaya 1971, 1973, 1980; Rudavskaya & Frolov 1974; Vidal 1974, 1976a, b, 1979b, 1981a, 1989, 1990; Vidal & Siedlecka 1983; Vidal & Knoll 1983; Vidal & Ford 1985; German 1974, 1981a, b, 1986; Hofmann 1976, 1985; Jankauskas 1978, 1979a, b, 1980a, b, 1982, 1989; Knoll 1982a, b, 1984; Knoll & Calder 1983; Knoll & Swett 1985, 1987; Bloeser 1985; Awramik *et al.* 1985; Mikhailova 1986; Germs *et al.* 1986; Yin 1985, 1987; Damassa & Knoll 1986; Pyatiletov 1980, 1985, 1988; Pyatiletov & Rudavskaya 1985; Zang & Walter 1989; Baudet *et al.* 1989). This event is contemporaneous with other significant events, such as the appearance and radiation of a shelly fauna consisting of *Platysolenites, Onuphionella, Aldanella* and *Anabarella* (Lendzion 1983a, b; Fig. 6), a general change of the ichnofaunal assemblages (Paczesna 1985, 1986), and a recorded decline among vendotaenids (Gnilovskaya 1979a; Lendzion 1983a, b; Moczydłowska & Vidal 1986).

The first appearance of shelly fauna is observed in the upper part of the Włodawa Formation. This part of the sequence was referred to the *Sabellidites* Zone by Areń & Lendzion (1978) and Lendzion (1983a, b), but here it is regarded as part of the *Platysolenites antiquissimus* Interval-zone (Moczydłowska & Vidal 1986; Moczydłowska 1988a, 1989; Fig. 6). The first shelly fossils consist of possible annelid tubes (Yanishevsky 1926, 1940; Kirjanov 1968; Areń & Lendzion 1978; Lendzion 1983b; Signor & McMenamin

1988) or, alternatively, foraminiferans (Føyn & Glaessner 1979; Glaessner 1984), e.g., *Platysolenites antiquissimus* Eichwald, *Platysolenites* sp., and *Onuphionella agglutinata* Kirjanov (more frequently occurring in the Mazowsze Formation), and the molluscs *Aldanella polonica* Lendzion [= *Aldanella attleborensis* (Shaler & Foerste)] and *Anabarella* sp. (Areń & Lendzion 1978; Areń *et al.* 1979b; Lendzion 1983a, b; Lendzion & Posti 1983; Landing 1988b).

Trace fossils from beds across the Vendian and Lower Cambrian in the Lublin Slope are clearly differentiated (Paczeŝna 1985, 1986). The assemblage from the Lublin Formation is poor in terms of ichnospecies. Trace fossils in the Włodawa Formation consist of rare meandering trails of low diversity. The trace fossil assemblage from these units is regarded as diagnostic of the late Vendian (Paczeŝna 1986). The ichnofauna from the Mazowsze Formation is rich and taxonomically more diverse, and it also contains ichnospecies considered as Cambrian index taxa (Alpert 1977; Crimes & Germs 1982; Paczeŝna 1986; Crimes 1987; Narbonne *et al.* 1987).

Vendotaenids are very abundant in the Lublin Formation and less common in the Włodawa Formation. They have been considered as Vendian and early Cambrian index-taxa. Thus, *Vendotaenia antiqua* Gnilovskaya from the Lublin Formation, defining the *Vendotaenia* Zone, was considered to indicate a late Vendian age, while *Tyrasotaenia podolica* Gnilovskaya and *T. tungusica* Gnilovskaya (together with *Sabellidites cambriensis* Yanischevsky) from the Włodawa Formation (referred to the *Sabellidites* Zone) were believed to indicate an early Cambrian age (Lendzion 1983a, b). However, the stratigraphic range of species of *Tyrasotaenia* (possibly conspecific with *Vendotaenia*; Vidal 1989) is more comprehensive and overlaps with the range established for *V. antiqua* (Gnilovskaya 1979a, 1983, 1988). Vendotaenids are known to occur in deposits considered to be Upper Vendian and Lower Cambrian in the East European and Siberian Platforms (Gnilovskaya 1979a, 1983, 1988), but my own observations indicate that remains of vendotaenids are also present in trilobite-bearing strata in the Lublin Slope. *Tyrasotaenia* sp. was also found in the Lontova horizon of the EEP within the U.S.S.R. (Bessonova & Chumakov 1979). The Lontova horizon is generally regarded to be within the range of the *Platysolenites* Zone in Poland (Volkova 1973; Areń & Lendzion 1978; Lendzion 1983a, b). Thus, having comprehensive and overlapping ranges, vendotaenids are stratigraphically valuable for marking late Vendian to early Cambrian deposits but not for more detailed subdivision.

Sabelliditids occur in the Włodawa (*Sabellidites cambriensis*) and Mazowsze Formations (*Sabellidites* sp.; Areń & Lendzion 1978; Areń *et al.* 1979b; Lendzion 1983a, b; Fig. 6). The systematic position of these fossils is still uncertain (Yanishevsky 1926, 1940; Sokolov 1965, 1967, 1968, 1972; Urbanek & Mierzejewska 1977, 1983; Urbanek 1979). Sabelliditids are organic-walled tubular fossils. As demonstrated by ultrastructural studies (Urbanek & Mierzejewska 1977, 1983), the fossils consist of organic matter lacking mineral components.

Insofar as the above palaeobiological events recorded around the *Sabellidites–Vendotaenia* and *Platysolenites antiquissimus* Zones are real, the emergence of a Palaeozoic-type acritarch assemblage (Moczydłowska & Vidal 1986; Moczydłowska 1988a, 1989) defining the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone is here taken to mark the base of the Cambrian System in the Lublin Slope.

## The Precambrian–Cambrian boundary reference section

The drillcore Kaplonosy IG-1 is proposed as the reference section for the Vendian–Cambrian boundary in the Lublin Slope (Moczydłowska 1989; Fig. 7 herein). The Upper Vendian and Lower Cambrian beds constitute an apparently continuous sedimentary record (Jaworowski 1978, 1980). The deposits consist of alternating sandstones, siltstones and shales (Areń & Lendzion 1978; Juskowiakowa 1978; Jaworowski 1978; Wichrowska 1978; Lendzion 1983a), and represent a marine transgressive sequence over a marginal zone of the pre-Vendian platform (Jaworowski 1978, 1980; Areń *et al.* 1979b; Lendzion 1983a). The macroscopic fossil record in the Kaplonosy IG-1 section according to Lendzion (1972a), Areń & Lendzion (1978) and Gnilovskaya (1979a) is shown in Fig. 7. Acritarchs from this drillcore were previously reported by Volkova (1969a, b, 1973; *in* Volkova *et al.* 1979, 1983) who identified an assemblage including *Leiosphaeridia* sp., *Tasmanites*(?) *tenellus* Volkova, *Leiomarginata simplex* Naumova, *Granomarginata prima* Naumova and *G. squamacea* Volkova. The microbiotas recovered from Kaplonosy IG-1 in this study are rich and taxonomically diverse (Appendices 1, 6). Almost all species known from the transitional Vendian–Cambrian sequence in the Lublin Slope were recorded (Fig. 6), the only exceptions being *Pterospermella vitalis* Jankauskas and *Cymatiosphaera* sp. The change in acritarch complexity, from the morphologically poorly diversified Vendian-type *Leiosphaeridia* assemblage to the morphologically polyspecific Cambrian-type assemblage characterizing the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone, is observed at the interval 1346.8–1339.3 m (Appendices 1, 6). The first specimens of Cambrian age-diagnostic species (*Comasphaeridium agglutinatum* Moczydłowska and *Asteridium* sp.) occur at the depth of 1342.5 m, which was the suggested level of the Precambrian–Cambrian boundary in the Kaplonosy IG-1 drillcore (Moczydłowska 1988a, 1989; Appendix 6, Fig. 7).

## Supplementary comments

The position of the Precambrian–Cambrian boundary in Poland established on the acritarch evidence (Fig. 6) is in agreement with a previous biostratigraphic suggestion by Volkova (1969a, 1973; *in* Areń & Lendzion 1978). Volkova concluded that deposits referred to the *Sabellidites* Zone in the Radzyń IG-1 drillcore are Precambrian in age (Volkova 1969a) and that the acritarch assemblage occurring in the interval corresponding to the *Sabellidites* Zone in the Radzyń IG-1 drillcore is 'similar to the Precambrian assemblage' (Volkova 1973). In reality, the acritarch assemblage

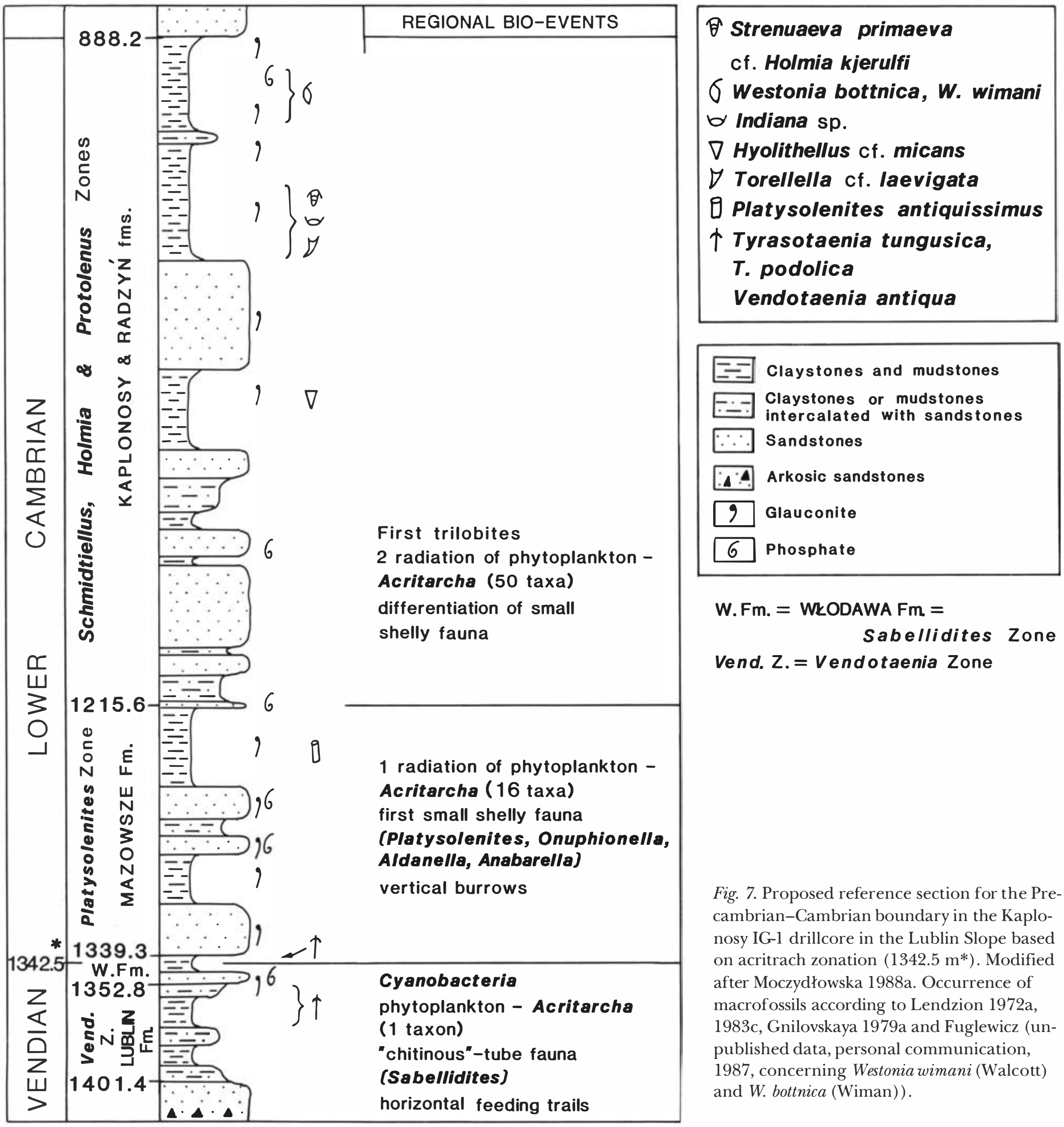

*Fig. 7.* Proposed reference section for the Precambrian–Cambrian boundary in the Kaplonosy IG-1 drillcore in the Lublin Slope based on acritrach zonation (1342.5 m*). Modified after Moczydłowska 1988a. Occurrence of macrofossils according to Lendzion 1972a, 1983c, Gnilovskaya 1979a and Fuglewicz (unpublished data, personal communication, 1987, concerning *Westonia wimani* (Walcott) and *W. bottnica* (Wiman)).

from the *Sabellidites* Zone does not differ from the older assemblages occurring in the Upper Vendian Lublin Formation in Poland and the time-equivalent Kotlin Formation in the EEP within the U.S.S.R. Previous biostratigraphic investigations of the Lublin region as a rule did not take these conclusions into consideration, but Areń & Lendzion (1978) mentioned Volkova's opinion indicating that the acritarch assemblage from the *Sabellidites* Zone in the Lublin region is characteristic of the uppermost Vendian.

*Micrhystridium tornatum* Volkova was reported (Volkova 1969a, 1972, 1973; Volkova *et al.* 1979, 1983; Areń & Lendzion 1974b) in deposits older than the Mazowsze Formation (the latter in a core interval assigned by Areń & Lendzion 1978 and referred to the *Platysolenites* Zone) in the Radzyń IG-1 drillcore. These reports are insufficiently documented since the number of specimens is contradictory and micrographs were never published. Volkova (1969a, p. 74) mentioned the occasional occurrence of *Micrhystridium* cf. *tornatum* in pre-Mazowsze beds. She reported one specimen of *Micrhystridium tornatum* at the depth of 1625.4–1630.8 m (in beds of the *Vendotaenia* Zone) and one additional specimen at 1593.9 m (in beds of the *Sabellidites* Zone; Volkova 1969a, p. 75). However, this is contradicted by her own statement that the only occurrence of *Micrhystridium tornatum* is at the depth of 1515.8 m within beds assigned to the *Platysolenites* Zone (Volkova 1969b, p. 229). Additionally, relative estimates of the frequency of acritarchs in the *Platysolenites* Zone in this section given by Volkova (1969a) result in an absolute figure of 2.3 specimens of *M. tornatum* (cf. Volkova 1969a, table on p. 75).

Subsequent investigations of the same sequence in the Radzyń IG-1 drillcore (Volkova 1972) failed to reveal this species. Later, Volkova (1973) and Volkova *et al.* ( 1979, 1983) reported *M. tornatum* in the Rovno horizon (=*Sabellidites* Zone; then regarded as of Cambrian age) in the Radzyń IG-1 drillcore. This report refers to the above mentioned single specimen of *M.* cf. *tornatum* (Volkova 1969a). In conclusion, the above information seems to indicate that *M. tornatum* is absent in the Upper Proterozoic of Poland. The present study demonstrates that *Micrhystridium tornatum* Volkova, attributed herein to *Asteridium tornatum* (Volkova) comb. nov., does not occur in rocks older than the Mazowsze Formation (as defined by Areń & Lendzion 1978 and referred to the *Platysolenites* Zone). This conclusion is based on the examination of 127 fossiliferous samples (out of 197 investigated) through the transitional sequence comprising the Białopole, Lublin, Włodawa and Mazowsze Formations (Figs. 2 and 3).

# Vendian and Lower Cambrian biostratigraphy in the Lublin Slope

The Upper Vendian and Lower Cambrian strata in the pre-Vendian platform in Poland (the EEP) have been subdivided into six bio-zones on the basis of trilobites, small shelly fossils, 'chitinous' fossils and vendotaenids (Lendzion 1969a, b, 1972a, b, 1976, 1982, 1983a, b, 1986a, b; Areń & Lendzion 1974a, b, 1978, 1979). In ascending stratigraphic order the following zones were recognized: *Vendotaenia* Zone (late Vendian in age), *Sabellidites* Zone, *Platysolenites* Zone, *Mobergella* Zone, and *Holmia* and *Protolenus* informal zones. The five latter zones were considered to be early Cambrian (Areń & Lendzion 1974a, b, 1978; Lendzion 1983a, b). The *Sabellidites*, *Platysolenites* and *Mobergella* Zones were included in the Klimontovian Stage, regarded as the lowest part of the Lower Cambrian and comprising the so-called 'sub-*Holmia*' zones (Areń & Lendzion 1974a, b, 1978; Areń *et al.* 1979; Lendzion 1983a, b). The Klimontovian Stage was considered to be contemporaneous with the Baltic Stage in the East European Platform and the Tommotian Stage in the Siberian Platform (Areń & Lendzion 1974a, b, 1978). The base of the *Sabellidites* Zone was proposed by Lendzion (1983a, b) as the lower boundary of the Cambrian System in the EEP in Poland.

Recent micropalaeontologic evidence suggests that the *Sabellidites* Zone is late Vendian in age and that the Precambrian–Cambrian boundary could be placed at the base of the revised *Platysolenites antiquissimus* Interval-zone (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989; see below, Fig. 6). The stratigraphic status of the *Mobergella* Zone in Poland as a pre-trilobite zone and its correlation with the Lower Cambrian sequences in Scandinavia (Lendzion 1972b, 1975, 1976, 1982, 1983a, b, d, 1986a, b; Areń & Lendzion 1974a, 1978) was questioned by Ahlberg *et al.* (1986), Moczydłowska & Vidal (1986) and Moczydłowska (1988a). The grounds for that is the co-occurrence of trilobites and *Mobergella* in Norway (Bergström 1970, 1980, 1981; Ahlberg & Bergström 1978; Ahlberg, 1984). The biostratigraphic subdivision of the Upper Vendian and Lower Cambrian strata in the EEP in Poland (Areń & Lendzion 1974a, 1978; Areń *et al.* 1979; Lendzion 1983a, b; Lendzion *in* Mens *et al.* 1987, 1990) is disputable with respect to the recognized ranges of biozones (Moczydłowska 1988a, 1989; Figs. 6, 8) and the position of the Precambrian–Cambrian boundary (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989). In this paper the previous record of macroscopic fossils is analyzed and related to micropalaeontological data (Volkova 1969a, b, 1973; Volkova *et al.* 1979, 1983; Moczydłowska 1980, 1981, 1988a, 1989; Moczydłowska & Vidal 1986, 1988a, b; Vidal 1989) that were not considered in former studies.

The *Vendotaenia* Zone has been assumed to embrace the range of *Vendotaenia antiqua*, and it encompasses the Lublin Formation (Lendzion 1983a, b). The overlying *Sabellidites* Zone is determined by the range of *Sabellidites cambriensis* Yanishevsky. Its lower boundary is delimited by the appearance of *S. cambriensis* in co-occurrence with *Tyrasotaenia podolica* Gnilovskaya and *T. tungusica* Gnilovskaya (Lendzion 1983b). In its present definition, the zone comprises the Włodawa Formation (Areń & Lendzion 1978; Lendzion 1983a, b). However, when establishing the ranges of the *Vendotaenia* and *Sabellidites* Zones (Lendzion 1983b), the additional occurrence of *T. podolica* and *T. tungusica* in the Lublin Formation (Gnilovskaya 1979a) was omitted. This is also the case with the occurrences of *Vendotaenia antiqua* and *V.* sp. in the upper part of the Białopole Formation (Areń *et al.* 1979b; Lendzion 1983b, Fig. 4). Moreover, in other regions *Sabellidites cambriensis* and *Sabellidites* sp. were reported in strata corresponding to zones much younger that the *Sabellidites* Zone (Areń *et al.* 1979c; Keller & Rozanov 1979b; Moczydłowska 1989; Fig. 6).

Vendotaenids (*Vendotaenia* sp.) were observed in rocks attributed to the Mazowsze Formation in drillcore Radzyń IG-1. This occurrence is in beds substantially younger than formerly reported occurrences. This is taken to indicate that the stratigraphic range of vendotaenids in the Lublin Slope is more comprehensive than previously supposed, ranging into strata attributed to the *Platysolenites* Zone. Specimens attributed to *Tyrasotaenia* sp. were also reported from rocks of the Lontova horizon (correlated with the *Platysolenites* Zone by Areń & Lendzion 1978 and Keller & Rozanov 1979b) in the Orsha Depression and in the Moscow Syneclise in the U.S.S.R. sector of the EEP (Bessonova & Chumakov 1979). This is evidently witness of the comprehensive stratigraphic ranges of these fossils. These observations are in agreement with the occurrences of vendotaenids (*Vendotaenia* and *Tyrasotaenia*) in the Upper Vendian and Lower Cambrian elsewhere (Gnilovskaya 1979a, 1983). Thus, because of the co-occurrence of *T. tungusica* and *T. podolica* in the Upper Vendian and Lower Cambrian (Gnilovskaya 1979a, 1983) it is difficult to support the idea that the species (together with *S. cambriensis*) could define the lower boundary of the Cambrian in the Lublin Slope (Lendzion 1983b).

The occurrence of the *Sabellidites* fauna in deposits younger than those correlated with the *Sabellidites* Zone (*sensu* Areń & Lendzion 1978; Lendzion 1983a, b) is also known

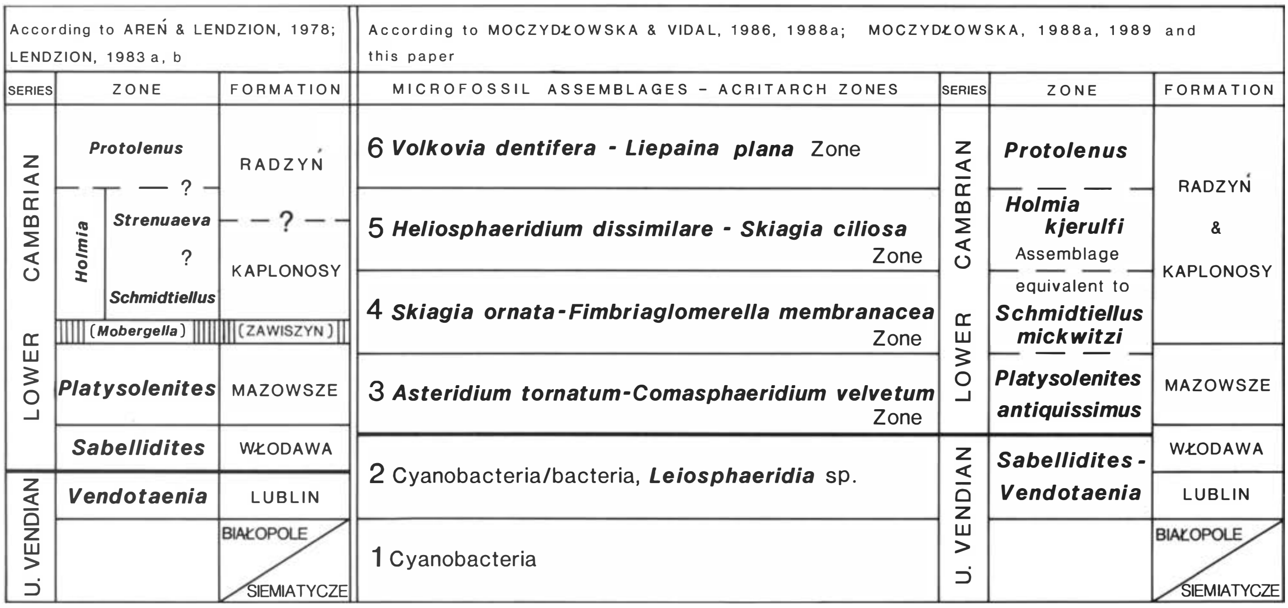

*Fig. 8.* Proposed formal acritarch-based and faunal subdivision of the Lower Cambrian in the Lublin Slope in relation to formerly defined faunal zones. Broken lines indicate approximate boundaries and vertical stripes hiati.

in the other parts of the U.S.S.R. sector of the EEP (Kirjanov 1979a; Bessonova & Piscun 1979; Bessonova & Chumakov 1979; Areń *et al.* 1979a). Finds of *Sabellidites* sp. in Poland were reported from the Mazowsze Formation which corresponds to the *Platysolenites* Zone (Areń *et al.* 1979b). Hence, *Sabellidites* cannot be treated as the index fossil (Lendzion 1983b, p. 673) of the *Sabellidites* Zone within the zonal range indicated by Areń & Lendzion (1978) and Lendzion (1983a, b; *in* Mens *et al.* 1987, 1990). The status of the *Vendotaenia* and *Sabellidites* Zones seems therefore unclear and the significance of these taxa as index fossils questionable. In this connection it is interesting to note that about 20 tubular fragments deriving from specimens of *S. cambriensis* ('chitinous' fauna) are the foundation of the *Sabellidites* Zone in the Lublin Slope, while 21 specimens of *Aldanella polonica* (shelly fauna) in the uppermost part of the *Sabellidites* Zone in Łopiennik IG-1 appear to have been inexplicably ignored (Areń & Lendzion 1978; Lendzion 1983a, b). Similarly, little attention was paid to the significance of the occurrence of other fossils (*Platysolenites antiquissimus*, *Onuphionella agglutinata*, *Anabarella* sp.) in the upper part of the *Sabellidites* Zone (Fig. 6) (cf. Lendzion 1983b).

Here, a combination of both zones into the *Sabellidites–Vendotaenia* Interval-zone is proposed (Figs. 6, 8). This biostratigraphic unit has previously been referred to as a super-zone (Moczydłowska & Vidal 1986) or zone (Moczydłowska & Vidal 1988a and Moczydłowska 1989). In the Lublin Slope the *Sabellidites–Vendotaenia* Interval-zone is herein proposed to embrace rocks of the Lublin and Włodawa Formations, except for the uppermost part of the latter unit (Figs. 6, 8). The lower range of the zone can be extended to the upper part of the Białopole Formation where the occurrence of vendotaenids was recorded (Areń *et al.* 1979b; Lendzion 1983b, p. 674). However, the name of the drillcore and the depth of the occurrence were not provided and it is therefore impossible to be more precise concerning the basal boundary of the zone (Moczydłowska 1989; Fig. 6). The upper boundary of the zone is delimited by the appearance of *Platysolenites*, a typical taxon of the succeeding zone (Moczydłowska 1989; Fig. 6). The *Sabellidites–Vendotaenia* Interval-zone is characterized by the occurrence of 'chitinous' sabelliditids (Sokolov 1965, 1969, 1972; Urbanek & Mierzejewska 1977, 1983; Urbanek 1979) and vendotaenids (Gnilovskaya 1971, 1974, 1979a, b), but the typical taxa of the zone range above its upper boundary (Fig. 6). The microfossils occurring in the zone belong to the second assemblage, which yielded only *Leiosphaeridia* sp. and cyanobacterial microfossils (Moczydłowska 1989; Figs. 6, 8). Thus, the *Sabellidites–Vendotaenia* Interval-zone is considered to constitute the uppermost zone of the Vendian in the Lublin Slope (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989).

The succeeding *Platysolenites* Zone was recognized over the entire EEP in Poland (Areń & Lendzion 1978; Lendzion 1983a, b; Mens *et al.* 1987, 1990). *Platysolenites antiquissimus* Eichwald was regarded as an index taxon (Lendzion 1983a, p. 9), but its occurrence range is wider than the range of the zone (Areń & Lendzion 1978; Bergström 1981; Lendzion 1983a, b; Mens *et al.* 1987, 1990). The zone was defined as an acme-zone (Lendzion 1983b). The hitherto defined range of the *Platysolenites* Zone is controversial and it appears difficult to regard it as an acme-zone because 'numerous specimens occur in the *Platysolenites* Zone and a few occur in the upper part of the *Sabellidites* Zone' (Areń & Lendzion 1978; Lendzion 1983a, b). Furthermore, there is no exact information about the quantitative distribution of the species, and the only documented numerical data concerning the occurrence of *P. antiquissimus* refer to 31 specimens in beds attributed to the *Platysolenites* Zone in four drillcores at four different levels (Lendzion 1972a, b). Thus, this 'acme-zone' encompasses a variable rock thickness which in the various drillcores ranges from 45 to 123 m (Lendzion 1983a) in the EEP in Poland (Fig. 1). Here, an extended range of the *Platysolenites* Zone (*sensu* Areń & Lendzion 1978; Lendzion 1983a, b; Mens *et al.* 1987, 1990) is proposed reaching down to the level of the first appearance of *Platysolenites antiquissimus* or *Platysolenites* sp. (Moczydłowska 1989). In its present definition the zone includes rocks previously attributed to the upper part of the *Sabellidites* Zone (*sensu* Areń & Lendzion 1978; Lendzion 1983a, b; Mens *et al.* 1987, 1990). The formal name *Platysolenites antiquissimus* Interval-zone (Figs. 6, 8) is here selected in favour of the former *Platysolenites* Zone.

The general concept was that the top of the *Platysolenites* Zone in Poland coincided with the base of the next succeeding zone delimited by the range of the *Mobergella* fauna (Lendzion 1972b, 1976, 1982, 1983a, b, d; Areń & Lendzion 1974a, 1978). The upper range of the *Platysolenites* Zone in Scandinavia is marked by the appearance of a trilobite fauna (*Holmia* cf. *mobergi*) more or less contemporaneous with *Mobergella* and *Platysolenites* (Skjeseth 1963; Ahlberg & Bergström 1978; Bergström 1981; Ahlberg 1984; Ahlberg *et al.* 1986). The *Mobergella* Zone in Poland was originally recognized below the *Holmia* zone (Fig. 8) in the Baltic Syneclise and the Podlasie Depression (Fig. 1). The lack of finds of the *Mobergella* fauna in the Lublin Slope was attributed to the existence of a supposed hiatus (Areń & Lendzion 1978; Lendzion 1983a, b; Lendzion *in* Mens *et al.* 1987, 1990) in a sedimentologically continuous sequence (Jaworowski 1978, 1980). Micropalaeontologic investigations indicate the complete nature of the sedimentation record of the sequence throughout the Lower Cambrian in the Lublin Slope (Moczydłowska & Vidal 1986). Here, the acritarch assemblage deriving from the sequence above the rocks of the *Platysolenites* Zone and referred to the lower part of the *Holmia* zone *sensu* Areń & Lendzion 1978 and Lendzion 1983a, b (i.e. Assemblage 4, Fig. 8) is comparable to the Scandinavian assemblage occurring in deposits referred to the *Schmidtiellus mickwitzi* Zone (Vidal 1981b, c; Bergström 1981; Ahlberg *et al.* 1986; Moczydłowska & Vidal 1986). Strata containing the *Mobergella* fauna in Scandinavia yielded an acritarch assemblage which does not differ from the assemblage recovered from the *Holmia kjerulfi*/*Holmia inusitata* Zones (Vidal 1981b, c; Moczydłowska & Vidal 1986; Hagenfeldt 1989a; Vidal & Nystuen 1991). The acritarch assemblage in rocks belonging to the *Mobergella* Zone in the Kościerzyna IG-1 and Prabuty IG-1 drillcores in the Baltic Syneclise (Jankauskas *in* Volkova *et al.* 1979, 1983; Moczydłowska, unpublished data) and in the Okuniew IG-1 drillcore in the Podlasie Depression (Moczydłowska 1980, 1981) comprises species having stratigraphic ranges corresponding to the *Schmidtiellus mickwitzi* and *Holmia kjerulfi* Zones. In any event, the beds with *Mobergella* are coeval with trilobite-bearing strata elsewhere.

As mentioned above, a hiatus was inferred to occupy the span of the *Mobergella* Zone in the Lublin Slope, presumably as the result of epeirogenic movements (Lendzion 1983a, b). The hiatus was thus inferred from the negative evidence provided by the absence of the *Mobergella* fauna. Subsequently, without forwarding any additional evidence, Lendzion (1986b) proposed the recognition of the *Mobergella* Zone also in the Lublin Slope. However, the poorly recognized stratigraphic range of the *Mobergella* fauna (Bergström 1970; Ahlberg *et al.* 1986; Moczydłowska & Vidal 1986; Moczydłowska 1988a) and its limited geographic distribution (probably because of facies control; Bergström 1970, 1981; Martinsson 1974; Stanley 1976; Bengtson 1977; Landing *et al.*1980; Jaworowski 1980; Nowlan *et al.* 1985) seem to constitute unsuitable features for establishing the range of a biozone.

The Klimontovian Stage, as defined comprising strata referred to the pre-trilobite Cambrian in Poland (Areń & Lendzion 1974a, b, 1978; Lendzion 1975, 1976, 1977, 1982, 1983a, b, d), should be rejected. This is because the *Mobergella* Zone is proven contemporaneous with or younger than the *Schmidtiellus mickwitzi* Zone in Scandinavia and its correlative in Poland, and because the *Sabellidites* Zone is Vendian in age (Bergström 1970, 1981; Ahlberg *et al.* 1986; Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989).

Strata immediately overlying beds formerly attributed to the 'Klimontovian Stage' were referred to the *Holmia* and *Protolenus* zones on the basis of trilobite faunas (Lendzion 1969a, b, 1972a, 1983a, b; Areń & Lendzion 1978). However, the ranges of index taxa defining the zones were never clearly delimited. The ranges of these zones in the Lublin Slope are poorly documented and the data are contradictory as the only drillcores ever taken into consideration are Kaplonosy IG-1 and Radzyń IG-1 (cf. Lendzion 1969a, b, 1972a; Areń & Lendzion 1978).

The *Holmia* Zone was 'preliminarily' subdivided into the *Schmidtiellus* and *Strenuaeva* subzones (Lendzion 1983b). However, there is no satisfactory information as to which part of the rock sequence (formation and depth) is referred to the discrete subzones. Moreover, deposits attributed to the *Schmidtiellus* subzone (e.g. Kaplonosy formation, Lendzion 1983a, b) were correlated with the *Holmia inusitata* Zone in Scandinavia (Mens *et al.* 1987, p. 118, 1990, chart). Consequently, the *Schmidtiellus* subzone in Poland was regarded by Lendzion (*in* Mens *et al.* 1987, p. 118, 1990, chart) as younger than the *Schmidtiellus* Zone in Scandinavia. Even more controversial are the data concerning the ranges of zones within the discrete formations in the Lublin Slope. Thus, substantial differences in attribution appear even within the same paper (cf. Mens *et al.* 1987, 1990). For example, it is stated that the Kaplonosy formation (lower part of the *Holmia* zone; Lendzion 1983a, b) at present is attributed to the *Rusophycus parallelum*, *Mobergella* & *Schmidtiellus mickwitzi* and *Holmia inusitata* Zones (Mens *et al.* 1987, pp. 50–51 and 1990, p. 28). However, in the correlation table (Mens *et al.* 1987, p. 118, and chart) the Kaplonosy formation is shown as corresponding to the *Holmia inusitata* Zone alone, while the *Rusophycus* and *Mobergella* & *Schmidtiellus* Zones are shown as missing due to the previously discussed hypothetical hiatus in the sequence. Subsequently, the Radzyń formation (upper part of *Holmia* zone and *Protolenus* zone, Lendzion 1983a, b) was referred to the *Holmia kjerulfi* and *Proampyx linnarssoni* Zones (Mens *et al.* 1987, pp. 74–75 and 1990, p. 42), while in the correlation table in the same papers (Mens *et al.* 1987, p. 118 and chart) the upper part of the Radzyń formation (=*Protolenus* zone, Lendzion 1983a, b) is shown as missing due to a hiatus that is supposed to comprise the succeeding *Proampyx linnarssoni* Zone. Hence, the *Protolenus* zone in Poland could be younger than the *Proampyx linnarssoni* Zone in Sweden. Nevertheless, it was also mentioned that the *Proampyx linnarssoni* Zone corresponds to the lower part of the *Protolenus* zone in Poland (Mens *et al.* 1987, p. 21, and 1990).

Fossils supposedly defining the *Protolenus* zone in the subsurface of the platform in Poland were only identified at the generic level (Lendzion 1983a, b). Hence, the zone is established on uncertain grounds. Similarly to the *Holmia* zone (with its subzones *Schmidtiellus* and *Strenuaeva*), the *Protolenus* zone is not formally established.

Presently, three acritarch-based assemblage-zones are distinguished (Assemblages 4–6; Fig. 8) for the part of the Lower Cambrian sequence that was previously referred to the *Holmia* (*Schmidtiellus+Strenuaeva*) and *Protolenus* zones (Lendzion 1983a, b). The co-occurrence of acritarch assemblages with a macrofauna defining trilobite zones in the platform area of Poland and in Scandinavia (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1989; see 'Correlation of the Lower Cambrian'; Fig. 8) seems to indicate that the range of the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone corresponds to the *Schmidtiellus mickwitzi* Zone in Scandinavia. *Schmidtiellus mickwitzi* was never found in Poland, and therefore the zone cannot be recognized. Accordingly, the strata in Poland here referred to as the *S. ornata – F. membranacea* Assemblage-zone are also regarded as time-equivalent to the *Schmidtiellus mickwitzi* Zone (Figs. 8, 10, 11). Only *Schmidtiellus* sp. was reported in the drillcore Siedliska IG-1 (at a depth of 2835.0 m) in the Lublin Slope, and ?*Schmidtiellus* sp. from drillcore Wyszków IG-1 (at a depth of 2115.2 m) in the Podlasie Depression (Areń & Lendzion 1978, 1979). The range of *Schmidtiellus* sp. in these areas is below the lowest recognized range of *Holmia kjerulfi* (Linnarsson) (Lendzion 1983b). However, acritarch assemblages comparable to the *Skiagia ornata – Fimbriaglomerella membranacea* assemblage were recovered from the Norretorp Formation (Vidal 1981b, 1985), a unit that yielded the index fossil defining the *Schmidtiellus mickwitzi* Zone in Sweden (Bergström 1973, 1981; Ahlberg 1984; Ahlberg *et al.* 1986), and in the Lükati Formation in Estonia (Volkova 1968; Volkova *et al.* 1979, 1983) which also yielded *Schmidtiellus mickwitzi* (Schmidt) (Schmidt 1888, 1889; Bergström, 1973; Mens & Pirrus 1977, 1979).

The range of the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone corresponds to the *Holmia kjerulfi* Assemblage-zone (Fig. 8). The latter zone is proposed also to embrace the *Holmia inusitata* Zone as defined in Sweden (Bergström 1981; Ahlberg *et al.* 1986; Moczydłowska 1989; see 'Acritarch-based correlation of the Lower Cambrian'; Fig. 11).

The youngest acritarch zone recognized in the Lublin area is the *Volkovia dentifera – Liepaina plana* Assemblage-zone that is contemporaneous with the *Protolenus* zone (Fig. 8).

# Acritarch-based correlation of the Precambrian–Cambrian boundary

## Preface

Intense investigation aiming at establishing the Precambrian–Cambrian boundary has been undertaken during the last 10–15 years. Research efforts have been focused on the evolution and recorded changes of the organic world (Brasier 1979, 1985, 1986, 1989; Cowie 1981, 1985; Cloud & Glaessner 1982; Vidal & Knoll 1982; Glaessner 1984; Luo *et al.* 1984; Rozanov 1984a; Conway Morris 1987b; Crimes 1987; Fedonkin 1987; McMenamin 1987; Narbonne *et al.* 1987; Landing *et al.* 1989; Qian & Bengtson 1989; see Cowie & Brasier 1989 for a recent review). For this purpose, various groups of fossils have been considered as possible indicators of the boundary on the basis of observable biotic events. It is only recently that palaeoenvironmental global changes affecting the Earth's oceanic and atmospheric chemistry were considered as possible markers to define and correlate the Precambrian–Cambrian boundary (Towe 1981; Hayes *et al.* 1983; Schidlowski *et al.* 1983; Valentine 1984; Walker 1984; Knoll *et al.* 1986; Magaritz *et al.* 1986; Tucker 1986; Kasting 1987; Schidlowski 1987, 1988; Cloud 1988).

Among the groups of fossils considered, particular attention was paid to trilobites, small shelly fossils, and trace fossils. At various stages in the investigation of Precambrian–Cambrian boundary strata, either of these groups of fossils was regarded as the 'best of the choice' tool for recognizing this boundary. Traditionally, the zonation of the Lower Cambrian was based on available (if only scarce) trilobite faunas (Hutchinson 1962; Sdzuy 1972, 1978; Orłowski 1974, 1985; Ahlberg & Bergström 1978; Nelson 1978; Bergström 1981; Egorova *et al.* 1983; Lendzion 1983b; Ahlberg *et al.* 1986), small shelly fossils (Rozanov & Missarzhevsky 1966; Rozanov *et al.* 1969; Bengtson 1977; Bengtson & Fletcher 1983; Grigoreva 1984; Lendzion 1983b; Bengtson & Conway Morris 1984; Glaessner 1984; Luo *et al.* 1984; Nowlan *et al.* 1985; Orłowski 1987; Landing 1988b; Landing *et al.* 1989; Qian & Bengtson 1989) and, more recently, trace fossils (Fedonkin 1977, 1981, 1983, 1985; Alpert 1977; Palij *et al.* 1983; Crimes & Anderson 1985; Fritz & Crimes 1985; Nowlan *et al.* 1985; Crimes 1987, 1988; Narbonne *et al.* 1987; Narbonne & Myrow 1988). However, perhaps having pelagic larval stages, in their occurrence as fossils these groups of organisms are in all instances restricted to rocks suggesting shallow marine depositional environments. The latter feature possibly adds to their proven inherent disadvantages for global biostratigraphy.

The scarcity or absence of trilobites in lowermost Cambrian strata has resulted in insurmountable difficulties for the definition and regional correlation of the Precambrian–Cambrian boundary. Additionally, trilobites, small shelly fossils and trace fossils are dependent on such factors as provincialism, endemism, facies control, long stratigraphic ranges and (like many other groups of fossils) taxonomic inconsistencies (Banks 1970; Stanley 1976; Landing *et al.* 1980; Luo 1984; Bergström & Gee 1985; Jiang 1985; Mount & Signor 1985; Theokritoff 1985; Narbonne *et al.* 1987; Conway Morris 1988; Fedonkin 1988; Landing 1988a, b, 1989; Landing *et al.* 1988, 1989; Qian & Bengtson 1989; Cowie & Brasier 1989). These facts hamper their utilization as biostratigraphic markers.

Major progress has been achieved during recent years in the investigation of microfossils of encysted plant protists (Volkova *et al.* 1979; Eisenack *et al.* 1973, 1976, 1979a, b; Vidal 1976a, 1981a, b; Tappan 1980; Vidal & Knoll 1982, 1983; Downie 1982; Knoll 1982a, b, 1984; Knoll & Swett 1987; Martin & Dean 1981, 1988; Welsch 1984, 1986; Jankauskas 1989). At the present stage of knowledge, it appears that acritarchs offer a viable alternative to 'established' groups of fossils as correlation tool. This is mainly because their motile stages were largely planktic and distributed in a wide variety of depositional settings. Numerous studies have thus dealt with the possible relationship between groups of taxa (assemblages) and sedimentary facies (Staplin 1961; Vidal 1976a; Nautiyal 1976, 1977; Jacobson 1979; Dorning 1981; Al-Ameri 1983; Moczydłowska & Vidal 1986; McClure 1988; Vidal & Nystuen, 1990, 1991).

As is the case with many other groups of microfossils, acritarchs can be generally recovered in substantial numbers. Typically, fossiliferous samples may yield hundreds or even thousands of specimens of any particular taxon. Admittedly, some taxa are usually rare and can only be counted in much smaller numbers. But mostly there is some occurrence where discrete form-taxa are comparatively well defined through the study of large, representative populations. The application of the study of fossil phytoplankton to solve major stratigraphic problems has gained a strong foothold in the investigation of Phanerozoic strata (Gray & Boucot 1972; Martin 1982; Thierstein 1982; Hultberg 1986; Yin 1986; Brinkhuis & Leereveld 1988; Brinkhuis & Zachariase 1988; Brinkhuis *et al.* 1988; Gray 1988; Whelan 1988). Microfossils of algal protists (acritarchs and cyanobacteria) were primarily used in the biozonation of the terminal Proterozoic and Lower Cambrian units in the EEP in the U.S.S.R. (Volkova 1973, 1985; Volkova *et al.* 1979, 1983; Areń *et al.* 1979a; Bessonova & Chumakov 1979; Bessonova & Piscun 1979; Mens & Pirrus 1979; Kirjanov 1979; Velikanov 1979).

Recent revisions based on technical improvements have verified and greatly corrected the initial quality of acritarch data. At the present stage of knowledge it appears that improved levels of palaeobiological inquiry have opened the possibility for interregional biostratigraphy and correlation. However, spurious data are still contributing to widespread misconceptions. These derive from improper taxonomic assignations which have led to erroneous conclusions (Knoll & Butterfield 1989; Vidal 1990; Vidal & Nystuen 1990). In some cases diagnostically ornamented acritarch taxa in Proterozoic strata were erroneously attributed to Palaeozoic genera (Pyatiletov 1976, 1986, 1988; Volkova *et al.* 1980; Luo *et al.* 1984; Awramik *et al.* 1985; Pyatiletov & Rudavskaya 1985; Yin 1985, 1987; Wang 1985; Zang 1988a, b; Zang & Walter 1989; Jankauskas 1989). This opened the door to misconception and led to supposed diachronous occurrences of certain taxa (Pyatiletov 1976, 1986; Pyatiletov *in* Volkova *et al.* 1980; Khomentovsky 1984, 1986; Brasier 1989).

The very abundant and comprehensive acritarch records deriving from various locations within the EEP (Volkova 1962, 1964, 1965, 1968, 1973, 1974a, b, 1976, 1981a, b, c, 1985; Volkova *et al.* 1979, 1983; Ważyńska 1967; Kirjanov 1968, 1974; Fridrichsone 1971; Umnova & Vanderflit 1971; Jankauskas 1972, 1974, 1975, 1976; Jankauskas & Posti 1976; Paškevičienė 1980, 1986; Moczydłowska 1981, 1988a, 1989; Moczydłowska & Vidal 1986, 1988b) and the North-Atlantic region (Vanguestaine 1967, 1970, 1978; Vidal 1979b, 1981a, b, c, 1985; Vidal & Dawes 1980; Vidal & Knoll 1983; Vidal & Siedlecka 1983; Vidal & Peel 1984; Vidal & Ford 1985; Gardiner & Vanguestaine 1971; Potter 1974; Downie 1974, 1982; Knoll 1982a, b, 1984; Knoll & Swett 1985, 1987; Martin & Dean 1983; Moczydłowska & Vidal 1986; Germs *et al.* 1986; Baudet *et al.* 1989; Palacios Medrano 1989; Vidal & Nystuen 1990, 1991), China (Yin 1980, 1983, 1985, 1987; Awramik *et al.* 1985; Wang 1985; Wang & Chen 1987; Zang 1988b), Australia (Zang 1988b; Zang & Walter 1989), Maly Karatau in Kazakhstan (Ogurtsova 1985) and the Siberian Platform (Volkova *et al.* 1980; Rudavskaya 1980; Volkova 1981c; Faizulina *et al.* 1982; Rudavskaya & Vassileva 1984; Pyatiletov & Rudavskaya 1985; Pyatiletov 1988; Jankauskas 1989) provide abundant evidence for attempting to define the Precambrian–Cambrian boundary on the basis of acritarchs. This has been successfully accomplished concerning the vast area of the EEP, Baltoscandia, Greenland and Svalbard, and it may also apply to Siberia, Newfoundland and China. From the point of view of stratigraphic completeness, continuity and co-occurrence of microphytoplankton with other groups of fossils, the Lake Mjøsa region in southern Norway and Finnmark in northern Norway are promising for a precise recognition of the Precambrian–Cambrian boundary.

The Lublin sequence offers a continuous siliciclastic shelf succession accumulated on a passive platform margin and has yielded a continuous record of microfossils accompanied by small shelly fossils, trilobites and trace fossils. This has resulted in a well documented acritarch-based boundary (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989). Ongoing studies of stable isotopes and isotopic dating of volcanic rocks below the transitional Vendian–Cambrian sequence in the Lublin Slope may add further detail to this sequence. Nevertheless, despite obvious advantages, the Precambrian–Cambrian sequence on the Lublin Slope is a subsurface sequence and this prevents it from being considered as other than a supplementary reference section for the Precambrian–Cambrian boundary.

## The East European Platform

The first biostratigraphic subdivision of the Upper Proterozoic and Lower Cambrian based on organic-walled microfossils was elaborated for the western part of the EEP in the U.S.S.R. (Volkova 1973; Volkova *et al.* 1979, 1983; Fig. 9). The transitional Vendian–Cambrian deposits were thus

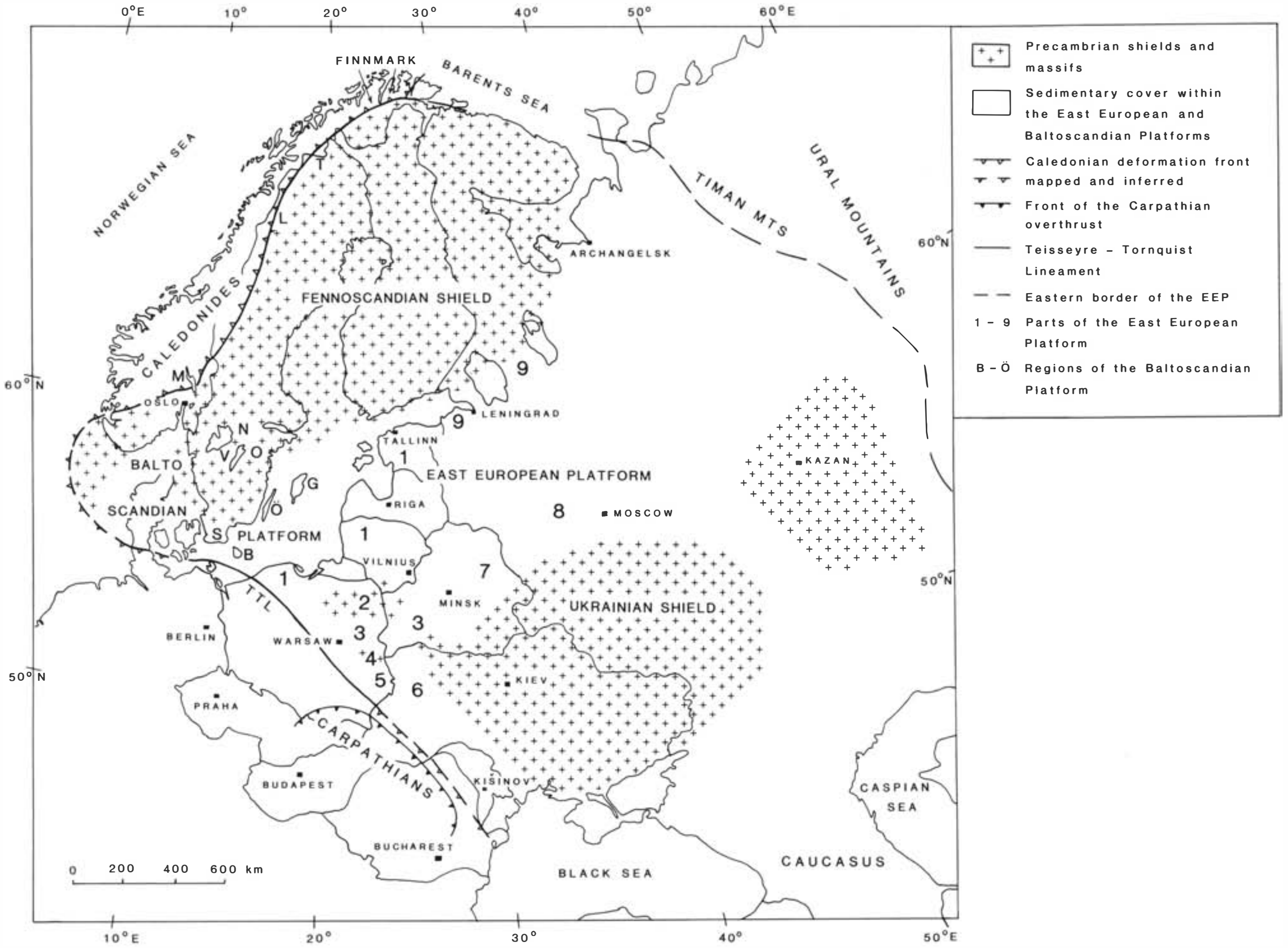

*Fig. 9.* Simplified tectonic framework of the East European Platform and the Baltoscandian Platform showing regions with the late Vendian and Cambrian deposits yielding age-diagnostic acritarch assemblages. The East European Platform tectonic units: 1 – Baltic Syneclise. 2 – Mazury–Byelorussia Anteclise. 3 – Podlasie–Brest Depression. 4 – Łuków–Wisznice Horst. 5 – Lublin Slope of Platform. 6 – Volhynian–Podolian Slope of Platform. 7 – Orsha Depression. 8 – Moscow Syneclise. 9 – southern slope of the Fennoscandian Shield. Regions within the Baltoscandian Platform: B – Bornholm. G – Gotland. L – Laisvall. M – Lake Mjøsa area. N – Närke. O – Östergötland. S – Scania. T – Lake Torneträsk area. V – Västergötland. Ö – Öland. Tectonic units compiled according to Pożaryski 1977a, Keller & Rozanov 1979b, Gee & Sturt 1985.

subdivided into stratigraphic units (horizons). In Soviet usage the term horizon (Russian *gorizont*) embraces different categories of geologic units: bio-, litho-, and chronostratigraphic. Thus, for example, according to Keller & Rozanov (1979b) the term horizon carries the alternative meaning of zone (p. 221), formation (p. 155) or stage (p. 213). Lately, the term 'horizon' was used as a 'regional stage' (Mens *et al.* 1987, 1990). In such a confusing situation, the term 'horizon' in the present paper will be exclusively applied to the biostratigraphic units in the U.S.S.R. (Fig. 10). Horizons were established on the basis of the stratigraphic ranges of individual diagnostic acritarch taxa and groupings of taxa called assemblages (Volkova 1973; Volkova *et al.* 1979, 1983). The Lower Cambrian was divided into five biozones ('horizons') (Fig. 10), in ascending order the Rovno, Lontova, Talsy (=Lükati), Vergale and Rausve 'horizons' (Volkova *et al.* 1979, 1983).

The age of the Rovno horizon was the subject of much discussion, being alternatively regarded as early Cambrian (Volkova *et al.* 1979, 1983; Keller & Rozanov 1979a, b, 1980; Velikanov *et al.* 1983; Makhnach *et al.* 1986; Mens & Pirrus 1986; Paškevičienė 1986; Mens *et al.* 1990) or late Precambrian, i.e. Vendian in age (Sokolov 1974; Rozanov & Sokolov 1980, 1982; Sokolov & Ivanovsky 1985; Sokolov & Fedonkin 1985; Volkova 1985). Consequently, the age attributed to the Rovno horizon has played a very significant role concerning the position of the Precambrian–Cambrian boundary, alternatively placed at the base or top of the horizon. Criteria for bracketing the relative age of the Rovno horizon were the occurrences of a shelly fauna, soft-bodied metazoans, trace fossils, acritarchs and vendotaenids (Volkova 1968, 1973, 1974, 1985; Fedonkin 1976, 1977, 1980a, 1983, 1985; Mens & Pirrus 1979, 1986; Luchinina *et al.* 1978; Gnilovskaya 1979a, 1985; Keller & Rozanov 1979a, b; Palij *et al.* 1983; Volkova *et al.* 1979, 1983; Rozanov & Sokolov 1982; Sokolov & Ivanovsky 1985; Sokolov & Fedonkin 1985).

Sabelliditids occurring in the Rovno horizon have been regarded as of prime importance and believed to mark the base of the Cambrian (Kirjanov 1968, 1969, 1979a; Areń *et al.* 1979c; Keller 1982). They have generally been treated as shelly fossils, although they lack mineralized skeletal components and are built exclusively of organic compounds (Sokolov 1965, 1967, 1972; Urbanek & Mierzejew-

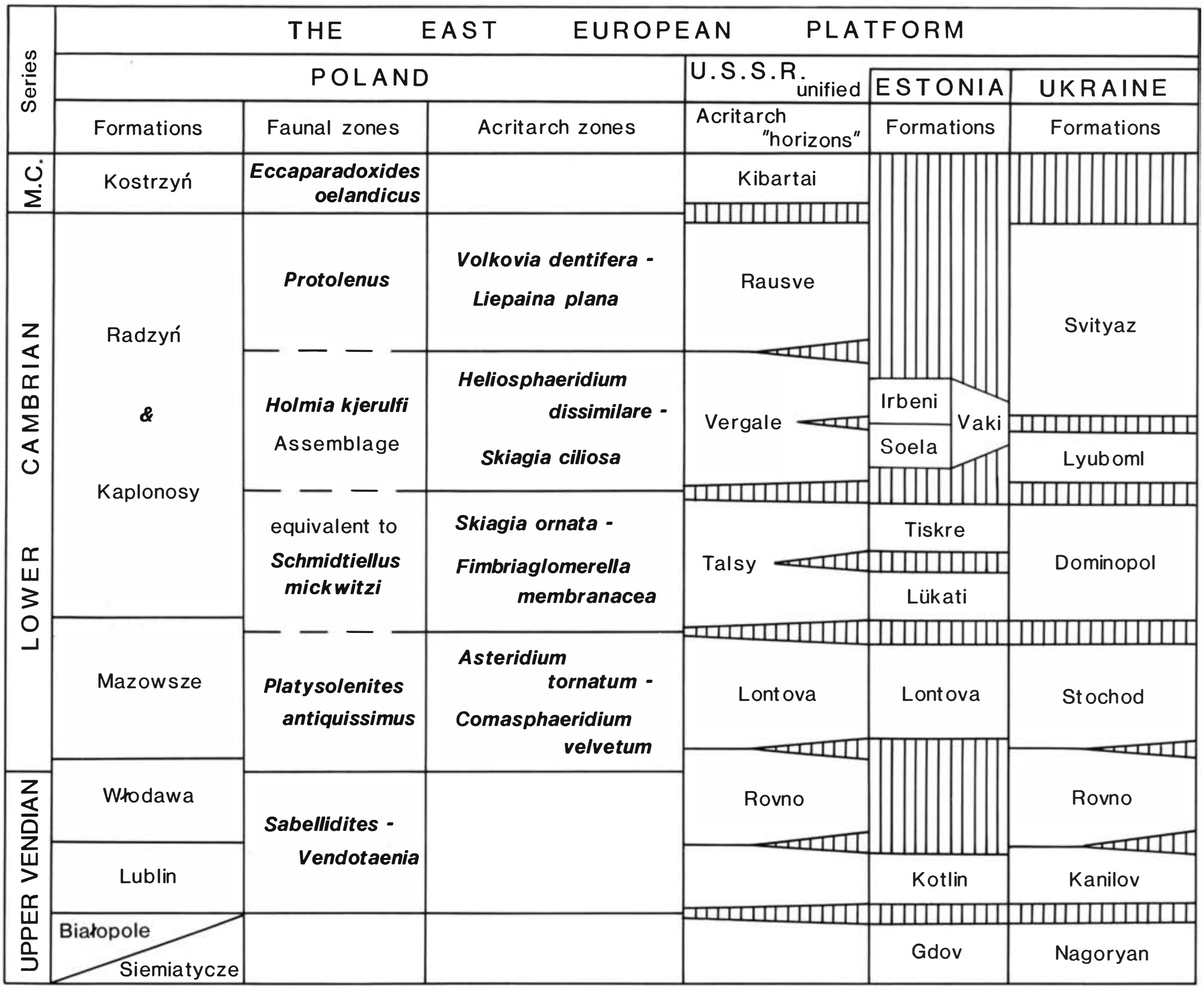

*Fig. 10.* Acritarch-based correlation of Lower Cambrian strata within the East European Platform in Poland and the U.S.S.R. Data for the U.S.S.R. modified after Volkova 1968, 1973; Kirjanov 1969, 1979a; Mens & Pirrus 1977, 1979; Keller & Rozanov 1979b; Velikanov 1979; Volkova *et al.* 1979; Mens *et al.* 1990. Broken lines stand for approximate boundaries and vertical stripes indicate hiati.

ska 1977, 1983; Urbanek 1979). Over much of the EEP, sabelliditids occur for the first time in rocks of the Rovno Formation (stratotype for the Rovno horizon) where they are particularly abundant (Keller & Rozanov 1979b). But sabelliditids are by no means restricted to the Rovno horizon and range well into younger units (Kirjanov 1979a; Bessonova & Piscun 1979; Bessonova & Chumakov 1979; Areń *et al.* 1979a, c; Sokolov 1985).

Shelly (although agglutinated) fossils belonging to the genus *Platysolenites* appear in the upper part of the Rovno horizon and are more numerous and diversified in younger strata (Kirjanov 1968, 1979a; Posti 1978; Mens & Pirrus 1979; Rozanov 1979, 1983; Sokolov 1985). The assemblage of soft-bodied metazoans, trace fossils and vendotaenids recorded in the Rovno horizon does not significantly differ from underlying strata attributed to Vendian zones (Sokolov & Ivanovsky 1985; Sokolov & Fedonkin 1985).

Among biostratigraphically significant microfossils reported from the transitional Vendian–Cambrian sequence, the oldest were attributed to *Micrhystridium tornatum* Volkova (here transferred to *Asteridium tornatum* (Volkova) comb. nov.). The microfossils were described from the Vendian Kotlin Formation that underlies the Rovno Formation (Volkova *et al.* 1979, 1983). The occurrence of the species in the Kotlin Formation must be considered as very rare since it is restricted to a single locality in the Redkino drillcore in the Moscow Syneclise (Volkova 1968, 1969b, 1973; Volkova *et al.* 1979, 1983). However, the number of recovered specimens and the detailed stratigraphic position within the sequence was never mentioned, and micrographs of the fossils were never published. The occurrence of *Asteridium tornatum* in the late Vendian Lublin and Włodawa Formations in Poland could not be confirmed by the present study. The single poorly documented occurrence in the Proterozoic of the EEP thus seems questionable.

Additional microfossils in the Kotlin Formation consist of *Ambiguaspora parvula* Volkova, *Leiosphaeridia* sp. and fragments of undetermined cyanobacterial filaments and of forms attributed to *Oscillatorites* sp. (Volkova *et al.* 1979, 1983), all lacking biostratigraphic significance.

Rocks attributed to the stratigraphically succeeding Rovno horizon were reported to yield leiosphaerid acritarchs of various species, e.g. *Leiosphaeridia bicrura* Jankauskas, *L. pylomifera* Paškevičienė and *L. dehisca* Paškevičienė. The two latter species were regarded as restricted to the horizon (Volkova *et al.* 1979, 1983). However, these fossils lack diagnostic features justifying their assignation to separate taxa (see 'Palaeontological descriptions'). In fact, comparison of specimens of *Leiosphaeridia* from the Kotlin Formation (Volkova *et al.* 1979, Pl. 35–37), Rovno horizon (Volkova *et al.* 1979, Pl. 13, 31) and Lower and Middle Cambrian horizons (Lontova – Kibartai; Volkova *et al.* 1979, Pl. 34) meets overwhelming difficulties since no reliable diagnostic features can be observed. Observable features differing between the specimens are in all instances related to the state of preservation. This may as well apply to various claimed mechanisms of excystment (Vavrdová 1976) which may seem readily explainable in terms of different patterns of post-depositional compression. Strongly corroded specimens of *Leiosphaeridia* spp. occur in the Kotlin Formation while better preservation characterizes younger horizons (cf. Volkova *et al.* 1979, 1983). This feature only reflects substantial differences in post-depositional palaeoenvironmental conditions (Germs *et al.* 1986). The specimens attributed to *L. bicrura* and *L. dehisca* display excystment by median split, while *L. pylomifera* reveals a rounded pylome, a common feature among Palaeozoic acritarchs (Vavrdová 1976; Brasier 1980). Nevertheless, well-developed circular pylomes were recorded also among late Proterozoic Riphean spheromorphs (Vidal 1976; Vidal & Ford 1983). Thus, this feature does not provide sufficient basis for erecting new form-species. Additionally, *L. dehisca* was also reported from the Lontova horizon in Byelorussia (Bessonova & Piscun 1979), the Orsha Depression and the western part of the Moscow Syneclise (Bessonova & Chumakov 1979). By itself this latter circumstance excludes the possibility of regarding the species as an index taxon for the Rovno horizon.

Additional microfossils claimed to be characteristic of the Rovno horizon include *Retisphaeridium densum* Paškevičienė and *Teophipolia lacerata* Kirjanov (Volkova *et al.* 1979, 1983). Specimens referred to *R. densum* (Volkova *et al.* 1979, Tabl. 29, Figs. 6, 7) appear to represent rather corroded and compacted leiosphaerids and are not attributable to the genus *Retisphaeridium* Staplin, Jansonius & Pocock, 1965. The species *T. lacerata* is also known from the decidedly younger Lower Cambrian Hardeberga Sandstone in Sweden (G. Vidal, personal communication) and this suggests a considerably extended stratigraphic range.

Also, *Ceratophyton vernicosum* Kirjanov reported to occur in the Rovno and the succeeding Lontova horizons has a substantially wider stratigraphic range than previously reported within the EEP by Volkova *et al.* (1979, 1983). The species occurs also in the lower part of the Kaplonosy and Radzyń formations referred to as the equivalent of the *Schmidtiellus mickwitzi* Zone (Figs. 5, 8) in the Lublin Slope. This part of the sequence was correlated with the Talsy horizon (Volkova 1969a, 1973; Areń & Lendzion 1978; Volkova *et al.* 1979, 1983; Keller & Rozanov 1979b; Urbanek & Rozanov 1983; Figs. 10, 11). The species is also recorded in the Lower Cambrian Hardeberga Sandstone in Sweden and in the 'Green Shales' in Bornholm, Denmark (Moczydłowska & Vidal 1986), which might belong to the *Schmidtiellus mickwitzi* Zone (Fig. 11), and in the Tokammane Formation in Spitsbergen, Svalbard, which is considered to be contemporaneous with the Lontova horizon (Knoll & Swett 1987).

Accordingly, the Rovno horizon is characterized by the occurrence of acritarchs referred to *Leiosphaeridia* sp., *T. lacerata* and the problematicum *C. vernicosum* (neither of which appear to have much biostratigraphic significance), and additionally, *Micrhystridium tornatum*, which is well known to occur in the Cambrian (Volkova 1968, 1973; Downie 1974, 1982; Vanguestaine 1978; Volkova *et al.* 1979; 1983; Vidal 1981a, b, c; Moczydłowska 1981, 1989). The occurrence of *M. tornatum* in deposits referred to the Rovno horizon was reported from Latvia (drillcores Aluksne and Baltanava), the Moscow Syneclise (drillcore Redkino) and the Leningrad district (Volkova 1968, 1969b, 1973, 1981b, 1985; Volkova *et al.* 1979, 1983). However, detailed information concerning the relative location in the sequences is not available. Only in the southern part of the Fennoscandian (=Baltic) Shield (which includes the Leningrad district) the occurrence of *M. tornatum* was more 'precisely' reported as the uppermost part of the Rovno horizon (Mens & Pirrus 1979).

From the point of view of continuity rocks attributed to the Rovno horizon are in transitional contact with the overlying rocks of the Lontova horizon only in the Ukraine and in the southern slope of the Fennoscandian Shield (Kirjanov 1968, 1969, 1979a; Mens & Pirrus 1979; Keller & Rozanov 1979b; Mens *et al.* 1987, 1990). In areas of continuous sedimentation, the uppermost part of the Rovno horizon yielded the first finds of *Platysolenites antiquissimus* (Kirjanov 1968, 1969, 1979a; Mens & Pirrus 1979; Rozanov 1979, 1983). In the southern slope of the Fennoscandian Shield coeval beds also yielded *M. tornatum* (Mens & Pirrus 1979). A characteristic acritarch assemblage occurs in rocks of the succeeding Lontova horizon together with a shelly fauna consisting of *P. antiquissimus*, *Onuphionella agglutinata*, *Aldanella kunda*, and a 'chitinous' fauna attributed to *Sabellidites cambriensis* and *S.* sp. (Volkova *et al.* 1979, 1983; Keller & Rozanov 1979b; Rozanov 1979, 1983).

Looking at the fossil record within discrete areas of the EEP in the U.S.S.R. it appears that the acritarch assemblage consisting of *Leiosphaeridia* sp. is accompanied by *S. cambriensis* and *S.* sp. The appearance of *P. antiquissimus* coincides with the occurrence of *Micrhystridium tornatum* and the 'Lontova-type' acritarch assemblage. This is taken as a good marker bed. Accordingly, in this paper only the upper part of the Rovno horizon, yielding *Platysolenites* and *Asteridium tornatum* (Volkova) comb.nov., is attributed to the Cambrian System (Moczydłowska 1989; Figs. 10, 11).

The microfossil assemblage recorded in rocks of the *Sabellidites–Vendotaenia* Zone in the Lublin Slope in Poland (Assemblage 2; Fig. 8), which was regarded as Vendian in age (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989), is comparable to the assemblage occurring in the Kotlin Formation and the bulk of rocks of the Rovno horizon (except for its upper part) in the U.S.S.R. (Fig. 10).

The microfossil assemblage defining the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone in the

Lublin region, which is contemporaneous with the *P. antiquissimus* Interval-zone (Fig. 8), consists of species that appear in the Lontova and Talsy horizons in the platform areas within the U.S.S.R. It additionally contains some new species (Moczydłowska & Vidal 1986; Moczydłowska 1988a). But it does not include any species of *Baltisphaeridium* (here referred to *Globosphaeridium* n.gen. and *Skiagia*) that are diagnostic of the Talsy horizon (Volkova *et al.* 1979, 1983). However, the assemblage under discussion is rich in specimens attributed to species of *Pterospermella*, previously known to appear first in the Talsy horizon.

In the Lublin Slope the acritarchs *Lophosphaeridium tentativum* Volkova, *Asteridium lanatum* (Volkova) comb. nov., *Comasphaeridium strigosum* (Jankauskas) Downie, *Pterospermella vitalis* Jankauskas and *Tasmanites bobrowskae* Ważyńska (previously known from the Talsy horizon) appear in the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone. The occurrence of acritarchs previously regarded as first appearing in the Talsy horizon (Volkova *et al.* 1979, 1983) in older deposits (e.g. in the Lontova horizon) was also noted in the U.S.S.R. For example, *T. bobrowskae* occurs in a correlative of the Lontova horizon in Volhynia (Shepeleva 1969), and in the Lontova horizon in Byelorussia (Bessonova & Piscun 1979), the Orsha Depression and the Moscow Syneclise (Bessonova & Chumakov 1979). Thus, differences in the composition of the acritarch assemblages between the *Asteridium tornatum – Comasphaeridium velvetum* Zone in Poland and the corresponding Lontova horizon in the U.S.S.R. have to do with the more comprehensive stratigraphic ranges observed for some so-called Talsy 'age-diagnostic' species, reflected in their seemingly earlier appearances in the Lublin area. Discrepancies in stratigraphic ranges could be a function of insufficient sampling or perhaps be due to a more complete record of microfossils in the continuous sequence in the Lublin Slope. A previously recognized sedimentation break at the disconformable contact between the deposits of Lontova and Talsy horizons in the U.S.S.R. (Mens & Pirrus 1977; Keller & Rozanov 1979b) has caused a hiatus (Fig. 10).

The *Asteridium tornatum – Comasphaeridium velvetum* Zone is here regarded as corresponding to the Lontova horizon and the uppermost part of the Rovno horizon (Fig. 10). These acritarch zones are contemporaneous with the *P. antiquissimus* Zone according to its modified range (Moczydłowska 1989; Figs. 6, 8, 10). Previously, the Lontova horizon was correlated with the *Platysolenites* Zone (*sensu* Areń & Lendzion 1978 and Lendzion 1983a, b) or with the *Platysolenites* Zone and the lower part of the *Mobergella* Zone (Lendzion 1983a). The overlying Talsy horizon is regarded as the oldest unit in the EEP within the U.S.S.R. containing Lower Cambrian trilobites (Kirjanov & Chernysheva 1967; Mens & Pirrus 1977; Kirjanov 1979; Keller & Rozanov 1979b) and has been correlated with the *Holmia* zone in Poland (Areń & Lendzion 1978), or alternatively, with the upper part of the *Mobergella* Zone and the lower part of the *Holmia* zone (Lendzion 1983a).

## The Baltoscandian Platform

In Scandinavia the Upper Proterozoic and Lower Cambrian sedimentary sequences occur within the Caledonide Orogen and the Baltoscandian Platform (Martinsson 1974; Kumpulainen & Nystuen 1985; Føyn 1985; Bergström & Gee 1985; Fig. 9). Within the Caledonides, Upper Proterozoic and Lower Cambrian rocks are present in allochthonous and parautochthonous occurrences within thrust sheets and in autochthonous areas along the thrust front of the orogen (see Kumpulainen & Nystuen 1985 for a recent review). The allochthonous units were originally deposited in the western Baltoscandian basins bordering the Baltoscandian continental platform, where autochthonous and parautochthonous formations were deposited during regional subsidence (Kumpulainen & Nystuen 1985). Major areas of autochthonous unmetamorphosed sedimentary successions in northern Scandinavia are in East Finnmark, around the Tanafjord and Varangerfjord areas and around the Laksefjord, Porsangerfjord and Alta regions in northern Norway (Banks *et al.* 1971, 1974; Siedlecka & Siedlecki 1971; Johnson *et al.* 1978; Føyn 1985). Additional areas along the Caledonian thrust front from Finnmark in northeastern Norway to the Lake Mjøsa region in southwestern Norway (e.g. around Lake Torneträsk and in Laisvall in northern Sweden) are referred to the Vendian and Lower Cambrian Dividal Group (Kulling 1964; Vogt 1967; Føyn 1967, 1985; Føyn & Glaessner 1979; Kumpulainen & Nystuen 1985; Bergström & Gee 1985; Ahlberg, 1985).

In Baltoscandia, the most complete transitional sequence through Upper Proterozoic – Lower Cambrian strata is developed in the Tanafjord–Varangerfjord region. Its thickness is about 5000 m and comprises units attributed to the Upper Riphean, Vendian, Cambrian and Tremadocian (cf. Føyn 1985 for a recent review). Upper Proterozoic deposits reaching a thickness of about 3000 m are divided into three groups of strata, each separated by an unconformity (Johnson *et al.* 1978; Siedlecki 1980; Føyn 1985). In ascending order, the sequence is initiated by the Vadsø Group (dominantly fluvial according to Banks *et al.* 1971, although micropalaeontological evidence suggests largely marine deposition, Vidal 1981a), followed by shallow-marine deposits of the Tanafjord Group, and the glacial and marine Vestertana Group (Reading 1965; Siedlecka & Siedlecki 1971; Banks *et al.* 1971, 1974; Føyn 1985). The upper part of the Vestertana Group consists of the Stappogiedde Formation (500–550 m in thickness) and the Breivik Formation (600 m thick). These two formations form a continuous transgressive marine succession of Precambrian to Cambrian strata (Reading 1965; Føyn 1967, 1985; Banks 1970; Bank *et al.* 1971, 1974; Siedlecka & Siedlecki 1971; Johnson *et al.* 1978; Føyn & Glaessner 1979; Siedlecki 1980). The lithostratigraphic and depositional character of the Upper Proterozoic–Cambrian sequence in the Tanafjord–Varangerfjord region is complex (Reading 1965; Banks *et al.* 1971, 1974; Siedlecka & Siedlecki 1971; Johnson *et al.* 1978; Siedlecki 1980). Its age is bracketed by isotopic (Pringle 1973; Sturt *et al.* 1975) and biostratigraphic age determinations (Føyn 1967, 1985; Banks 1970; Føyn & Glaessner 1979; Bertrand-Sarfati & Siedlecka 1980;

Vidal 1981a, 1985). Isotopic dating of the Klubbnes Formation at the base of the Vadsø Group yielded an age of 807±19 Ma. The Nyborg Formation of the Vestertana Group gave an age of 653±7 Ma, and the cleavage of the Stappogiedde Formation was dated to 504±7 Ma (Pringle 1973; Føyn 1985; recalculated by Sturt *et al.* 1975). The Vadsø Group, except the uppermost Ekkerøy Formation, contains acritarch assemblages previously known in Upper Riphean units in the U.S.S.R., in the middle and lower part of the Upper Visingsö Group in Sweden, and in the Upper Eleonore Bay Group of East Greenland (Vidal 1981a). Thus the group is considered to be late Riphean in age (Vidal 1981a, 1985; Føyn 1985). On the basis of the acritarch evidence, the Ekkerøy Formation at the top of the Vadsø Group and the lower part of the overlying Tanafjord Group is regarded to be early Vendian in age (Vidal 1981a, 1985). The Grasdal Formation of the uppermost Tanafjord Group yielded stromatolites interpreted to be late Riphean to Vendian in age (Bertrand-Sarfati & Siedlecka 1980).

The overlying Vestertana Group, with its continuous sequence across the Precambrian–Cambrian boundary within the Stappogiedde or Breivik Formation (Banks 1970; Føyn & Glaessner 1979; Vidal 1981a, 1985; Føyn 1985), contains small shelly fossils, 'chitinous' fossils and trace fossils (Føyn 1937, 1967, 1985; Reading 1965; Banks 1970; Føyn & Glaessner 1979). Recently, imprints of certain Ediacara-type soft-bodied metazoans and trace fossils were recovered from the Stappogiedde Formation (Farmer *et al.* 1991). Remains of vendotaenids were reported from the Stappogiedde Formation (Vidal 1981a) and were recently recovered from the Lower Breivik Member of the Breivik Formation (personal observations).

The first trace fossils occurring in the Stappogiedde Formation are simple vertical burrows and horizontal trails, while *Phycodes pedum* first appears at the base of the Breivik Formation within the lowest 3 m of the Lower Breivik Member (Banks 1970). *Platysolenites antiquissimus* occurs about 150 m above the base of the Breivik Formation (Banks 1970) and it is well known also in correlatives of this formation within the Dividal Group at other localities in northern Scandinavia (Føyn 1967, 1985; Føyn & Glaessner 1979). The acritarch assemblage from the Breivik Formation contains *Micrhystridium* sp. (= *Asteridium* sp.) together with *P. antiquissimus* (Vidal 1981a). Elsewhere *Micrhystridium* is known to occur in Cambrian and younger strata (see 'Acritarch-based correlation of the Precambrian–Cambrian boundary', The EEP).

On palaeontologic evidence the Precambrian–Cambrian boundary was placed at the transitional beds between the Stappogiedde Formation and the Breivik Formation (Banks 1970; Banks *et al.* 1971), or in the uppermost part of the Stappogiedde Formation (Føyn & Glaessner 1979; Vidal 1981a). The base of the Breivik Formation was proposed by Daily (1972) and Føyn (1985) as the alternative level of the Precambrian–Cambrian boundary. The transitionally overlying Duolbasgaissa Formation of the Digermul Group (Johnson *et al.* 1978; Siedlecki 1980; Føyn 1985) contains the ichnofossil *Rusophycus dispar* and poorly preserved trilobites attributed to *Holmia mobergi* (?), taken to indicate the *Schmidtiellus mickwitzi* Zone of the Lower Cambrian (Bergström 1981; Ahlberg 1984; Bergström & Gee 1985).

A time equivalent Upper Proterozoic – Lower Cambrian sequence is exposed also in the Laksefjord region, where the Tanafjord Group and Vestertana Group, including the *Platysolenites*-bearing Breivik Formation, are recognized (Føyn 1967, 1985). Among the autochthonous sections of the Dividal Group along the Caledonian front, the most complete sequence is at Mt. Luopakte, south of Lake Torneträsk (Moberg 1908; Kulling 1964; Føyn 1967; Thelander 1982). It consists of rocks ranging in age from Vendian to Middle Cambrian (Kulling 1964; Vogt 1967; Føyn 1967, 1985). The Dividal Group is subdivided into informal lithostratigraphic members I, II, III (correlated with the Stappogiedde Formation), attributed to the Vendian, which are overlain by strata referred to the Lower Cambrian (Kumpulainen & Nystuen 1985; Føyn 1985). Vendotaenids and Vendian acritarchs were reported in the second lithostratigraphic unit (Vidal 1981a). The possible medusoid fossil *Kullingia concentrica* Glaessner occurs in rocks corresponding to member III (Kulling 1964, 1972; Føyn 1967, 1985; Føyn & Glaessner 1979). The three lower members contain an assemblage of trace fossils comparable to those in the Stappogiedde Formation (Banks 1973). A depositional break was inferred within the upper part of member III, and this break is considered to represent the boundary between the Vendian and Cambrian (Vidal 1981c, 1985; Føyn 1985). The overlying beds contain *Platysolenites antiquissimus*, *Volborthella tenuis* and *Hyolithes* sp. (Kulling 1964; Føyn & Glaessner 1979; Ahlberg 1985) as well as the acritarch species *Leiosphaeridia* sp., *Lophosphaeridium tentativum*, *Tasmanites* sp., and *Comasphaeridium strigosum* (Vidal, unpublished). The upper part of the sequence contains a fauna including *Strenuaeva inflata* Ahlberg & Bergström, *Comluella? lapponica* Ahlberg, and *Proampyx triangularis* Ahlberg & Bergström. This fauna is attributed to the *Holmia kjerulfi*-group Zone (Ahlberg & Bergström 1978; Ahlberg 1979, 1980, 1985; Bergström & Gee 1985).

In the Laisvall region the crystalline basement is covered by rocks of the Laisvall Group and Middle and/or Upper Cambrian shales (Willdén 1980; Bergström & Gee 1985). The lower part of the Laisvall Group contains an Ediacara-type medusoid fossil (Kulling 1964) and is referred to the Vendian. On micropalaeontologic evidence (acritarchs) the base of the Cambrian is located at the bottom of the Grammajukku Formation (Vidal 1981a) which constitutes the upper part of Laisvall Group. Non-trilobite trace fossils, shelly fossils and trilobites occur in this formation which can probably be referred to the *Holmia kjerulfi*-group Zone (Kautsky 1945; Ahlberg & Bergström 1978; Bergström 1980, 1981; Ahlberg 1984, 1985; Bergström & Gee 1985). This section contains a disconformity at the bottom of the Grammajukku Formation (Willdén 1980; Ahlberg 1984) which marks the base of the Cambrian (Vidal 1981a, c, 1985).

Summarizing, among several well-exposed and recognized transitional Upper Proterozoic – Lower Cambrian sequences in Scandinavia the Tanafjord–Varangerfjord region seems to be the very promising section for recognizing the Precambrian–Cambrian boundary. The sequence is evidently continuous, relatively well known from the lithostratigraphic, sedimentologic and tectonic points of view, and several units have been isotopically dated (see Føyn 1985; Kumpulainen & Nystuen 1985; Bergström & Gee 1985). A transition from the post-glacial Vendian into Lower Cambrian strata is well documented biostratigraphically (Føyn & Glaessner 1979; Bergström & Gee 1985; Vidal 1985). Hitherto existing palaeontologic records comprise 'chitinous' fossils, small shelly fossils, trace fossils, trilobites and microfossils (acritarchs and cyanobacteria) which are fully comparable with the transitional Precambrian–Cambrian sequences elsewhere. Particularly the acritarch evidence (Vidal 1981a, 1985, and unpublished ongoing studies) are promising for the recognition of the microbiotic changes and radiation of phytoplankton at the turn of Proterozoic and Phanerozoic. The equivalent continuous sequences at Laksefjord, or sequences with depositional breaks at Lake Torneträsk (Mt Luopakte), Laisvall, Barents Sea and Lake Mjøsa regions, provide analogous fossil successions which indicate rather complete microbial and faunal records. The above mentioned supplementary reference sections are overlain by trilobite-bearing Lower Cambrian strata, thus providing a marker level for the sequences under consideration.

## The Siberian Platform

Available micropalaeontological data from the transitional Vendian–Cambrian strata in the Siberian Platform are relatively less comprehensive than in the EEP. The predominance of carbonate facies in the Siberian Platform undoubtedly constitutes the main cause of the scarce occurrences of acritarch assemblages. This is because these lithofacies are generally not suitable for the preservation of organic-walled microfossils. However, the reported co-occurrence of acritarch assemblages with shelly fossils considered as index taxa of the earliest Cambrian in Siberia is significant (Ogurtsova 1975; Rudavskaya & Vassileva 1984) for defining the Precambrian–Cambrian boundary. It also adds to the correlation of strata in different regions and to the timing of the early radiation of phytoplankton and skeletal faunas (Moczydłowska & Vidal 1988a).

The transitional Vendian–Cambrian deposits in the Siberian Platform comprise, in ascending order, the Yudomian, Tommotian and Atdabanian Stages (Ivanovskaya 1980; Rozanov & Sokolov 1984). The Yudomian Stage embraces the Yudoma Formation including the Nemakit–Daldyn horizon and is considered to be Vendian in age (Rozanov & Sokolov 1984; Sokolov & Ivanovsky 1985; Sokolov & Fedonkin 1985; Khomentovsky 1984, 1986). The Tommotian Stage is regarded as the lowermost part of the Cambrian System in the Siberian Platform (Rozanov & Missarzhevsky 1966; Rozanov *et al.* 1969; Raaben 1981; Rozanov & Sokolov 1982, 1984; Sokolov & Zhuravleva 1983). It consists of the upper part of the Yudoma Formation and the Pestrotsvet Formation (Rozanov & Sokolov 1984). The lower boundary of the Tommotian Stage is defined at the base of the *Aldanocyathus sunnaginicus* Zone and it has been proposed as the stratotype for the Proterozoic–Cambrian boundary (Rozanov & Sokolov 1982, 1984; Rozanov 1984a, b). The zonation of the Tommotian Stage is based on archaeocyathan assemblages that define the *Aldanocyathus sunnaginicus* Zone, *Dokidocyathus regularis* Zone and, uppermost, the *Dokidocyathus lenaicus – Tumuliolynthus primigenius* group Zone. The mass appearance of skeletal fossils occurs in the *A. sunnaginicus* Zone (Rozanov & Sokolov 1984). Rocks of the Atdabanian Stage contain the oldest trilobite fauna in Siberia, including trilobites of the genus *Profallotaspis* (Egorova *et al.* 1983; Rozanov & Sokolov 1984).

Small shelly fossils in Tommotian strata are generally regarded as biostratigraphically significant (Rozanov *et al.* 1969; Rozanov & Sokolov 1984; Brasier 1989). The implied order of appearance preceding the rise of 'more advanced' faunas (e.g. trilobites) is significant in that it has become an essential part of various models aiming at explaining the rise, radiation and skeletonization among marine invertebrates (Termier & Termier 1960; Brasier 1979, 1985, 1989; Lowenstam & Margulis 1980; Glaessner 1984; Conway Morris 1987a, b). However, outside the type area of the Tommotian, some of the supposedly age-diagnostic index fossils of the Tommotian have been reported to occur together with trilobites, which by virtue of concept, would imply a younger age than in Siberia. In Canada *Sunnaginia imbricata* (and possibly *Turcutheca*) was reported together with trilobites of the *Callavia* Zone (Landing *et al.* 1980). In southeastern Sweden, *Mobergella holsti* was recorded in sandy units considered as roughly contemporaneous with the Lower Cambrian zone with *Dokidocyathus lenaicus* and *Majatheca tumefacta* in Siberia (Bengtson 1970, 1977). Subsequently, on faunal grounds, the rocks were considered as time equivalent with shale–carbonate facies rocks attributed to the *Schmidtiellus mickwitzi* trilobite Zone in southern Norway (Bergström 1981) containing *Holmia* cf. *mobergi*, *Platysolenites antiquissimus* and *Mobergella* fauna (Skjeseth 1963; Bengtson 1977; Bergström 1981; Ahlberg *et al.* 1986). Bergström (1981) suggested that part of the Tommotian sequence in Siberia may be contemporaneous with the *Schmidtiellus mickwitzi* Zone in the Baltic region. The *Mobergella*-bearing units in southeastern Sweden and southern Norway have yielded acritarchs diagnostic of Vergale age (Vidal 1981b; Moczydłowska & Vidal 1986; Hagenfeldt 1989a; Vidal & Nystuen 1991). Furthermore, in the subsurface of the Baltic Syneclise in Poland, beds with *Mobergella* have yielded acritarchs previously known from the trilobite-bearing Talsy and Vergale horizons (Jankauskas *in* Volkova *et al.* 1979; Moczydłowska 1981 and unpublished data).

Acritarch assemblages deriving from the Yudomian and Tommotian Stages in the Siberian Platform have provided data which should be taken into consideration in any discussion on biostratigraphic interregional correlation. Acritarchs from the *Aldanocyathus sunnaginicus* Zone closely resemble those from the Lontova horizon (*Platysolenites antiquissimus* Zone) in the EEP (Ogurtsova 1975). However, the acritarch taxa considered by Ogurtsova (1975) have long stratigraphic ranges in the EEP (Volkova *et al.* 1979, 1983), where they range into trilobite-bearing strata attributed to the Talsy horizon. Hence, they lack biostratigraphic precision for ascertaining the relative age of the Tommotian (cf. Rozanov & Sokolov 1984) in relation to acritarch and trilobite-bearing beds in the EEP. An acritarch assemblage undoubtedly corresponding to the assemblage recovered from the trilobite-bearing Talsy horizon and the time-equivalent *Schmidtiellus mickwitzi* Zone in the Lublin Slope in Poland and in Baltoscandia was discovered in deposits of the *Dokidocyathus regularis* Zone of the Tommotian Stage (Rudavskaya & Vassileva 1984). The acritarchs from rocks of the *D. regularis* Zone were reported in association with a Tommotian shelly fauna consisting of *Tommotia, Aldanella, Anabarites, Turcutheca, Ladatheca* and *Chancelloria* (Rudavskaya & Vassileva, 1984).

Units underlying the Tommotian sequence (Yudoma Formation, Nemakit–Daldyn Horizon, Moty Formation) in Siberia have locally yielded Cambrian acritarch taxa. Thus, the upper part of the Nemakit–Daldyn horizon in the Anabar Uplift gave an assemblage of shelly fossils and acritarchs characteristic of the Lower Cambrian Lontova horizon in the EEP (Luchinina *et al.* 1978; Kirjanov *in* Volkova *et al.* 1980). On the basis of acritarch evidence, Rudavskaya & Frolov (1974) regarded the upper part of the Yudoma Formation as early Cambrian in age. Taxa characteristic for the Talsy and Vergale horizons were documented to occur in the Yudoma Formation, Moty Formation, Kurovsk Formation and Kiessiusinsk Formation of the Yudomian Stage in the Siberian Platform (Pyatiletov & Rudavskaya 1985). Acritarch taxa previously known from trilobite-bearing strata elsewhere were reported from the Moty Formation in Siberia (Rudavskaya 1971, 1973, 1980; Faizulina *et al.* 1973, 1982; Volkova *et al.* 1980; Akulcheva *et al.* 1981; Pyatiletov & Rudavskaya 1985). However, it was interpreted as indicating a much earlier (late Proterozoic) appearance for these microfossils in the Siberian Platform than elsewhere (Pyatiletov 1976, 1986; Pyatiletov *in* Volkova *et al.* 1980; Khomentovsky 1984, 1986). Disregarding the widespread record of rich and diverse acritarch assemblages of Cambrian age (Rudavskaya 1971, 1973, 1980; Rudavskaya & Frolov 1974; Luchinina *et al.* 1978; Volkova *et al.* 1980; Akulcheva *et al.* 1981; Faizulina *et al.* 1973, 1982; Pyatiletov & Rudavskaya 1985), Yudomian strata in numerous regions of the Siberian Platform were referred to the Vendian by Khomentovsky (1984, 1986), Sokolov & Fedonkin (1984, 1985) and Sokolov & Ivanovsky (1985). Hence, claiming strong diachronism, lowermost Cambrian acritarch assemblages from the EEP were regarded as Riphean in the Siberian Platform. The same assemblages that are known to coexist with early trilobites and shelly faunas in the EEP, Scandinavia and Greenland were considered as Vendian by Khomentovsky (1984, 1986).

In the light of available evidence, Moczydłowska & Vidal (1988a) concluded that the Tommotian Stage does not represent the oldest Cambrian deposits on the Siberian Platform. They suggested that deposits referred to the Tommotian Stage in Siberia are, in part, time-equivalent to the trilobite-bearing Talsy (Lükati) horizon in the EEP. The co-occurrence of Vergale age-diagnostic acritarchs with a *Mobergella* fauna (Hagenfeldt 1989a; Vidal & Nystuen 1991) and Talsy age acritarchs with the Tommotian shelly fauna from the *Dokidocyathus regularis* Zone (Rudavskaya & Vassileva 1984) may have further implications. It seems that part of the Tommotian including the *Dokidocyathus regularis* Zone and the *Dokidocyathus lenaicus* Zone (with *Mobergella*) may be contemporaneous with the trilobite *Schmidtiellus mickwitzi* and *Holmia kjerulfi* Zones in Scandinavia and Poland (Fig. 11). The acritarch evidence (Rudavskaya 1971, 1973, 1980; Rudavskaya & Frolov 1974; Faizulina *et al.* 1973, 1982; Luchinina *et al.* 1978; Volkova *et al.* 1980; Akulcheva *et al.* 1981; Pyatiletov & Rudavskaya 1985) indicates also that part of the Yudomian Stage, including the Nemakit–Daldyn horizon and the Moty Formation, may belong to the Cambrian System (Moczydłowska & Vidal 1988a). Available data are not conclusive concerning the lower age limit of the Tommotian in relation to possible correlatives in the EEP and Baltoscandia. However, the established age relations and the possible existence of depositional breaks speak against the Tommotian as a suitable stratotypic sequence for the Precambrian–Cambrian boundary. The basic considerations for promoting this point of view are that shelly faunas in the type Tommotian area and elsewhere are contemporaneous with well-known trilobite faunas.

Models dealing with metazoan radiation and skeletonization heavily rely on evidence from the Tommotian of Siberia. Regional correlations built up on acritarch databases indicate the coexistence in time of 'primitive' shelly metazoans and trilobite faunas. Hence, if proven correct, these models demand substantial revision. As established by acritarch data, the contemporaneous occurrence of trilobites and small shelly faunas remove previous obstacles in defining the Proterozoic–Cambrian boundary, which could be established at the first occurrence of either group awaiting, refinement through the study of acritarchs.

## The South China Platform

Investigations of the transitional Sinian–Cambrian strata in China have been carried out during the last decade with the purpose of defining a stratotype candidate of the Precambrian–Cambrian boundary (Xing 1982; Xing *et al.* 1982, 1984; Xing & Luo 1984; Luo *et al.* 1984; Jiang 1984, 1985; Song 1984; Xue 1984; Wang 1986; Yin 1987; Zhang *et al.* 1987). Lithologic, sedimentologic, palaeontologic and radiometric data have been generated for deposits of the Dengyingxia'an, Meishucunian and Qiongzhusian Stages in the selected Meishucun section in Yunnan Province (Luo *et al.* 1984; Xing & Luo 1984; Song 1984; Xue 1984). The Meishucun sequence was chosen as the most adequate section in China to satisfy conditions for the stratotype candidate which were established during the IUGS–IGCP Conference, Project 29, in Bristol, 1983 (Luo *et al.* 1984; Xing & Luo 1984; Cowie 1985). The distribution of individual groups of fossils within the terminal Upper Sinian and Lower Cambrian strata in China resembles in many aspects the transitional Vendian–Cambrian units in the East European and Siberian Platforms, Baltoscandia and Newfoundland. This applies to fossil successions comprising soft-bodied metazoans, shelly fossils, trace fossils, trilobites and vendotaenids (cf. Keller & Rozanov 1979a; Sokolov & Zhuravleva 1983; Xing *et al.* 1982, 1984; Xing & Luo 1984; Luo *et al.* 1984; Song 1984; Jiang 1985; Crimes & Jiang 1986; Narbonne *et al.* 1987; Landing *et al.* 1989; Qian & Bengtson

1989). The vertical distribution of acritarchs is less well known.

The boundary stratotype section at Meishucun (Luo *et al.* 1984) has yielded microfossil assemblages that are difficult to compare with any other previously known biotas. Certain species (e.g. species of *Hubeisphaera, Dictyosphaera, Scaphospinosa, Triangumorpha, Pseudodiacrodium, Fuchunshania, Monotrematosphaeridium*) are not recognized elsewhere. Many others may represent various preservational stages of microfossils whose morphological features may be artifacts of preservation (e.g. *Archaeopertusina, Asperatopsophosphaera, Leiopsophosphaera, Pseudozonosphaera*). Furthermore, there are evident erroneous attributions to well-established acritarch genera (*Micrhystridium, Archaeodiscina, Lophosphaeridium, Polyedrixium*; Deunff 1954, 1971; Rudavskaya 1971; Eisenack *et al.* 1973, 1976, 1979a, b; Volkova *et al.* 1979, 1983). In general, many specimens described as acritarchs might represent unidentifiable kerogenous fragments and poorly preserved, corroded spheromorphs and blobs of sapropel (Luo *et al.* 1984, Pl. 18, 20) lacking any palaeobiological and biostratigraphic significance. Additionally, the cyanobacterial microfossil *Bavlinella faveolata* Schepeleva (Luo *et al.* 1984, Pl. 20:7–8) has been recently transferred to *Sphaerocongregus variabilis* Moorman (Moorman 1974; Vidal 1976; Vidal & Nystuen 1990). *Laminarites antiquissimus* (Luo *et al.* 1984) is presently attributed to *Vendotaenia antiqua* (Gnilovskaya 1971, 1975, 1979a, 1983; Vidal 1989) and is of limited biostratigraphic significance.

Specimens referred to *Micrhystridium spinosum* and *M.* sp. deriving from the Sinian Jiucheng Member and Baiyanshao Member (Luo *et al.* 1984, Pl. 20:19, 20) and *Micrhystridium* sp. from the Cambrian Yu'anshan Member (Luo *et al.* 1984, Pl. 18:27) may be kerogen fragments.

Among the acritarch assemblages the only diagnostic microfossils are specimens attributed to *Baltisphaeridium multispinosum* (Luo *et al.* 1984, Pl. 18:1) deriving from the Cambrian trilobite-bearing Yu'anshan Member. They can be attributed to *Skiagia ciliosa* (Volkova) Downie (Volkova 1969b, 1981b; Volkova *et al.* 1979, 1983; Downie 1982). Thus, the only certain evidence of biostratigraphically significant acritarchs derives from the Lower Cambrian trilobite-bearing Qiongzhusian Stage in the Meishucun section (Xing *et al.* 1982, 1984; Xing & Luo 1984; Luo *et al.* 1984). The occurrence of *S. ciliosa* in the Yu'anshan Member of the Qiongzhusi Formation leads to the conclusion that this part of the sequence could not, in any event, be older than the Vergale horizon in the EEP of the U.S.S.R., or the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in Poland. Both of these are time-equivalent with the *Holmia kjerulfi* Assemblage-zone in the Lublin Slope and *Holmia inusitata* and *Holmia kjerulfi* Zones in Baltoscandia (Volkova 1969b, 1981b; Volkova *et al.* 1979, 1983; Vidal 1981b, c; Moczydłowska 1981, 1989; Moczydłowska & Vidal 1986; Figs. 10, 11).

The plant microfossils, including *Sphaerocongregus variabilis, Vendotaenia, Tyrasotaenia* and *Chuaria*, deriving from the Sinian Dengyingxia'an Stage rocks (Luo *et al.* 1984) are comparable with the assemblages of Vendian age recovered in the East European and Siberian Platforms, and Baltoscandia (Gnilovskaya 1971, 1974, 1975, 1979a, 1983, 1985; Vidal 1976, 1979b, 1981a, b, c). The rocks of the Lower Cambrian Meishucunian Stage in the Meishucun section contain few age-diagnostic taxa.

New acritarch species were described from the Niutitang Formation and the underlying Yangjiaping Formation in southwestern China by Wang (1985). The Niutitang Formation was considered as Cambrian, whereas the Yangjiaping Formation was regarded as coeval with the Meishucun Formation. Both units have been referred to the Sinian (Wang 1985). Acritarchs were generally studied in petrographic thin sections, with the single exception of a species reported from acid-resistant residues. It is difficult to compare the microfossils with forms described elsewhere from palynological preparations, because of the different preservation caused by the incompatible preservational media (e.g. cherts and shales). However, specimens ascribed by Wang (1985) to various species of the new genus *Paracymatiosphaera* seem to pertain to a colonial cyanobacterium belonging to Order Chroococcales (Palacios Medrano 1989) and are possibly senior synonyms of *Palaeogomphosphaeria cauriensis* Palacios Medrano, 1989. Additional new species (*Radiophycus yangjiapingensis* and *Micrhystridium ampliatum*) may be synonyms, and their appearance in published micrographs as well as their descriptions do not indicate any diagnostic differences. They resemble some species of *Heliosphaeridium* n.gen. However, preservational discrepancies prevent a more precise comparison.

Correlation of the proposed Precambrian–Cambrian boundary sequence in China with other regions on the sole basis of acritarchs is, at this stage, premature. This is because of the uncertain and unreliable nature of the taxonomic attributions of individual taxa. Furthermore, because numerous species are 'new' and/or not recognized elsewhere (Sin & Liu 1976; Yin & Li 1978; Yin 1980, 1983, 1985, 1987; Wang 1981, 1985; Luo *et al.* 1984; Wang & Chen 1987) their ranges are poorly established.

In contrast to the underlying sequences, the trilobite-bearing Qiongzhusian Stage is well documented and contains abundant diagnostic acritarch species. A recent study of the Qiongzhusi Formation in Yunnan Province (Zang 1988b) provided abundant well preserved acritarchs fully comparable with forms previously known from numerous localities in Europe, Siberia and North America (see above). Rocks of the Lower Cambrian Yu'anshan Member of the Qiongzhusi Formation in Yunnan Province occur at the Qiongzhusi section near Kunming City and at the Maotianshan drillhole near Chengjiang County. They yielded acritarch assemblages consisting of *Skiagia orbiculare, S. ornata, S. compressa, S. scottica, S. ciliosa, Comasphaeridium strigosum* and *Alliumella baltica* (Zang 1988b). This assemblage corresponds to that from rocks attributed to the Vergale horizon in the EEP of the U.S.S.R., and the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in Poland (Volkova *et al.* 1979, 1983; Moczydłowska 1989; Fig. 10).

The Yu'anshan Member of the Qiongzhusi Formation in the South China Platform is referred to the trilobite *Eoredlichia–Wutingaspis* Zone (=*Yunnanocephalus* Zone) (Zang 1988b). Hence, the acritarch record suggests that the *Eoredlichia–Wutingaspis* Zone is time-equivalent to the *Holmia* *kjerulfi* Assemblage-zone in Poland and the *Holmia inusitata* and *Holmia kjerulfi* Zones in Baltoscandia (Fig. 11). In conclusion, the zone with *Eoredlichia–Wutingaspis* (Zang 1988b) and *Eoredlichia–Parabadiella* (Luo *et al.* 1984) is not the oldest trilobite zone except locally. Rocks corresponding to this zone in Baltoscandia and Poland (= *Holmia kjerulfi* Assemblage-zone) are underlain by those attributed to the *Schmidtiellus mickwitzi* Zone (Ahlberg & Bergström 1978; Bergström 1981; Bergström & Ahlberg 1981; Lendzion 1983b; Ahlberg *et al.* 1986; Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1989; Fig. 11). Consequently, at least the upper part of the Meishucunian Stage, regarded previously as pre-trilobite (Xing *et al.* 1982, 1984; Xing & Luo 1984; Luo *et al.* 1984), appears time-equivalent to the *Schmidtiellus mickwitzi* Zone. Hence, the regional stages in the South China Platform seem to be younger than previously believed, as was the case with the local stages in the Siberian Platform (see above).

## The Avalon Platform

The Avalon Zone of Newfoundland, Canada, consists of Upper Precambrian – Lower Cambrian platform deposits which under continuous subsidence accumulated in marine environments (Narbonne *et al.* 1987; Myrow 1987; Landing *et al.* 1988, 1989). A transitional sequence exposed at Fortune Head in the Burin Peninsula was proposed as the global stratotype section for the Precambrian–Cambrian boundary (Narbonne *et al.* 1987). The boundary is defined within the Chapel Island Formation (Crimes 1987, 1988; Myrow 1987; Narbonne *et al.* 1987; Landing 1988b; Landing *et al.* 1989). The apparently continuous succession of the Chapel Island Formation is composed of siliciclastic rocks with minor carbonates (Myrow 1987; Narbonne *et al.* 1987; Landing *et al.* 1989). The formation has yielded a record of trace fossils, small shelly fossils, soft-bodied fossils (vendozoans), vendotaenids and organic-walled microfossils (Bengtson & Fletcher 1983; Crimes & Anderson 1985; Crimes 1987, 1988; Narbonne & Myrow 1988; Narbonne *et al.* 1987; Landing *et al.* 1989). The abundance of rich and well-preserved trace fossils within the Chapel Island Formation allowed recognition of three zones within the Upper Precambrian and Lower Cambrian part of the sequence (Crimes 1987, 1988; Narbonne *et al.* 1987; Narbonne & Myrow 1988).

In the proposed stratotype locality at Fortune Head, the Chapel Island Formation includes the *Harlaniella podolica* Zone, referred to the Upper Precambrian (Upper Vendian), and succeeding *Phycodes pedum* Zone and *Rusophycus avalonensis* Zone of the Lower Cambrian (Crimes 1987, 1988; Narbonne & Myrow 1988; Narbonne *et al.* 1988). Small shelly fossils, 'chitinous' fossils (*Sabellidites cambriensis*) and vendotaenids are sparsely distributed (Bengtson & Fletcher 1983; Narbonne *et al.* 1987; Landing 1988b; Landing *et al.* 1988, 1989).

The study of organic-walled microfossils from this section is still at an initial stage. The preliminary examination of samples deriving from the sequence comprising the Chapel Island Formation and Random Formation in the Fortune Head section yielded scarce and poorly preserved acritarchs (G. Vidal & M. Moczydłowska, unpublished observations). No biostratigraphically significant species were found. The assemblage contains leiosphaerids and vendotaenid fragments. The poor results were most likely a result of insufficient sampling.

In the Avalon Platform early Cambrian acritarchs are currently known from the Brigus Formation, attributed to the upper part of the Lower Cambrian (Martin & Dean 1983). Contrary to the poor acritarch record from the Lower Cambrian, Middle and Upper Cambrian rocks have yielded rich and well-documented assemblages (Martin & Dean 1981, 1983, 1984, 1988). The palynological data obtained from the Chamberlain's Brook Formation and the Manuels River Formation on Random Island permitted an establishment of an acritarch zonation related to existing trilobite zones (Martin & Dean 1981, 1983, 1984, 1988). Comprehensive palaeontological and stratigraphic studies of microfloras from the Cambrian strata of the Avalon Platform in eastern Newfoundland allowed a more accurate correlation with strata in Baltoscandia, Great Britain, Spain and the Gondwana region (Martin & Dean 1988). A more detailed future study of the Lower Cambrian sequence might complete the acritarch-based biostratigraphic zonation, thus allowing comparison with existing subdivisions elsewhere.

# Acritarch-based correlation of the Lower Cambrian

## Preface

The aim of this chapter is to sort out the correlation of Lower Cambrian in different regions within the East European Platform, the Baltoscandian Platform and the Caledonides on the basis of diagnostic assemblages of the acritarch microphytoplankton. This requires a thorough examination of the status of previously established biozones.

The existing biostratigraphic subdivisions of the Lower Cambrian were established on faunal grounds, particularly on the basis of trilobites, small shelly fossils, and to some extent trace fossils. The subdivisions are regional and difficult to compare, since the index fossils are generally rare and in some instances restricted to local occurrences. Also, their stratigraphic ranges are often not fully recognized.

The trilobite zonation was introduced in Scandinavia already in the previous century, and it has a comprehensive history of research (see detailed review by Martinsson 1974; also Bergström 1981; Ahlberg 1984; Ahlberg *et al.* 1986). However, faunas defining the discrete zones derive from lithologic units separated by sedimentary breaks and exposed in discontinuous sections. Correlations of these units are largely based on the assumption that the zonal boundaries coincide with the formational boundaries, since the index fossils are usually too rare to allow a more exact biostratigraphic analysis. Index fossils are, in some cases, known as a single specimen or a few fragments (*Holmia* *inusitata*, *Schmidtiellus mickwitzi*), and their geographic distribution is poorly known.

The record of the trilobite fauna in the platform areas of Poland and the U.S.S.R. is also limited, since in all but a few cases in the U.S.S.R. the fossils were recovered from drillcores. Even though the rock sequence is continuous, as in the Lublin Slope, the stratigraphic ranges of some index-taxa are not satisfactorily recognized (e.g. *Schmidtiellus* and *Protolenus*) because of the rarity of the finds. On the contrary, phytoplanktic microfossils occur in nearly all lithostratigraphic units. Successive acritarch assemblages from continuous sections in the EEP are recognized in the Baltoscandian Platform and the Caledonides (Fig. 11). Unavoidably, the proposed acritarch-based correlation challenges the formerly accepted ranges of certain trilobite and shelly fossil species and the attribution of some lithostratigraphic units to particular biozones (see discussion below; cf. Bergström 1981; Lendzion 1983a, b; Ahlberg 1984; Ahlberg *et al.* 1986; Mens *et al.* 1990). Acritarchs are the only fossil group commonly occurring in most marine sedimentary rocks and having relatively well-defined ranges. These features provide the opportunity to compare the ranges recorded for sparsely distributed invertebrate fossils co-occurring with acritarchs and also for comparing the biozonation of strata in various regions.

## The East European Platform

### *The U.S.S.R.*

The subdivision of the Lower Cambrian based on acritarch assemblages was first established by Volkova (1973) and Volkova *et al.* (1979, 1983) for the EEP within the U.S.S.R. (see 'Acritarch-based correlation of the Precambrian–Cambrian boundary', The EEP; Fig. 10 ). In ascending stratigraphic order the established scheme comprises the Rovno, Lontova, Talsy, Vergale and Rausve 'horizons'. As mentioned above, most of the Rovno horizon is regarded as Vendian (Fig. 10). The discrete horizons include different formations containing diagnostic acritarch assemblages. Thus, according to the *International Stratigraphic Guide* (Hedberg 1976) the distinguished horizons have the status of informal biostratigraphic units. Originally, the Lontova and Talsy (=Lükati) horizons were defined on the basis of acritarch assemblages deriving from the Lontova Formation (Lontova horizon) and the Lükati and Tiskre Formations (Talsy horizon) in Estonia and their correlatives in Latvia, the Moscow Syneclise and Poland (Volkova 1968, 1969a, b; 1973; Volkova *et al.* 1979, 1983; Mens & Pirrus 1977, 1979; Fig. 10). Acritarch assemblages comparable to the Lontova and Talsy assemblages have been described from the Ukraine (Kirjanov 1968, 1969). The Vergale horizon was established on the basis of a characteristic acritarch assemblage obtained from the upper part of the *Holmia* zone in the Lublin Slope and time-equivalent rocks in Latvia (Volkova 1969a, b, 1973; Birkis *et al.* 1970, 1972). An assemblage similar to the Vergale assemblage was also recognized in the Ukraine (Kirjanov 1969). The Rausve horizon was introduced to embrace strata containing an acritarch assemblage deriving from the *Protolenus* zone in the Lublin Slope in Poland and coeval strata in Latvia and Lithuania (Volkova 1969a, b, 1973; Jankauskas 1972; Volkova *et al.* 1979, 1983). It is evident that the discrete acritarch assemblages which define the established horizons (Volkova 1968, 1973; Kirjanov 1969; Volkova *et al.* 1979, 1983) emanate from various formations in different regions of the vast area of the EEP within the U.S.S.R. (Volkova 1964, 1968, 1973, 1974a,b; Kirjanov 1968, 1969, 1974, 1979a; Birkis *et al.* 1970, 1972; Fridrichsone 1971; Umnova & Vanderflit 1971; Jankauskas 1972, 1974, 1975, 1976; Jankauskas & Posti 1973, 1976; Volkova *et al.* 1979, 1983) and Poland (Volkova 1969a, b, 1973; Volkova *et al.* 1979, 1983).

The combined stratigraphic scheme for the Lower Cambrian of the EEP within the U.S.S.R. (Volkova *et al.* 1979, 1983) is composed of a succession of acritarch assemblages deriving from discontinuous sequences scattered within the vast areas of the Volhynian–Polessian Trough (Fig. 9), the Podlasie–Byelorussia Depression, the Orsha Depression and western part of the Moscow Syneclise, the Baltic Syneclise and the southern part of the Fennoscandian (=Baltic) Shield (Kirjanov 1969, 1979a; Mens & Pirrus 1977, 1979; Areń *et al.* 1979a; Bessonova & Chumakov 1979; Bessonova & Piskun 1979; Mens *et al.* 1987, 1990). Most of the formations containing the characteristic assemblages (e.g. Rovno, Lontova, Talsy, Vergale and Rausve-like assemblages) are separated by depositional breaks and display different degrees of completeness in the discrete areas (Keller & Rozanov 1979b). The only transitional contacts between consecutive formations (and the corresponding horizons) are observed between the Rovno and Lontova horizons and between the Vergale and Rausve horizons in parts of the Ukraine, Lithuania, Latvia and the Leningrad region (Kirjanov 1968, 1969, 1979a; Areń *et al.* 1979a; Mens *et al.* 1990; Fig. 10). It seems evident that the acritarch assemblages recorded in the Soviet part of the EEP represent a discontinuous succession of microphytoplankton. Thus, the real stratigraphic ranges of discrete taxa were never fully recognized and this may explain recorded overlapping co-occurrences of certain acritarch species in sequences evidently representing a more complete rock record. In Scandinavia an acritarch complex consisting of *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal, *C. molliculum* Moczydłowska & Vidal, *Fimbriaglomerella membranacea* (Kirjanov) Moczydłowska & Vidal, and *F. minuta* (Jankauskas) Moczydłowska & Vidal, species previously regarded as restricted to the Talsy horizon (Volkova *et al.* 1979, 1983), co-exist with *Skiagia ciliosa* (Volkova) Downie (Vidal 1981b; Moczydłowska & Vidal 1986, 1988b; Eklund 1990; Hagenfeldt 1989a; Moczydłowska 1989; Fig. 5), a species known to appear in the Vergale horizon (Volkova *et al.* 1979, 1983). In the Lublin Slope, *Asteridium lanatum* (Volkova) comb. nov., *Comasphaeridium strigosum* (Jankauskas) Downie, *Lophosphaeridium tentativum* Volkova, *Pterospermella vitalis* Jankauskas, and *Tasmanites bobrowskae* Ważyńska, all formerly believed to appear in the Talsy horizon (Volkova *et al.* 1979, 1983), were demonstrated to occur in rocks corresponding to the Lontova horizon (Moczydłowska & Vidal 1986; Moczydłowska 1989; Figs. 5, 10). Lack of attention to such occurrences has caused finds of assemblages with species having overlapping ranges to be interpreted as of 'mixed composition' (Mens *et al.* 1987, 1990).

The subdivision of the Lower Cambrian in the EEP within the U.S.S.R. was modified recently by Mens (*in* Mens *et al.* 1987, 1990). In the new proposed scheme the previously established horizons were replaced by 'regional stages'. The proposed regional stages literally replace 'horizons' and are defined on the basis of discrete acritarch assemblages characteristic of the stratotypic formations and corresponding 'horizons'. Unfortunately, the acritarch assemblages and the modified Lower Cambrian acritarch-based stratigraphic scheme are not accompanied by complete references to the original subdivision as introduced by Volkova (1973) and Volkova *et al.* (1979, 1983). The previous horizons were transferred to the rank of chronostratigraphic 'regional stages'. Thus, for example, the original Lontova horizon was renamed the Lontova 'regional stage' (Mens *et al.*, 1987, 1990). Both entities, 'horizons' and 'regional stages', are informal units according to the *International Stratigraphic Guide* (Hedberg 1976) and are recognized in the U.S.S.R. in local subdivisions (Spizharski *et al.* 1983, 1986; Mens *et al.* 1987, 1990). The change of the status and renaming of previously established units leads to additional confusion concerning interregional correlation. The former Talsy horizon was renamed on Dominopol' 'regional stage' (Mens *et al.* 1987, 1990). The reason was to restore the priority of the name erected by Kirjanov (Kirjanov 1969; Mens *et al.* 1987, p. 18, and 1990, p. 10). But despite this explanation the Vergale and Rausve horizons were not renamed following Kirjanov's nomenclature (Kirjanov 1969). The selectiveness of the name transfers appears unjustified. Kirjanov (1969) erected the horizons on the basis of assemblages deriving from local rock units with the rank of formations. Thus, they generally were not recognized over the whole platform area in the U.S.S.R. Later, Volkova (1973) established a unified acritarch subdivision of the Lower Cambrian (into horizons), using for this purpose more comprehensive data collected from various regions in the U.S.S.R. and also Poland. This obviously included the data presented by Kirjanov (1969). The subdivision introduced by Volkova (1973) was later emended by Volkova *et al.* (1979, 1983), taking into consideration widely accepted data available at this time, and the resulting subdivision seems to have been accepted. In the present paper, the acritarch-based subdivision of the Lower Cambrian proposed by Volkova *et al.* (1979, 1983) is adopted, whereas the changes proposed by Mens *et al.* (1987, 1990) are not followed.

### *Poland*

The Lower Cambrian of the Lublin Slope represents a continuous sedimentation record (Jaworowski 1978, 1980) with a nearly continuous succession of fossil phytoplankton (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989; Fig. 5; Appendices 1–10). The acritarch assemblages recorded in the Lower Cambrian sequence define the proposed formal zones (Fig. 8; Appendices 6–10) which do not coincide with the previously established lithostratigraphic units (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989; Figs. 8, 10). Comparison of acritarch zones in the Lublin Slope with the horizons established for the U.S.S.R. reveals that the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone comprises the Lontova horizon and the uppermost part of the Rovno horizon (Moczydłowska 1989; Fig. 10). The *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone corresponds to the herein redefined *Platysolenites antiquissimus* Interval-zone (Figs. 6, 8) in the Lublin Slope. The acritarch assemblage diagnostic for this zone (Moczydłowska 1989; Fig. 5) co-occurs with a fauna including *Platysolenites antiquissimus* Eichwald, *Platysolenites* sp., *Onuphionella agglutinata* Kirjanov, *Aldanella polonica* Lendzion [= *Aldanella attleborensis* (Shaler & Foerste)], *Anabarella* sp., *Sabellidites cambriensis* Yanischevsky, *Sabellidites* sp. (Areń & Lendzion 1978; Lendzion 1983a, b; Landing 1988b), vendotaenids (Gnilovskaya 1979a, 1983) and trace fossils (Pacześna 1985, 1986). Rocks contemporaneous with the Lontova horizon in the U.S.S.R. also yielded *Aldanella kunda* (Öpik), *Onuphionella* sp., *Sokoloviina costata* Kirjanov, and *Saarina* sp. (Keller & Rozanov 1979a, b). According to a recent revision of *Platysolenites* by Rozanov (1979, 1983), *P. antiquissimus* Eichwald includes numerous conspecific taxa: *P. lontova* Öpik, *Yanishevskyites petropolitanus* (Yanishevsky) and *Spirosolenites spiralis* Føyn & Glaessner. *Platysolenites spiralis* Posti, 1978, can be added to this synonymy as a senior homonym of *S. spiralis.* Subsequently revised species comprise *Aldanella polonica* Lendzion and *A. kunda* (Öpik), both of which Landing (1988b) transferred to *Aldanella attleborensis* (Shaler & Foerste) as junior synonyms.

The succeeding *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone in the Lublin Slope is partly equivalent to the Talsy horizon (Moczydłowska 1989; Fig. 10) and with minor differences contains a comparable acritarch assemblage (Volkova *et al.* 1979, 1983; Fig. 5). The acritarchs *Heliosphaeridium coniferum* (Downie) comb. nov., *Skiagia pura* Moczydłowska, and *Skiagia scottica* Downie recorded in this zone were not found in the Talsy horizon. On the other hand, *Alliumella baltica* Vanderflit and *Tasmanites volkovae* Kirjanov occur in the Talsy horizon (Volkova *et al.* 1979, 1983), but they are absent in the Lublin Slope (Fig. 5). However, the stratigraphically diagnostic species of *Skiagia*, *Fimbriaglomerella*, *Comasphaeridium* and *Asteridium* (see 'Microfossil assemblages – acritarch zones') co-occur in rocks attributed to the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone in Poland and in the Talsy horizon in the U.S.S.R. (Volkova *et al.* 1979, 1983; Moczydłowska 1989; Figs. 5, 11).

The *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone corresponds to the correlative of the *Schmidtiellus mickwitzi* Zone in the Lublin Slope (Moczydłowska 1989; Figs. 8, 10). The latter zone (Lendzion 1983b; Moczydłowska & Vidal 1988a; Moczydłowska 1989) has yielded *Schmidtiellus* sp., *Volborthella tenuis* Schmidt, *Torellella* cf. *laevigata* (Linnarsson), *Hyolithellus* cf. *micans* Billings, *Lingulella* cf. *nathorsti* Linnarsson, *Botsfordia* cf. *caelata* (Hall), and *Obolella* cf. *rotundata* Kiaer (Areń & Lendzion 1978; Lendzion 1983a, b). However, *O. rotundata* Kiaer was transferred to *Magnicanalis rotundatus* (Kiaer) (Rowell 1962).

Within the platform area in the U.S.S.R., additional fossils are known from strata that are time-equivalent to the Talsy horizon, e.g. *Schmidtiellus mickwitzi* (Schmidt), *Schmidtiellus* sp., *Wolynaspis unica* N. Tchernysheva, *Volborthella* sp., *Platysolenites antiquissimus* Eichwald, *Mickwitzia monilifera* (Linnarsson), *M. formosa* (Wiman), *M. concentrica* Gorjansky, *Luekatiella discinoides* (Schmidt), *Luekatiella* sp., *Torellella* cf. *laevigata* (Linnarsson), *Torellella* sp., *Scenella discinoides* Schmidt, *S. tuberculata* Schmidt, and *Paterina rara* Gorjansky (Schmidt 1888; Kirjanov & Chernysheva 1967; Mens & Pirrus 1977; Keller & Rozanov 1979a, b).

The succeeding *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in the Lublin Slope is time-equivalent to the Vergale horizon (Moczydłowska 1989; Fig. 10). The diagnostic acritarch assemblage of this zone (Fig. 5) differs from the Vergale assemblage (Volkova *et al.* 1979, 1983) in that it contains additional taxa including *Heliosphaeridium coniferum* (Downie) comb. nov. and *Skiagia scottica* Downie. On the other hand, *Skiagia insigne* (Fridrichsone) Downie, *Lophosphaeridium dubium* (Volkova) comb. nov., and *Comasphaeridium strigosum* (Jankauskas) Downie, known from the Vergale horizon (Volkova *et al.* 1979, 1983), are not present in the assemblage (Fig. 5). However, this minor variation in the specific composition of the assemblages may not be significant, since all the mentioned species have comprehensive stratigraphic ranges.

The *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone corresponds to the *Holmia kjerulfi* Assemblage-zone as defined within the Lublin Slope (Moczydłowska & Vidal 1988a; Moczydłowska 1989; Fig. 8). The diagnostic acritarch assemblage (Fig. 5) co-occurs with a fauna consisting of *Holmia kjerulfi* (Linnarsson), *Holmia grandis* Kiaer, *Ellipsocephalus* cf. *gripi* (Kautsky), *Strenuaeva primaeva* (Brögger), *Strenuella* aff. *salopiensis* Cobbold, *Strenuella* sp. ex gr. *polonica* Samsonowicz, *Germaropyge* aff. *sanctacrucensis* Samsonowicz, *Volborthella tenuis* Schmidt, *Torellella* cf. *laevigata* (Linnarsson), *Torellella* cf. *holmi* Kiaer, *Hyolithellus* cf. *micans* Billings, *Lingulella* cf. *nathorsti* Linnarsson, *Botsfordia* cf. *caelata* (Hall), *Magnicanalis* cf. *rotundatus* (Kiaer), *Acrothele prima* (Matthew) and *Acrotreta gemmula* Matthew (Lendzion 1983a, b; Rowell 1962).

Fossils occurring in strata referred to the Vergale horizon and regarded as contemporaneous with the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone comprise additionally *Germaropyge*(?) *mendosa*, *Platysolenites* sp., *Acrothele* cf. *bellapunctata* Walcott, *Westonia* sp., *Lingulella* sp., and *Luekatiella* sp. (Keller & Rozanov 1979a, b).

The next succeeding zone recognized in the Lublin Slope, the *Volkovia dentifera – Liepaina plana* Assemblage-zone, is contemporaneous with the Rausve horizon (Moczydłowska 1989; Fig. 10). The difference between the specific composition of the assemblages defining them has to do with the presence of *Skiagia scottica* Downie and *Heliosphaeridium longum* Moczydłowska which have not been reported from the Rausve horizon (Fig. 5). On the other hand, some of the species occurring in the Rausve horizon (e.g. *Comasphaeridium strigosum* (Jankauskas) Downie, *Tasmanites bobrowskae* Ważyńska, *T. volkovae* Kirjanov, *Skiagia orbiculare* (Volkova) Downie, *S. ornata* (Volkova) Downie, *Heliosphaeridium radzynicum* (Volkova) comb. nov. and *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas & Kirjanov) were not recovered from the unit in the Lublin Slope (Fig. 5). All the species missing in the Lublin area have long ranges, and their absence in this particular zone appears of little stratigraphic significance.

The *Volkovia dentifera – Liepaina plana* Assemblage-zone corresponds to the *Protolenus* zone (Moczydłowska 1989; Fig. 8). Its diagnostic assemblage co-occurs with a fauna consisting of *Protolenus* sp., *Kingaspis* (*Kingaspis*) *borealis* Lendzion, *Ellipsocephalus hoffi* (Schlotheim), *Torellella holmi* Kiaer, *Hyolithellus* sp., *Westonia bottnica* (Wiman), and *Lingulella westergaardi* Kautsky (Lendzion 1983a, b). Strata of the contemporaneous Rausve horizon yielded additional faunal components, including *Volborthella* cf. *tenuis* Schmidt, *Lingulella* cf. *nathorsti* Linnarsson, *Westonia* sp., *Ceratiocaris* sp., and *Luekatiella* sp. (Keller & Rozanov 1979a, b).

The herein proposed biostratigraphic correlation of zones recognized in the Lublin Slope with horizons in the U.S.S.R. (Fig. 10) is in disagreement with the correlation chart recently proposed by Mens, Bergström & Lendzion (1987, 1990). This particularly concerns a supposed lack of correlatives of the Talsy horizon (Dominopol' 'regional stage' according to the nomenclature by Mens *et al.* 1987, 1990) in the Lublin Slope (Mens *et al.* 1987, 1990, chart, position 21). As mentioned above the existence of a hiatus between the Mazowsze and Kaplonosy Formations (Areń & Lendzion 1978; Lendzion 1983a, b; Mens *et al.* 1987, 1990) is contradicted by existing sedimentologic data (Jaworowski 1978, 1980) and by micropalaeontological evidence (Moczydłowska & Vidal 1986, 1988a; Moczydłowska 1988a, 1989). Based on acritarch evidence, the lower part of the Kaplonosy formation (Areń & Lendzion 1978; Lendzion 1983a, b; Figs. 8, 10) was shown to be contemporaneous with the Talsy horizon (Volkova 1973; Volkova *et al.* 1979, 1983). This opinion was reiterated by Moczydłowska & Vidal (1986, 1988a) and by Moczydłowska (1988a, 1989; Fig. 10). Consequently, the lower part of the Kaplonosy formation was referred to the Talsy (=Lükati) horizon by Areń & Lendzion (1978), Lendzion (1983a), and Keller & Rozanov (1979b, Fig. 36). The Talsy acritarch assemblage was regarded as characteristic of the lower part of the *Holmia* zone (Volkova 1973), e.g. the Kaplonosy formation (Areń & Lendzion 1978; Lendzion 1983a, b). Paradoxically, this assemblage was originally established on the basis of the acritarch record deriving from the Radzyń IG-1 and Kaplonosy IG-1 drillcores from the Lublin Slope (Volkova 1969a, b, 1973). Therefore, the Kaplonosy formation, being partly the source of the acritarch assemblage defining the Talsy (=Lükati) horizon, has to be correlated with this horizon. These circumstances were apparently ignored by Lendzion (*in* Mens *et al.* 1987, 1990), and a hiatus comprising strata time-equivalent to the Talsy horizon was inferred for the Lublin Slope. The result of this was a reduction in the time range implied by the Kaplonosy formation (Mens *et al.* 1987, 1990, correlation chart, position 21). This contradicts Lendzion's own previous statements (Areń & Lendzion 1978; Lendzion 1983a, b). The *Schmidtiellus* subzone proposed for the lower part of the *Holmia* zone in the Lublin Slope area (Lendzion 1983b, p. 674, 677) was established on the presence of *Schmidtiellus*

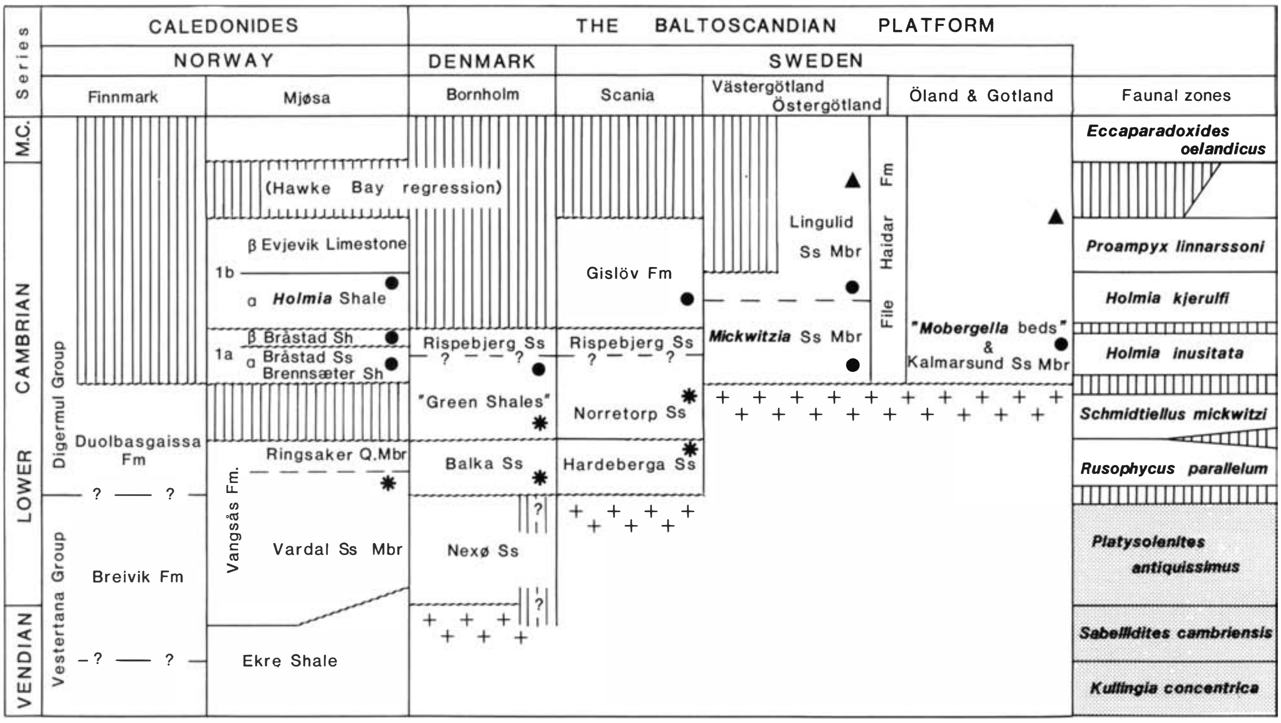

*Fig. 11.* Interregional acritarch-based correlation of Lower Cambrian strata in the East European Platform, the Baltoscandian Platform and the Scandinavian Caledonides. Modified after Volkova *et al.* (1979, 1983), Keller & Rozanov (1979b) for the U.S.S.R.; Vidal (1981a, b, c, 1985), Moczydłowska & Vidal (1986), Eklund (1990), Vidal & Nystuen (1990, 1991) for the Baltoscandian Platform and Scandinavian Caledonides. Dotted area indicates the informal faunal zones recognized only in the northern Scandinavian Caledonides (after Føyn & Glaessner 1979 and Bergström 1981). Broken lines are for uncertain or approximate boundaries, vertical stripes indicate hiati, wavy line unconformities and crosses marks stand for crystalline basement. The square, asterisk, circular and triangle symbols indicate occurrences of acritarch assemblages defining acritarch zones established in the Lublin Slope.

sp. in the Siedliska IG-1 drillcore (Areń & Lendzion 1978, p. 40) from the Lublin Slope (Lendzion 1983a, p. 15). The significance of this fact was also overlooked by Lendzion (*in* Mens *et al.* 1987, 1990, chart position 21), who indicated a hiatus comprising strata corresponding to the whole time range of the *Schmidtiellus* Zone. Thus, the Kaplonosy formation was regarded as substantially younger.

## The Baltoscandian Platform

### *Scania*

In Scania (southern Sweden) the Lower Cambrian rocks rest unconformably on the Proterozoic crystalline basement and are overlain by the Middle Cambrian Alum Shale Formation (for a recent review, see Bergström & Gee 1985). In ascending order, this generally shallow-marine sequence is subdivided (mostly informally) into the Hardeberga Sandstone, Norretorp Sandstone, Rispebjerg Sandstone and the Gislöv Formation.

As a lithologic entity, the Hardeberga Sandstone has been known since the end of the nineteenth century (Angelin 1878) and the stratigraphic interest of this unit has a long history. The Hardeberga Sandstone rests on the crystalline basement in Scania (Hadding 1929, 1932; Lindström & Staude 1971; Bergström 1981; Bergström & Gee 1985), or on the non-marine Nexø Sandstone on the island of Bornholm (V. Poulsen 1966; Martinsson 1974; Bergström & Gee 1985). The Hardeberga Sandstone, or the Hardeberga Formation (Bergström & Gee 1985; Hamberg 1991), includes the Lunkaberg, Vik, Brantevik and Tobisvik Members (Lindstöm & Staude 1971; Bergström & Ahlberg 1981; Bergström & Gee 1985; Hamberg 1991). The unit consists of arkosic sandstone and conglomerate at the bottom of the sequence, gradually replaced by pure quartzarenitic sandstone interbedded with glauconitic sandstone containing phosphate nodules. Locally (e.g. at Brantevik in southeastern Scania), intraformational conglomerate is present (Hadding 1929, 1932; Regnéll 1960; Bergström 1970; Lindström & Staude 1971). The formation reaches a maximum thickness of about 115–120 m (Hadding 1929, 1932; Lindström & Staude 1971; Hamberg 1991). The sequence was deposited in shallow prograding shoreface to offshore environments and consists of several marine erosion surfaces (ravinements) separating each discrete set of marine facies associations (Hamberg 1991).

The Hardeberga Sandstone is sparsely fossiliferous, but it contains trace fossils, including a single trilobite mould, hyoliths and acritarchs (Bergström 1970, 1981; Vidal 1981b, c; Ahlberg 1984). Trace fossils include *Rusophycus parallelum* Bergström, *Scolithos linearis* Haldeman, *Syringomorpha nilssoni* (Torell), *Psammichnites gigas* (Torell), *Monocraterion* and *Diplocraterion* (Hadding 1929; Westergård 1931; Bergström 1970, 1981; Lindström & Staude 1971; Lindström 1972; Ahlberg 1984; Bergström & Gee 1985). The Hardeberga Sandstone was referred to the '*Rusophycus*

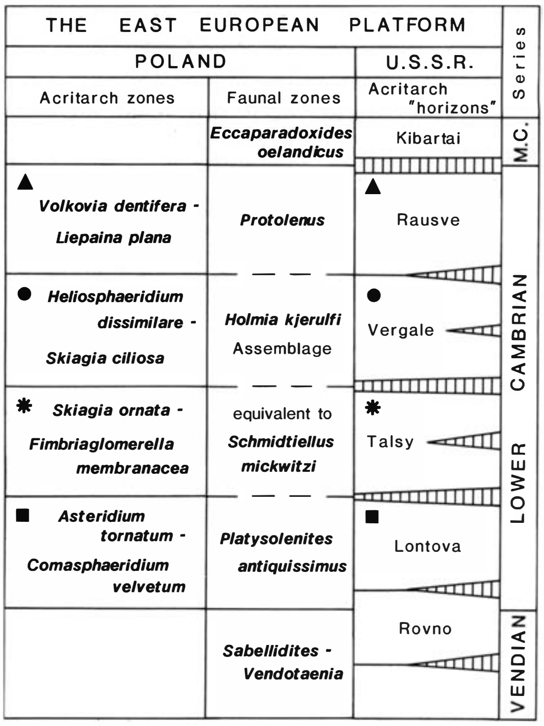

*Fig. 11* (continued).

*parallelum* zone', supposed to represent the upper part of the *Platysolenites antiquissimus* Zone (Bergström 1981; Ahlberg 1984; Bergström & Gee 1985). Recently, the *Rusophycus parallelum* Zone was excluded from the *Platysolenites antiquissimus* Zone (Mens *et al.* 1990).

Rocks of the Hardeberga Sandstone contain a depauperate, but stratigraphically significant acritarch assemblage (Vidal 1981b, c). This assemblage includes *Granomarginata squamacea* Volkova, *Lophosphaeridium tentativum* Volkova, *Asteridium lanatum* (Volkova) comb. nov., *A. tornatum* (Volkova) comb. nov., *Comasphaeridium strigosum* (Jankauskas) Downie, *C. brachyspinosum* (Kirjanov) Moczydłowska & Vidal, *Globosphaeridium cerinum* (Volkova) comb. nov., *Fimbriaglomerella membranacea* (Kirjanov) Moczydłowska & Vidal, *Pseudotasmanites parvus* Kirjanov, *Dictyotidium birvetense* Paškevičienė, and *Tasmanites tenellus* Volkova. On this basis, rocks of the Hardeberga Sandstone were referred to the *Holmia* A 'stage' or to the Lükati (=Talsy) horizon (Vidal 1981b, c; Moczydłowska & Vidal 1986). The acritarch assemblage of the Hardeberga Sandstone is comparable to the assemblage defining the *Skiagia ornata – Fimbriaglomerella membranacea* Zone in Poland and the Talsy horizon in the U.S.S.R. (Moczydłowska 1989; Figs. 5, 11).

The Hardeberga Sandstone in Scania is overlain by the Norretorp Sandstone (Bergström 1970; Martinsson 1974), also called the Norretorp Glauconitic Sandstone (Lindström & Staude 1971; Lindström 1972), the Norretorp Siltstone (Ahlberg & Bergström, 1978), or the Norretorp Formation (Bergström 1981; Bergström & Ahlberg 1981; Bergström & Gee 1985). In some areas of Scania the boundary between the Hardeberga Sandstone and the Norretorp Sandstone is lithologic and distinguished by a shift from white quartzite to phosphatic sandstone (e.g. in the quarry at Hardeberga; Hadding 1929; Bergström 1970; Bergström & Gee 1985). But at other localities conglomerates and sedimentary breccias occur at the bottom of the Norretorp Sandstone (for example in the Simrishamn area; Lindström & Staude 1971; Vidal, personal communication) which seem to indicate a sedimentary break and the presence of a hiatus (Lindström & Staude 1971; Lindström 1972; Ahlberg & Bergström 1978; Vidal 1981c).

The Norretorp Sandstone consists of alternating calcareous, quartzitic and glauconitic sandstones and siltstones with phosphorite nodules (Hadding 1929, 1932; Bergström 1970; Lindström & Staude 1971). The thickness of the formation ranges from 4 to 25 m (Lindström & Staude 1971; Bergström & Gee 1985). The trilobites *Schmidtiellus mickwitzi torelli* (Moberg), *Holmia mobergi* Bergström, *Kjerulfia? lundgreni* (Moberg) and additional shelly fossils, such as *Volborthella tenuis* Schmidt, hyoliths, brachiopods and trace fossils, including *Cruziana dispar* Linnarsson, were reported from the unit (Moberg 1892, 1899; Bergström 1970, 1973a, 1981; Ahlberg & Bergström 1978; Bergström & Ahlberg 1981; Ahlberg 1984; Bergström & Gee 1985; Ahlberg *et al.* 1986; Bergström & Peel 1988). Based on trilobite evidence the Norretorp Sandstone was referred to the *Schmidtiellus mickwitzi* Zone (Bergström 1981; Ahlberg 1984; Ahlberg *et al.* 1986), also named the *Schmidtiellus mickwitzi* and *Mobergella* zone (Bergström & Gee 1985; Mens *et al.* 1990). The acritarch assemblage recovered from the Norretorp Sandstone includes *Archaeodiscina umbonulata* Volkova, *Granomarginata squamacea* Volkova, *Globosphaeridium cerinum* (Volkova) comb. nov., *Lophosphaeridium dubium* (Volkova) comb. nov., *L. tentativum* Volkova, *Skiagia orbiculare* (Volkova) Downie, *S. ornata* (Volkova) Downie. It was considered to indicate a *Holmia* A or *Holmia* A–B age (Vidal 1981b, c, 1985). This assemblage is comparable to the one defining the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone in the Lublin Slope and the Talsy Horizon in the U.S.S.R. (Moczydłowska 1989; Figs. 5, 11).

The overlying Rispebjerg Sandstone consists of coarse-grained calcareous and glauconitic sandstones rich in pyrite, and phosphoritic thin layers and nodules. Rocks of this unit display discontinuity surfaces (Hadding 1929, 1932, 1958; Regnéll 1960; Bergström 1970; Lindström & Staude 1971; Lindström 1972). The thickness of the formation is about 1–3 m (Lindström & Staude 1971; Bergström & Gee 1985). The formation was first recognized on the island of Bornholm, Denmark (Hansen 1936; V. Poulsen 1966; C. Poulsen 1967; de Marino 1980b) and subsequently in Scania (Bergström 1970; Lindström & Staude 1971; Bergström & Ahlberg 1981; de Marino 1980b; Bergström & Gee 1985).

In Scania the Rispebjerg Sandstone rests disconformably on the Norretorp Sandstone (Lindström & Staude 1971; Lindström 1972; Ahlberg & Bergström 1978; Vidal 1981b, c). It is also disconformably overlain by the Gislöv Formation (Lindström & Staude 1971; de Marino 1980a; Bergström & Ahlberg 1981; Ahlberg, 1984). Phosphatic conglomerates at the base and top, and a discontinuity surface on top of the formation (Lindström & Staude 1971; Bergström & Ahlberg 1981; Vidal 1981b) imply the existence of hiati (Ahlberg & Bergström 1978; Vidal 1981c). The Rispebjerg Sandstone in Scania has only yielded indeterminable fragments of fossils and a *Teichichnus*-like trace fossil (Ahlberg 1984; Bergström & Gee 1985). Acritarchs have not been found (Vidal 1981b, c). Thus, the zonal attribution of the formation to the *Holmia inusitata* Zone (Bergström 1981; Ahlberg 1984; Bergström & Gee 1985; Ahlberg *et al.* 1986; Mens *et al.* 1990) is based exclusively on the indirect evidence provided by the position between the *Schmidtiellus mickwitzi* Zone (Norretorp Sandstone) and the *Holmia kjerulfi*-group Zone (Gislöv Formation; Bergström & Ahlberg 1981).

The overlying Gislöv Formation consists of silty limestones, siltstones and shales attaining a total thickness of 1–3 m (Bergström & Ahlberg 1981; Bergström & Gee 1985). It rests disconformably on the Rispebjerg Sandstone and contains glauconitic limestones and phosphatic nodules in the uppermost part. These define the junction of the formation with the overlying Middle Cambrian Alum Shale Formation (Martinsson 1974; de Marino 1980a; Bergström & Ahlberg 1981; Bergström & Gee 1985). Discontinuity surfaces were reported at the top of the formation at some localities (Bergström & Ahlberg 1981). A hiatus, probably reflecting the Hawke Bay regression, was indicated between the Gislöv and Alum Shale Formations (Bergström 1981; Bergström & Gee 1985; Mens *et al.* 1990). The Gislöv Formation has yielded a diverse fossil fauna including numerous trilobite taxa referable to *Holmia, Proampyx, Comluella?, Ellipsocephalus, Strenuaeva, Calodiscus* and various shelly fossils such as brachiopods, hyoliths, helcionellids, ostracodes, lapworthellids and hyolithelminthids (Bergström 1973a, 1981; Ahlberg & Bergström 1978; Bergström & Ahlberg 1981; Ahlberg 1984). On the basis of trilobite evidence the Gislöv Formation is referred to the *Holmia kjerulfi*-group Zone and the *Proampyx linnarssoni* Zone (Bergström 1981; Bergström & Ahlberg 1981; Ahlberg 1984; Bergström & Gee 1985; Ahlberg *et al.* 1986). Acritarchs are scattered and limited to specimens of *Leiosphaeridia* sp. and *Skiagia ciliosa* (Volkova) Downie which may suggest a late *Holmia* age (Vidal 1981b, c). However, *S. ciliosa* is known to occur in the Vergale and Rausve horizons in the U.S.S.R. (Volkova *et al.* 1979, 1983) and in assemblages defining the *Heliosphaeridium dissimilare – Skiagia ciliosa* and *Volkovia dentifera – Liepaina plana* Assemblage-zones in the Lublin Slope in Poland (Moczydłowska 1989; Figs. 5, 11).

### *Bornholm*

The Lower Cambrian succession on the island of Bornholm rests on the crystalline basement and is overlain by the Middle Cambrian Alum Shale Formation (Hansen 1936; V. Poulsen 1966, 1978; Martinsson 1974; Surlyk 1980; Bergström & Gee 1985). In ascending order the sequence consists of the Nexø Sandstone, the Balka Sandstone, the 'Green Shales' and the Rispebjerg Sandstone (Hansen 1936; V. Poulsen 1966, 1978; Fig. 11). Recently Surlyk (1980) regarded the two former units as formal formations (the Nexø Sandstone Formation and the Balka Sandstone Formation) whereas he referred the two latter to the informal Læså formation. The Læså formation comprises the lower Broens Odde member (='Green Shales') and the upper Rispebjerg Sandstone member.

With the exception of the basal Nexø Sandstone, the Lower Cambrian succession in Bornholm is comparable to that in Scania, and the discrete units are regarded as time-equivalent. Thus, the Balka Sandstone is the counterpart of the Hardeberga Sandstone and the 'Green Shales' correspond to the Norretorp Sandstone (V. Poulsen 1966, 1978; Lindström & Staude 1971; Bergström & Ahlberg 1981; Bergström & Gee 1985). The Nexø Sandstone consists of continental–fluvial red arkosic sandstones (Hansen 1936, 1937; V. Poulsen 1966, 1978; Martinsson 1974; Surlyk 1980; Bergström & Ahlberg 1981; Bergström & Gee 1985) which may be partly eolian (Dam & Clemmensen, 1988). The thickness of the Nexø Sandstone is about 100 m (Hansen 1936; Lindström & Staude 1971; Surlyk 1980). The rocks are unfossiliferous (V. Poulsen 1966; Martinsson 1974). Hence, the relative age of the formation is uncertain and on indirect evidence alone it was tentatively ascribed to the lower part of the *Platysolenites* Zone (Bergström & Gee 1985) or to the upper part of the *Platysolenites antiquissimus* Zone (Mens *et al.* 1990).

The Nexø Sandstone is transitionally overlain by evidently nearshore marine quartzitic sandstones of the Balka Sandstone (or Hardeberga Sandstone; Hansen 1936; V. Poulsen 1966; C. Poulsen 1967; Lindström & Staude 1971; Martinsson 1974; Surlyk 1980; Bergström 1981; Bergström & Ahlberg 1981). The Balka Sandstone attains a thickness of about 60 m (V. Poulsen 1966; C. Poulsen 1967; Martinsson 1974; Surlyk 1980) and contains fossil remains resembling *Byronia* Matthew and the trace fossils *Monocraterion* [=*Tigillites*], *Diplocraterion, Skolithos, Planolites* and *Palaeophycus* (V. Poulsen 1966; C. Poulsen 1967; Clausen & Vilhjámsson, 1986), and acritarchs (Vidal 1981b, c). As in Scania, the formation has been referred to the upper part of the *Platysolenites antiquissimus* Zone (Bergström 1981; Bergström & Gee 1985) or to the *Rusophycus parallelum* Zone (Mens *et al.*, 1990). Acritarchs deriving from shales within the Balka Sandstone are few and include *Lophosphaeridium tentativum* Volkova and *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal. They were considered to indicate a *Holmia* A age (Vidal 1981b, c; Moczydłowska & Vidal 1986). The recorded species occur in the Talsy horizon in the U.S.S.R. (Volkova *et al* 1979, 1983) and in the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone in the Lublin Slope in Poland (Moczydłowska 1989; Figs. 5, 11).

The succeeding unit, the 'Green Shales' (Forchhammer 1835; Grönwall 1899; Hansen 1936, 1937; V. Poulsen 1966, 1978; C. Poulsen 1967), or the Broens Odde member (Surlyk 1980) consists of glauconitic and phosphatic siltstones with intraformational phosphatic nodules and quartz-phosphatic conglomerates at the bottom (V. Poulsen 1966; C. Poulsen 1967; Martinsson 1974; Surlyk 1980; Vidal 1981b). Redeposition was indicated within the member (Lindström & Staude 1971). The thickness of the member is about 100 m (Hansen 1936; V. Poulsen 1966; C. Poulsen 1967; Lindström & Staude 1971; Martinsson 1974; Surlyk 1980). The fossil record of this unit derives from a strongly phosphatized bed containing black phosphorite nodules within the glauconitic siltstones. The fossils were retrieved almost exclusively from the phosphatic nodules (C. Poulsen 1967). The fauna is essentially endemic and sparse and includes species of *Hyolithes, Hyolithellus, Coleoloides, Halkieria, Orthotheca, Circotheca, Prosinuites, Fordilla, Pseudorthotheca, Glauderia, Proplina*?, *Pollicina*? and *Trapezotheca*? (V. Poulsen 1966; C. Poulsen 1967; Bengtson 1985). The trace fossil association recovered from the rocks of this member consists of *Planolites, Diplocraterion, Teichichnus, Rhizocorallium, Palaeophycus* and *Buthotrephis* (Clausen & Vilhjámsson 1986). The 'Green Shales' member was referred to the *Schmidtiellus mickwitzi* Zone (Bergström 1981; Bergström & Ahlberg 1981; Bergström & Gee 1985; Mens *et al.* 1990) on the indirect evidence of lithologic similarities with the Norretorp Formation, which was originally referred to this zone.

A diverse acritarch assemblage deriving from the 'Green Shales' consists of *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal, *C. strigosum* (Jankauskas) Downie, *Fimbriaglomerella membranacea* (Kirjanov) Moczydłowska & Vidal, *F. minuta* (Jankauskas) Moczydłowska & Vidal, *Globosphaeridium cerinum* (Volkova) comb. nov., *Goniosphaeridium primarium* (Jankauskas) Downie, *G. varium* (Volkova) Downie, *Asteridium tornatum* (Volkova) comb. nov., *A. lanatum* (Volkova) comb. nov., *Granomarginata squamacea* Volkova, *Lophosphaeridium tentativum* Volkova, *L. dubium* (Volkova) comb. nov., *Tasmanites bobrowskae* Ważyńska, *T. tenellus* Volkova, *Skiagia ornata* (Volkova) Downie, *S. ciliosa* (Volkova) Downie, *Archaeodoscina umbonulata* Volkova, *Dictyotidium priscum* Kirjanov & Volkova, *Pterospermella solida* (Volkova) Volkova, and *Pterospermopsimorpha wolynica* Kirjanov (Vidal 1981b, c; Moczydłowska & Vidal 1986). The assemblage was recovered from a single composite sample of phosphate nodules in the 'Hyolithid and phosphate' informal member (Hansen 1936) in the middle part of the unit (Vidal 1981b). The phosphate nodules are probably reworked intraformational phosphates. Because of their previously recorded stratigraphic ranges in the U.S.S.R., the recovered acritarchs were regarded as a 'mixed' assemblage containing species attributed to *Holmia* A or *Holmia* B ages (Vidal 1981b). Therefore, the assemblage was suggested to indicate an age (*Holmia* A = Talsy) possibly older than the depositional age of the unit (Vidal 1981b). However, recent data establish this particular co-occurrence of acritarch species also in sequences in northeastern Poland (Moczydłowska 1981), in the Lake Mjøsa region in southern Norway (Moczydłowska & Vidal 1986, 1988b) and in Östergötland, southeastern Sweden (Eklund 1988, 1990). Because of the significance attributed to the first occurrence of *Skiagia ciliosa, Goniosphaeridium varium, Pterospermella solida* and *Dictyotidium priscum* (Volkova *et al* 1979, 1983; Fig. 5), the data above are here taken to indicate that the assemblage recovered by Vidal (1981b) from the 'Green Shales' is time-equivalent with the Vergale horizon in the U.S.S.R. and the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in the Lublin Slope (Moczydłowska & Vidal 1986; Moczydłowska 1989; Fig. 11). This condition is in agreement with the previous observation that the assemblage from the 'Green Shales' has not much in common with acritarchs recovered from the Norretorp formation (Vidal 1981b). Additional samples from siltstones in the lower part of the 'Green Shales' yielded an assemblage of acritarchs exclusively known to occur in the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone in the Lublin Slope and the Talsy horizon in the U.S.S.R. (Moczydłowska & Vidal, in preparation). This suggests that rocks of the 'Green Shales' were deposited during the time comprising the *Skiagia ornata – Fimbriaglomerella membranacea* and *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zones in the Lublin Slope, i. e. corresponding to the Talsy and Vergale horizons in the U.S.S.R. (Moczydłowska 1989; Fig. 11). Thus the unit has a wider biostratigraphic bracketing than previously recognized (Bergström & Ahlberg 1981; Mens *et al* 1990).

The immediately younger Rispebjerg Sandstone consists of coarse-grained calcareous, glauconitic and siliceous sandstone intercalated with the phosphorite layers (Hansen 1936; V. Poulsen 1966; C. Poulsen 1967; Martinsson 1974; de Marino 1980b). The thickness of the member is about 1–3 m (Hansen 1936; V. Poulsen 1966; C. Poulsen 1967; de Marino 1980b; Surlyk 1980). Discontinuity surfaces (erosive contacts between the layers) and pyritic conglomerate occur within the member (Hansen 1937; V. Poulsen 1963; de Marino 1980b). The contact between the Rispebjerg Sandstone and the underlying 'Green Shales' was considered as gradual (V. Poulsen 1966; C. Poulsen 1967; Martinsson 1974). The contact is presently not accessible (de Marino 1980b). The top of the Rispebjerg Sandstone is erosive, indicating a stratigraphic hiatus separating the member from the overlying Middle Cambrian rocks (V. Poulsen 1963, 1965, 1966, 1978; Martinsson 1974; de Marino 1980b; Surlyk 1980). The member is poorly fossiliferous and has yielded a single specimen of the trace fossil *Cruziana dispar* Linnarsson and a fragment of *Hyolithellus micans* Billings. The latter might be possibly reworked within the member (C. Poulsen 1967; de Marino 1980b). On indirect evidence alone (see above) the Rispebjerg Sandstone was attributed to the *Holmia inusitata* Zone (Bergström 1981; Ahlberg 1984; Bergström & Gee 1985; Ahlberg *et al* 1986; Mens *et al* 1990).

### *Öland and Gotland*

On the islands of Öland and Gotland the Lower Cambrian sequence consists of the File Haidar Formation with the Kalmarsund Sandstone member at the base (Bergström & Gee 1985; Ahlberg 1989). The latter unit is overlain by a sequence informally named the *Mobergella holsti* zone, '*Mobergella* sandstone' or '*Mobergella* beds' (Moberg 1892; Westergård 1929; Thorslund & Westergård 1938; Hessland 1955; Regnéll 1960; Bengtson 1968; Martinsson 1974; Bergström 1981; Vidal 1981c; Moczydłowska & Vidal 1986). The File Haidar Formation consists of fine-grained sandstones and siltstones, generally with a basal conglomerate (Westergård 1929, 1940; Hadding 1929; Thorslund & Westergård 1938; Hessland 1955; Bengtson 1968; Martinsson 1974; Bergström 1981; Bergström & Gee 1985; Ahlberg 1989). Rocks of the File Haidar Formation rest on the crystalline basement and are overlain by Middle Cambrian strata (Thorslund & Westergård 1938; Bergström & Gee 1985; Ahlberg 1989). The thickness of the formation ranges from 20 to 157 m (Thorslund & Westergård 1938; Hessland 1955; Bergström & Gee 1985; Ahlberg 1989). The fossil record includes *'Strenuella' obscura* Thorslund & Westergård, *Eolimulus alatus* (Moberg), *Volborthella tenuis* Schmidt, *Mickwitzia monilifera* Linnarsson, *Torellella laevigata* (Linnarsson), *Mobergella holsti* (Moberg), *M. radiolata* Bengtson, *M. turgida* Bengtson, *Camenella baltica* (Bengtson), *Micromitra undosa* (Moberg) and *Hyolithellus* sp. (Moberg 1892; Thorslund & Westergård 1938; Åhman & Martinsson 1965; Bengtson 1968, 1977; Bergström 1981; Ahlberg 1989). On biostratigraphic grounds the range of the formation has been bracketed between the upper part of the *Platysolenites antiquissimus* Zone and the *Proampyx linnarssoni* Zone (Bergström 1981; Bergström & Gee 1985; Mens *et al.* 1990).

An acritarch assemblage recovered from the *Mobergella*-bearing strata in the Kalmarsund area includes diagnostic species such as *Comasphaeridium strigosum* (Jankauskas) Downie, *C. brachyspinosum* (Kirjanov) Moczydłowska & Vidal, *Globosphaeridium cerinum* (Volkova) comb. nov., *Fimbriaglomerella minuta* (Jankauskas) Moczydłowska & Vidal, *F. membranacea* (Kirjanov) Moczydłowska & Vidal, *Skiagia ciliosa* (Volkova) Downie, *Heliosphaeridium dissimilare* (Volkova) comb. nov., *Asteridium spinosum* (Volkova) comb. nov. In addition, species with wider stratigraphic ranges such as *Asteridium lanatum* (Volkova) comb. nov., *A. tornatum* (Volkova) comb. nov., *Lophosphaeridium tentativum* Volkova, *L. dubium* (Volkova) comb. nov., *Tasmanites tenellus* Volkova, *T. bobrowskae* Ważyńska and *Archaeodiscina umbonulata* Volkova were also recovered (Vidal 1981c; Moczydłowska & Vidal 1986). Based on acritarch evidence this part of the File Haidar Formation was regarded as *Holmia* A–B or B in age (Vidal 1981b, c, 1985; Moczydłowska & Vidal 1986). However, the assemblage may be correlated with similar assemblages from the Vergale horizon in the U.S.S.R. and the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in the Lublin Slope (Moczydłowska 1989; Fig. 11). If this correlation is correct, the sampled part of the sequence belongs to the *Holmia inusitata/Holmia kjerulfi* Zones. This also suggests that the range of the *Mobergella* fauna overlaps with that of the *Holmia inusitata/Holmia kjerulfi* Zones. Besides the *Mobergella* fauna there is no good faunistic evidence for establishing the lower range of the File Haidar Formation in the Kalmarsund area.

A recent acritarch study by Hagenfeldt (1988, 1989a, b), dealing with Lower and Middle Cambrian subsurface sequences underlying the Island of Gotland, the Island of Gotska Sandön, the Gulf of Bothnia, and additionally surface exposures in south central Sweden, provided abundant and age-diagnostic assemblages. The sequence penetrated on Gotland and Gotska Sandön is attributed to the File Haidar Formation (Bergström & Gee 1985) and yielded acritarch assemblages comparable to those previously recovered from the Lower Cambrian Vergale and Rausve horizons and the Middle Cambrian Kibartai horizon in the U.S.S.R. (Hagenfeldt 1988, 1989a, b). The investigated sections seem to indicate that the basal Lower Cambrian sequence in the Gotland area is contemporaneous with the Vergale horizon in the EEP. Thus, the lower part of the File Haidar Formation cannot be older than the *Holmia inusitata/Holmia kjerulfi* Zones (Moczydłowska 1989; Fig. 11). Extension of the lower biostratigraphically inferred range of the formation down to the *Platysolenites antiquissimus* Zone (Bergström 1981; Bergström & Gee 1985; Mens *et al* 1990) is in disagreement with individual acritarch-based biostratigraphy (Vidal 1981b, c; Vidal *in* Bergström & Gee 1985, p. 252; Moczydłowska & Vidal 1986; Hagenfeldt 1988, 1989a).

### *Västergötland and Östergötland*

In south-central Sweden (Västergötland, Östergötland and Närke) the File Haidar Formation comprises the *Mickwitzia* Sandstone and the Lingulid Sandstone local members (Westergård 1940; Martinsson 1974; Bergström 1981; Bergström & Gee 1985). In this region, the thickness of the formation is variable, ranging from 16 to 38 m (Westergård 1940; Thorslund & Jaanusson 1960; Eklund, 1990). The formation consists of fine-grained sandstones and siltstones which rest on the crystalline basement and are overlain by Middle Cambrian rocks (Westergård 1940; Martinsson 1974; Bergström & Gee 1985; Eklund, 1990).

The *Mickwitzia* Sandstone Member locally contains conglomerates at the base (Moberg 1911; Högbom & Ahlström 1924; Westergård 1940; Martinsson 1974; Vidal 1981b; Eklund 1990). The nature of the junction between the two members is the subject of much discussion. The junction was regarded as transitional (e.g. Westergård 1940; Martinsson 1974; Wikman *et al* 1980; Vidal 1985; Eklund 1990), but the presence of a stratigraphic hiatus has also been proposed (e.g. Bergström 1981; Bergström & Gee 1985; Mens *et al* 1990). The Lingulid Sandstone Member is overlain by glauconitic and phosphatic sandstones belonging to the Middle Cambrian *Eccaparadoxides oelandicus* Stage (Westergård 1940; Martinsson 1974; Bergström & Gee 1985; Eklund 1990).

The faunal record of the *Mickwitzia* Sandstone Member includes *Mickwitzia monilifera* Linnarsson, *Mobergella* spp., *Volborthella tenuis* Schmidt, *Torellella laevigata* (Linnarsson), *Paleomerus hamiltoni* Størmer, trace fossils including *Cruziana, Rusophycus, Diplocraterion* and *Teichichnus*, and the problematic sand-bodied *Spatangopsis* and *Protolyellia* (Nathorst 1881, 1886; Wiman 1903; Westergård 1940; Bergström 1971, 1981; Martinsson 1974; Ahlberg *et al.* 1986; Jensen 1990). The member was referred to the *Schmidtiellus mickwitzi* Zone (Bergström 1981; Bergström & Gee 1985).

The Lingulid Sandstone Member yielded *Holmiella* sp. and *Holmia grandis* Kiaer, and on the basis of the latter, the sequence has been referred to the *Holmia kjerulfi*-group Zone (Bergström 1981; Ahlberg 1984; Bergström & Gee 1985; Ahlberg *et al.* 1986).

Neither member has yielded a fauna diagnostic of the *Holmia inusitata* Zone. Nevertheless, the absence of fauna has been taken to support the existence of a hiatus separating both members (Bergström 1981; Bergström & Gee 1985; Mens *et al.* 1990). This point of view is, however, not supported by sedimentologic observations (Westergård 1940; Wikman *et al.* 1980; Eklund 1990) and the continuous nature of acritarch successions in Västergötland (Vidal 1981b, 1985; Moczydłowska & Vidal 1986) and Östergötland (Eklund, 1990).

In Östergötland, the acritarch succession in the *Mickwitzia* and Lingulid Sandstones seems continuous and overlapping, probably indicating a very condensed sequence (Eklund 1988, 1990). The continuity of the Östergötland succession is confirmed by a comparison with the assemblages in the sedimentologically continuous sequence of the Vergale and Rausve horizons in the U.S.S.R. (Volkova *et al.* 1979, 1983; Areń *et al.* 1979a; Bessonova & Piscun 1979; Kirjanov 1979; Mens & Pirrus 1979). Some of the acritarch species in these members (e.g., *Comasphaeridium molliculum, C. brachyspinosum, Fimbriaglomerella minuta* and *F. membranacea*) seem to have more comprehensive ranges, a feature that was not previously recorded in time-equivalent sequences where the rate of sedimentation was obviously higher (e.g. the Lublin Slope; Fig. 5).

The *Mickwitzia* Sandstone Member in Östergötland contains a diagnostic association of acritarchs that includes *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal, *C. strigosum* (Jankauskas) Downie, *C. molliculum* Moczydłowska & Vidal, *Globosphaeridium cerinum* (Volkova) comb. nov., *Goniosphaeridium primarium* (Jankauskas) Downie, *Tasmanites bobrowskae* Ważyńska, *T. volkovae* Kirjanov, *Skiagia orbiculare* (Volkova) Downie, *S. ornata* (Volkova) Downie, *S. compressa* (Volkova) Downie, *S. ciliosa* (Volkova) Downie, *Pterospermella solida* (Volkova) Volkova, *Cymatiosphaera postii* (Jankauskas) Jankauskas, *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas & Kirjanov, *Estiastra minima* Volkova, *Heliosphaeridium dissimilare* (Volkova) comb. nov., *Asteridium spinosum* (Volkova) comb. nov. and *Dictyotidium priscum* Kirjanov & Volkova (Eklund 1990). This assemblage allows comparison with the assemblage recorded from the Vergale horizon in the U.S.S.R. (Eklund 1990).

The Lingulid Sandstone Member yielded *Deunffia dentifera* (Volkova) Downie, *Baltisphaeridium latviense* Volkova, *Pterospermella vitrea* (Volkova) Volkova and *Leiovalia tenera* Kirjanov, all of which are diagnostic for the Rausve horizon (Eklund 1990). However, the uppermost part of the Lingulid Sandstone in Östergötland was suggested to range into the Middle Cambrian (Eklund 1990). Acritarchs from the uppermost part of the Lingulid Sandstone in outcrop at Kvarntorp, Närke, did not provide decisive data to establish the age of this part of the unit (Hagenfeldt 1988, 1989a).

In Västergötland, the basal part of the *Mickwitzia* Sandstone yielded an acritarch assemblage including *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal, *Goniosphaeridium* primarium (Jankauskas) Downie, *Globosphaeridium cerinum* (Volkova) comb. nov., *Skiagia orbiculare* (Volkova) Downie, *S. ornata* (Volkova) Downie, *S. compressa* (Volkova) Downie, *S. ciliosa* (Volkova) Downie, *Lophosphaeridium dubium* (Volkova) comb. nov., *Tasmanites tenellus* Volkova, *T. bobrowskae* Ważyńska, *Dictyotidium priscum* Kirjanov & Volkova, and *Cymatiosphaera postii* (Jankauskas) Jankauskas (Vidal 1981b, c; Moczydłowska & Vidal 1986). The assemblage was referred to the *Holmia* A–B or B–C (respectively, Vidal 1981b, c, 1985; Moczydłowska & Vidal 1986). It is here considered as suggesting time-equivalence with the Vergale horizon (Moczydłowska 1989; Fig. 11).

The Lingulid Sandstone Member contains acritarchs including *Skiagia orbiculare* (Volkova) Downie, *S. compressa* (Volkova) Downie, *S. ciliosa* (Volkova) Downie, *Goniosphaeridium primarium* (Jankauskas) Downie, *G. varium* (Volkova) Downie, *G. implicatum* (Fridrichsone) Downie, *Lophosphaeridium dubium* (Volkova) comb. nov., *L. tentativum* Volkova, *Asteridium lanatum* (Volkova) comb. nov., *Heliosphaeridium dissimilare* (Volkova) comb. nov., *H. obscurum* (Volkova) comb. nov., *Dictyotidium priscum* Kirjanov & Volkova, *Pterospermella solida* (Volkova) Volkova, *Leiovalia tenera* Kirjanov, and *Tasmanites volkovae* Kirjanov (Vidal 1981b, c; Moczydłowska & Vidal 1986). The assemblage was referred to as being of *Holmia* B or C age (Vidal 1981b, c, 1985; Moczydłowska & Vidal 1986). In this paper the assemblage is regarded as correlative with the Vergale horizon (Moczydłowska 1989; Fig. 11).

In Östergötland and Västergötland, acritarch evidence suggests that the basal part of the *Mickwitzia* Sandstone is time-equivalent to the Vergale horizon (Fig. 11). Based on the record of *Mickwitzia, Mobergella, Volborthella* and the trace fossil *Cruziana dispar*, the *Mickwitzia* Sandstone was referred to the *Schmidtiellus mickwitzi* Zone (Bergström 1981). The reason for this assumption was the co-occurrence of the mentioned fossils with *Schmidtiellus mickwitzi* and *Holmia mobergi* in other sections, e.g. in the Mjøsa region, Scania and Estonia (Bergström 1981; Ahlberg *et al.* 1986). However, taxa recorded in the *Mickwitzia* Sandstone have wide stratigraphic ranges, and their occurrence seems to be facies-controlled (Martinsson 1974; Landing *et al.* 1980; Bengtson & Fletcher 1983; Landing 1988a, b; Brasier 1989). Thus, this indirect correlation may be uncertain (Bergström 1981) and it appears likely that the *Mickwitzia* Sandstone belongs to the *Holmia inusitata* and/or *Holmia kjerulfi* Zone (Moczydłowska 1989; Fig. 11). This point of view is supported by the occurrence of acritarch assemblages in common with the *Holmia inusitata/Holmia kjerulfi* Zones in the other sequences in Scandinavia (Vidal 1981b, c; Moczydłowska & Vidal 1986; Fig. 11), the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in Poland (Moczydłowska 1989; Fig. 5) and the Vergale horizon in the U.S.S.R. (Volkova *et al.* 1979, 1983).

The Lingulid Sandstone was referred to the *Holmia kjerulfi*-group Zone on the basis of a single record of *Holmia grandis* Kiaer deriving from the upper part of the sequence in Västergötland (Bergström 1981; Ahlberg 1984; Ahlberg *et al.* 1986). Acritarch data from Västergötland allow referring also this part of the unit to the *Holmia kjerulfi*-group Zone elsewhere in Scandinavia (Vidal 1981b, c; Moczydłowska & Vidal 1986), the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in Poland (Moczydłowska 1989; Fig. 5) and the Vergale horizon in the U.S.S.R. (Fig. 11). In Östergötland, the Lingulid Sandstone additionally contains an acritarch assemblage diagnostic of the Rausve horizon in the U.S.S.R. (Eklund, 1990) and the *Volkovia dentifera – Liepaina plana* Assemblage-zone in Poland (Moczydłowska 1989; Fig. 11). Thus the Lingulid Sandstone seems to have a wider biostratigraphic range including the *Holmia kjerulfi* and *Proampyx linnarssoni* Zones in Baltoscandia, the Rausve horizon in the U.S.S.R., and the *Protolenus* zone in Poland (Vidal 1981c; Moczydłowska & Vidal 1986; Eklund 1988, 1990; Moczydłowska 1989; Fig. 11). Furthermore, the uppermost part of the Lingulid Sandstone is referred to the Kibartai horizon in the U.S.S.R. (Eklund 1988, 1990), which corresponds to the Middle Cambrian *Eccaparadoxides oelandicus* Zone (Keller & Rozanov 1979b).

The transitional contact between deposits containing Rausve-like and Kibartai-like assemblages in Östergötland indicates a continuous passage from the Lower to Middle Cambrian within the Lingulid Sandstone (Eklund 1988, 1990). This raises questions about the nature of a previously proposed hiatus at the slightly higher contact between the Lingulid Sandstone and the Alum Shale Formation (Martinsson 1974; Bergström 1981; Bergström & Ahlberg 1981; Ahlberg 1984; Bergström & Gee 1985; Mens *et al.* 1990).

### *Lake Mjøsa Region*

In the Lake Mjøsa region, southern Norway, the Lower Cambrian sequence consists, in ascending order, of the Vangsås Formation, the Brennsæter Shale and the Bråstad Sandstone (1aα beds), the Bråstad Shale (1aβ), the *Holmia* Shales (1bα), and the Evjevik Limestone (1bβ) (Braastad 1915; Kiaer 1916; Vogt 1924; Strand 1929; Henningsmoen 1956; Skjeseth 1963; Bjørlykke *et al.* 1967, 1976; Martinsson 1974; Bjørlykke 1978; Bergström 1981; Nystuen 1982, 1987; Bergström & Gee 1985; Dreyer 1988; Vidal & Nystuen 1991; Fig. 11 herein). The discrete formations are separated partly by transitional contacts or by unconformities comprising possible hiati (Fig. 11). The Lower Cambrian is overlain with angular erosional disconformity by Middle Cambrian strata (Skjeseth 1968; Bjørlykke 1974, 1983). The lowermost unit in the sequence is the Vangsås Formation. In the northern part of the Lake Mjøsa region this formation overlays the Ekre Shale formation with conformable contact, while in the southern part of the region the contact is an erosional disconformity (Skjeseth 1963; Bjørlykke *et al.* 1976; Bjørlykke 1978; Nystuen 1987; Dreyer 1988). The boundary between the formations is diachronous and reflects the progradation of the sedimentary basin during the marine transgression in the 'sparagmite' basins (Bjørlykke *et al.* 1976; Nystuen 1982, 1987; Dreyer 1988).

The contact between the Vardal Sandstone Member and the overlying Ringsaker Quartzite Member of the Vangsås Formation is conformable and gradual (Bjørlykke 1982; Nystuen 1982, 1987; Dreyer 1988). The Vangsås Formation is composed of deltaic and braided-stream coarse-grained sandstones and conglomerates with fine-grained interbeds in the lower part (the 'Vardal Sparagmite' = Vardal Sandstone Member) and shallow marine transgressive quartzitic sandstones in the upper part (the Ringsaker Quartzite Member) (Skjeseth 1963; Bjørlykke *et al.* 1967, 1976; Nystuen 1981, 1982, 1987; Dreyer 1988). The thickness of the Vardal Sandstone is variable, ranging between 200 and 800 m, while the Ringsaker Quartzite is 40–200 m thick (Bjørlykke *et al.* 1976; Bjørlykke 1978; Nystuen 1981, 1982; Dreyer 1988).

The Vardal Sandstone is unfossiliferous with the exception of very rare microfossil finds, including the cyanobacterial *Sphaerocongregus* sp. as well as the acritarchs *Leiosphaeridia* sp. and *Fimbriaglomerella minuta* (Vidal & Nystuen 1990). The latter species was considered as possibly indicating an early Cambrian age for the unit (Vidal & Nystuen 1990). The lower range of *F. minuta* is known to coincide with the *Skiagia ornata – Fimbriaglomerella membranacea* Assemblage-zone in the Lublin Slope (Moczydłowska 1989; Fig. 5). It may suggest that the upper part of the Vardal Sandstone (from which the specimens derived) corresponds to this zone (Fig. 11).

The poor fossil record of the Ringsaker Quartzite includes trace fossils at the top of the unit (*Skolithos, Monocraterion* and *Diplocraterion*), resembling the assemblage from the Hardeberga Sandstone in southern Sweden (Skjeseth 1963; Bergström 1970; Ahlberg & Bergström 1978; Bergström & Gee 1985). The rocks of the member are generally not suitable for the preservation of acritarchs (Vidal 1981b) but two poorly preserved specimens of unidentifiable acanthomorph acritarchs were recorded in mudstones within the unit (Moczydłowska & Vidal 1986; Vidal & Nystuen 1990). Mainly on lithostratigraphic grounds and the comparable occurrence of trace fossils, the Ringsaker Quartzite was regarded as a correlative of the Hardeberga Sandstone. It was thus referred to the *Rusophycus parallelum* Zone (Bergström 1981; Bergström & Gee 1985; Mens *et al.* 1987, 1990; Moczydłowska & Vidal 1988a; Moczydłowska 1989). However, the biostratigraphic range of the Vangsås Formation still remains uncertain.

The Ringsaker Quartzite is unconformably overlain by the transgressive Brennsæter Shale consisting of basal conglomerate, shales, siltstones and minor carbonates, and the Bråstad Sandstone made up of quartzitic sandstones which together form unit 1aα in the Lake Mjøsa region (Vogt 1924; Skjeseth 1963; Bjørlykke *et al.* 1976; Bjørlykke 1978; Bergström & Gee 1985; Nystuen 1987; Dreyer 1988). The thickness of the unit 1aα is approximately 2–6 m (Skjeseth 1963; Martinsson 1974; Bjørlykke 1978). This part of the sequence contains *Holmia* cf. *mobergi* Bergström (one fragment) and *Mobergella holsti* (Moberg), and the trace fossil *Cruziana dispar* Linnarsson (Vogt 1924; Skjeseth 1963; Bengtson 1968, 1977; Bergström 1970, 1973, 1980, 1981; Ahlberg & Bergström 1978; Føyn & Glaessner 1979; Ahlberg 1984; Bergström & Gee 1985). The occurrence of *Mobergella holsti* was not confirmed by Bengtson (1977), who referred to it as *Mobergella* sp.

The occurrence of *Platysolenites antiquissimus* Eichwald in the Bråstad Sandstone (Skjeseth 1963; Martinsson 1974) is uncertain since the beds with *Platysolenites* were originally correlated with beds containing *Volborthella* (Vogt 1924), which according to Skjeseth (1963) are referred to the overlying Bråstad Shale. It does not seem possible to establish on faunistic grounds alone the stratigraphic relationship between beds containing *Platysolenites* and those with *Mobergella* (1aα), succeeded by *Volborthella tenuis* and *Holmia inusitata* (1aβ) in the Lake Mjøsa region (Vogt 1924; Skjeseth 1963; Daily 1972; Bengtson 1977; Føyn & Glaessner 1979; Ahlberg *et al.* 1986). The reason is that the particular fossils are scarce and they occur in discontinuous sections in separated localities. Hence, their stratigraphic ranges are poorly known. The Brennsæter Shale and the Bråstad Sandstone (1aα beds) were regarded to be correlatives of the Norretorp Sandstone in Scania and were referred to the *Schmidtiellus mickwitzi* Zone (Bergström 1970, 1981; Ahlberg & Bergström 1978; Ahlberg 1984; Bergström & Gee 1985, Mens *et al.* 1990).

Rocks of the 1aα beds yielded an acritarch assemblage consisting of *Skiagia ornata* (Volkova) Downie, *S. compressa* (Volkova) Downie, *Granomarginata squamacea* Volkova, *Lophosphaeridium tentativum* Volkova, *Asteridium lanatum* (Volkova) comb. nov., *Comasphaeridium strigosum* (Jankauskas) Downie, *Cymatiosphaera postii* (Jankauskas) Jankauskas, and *Heliosphaeridium dissimilare* (Volkova) comb. nov. (Vidal 1981b, c; Moczydłowska & Vidal 1986; Vidal & Nystuen 1991). The age of the 1aα beds was inferred as *Holmia* A (Vidal 1981b,c), *Holmia* B (Moczydłowska & Vidal 1986), and more recently as a Vergale time-equivalent (Vidal & Nystuen 1991). Here, the assemblage of the 1aα beds is regarded as correlative to the assemblage defining the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone which corresponds to the *Holmia kjerulfi* Assemblage-zone in the Lublin Slope and to the Vergale horizon in the U.S.S.R. (Fig. 11). The implications of the suggested correlation might be that *Holmia mobergi*, recorded to co-occur with *Schmidtiellus mickwitzi* in Scania, has an overlapping stratigraphic range with *Holmia inusitata* and *Schmidtiellus mickwitzi* (cf. Bergström 1981; Ahlberg 1984; Ahlberg *et al.* 1986).

The immediately overlying Bråstad Shale (1aβ beds), consisting of conglomerates at the base, is composed of thin-bedded siltstones with a thickness from a few meters to 12 m (Vogt 1924; Skjeseth 1963). The unit yielded fossils attributed to *Volborthella tenuis* Schmidt and trilobites attributed to *Holmia inusitata* Ahlberg & Bergström (*Callavia* n. sp. = *Holmia* n. sp.) (Skjeseth 1963; Martinsson 1974; Ahlberg & Bergström 1978; Føyn & Glaessner 1979; Bergström 1980, 1981; Bergström & Ahlberg 1981; Vidal 1981b, c; Ahlberg 1984; Bergström & Gee 1985; Ahlberg *et al.* 1986). Possibly, *Platysolenites antiquissimus* Eichwald (Vogt 1924) also occurs in the same beds (see comment above). The Bråstad Shale is referred to the *Holmia inusitata* Zone (Ahlberg *et al.* 1986).

The acritarch record of the Bråstad Shale is rich and comprises diagnostic species such as *Skiagia orbiculare* (Volkova) Downie, *S. ornata* (Volkova) Downie, *S. compressa* (Volkova) Downie, *S. scottica* Downie, *S. ciliosa* (Volkova) Downie, *Globosphaeridium cerinum* (Volkova) comb. nov., *Fimbriaglomerella membranacea* Moczydłowska & Vidal, *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal, and *C. strigosum* (Jankauskas) Downie (Vidal 1981b, c; Moczydłowska & Vidal 1986; Vidal & Nystuen 1991). Based on the occurrence of this assemblage the unit was regarded to be of *Holmia* B (Vidal 1981b, c), *Holmia* C (Moczydłowska & Vidal 1986), or Vergale age (Moczydłowska 1989; Vidal & Nystuen 1991; Fig. 11). The acritarch assemblage of the Bråstad Shale (1aβ beds) is comparable to the assemblage from the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in the Lublin Slope in Poland and the Vergale horizon in the U.S.S.R. (Moczydłowska 1989; Fig. 11).

The next succeeding unit is the *Holmia* Shale and the Evjevik Limestone (1bα and 1bβ beds, respectively) (Vogt 1924; Skjeseth 1963; Bjørlykke 1974, 1983; Martinsson 1974; Bergström & Gee 1985). Unit 1b has a thickness of about 15–20 m and is composed of grey and green shales and calcareous shales passing into shales intercalated with limestones (Vogt 1924; Skjeseth 1963; Vidal & Nystuen 1991). The *Holmia* Shale yielded the trilobites *Holmia kjerulfi* (Linnarsson), *H. grandis* Kiaer, *Kjerulfia lata* Kiaer, *Strenuaeva primaeva* (Brögger), *Ellipsocephalus gripi* (Kautsky)?, and *Runcinodiscus* cf. *index* Rushton, and shelly fossils such as *Torellella* sp. (Kiaer 1916; Vogt 1924; Skjeseth 1963; Bergström 1973a; Ahlberg & Bergström 1978; Bergström & Ahlberg 1981; Ahlberg 1983). This trilobite association is attributed to the *Holmia kjerulfi*-group Zone (Bergström 1981; Ahlberg *et al.*, 1986). The Evjevik Limestone yielded the trilobites *Proampyx linnarssoni* (Kiaer) and *Ellipsocephalus gripi* (Kautsky)?, and the shelly fossil *Torellella laevigata* (Linnarsson) (Kiaer 1916; Vogt 1924; Skjeseth 1963; Bergström 1973a; Ahlberg & Bergström 1978). The sequence is referred to the *Proampyx linnarssoni* Zone (Bergström 1981; Ahlberg *et al.* 1986).

Acritarchs deriving from rocks of the *Holmia* Shale (1bα beds) include, among others, *Skiagia ciliosa* (Volkova) Downie, *S. compressa* (Volkova) Downie, *S. scottica* Downie, *Dictyotidium priscum* Kirjanov and Volkova, *Heliosphaeridium dissimilare* (Volkova) comb. nov., *Goniosphaeridium varium* (Volkova) Downie, *G. primarium* (Jankauskas) Downie, and *Globosphaeridium cerinum* (Volkova) comb. nov. They were considered to indicate a *Holmia* B or C age (Vidal 1981b, c; Moczydłowska & Vidal 1986) and be time-equivalent to the Vergale horizon (Moczydłowska 1989; Vidal & Nystuen, 1991). The assemblage corresponds to the *Heliosphaeridium dissimilare – Skiagia ciliosa* Assemblage-zone in Poland (Moczydłowska 1989; Fig. 11).

The partly bioclastic carbonate sequence attributed to the *Proampyx linnarssoni* Zone in the Lake Mjøsa area (Bergström & Ahlberg 1981; Bergström 1981) did not yield acritarchs, possibly due to extensive weathering (Moczydłowska & Vidal 1986). Thus, the biostratigraphic relationship of the *Proampyx linnarssoni* Zone with the acritarch zonation remains speculative. The proposed correlation between the *Proampyx linnarssoni* Zone and part of the *Protolenus* Zone in Poland and the Rausve horizon in the U.S.S.R. (Bergström 1981; Mens *et al.* 1990) is not satisfactorily proven either by trilobite or by acritarch evidence.

In areas where rocks of the *Proampyx linnarssoni* Zone are present, e.g. Lake Mjøsa area and Scania, there is no record of a Rausve-like acritarch assemblage (Vidal 1981b, c; Moczydłowska & Vidal 1986; Vidal & Nystuen 1991). Trilobites of this zone are unknown outside Baltoscandia and therefore a correlation with the trilobite zones elsewhere is indirect (Bergström & Ahlberg 1981) and uncertain. The Rausve horizon has no known trilobites except for a find of *Ellipsocephalus* sp. (Areń *et al.* 1979a; Keller & Rozanov 1979b). It contains a diagnostic acritarch assemblage which is comparable to the acritarch assemblage from beds of the *Protolenus* zone (Volkova 1973; Volkova *et al.* 1979, 1983).

The *Protolenus* zone has yielded trilobites attributed to *Kingaspis* (*Kingaspis*) *borealis* Lendzion, *Ellipsocephalus hoffi* (Schlotheim), and *Protolenus* sp. (Lendzion 1983a, b).

In Baltoscandia and in the EEP in Poland and the U.S.S.R., rocks attributed to the *Proampyx linnarssoni* Zone, *Protolenus* zone and the Rausve horizon are underlain by time-equivalent strata which have yielded comparable trilobite faunas and acritarch assemblages. In Baltoscandia and in Poland they are referred to the *Holmia kjerulfi* Assemblage-zone, while in the U.S.S.R. they are referred to the Vergale horizon (Volkova 1973; Volkova *et al.* 1979, 1983; Keller & Rozanov 1979b; Vidal 1981b, c, 1985; Lendzion 1983a, b; Ahlberg *et al.* 1986; Mens *et al.* 1990).

Strata attributed to the *Proampyx linnarssoni* Zone have no trilobites or acritarchs in common with beds referred to the supposedly time-equivalent *Protolenus* zone and Rausve horizon. Accordingly, the *Proampyx linnarssoni* Zone may be of a different age. It is possible that rocks referred to the *Proampyx linnarssoni* Zone could be attributed to the *Holmia kjerulfi* Assemblage-zone. The implication of this would be that the *Proampyx linnarssoni* fauna might be part of the fauna complex defining the *Holmia kjerulfi* Assemblage-zone.

# Systematic palaeontology

## Classification

Acritarchs are classified under an informal nomenclatural grouping – the Group Acritarcha Evitt, 1963 (Evitt 1963; Downie *et al.* 1963; Loeblich 1970; Eisenack *et al.* 1973; Tappan 1980). It is generally accepted that they derive from plant protists, and so their taxonomy follows the *International Code of Botanical Nomenclature* (Downie *et al.* 1961, 1963; Loeblich 1970; Tappan 1980). The informal taxonomic treatment results in name combinations that represent form-genera and form-species erected on the basis of morphological criteria alone.

Several different systems of classification were introduced during the course of pioneering studies. The microfossils were classified in morphological subgroups that include genera and species (Downie *et al.* 1963; Staplin *et al.* 1965; Timofeev 1966, 1969). However, such subgroups lack practical significance for taxonomic purposes. Additional attempts to create new entities (such as 'Paraordo, Parafamilia, Parageneres, Paraespeces') clearly deviate from a Linnean classification system (Deflandre & Deflandre 1964). These taxonomic entities are not recognized by any existing nomenclatural code and they are therefore invalid, while under the code of botanical nomenclature, form-genera have the same status as Linnean genera. This is particularly true in the case of acritarchs and dinoflagellates, as the encysted and motile stages of the life cycle of the organism concerned are of equal importance, representing the total organism during at least a part of its ontogenetic development (Loeblich 1970). Classifications treating acritarchs according to Linnean taxonomy (using class, order, family, genus and species) have also been proposed (Mädler 1963; Eisenack 1963b, 1969).

At the present stage, some acritarch genera are attributed to extant algal families. This applies for example to *Leiosphaeridia*, *Tasmanites*, *Cymatiosphaera* and *Pterospermella* (Loeblich & Wicander 1976; Tappan 1980), which as fossil genera were referred to the Prasinophyta among the green algae. Hence, although referred to fossil genera and families, they are placed among contemporaneous orders in the families Leiosphaeridiaceae, Tasmanitaceae, Cymatiosphaeridiaceae and Pterospermellaceae (Tappan 1980). The genus *Tasmanites* was referred to the algae in early papers by Newton (1875), Sommer (1956), Wall (1962) and Mädler (1963). Transmission electron microscopy studies of the wall ultrastructure of these microfossils (Jux 1968, 1969a, b) confirmed the similarity of tasmanitids to the modern prasinophycean genera *Pachysphaera* and *Halosphaera*. This notion was, however, formerly suggested by Wall (1962).

In contrast to the perforated wall observed among tasmanitids (Kjellström 1968) and the layered wall of *Pachysphaera* and *Halosphaera* (Jux 1969a, b), the species of *Leiosphaeridia* (referred to contemporaneous Halosphaeraceae; Wall 1962) possesses a homogeneous wall (Jux 1969b). Other Palaeozoic acritarchs (*Baltisphaeridium*, *Peteinosphaeridium*, *Goniosphaeridium*) also display a wall ultrastructure consisting of densely spaced radially arranged canals in the wall which resembles the wall of tasmanitids (Jux 1971). This suggests that many acritarchs could perhaps be closely related to the Prasinophyceae (Jux 1971; Tappan 1980). Hitherto, studies on the chemical composition and ultrastructure of the organic wall of the acritarchs have been undertaken only on a few genera (Eisenack 1938, 1963b; Timofeev 1956; Kjellström 1968; Jux 1968, 1969a, b, 1971; Colbath 1983; Bloeser 1985). The available data are insufficient to have an impact on the biological affinity of the whole group.

In this paper, only form-genera and form-species are considered, and they are arranged in alphabetic order as suggested by Loeblich (1970) and practiced by others (Loeblich & Wicander 1976; Loeblich & Tappan 1978; Vidal 1976a, 1979b, 1981a; Vidal & Siedlecka 1983; Vidal & Ford 1985; Tappan 1980; Wicander 1983; Wicander & Playford 1985).

## Taxonomic remarks

Assemblages of microphytoplankton from Cambrian deposits include abundant species of the small acanthomorphic acritarch *Micrhystridium* (Volkova 1968, 1969b; Volkova *et al.* 1979; Gardiner & Vanguestaine 1971; Downie 1974, 1982; Kirjanov 1974; Vanguestaine 1974, 1978; Jankauskas 1975, 1976; Jankauskas & Posti 1976; Pyatiletov 1976; Paškevičiene 1980; Vidal 1981a, b; Moczydłowska 1981, 1988a; Erkmen & Bozdoğan 1981; Welsch 1986). Diagnostic features common to these species are the morphology of the central body and processes, as well as the small dimensions, the diameter of the central body being generally less than 20 µm. Morphological variability concerns the general shape and distribution of the processes, the shape of their proximal base and distal terminations, and the presence or lack of communication between the

| | Deflandre, 1937 | Staplin, 1961 | Downie, Sarjeant 1963 | Staplin, Jansonius, Pocock, 1965 | Deflandre, 1966 | Sarjeant, 1967 |
|---|---|---|---|---|---|---|
| Vesicle | globular | subspherical to spherical | spherical or oval not divided into fields or plates | subspherical to subpolygonal | globular | spherical to oval not divided into fields or plates |
| Processes | variable appendages | simple spines generally uniform, numerous, bases sometimes arranged in a subpolygonal pattern, tapering to tubular, tips closed | simple, branching or ramifying, one type, with closed tips, without distal connections | several to numerous hollow spines, closed at the tips, spines broadly to narrowly conical | simple, sharp pointed, slender never connected | simple, branching or ramifying, with closed tips, without distal connections |
| Size | vesicle less than 20 µm | | mean and modal diameter of shell less than 20 µm | small to moderate vesicle | vesicle less than 20 µm | processes less than 20 µm |
| Communication of vesicle and processes | | | | processes cavity opening into and continuous with vesicle interior | | |
| Excystment | | | | | probably opening by dehiscence or line equatorial rupture, no pylome or archaeopyle | crescentic to horseshoe-shaped opening or irregular, no pylome or archaeopyle |
| Structure of wall | | | | no differentiation in wall structure between spines and vesicle | | |

*Fig. 12.* Comparative table of diagnostic features for the genus *Micrhystridium* Deflandre, 1937.

processes and central body cavity. Other important features are the proportions between the diameter of the central body and the length of processes.

The genus *Micrhystridium* Deflandre, 1937, was erected to embrace organic-walled microfossils from Cretaceous rocks. The diagnosis was simple and referred only to very generalized morphological features (Deflandre 1937, p. 31; Fig. 12). Despite the obviously insufficient description, different morphological species, from deposits ranging in age from early Palaeozoic to Recent (Downie & Sarjeant 1964), have been incorporated in the genus *Micrhystridium.* The genus has thus become a taxonomic 'waste basket' (Loeblich 1970) and been regarded as stratigraphically persistent (Sarjeant 1967; Eisenack *et al.* 1979a). The great morphological and dimensional diversity of the various fossil microorganisms referred to *Micrhystridium* was the direct cause of subsequent emendations of the genus (Fig. 12).

Inadequate consideration has been given to the particular diagnostic features of *Micrhystridium* (cf. Eisenack *et al.* 1979a, b). Therefore, it may seem that no part of the above mentioned diagnosis (Fig. 12) is completely satisfactory. Various species of micrhystrids from Jurassic and Cretaceous units (the latter including the original material for the genus *Micrhystridium*) have a two-layered vesicle wall. The processes are formed as projections of the outer layer or by both layers of the vesicle (Sarjeant 1967; Eisenack *et al.* 1979a). This important feature has never been mentioned in previous diagnoses. On the other hand, introducing the limitation of the overall dimensions among the diagnostic features of the genus seems of doubtful taxonomic value. This is because microfossils possessing the generic features display significant dimensional variability. These conditions were noted by numerous authors (e.g. Staplin 1961; Loeblich 1970; Cramer & Díez 1972; Wicander 1974; Vidal 1976a). The intraspecific size range among modern phytoplankton taxa is wide (Loeblich 1970), which turns the diagnostically chosen dimensional limit of 20 µm worthless from a biological and taxonomic point of view. This is particularly important concerning acritarchs since the group is probably polyphyletic (Downie *et al.* 1963; Loeblich 1970; Eisenack *et al.* 1973; Tappan 1980) and thus unlikely to be taxonomically related (despite superficial morphological similarity) over hundreds of millions of years. Looking at the appearance in the geologic record of morphologic features characteristic of microfossils referred to micrhystrids, the surface sculpture of the wall and processes and the excystment are known since the Ordovician (Loeblich & Tappan 1969; Eisenack *et al.* 1979a). The two-layered vesicle wall is observed among various species from the Jurassic and Cretaceous (Sarjeant 1967; Eisenack *et al.* 1979a).

The morphologies of Cambrian acritarchs referred to *Micrhystridium* match only the generalized features in the generic description. They include species with hollow processes communicating with the central body cavity as well as species with processes clearly separated from the interior of the vesicle. Among all the available emendations of the original diagnosis of *Micrhystridium,* only that of Staplin *et al.* (1965) indicated that the processes have free communication with the vesicle cavity. However, the existence of forms with solid processes has never been mentioned. Contrary to the micrhystrids occurring in the later Palaeozoic (cf. Eisenack *et al.* 1979a), the double-layered wall, excystment structures, and sculpture of wall or processes have never been observed in Cambrian species.

As seems the case with dinoflagellates (Evitt 1985), the geological record of acritarchs may represent a biased and selective fraction of the biological cycles of taxonomically more or less closely related algal clades among the phytoplankton (cf. Tappan 1980). Information concerning the ultrastructure of the vesicle and the chemical composition of micrhystrids, as possible indicator of their biological affinity, is not available at the moment. Thus it seems uncertain and probably unlikely that Cambrian (Downie 1974; Potter 1974; Volkova *et al*. 1979; Vidal 1981a, 1981b; Moczydłowska & Vidal 1986) and Mesozoic or Tertiary and Pleistocene (Downie & Sarjeant 1964; Sarjeant 1967) form-taxa referred to *Micrhystridium* are interrelated. These forms are morphologically different and they are separated in time by hundreds of millions years. Hence I conclude that the Cambrian acritarchs studied herein, previously described under the generic name *Micrhystridium*, should be referred to other genera.

My proposal is to transfer them to the two new form-genera *Asteridium* n.gen. and *Heliosphaeridium* n.gen. *Asteridium* includes species possessing solid processes separated from the interior of the vesicle, while species having hollow processes communicating with the central body cavity are referred to *Heliosphaeridium*. High power interference contrast microscopy has failed to disclose excystment features or any surface sculpture in either genus. SEM micrography of one of the species concerned (*Asteridium lanatum* (Volkova) comb. nov.) shows clearly the smooth nature of the surface (Knoll & Swett 1987, Fig. 8:7). Consequently, the two new genera differ from *Micrhystridium* by having a single-layered vesicle wall and by lacking surface sculpture and excystment. Additionally, *Asteridium* differs from *Comasphaeridium* Staplin, Jansonius & Pocock, 1965, by the definitely smaller dimensions of the vesicle and the morphology of the processes.

Acritarchs referred to the Cambrian species *Baltisphaeridium cerinum* Volkova, 1968, have solid processes. They thus differ from the genus *Baltisphaeridium* Eisenack, 1958, emend. Eisenack, 1969, which possesses processes with an inner cavity and are known to occur from the early Ordovician (cf. Eisenack *et al.* 1979a, b). Specimens of *Baltisphaeridium cerinum* and similar species are herein transferred to the new genus *Globosphaeridium* n.gen. This genus collects specimens having solid processes without an inner cavity. It differs from *Asteridium* n.gen. by the larger dimensions of the central body and longer processes. It additionally differs from *Comasphaeridium* Staplin, Jansonius & Pocock, 1965, by possessing less numerous, loosely distributed processes, and from *Elektoriskos* Loeblich, 1970, by lacking ornamentation on the wall.

## Palaeontologic descriptions

In the systematic part of this paper incomplete synonymies are given concerning data from the U.S.S.R. Only original descriptions and subsequent emendations will be cited; for further data the reader will be referred to reports by Volkova *et al.* (1979, 1983) from the EEP and to additional reports concerning the Lublin Slope. The occurrences of species in the U.S.S.R. part of the EEP are given in abbreviated form. Detailed geographic distribution and stratigraphic ranges of species have been published by Volkova *et al.* (1979, 1983). In this paper the Rovno 'horizon' is regarded as part of the Upper Proterozoic, being late Vendian in age as suggested by the evidence provided by non-shelly fauna and acritarchs (Rozanov & Sokolov 1980, 1982; Sokolov & Ivanovsky 1985; Sokolov & Fedonkin 1985; Volkova 1985; Moczydłowska & Vidal 1986; Moczydłowska 1989; Fig. 10). The range of the *Platysolenites antiquissimus* Interval-zone in the Lublin Slope is considered to include the uppermost part of the former *Sabellidites* Zone (Figs. 6, 8).

The *Holmia* and *Protolenus* informal zones are given as 's.l.' (*sensu lato*) in the lists of occurrences. This is because the zones have not been satisfactorily established and have only been referred to as the Kaplonosy and Radzyń formations (Areń & Lendzion 1978; Lendzion 1983a, b; see 'Vendian and Lower Cambrian biostratigraphy in the Lublin Slope'; Fig. 8). Thus the occurrences of a number of species reported by Volkova (1969a, b) and Volkova *et al.* (1979, 1983) were not established with enough precision.

## Group Acritarcha Evitt, 1963

### Genus *Alliumella* Vanderflit, 1971

*Type species*. – *Alliumella baltica* Vanderflit, 1971, *in* Umnova & Vanderflit, pp. 69–70, Pl. 2:42–48.

#### *Alliumella baltica* Vanderflit, 1971

Pl. 3I

*Synonymy*. – □1971 *Alliumella baltica* Vanderflit gen. et sp. nov. – Vanderflit *in* Umnova & Vanderflit, pp. 69–70, Pl. 2:42–48. □1974 *Alliumella baltica* Vanderflit, 1971 – Vanguestaine, Pl. 1:10. □1978 *Alliumella baltica* Vanderflit, 1971 – Vanguestaine, Pl. 4:8–10. □1979 *Alliumella baltica* Vanderflit, 1971 – Volkova *et al.*, p. 34, Pl. 28:7–11.

*Material*. – Eleven well-preserved specimens.

*Description*. – Smooth bulb-shaped central body with a tapering, more slender portion which develops into a single straight process. The single process has a widened proximal region and tapers towards the distal part, which is sharp-pointed or blunt (broken?).

*Dimensions*. – *N*=11. Diameter of central body 20–26 µm, $\bar{x}$=22.36±0.45 µm, σ=1.50 µm; length of processes 6–8 µm, $\bar{x}$=7.18±0.22 µm, σ=0.75 µm.

*Present record*. – Poland, Lublin Slope of the EEP: drillcore Łopiennik IG-1, Kaplonosy and Radzyń formations – Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range*. – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.), Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcore Biała Podlaska 1 and Podborowisko 1: Lower Cambrian, *Holmia* zone (s.l.), drillcore Okuniew IG-1: Lower Cambrian, *Protolenus* zone (s.l.) and Middle

Cambrian, *Eccaparadoxides oelandicus* Zone (Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons, Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Västergötland, File Haidar Formation, Lingulid Sandstone Member: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986). Belgium, Massif de Rocroi and Massif de Stavelot (Grand-Halleux drillcore), Middle Revinien: Middle(?) Cambrian (Vanguestaine 1974, 1978).

## Genus *Asteridium* n.gen.

*Type species.* – *Asteridium lanatum* (Volkova, 1969) comb. nov. (=*Micrhystridium lanatum* Volkova, 1969), Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, depth 1191.1–1196.0 m, Kaplonosy and Radzyń formations: Lower Cambrian, *Holmia* zone (Volkova, 1969b, p. 227, Pl. 50:27–28).

*Diagnosis.* – Organic-walled microfossils with small vesicle, spherical to oval, thin-walled, single-layered. Variable number of processes which do not differ in character from wall of central body. Processes solid, without communication with interior of central body. They are homeomorphic, simple in shape, cylindrical or slightly widened at base. Tips of processes taper, distal portions sharp-pointed, blunt or swollen. Length of processes usually smaller than diameter of central body. No excystment mechanism observed.

*Derivation of name.* – Latin *asteriscus*, asterisk, refers to the shape of the specimens.

*Species included.* – *Asteridium lanatum* (Volkova, 1969) comb. nov., *Asteridium pallidum* (Volkova, 1968) comb. nov., *Asteridium spinosum* (Volkova, 1969) comb. nov., *Asteridium tornatum* (Volkova, 1968) comb. nov.

### *Asteridium lanatum* (Volkova, 1969) comb. nov.

Pl. 1D–F

*Synonymy.* – □1969 *Micrhystridium lanatum* Volkova sp. nov. – Volkova, 1969b, p. 227, Pl. 50:27–28. □1979 *Micrhystridium lanatum* Volkova, 1969 – Volkova *et al.*, p. 14, Pl. 8:5–11. □1982 *Micrhystridium lanatum* Volkova, 1969 – Downie, p. 261, Fig. 6cc–dd. □1982 *Micrhystridium ellaensis* sp. nov. – Downie, p. 261, Fig. 7c–e. □1986 *Micrhystridium lanatum* Volkova – Moczydłowska & Vidal, Fig. 8E. □1987 *Micrhystridium lanatum* Volkova, 1969 – Knoll & Swett, p. 919, Figs. 8.4–8.6.

*Material.* – 194 well-preserved specimens.

*Description.* – Circular to oval central vesicle with wall surface covered by abundant and evenly distributed processes. The processes are uniform, hair-like, slender and of equal length. The bases of the processes are slightly widened, and the tips are sharp. Excystment not observed.

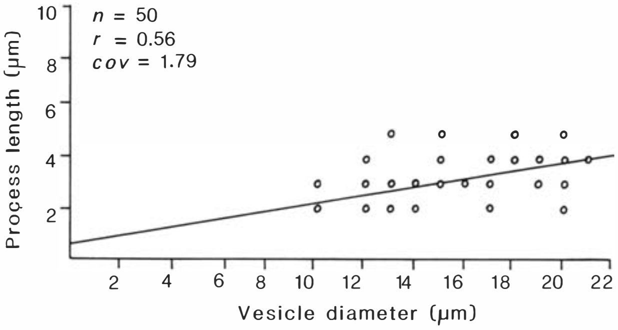

*Fig. 13.* Bivariate plot of size distribution of *Asteridium lanatum* (Volkova) comb.nov. in the Lower Cambrian of the Lublin Slope.

*Dimensions.* – *N*=50. Diameter of central body 10–21 µm, $\bar{x}$=14.82±0.47 µm; length of processes 2–5 µm, $\bar{x}$=3.02±0.13 µm, $\sigma$=0.95 µm (Fig. 13).

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Parczew IG-10 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcore Parczew IG-10, upper part of the Mazowsze Formation and drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Podlasie Depression, drillcores Biała Podlaska 1, Okuniew IG-1 and Podborowisko 1: Lower Cambrian, *Holmia* zone (s.l.); Baltic Syneclise, drillcores Kościerzyna IG-1 and Prabuty IG-1: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy, Vergale and Rausve horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B–C and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, $1a\alpha_1$–$1a\alpha_2$ and $1a\alpha$–$1b\beta$ beds: Lower Cambrian, *Holmia* B and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Ireland, Ribband Group, Booley Bay Formation: Lower–Middle Cambrian (Gardiner & Vanguestaine 1971). England, Hollybush Sandstone: Lower Cambrian (Downie 1982). Canada, Alberta, Mt Eisenhower, Gog Formation: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982; Moczydłowska & Vidal 1986) and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Asteridium pallidum* (Volkova, 1968) comb. nov.

Pl. 1I–J

*Synonymy.* – □1968 *Micrhystridium pallidum* Volkova sp. nov. – Volkova, p. 21, Pls. 4:5–9; 11:4. □1971 *Micrhystridium pallidum* Volkova, 1968 – Gardiner & Vanguestaine, pp. 188–189, Pl. 1:12. □1979 *Micrhystridium pallidum* Volkova, 1968 – Volkova *et al.*, p. 16, Pl.9:17–18.

*Material.* – 40 fairly well-preserved specimens.

*Description.* – Oval vesicles covered by few irregularly distributed processes. The processes are cylindrical with slightly widened, conical bases and blunt tips. Excystment not observed.

*Dimensions.* – *N*=40. Diameter of central body 8–15 μm, x̄=12.15±0.34 μm, σ=2.18 μm; length of processes 2 μm.

*Remarks.* – *Asteridium pallidum* (Volkova) comb. nov. differs from the other species of *Asteridium* by having irregular in shape processes with blunt distal portions.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations – Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* zone (s.l.); Baltic Syneclise, drillcore Prabuty IG-1: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy horizon (Volkova *et al.* 1979). Ireland, Bray Group, Thulla Formation and Ribband Group, Booley Bay Formation: Lower–Middle Cambrian (Gardiner & Vanguestaine 1971).

## *Asteridium spinosum* (Volkova, 1969) comb. nov.

Pl. 1G–H

*Synonymy.* – □1969 *Micrhystridium spinosum* Volkova sp. nov. – Volkova, 1969b, p. 229, Pl. 50:14–16. □1971 *Micrhystridium spinosum* Volkova, 1969b – Gardiner & Vanguestaine, p. 1900, Pl. 1:9. □1979 *Micrhystridium spinosum* Volkova, 1969 – Volkova *et al.*, p. 16, Pl. 9:25. □1982 *Micrhystridium spinosum* Volkova, 1969 – Downie, p. 262, Fig. 7f.

*Material.* – 56 well-preserved specimens.

*Description.* – Spherical to oval central vesicle possessing numerous processes evenly distributed on the surface of the central body. The simple processes are in the shape of long spines.

*Dimensions.* – *N*=56. Diameter of central body 7–12 μm, x̄=9.68±0.21 μm; length of processes 2–3 μm, x̄= 2.43±0.006 μm, σ=0.50 μm (Fig. 14).

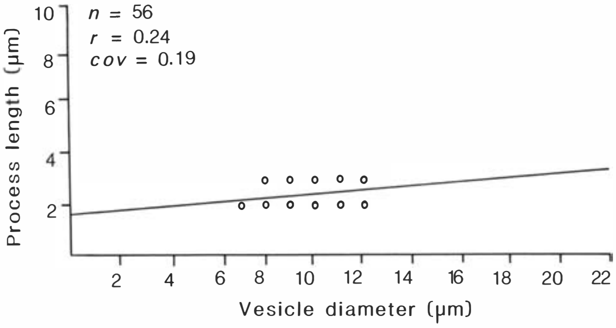

*Fig. 14.* Bivariate plot of size distribution of *Asteridium spinosum* (Volkova) comb.nov. in the Lower Cambrian of the Lublin Slope.

*Remarks.* – The species differs from *Asteridium tornatum* (Volkova) comb. nov. by having longer processes. It differs from *Heliosphaeridium obscurum* (Volkova) comb. nov. by having solid, uniform and more numerous solid processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.), Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcore Podborowisko 1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Ireland, Bray Group, Thulla Formation: Lower–Middle Cambrian (Gardiner & Vanguestaine 1971). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982).

## *Asteridium tornatum* (Volkova, 1968) comb. nov.

Pl. 1A–C

*Synonymy.* – □1964 *Micrhystridium* sp. – Volkova, p. 82, Pls. 2:9; 3:17–19. □1968 *Micrhystridium tornatum* Volkova sp. nov. – Volkova, p. 21, Pls. 4:1–4; 10:8. □1979 *Micrhystridium tornatum* Volkova, 1968 – Volkova *et al.*, p. 17, Pl. 9:14–16. □1982 *Micrhystridium tornatum* Volkova – Downie, Fig. 7j. □1982 *Micrhystridium minutum* sp. nov. – Downie, p. 261, Fig. 6ii. □1986 *Micrhystridium tornatum* Volkova – Moczydłowska & Vidal, Fig. 8D, F. □1987 *Micrhystridium tornatum* Volkova, 1968 – Knoll & Swett, p. 919, Figs. 8.8, 8.9.

*Material.* – 746 well-preserved specimens.

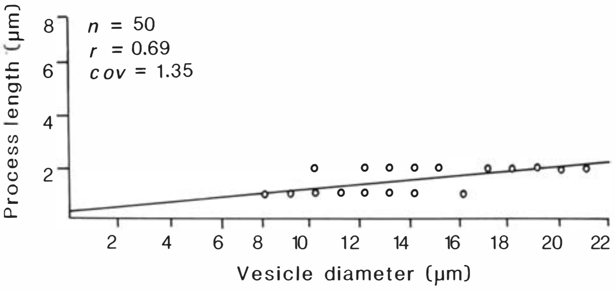

*Fig. 15.* Bivariate plot of size distribution of *Asteridium tornatum* (Volkova) comb.nov. in the Lower Cambrian of the Lublin Slope.

*Description.* – Circular to oval in outline vesicles covered by evenly distributed short, thorn-like processes. The wall of the central body usually displays small compaction folds.

*Dimensions.* – *N*=50. Diameter of central body 8–21 μm, $\bar{x}$=13.36±0.54 μm, σ=3.84 μm; length of processes 1–2 μm, $\bar{x}$=1.48±0.07 μm, σ=0.50 μm. Additionally, specimens forming clusters of up to 30 specimens range 5–10 μm in diameter of central body (Fig. 15).

*Remarks.* – The species differs from *Asteridium spinosum* (Volkova) comb. nov. by having short thorn-like processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Łopiennik IG-1, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcores Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Platysolenites* Zone, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcores Mielnik IG-1 and Podborowisko 1: Lower Cambrian, *Platysolenites* Zone; drillcore Biała Podlaska 1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Vendian, Kotlin Formation(?) and Rovno horizon(?); Lower Cambrian, Lontova, Talsy, Vergale and Rausve horizons; Middle Cambrian, Kibartai horizon; Siberian Platform, Olenek Uplift: Lower Cambrian, Tommotian Stage (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Canada, Alberta, Gog Formation and Mt Whyte Formation: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982; Moczydłowska & Vidal 1986) and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

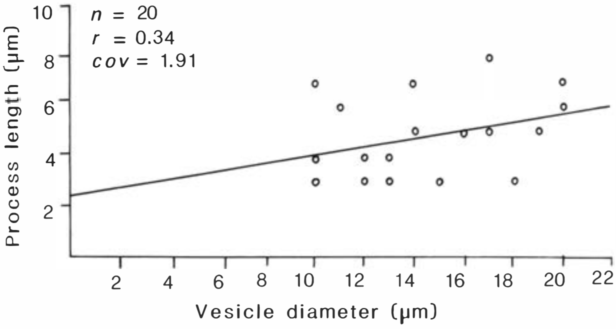

*Fig. 16.* Bivariate plot of size distribution of *Asteridium* sp. in the Lower Cambrian of the Lublin Slope.

## *Asteridium* sp.

*Material.* – 48 poorly preserved specimens.

*Description.* – Vesicles circular to oval in outline covered by solid processes. The processes are irregular, often with broken tips.

*Dimensions.* – *N*=20. Diameter of central body 10–20 μm, $\bar{x}$=14.65±0.78 μm; length of processes 3–8 μm, $\bar{x}$= 4.90±0.35 μm, σ=1.59 μm (Fig. 16).

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Kaplonosy IG-1, upper part of the Włodawa Formation and Mazowsze Formation, drillcores Terebiń IG-5 and Parczew IG-10, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone.

## Genus *Comasphaeridium* Staplin, Jansonius & Pocock, 1965

*Type species.* – *Comasphaeridium cometes* (Valensi, 1949) Staplin, Jansonius & Pocock, 1965, p. 192 [= *Micrhystridium cometes* Valensi, 1949, p. 545, Fig. 5:6].

## *Comasphaeridium agglutinatum* Moczydłowska, 1988

Pl. 1K–L

*Synonymy.* – □1986 *Comasphaeridium* n.sp. 3 – Moczydłowska & Vidal, Fig. 8B. □1988 *Comasphaeridium agglutinatum* n.sp. – Moczydłowska, pp. 4–6, Pl. 1:1; Fig. 3.

*Material.* – 44 specimens, most of them well-preserved.

*Description.* – Vesicles circular to oval in outline, covered by numerous simple and slender processes. The length of the processes varies within each discrete specimen. The processes are densely packed in the proximal part, being agglutinated to each other. The tips of the processes are

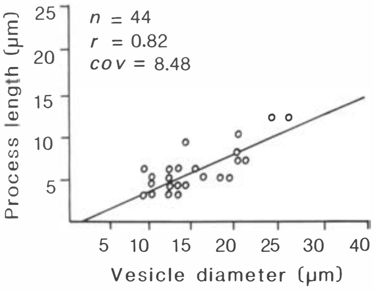

*Fig. 17.* Bivariate plot of size distribution of *Comasphaeridium agglutinatum* Moczydłowska in the Lower Cambrian of the Lublin Slope.

acuminate, flexible and anastomosing. The bases of the processes are slightly evexate.

*Dimensions.* – *N*=44. Diameter of central body 9–26 µm, $\bar{x}$=13.34±0.66 µm, σ=4.40 µm; length of processes 3–12 µm, $\bar{x}$=5.13±0.35 µm, σ=2.35 µm (Fig. 17).

*Remarks.* – *Comasphaeridium agglutinatum* Moczydłowska differs from *Comasphaeridium velvetum* Moczydłowska by its smaller vesicle, longer processes and their basally agglutinated morphology. It also differs from *Comasphaeridium strigosum* (Jankauskas) Downie by the shape of the processes and the fact that they are attached at the base.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Kaplonosy IG-1, upper part of the Włodawa Formation and drillcores Terebiń IG-5, Parczew IG-10 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone.

## *Comasphaeridium brachyspinosum* (Kirjanov, 1974) Moczydłowska & Vidal, 1988

Pl. 2E

*Synonymy.* – □1974 *Baltisphaeridium brachyspinosum* Kirjanov, sp. nov. – Kirjanov, pp. 120–121, Pl. 7:1. □1979 *Baltisphaeridium brachyspinosum* Kirjanov, 1974 – Volkova *et al.*, p. 8, Pl. 10:15. □1986 *Comasphaeridium* (=*Baltisphaeridium*) *brachyspinosum* (Kirj.) – Moczydłowska & Vidal, Fig. 9A–B. □1988 *Comasphaeridium brachyspinosum* (Kirjanov 1974) comb. nov. Moczydłowska & Vidal, 1988b, p. 3, Pl. 1:4.

*Material.* – Two well-preserved specimens.

*Description.* – Spherical vesicles (circular to oval in outline after compression) densely covered by closely arranged processes. The processes are thin, filiform and of equal length. Their proximal part is slightly thickened, resulting in an irregular outline of the central body.

*Dimensions.* – *N*=2. Diameter of central body 21–39 µm; length of processes 4–5 µm.

*Remarks.* – *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal differs from *C. strigosum* (Jankauskas) Downie by the irregular outline of the central body and thickened base of the processes. The processes are less numerous than in *C. strigosum.* Additionally, it differs from *C. molliculum* Moczydłowska & Vidal by its clearly delimited and stiff processes which, contrary to those of *C. strigosum*, are not agglutinated.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Talsy horizon; Siberian Platform: Lower Cambrian, Tommotian Stage, *Dokidocyathus regularis* Zone (Volkova *et al.* 1979; Rudavskaya & Vassileva 1984). Sweden, Scania, Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, Balka Sandstone and 'Green Shales': Lower Cambrian, *Holmia* A and B zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Moczydłowska & Vidal 1986).

## *Comasphaeridium formosum* Moczydłowska, 1988

Pl. 1M

*Synonymy.* – □1986 *Comasphaeridium* n.sp. 5 – Moczydłowska & Vidal, Fig. 8C. □1988 *Comasphaeridium formosum* n.sp. – Moczydłowska, p. 6, Pl. 1:4, Fig. 3.

*Material.* – One single very well-preserved specimen.

*Description.* – Vesicle oval in outline and covered by uniform and densely arranged processes closely attached in the proximal part. The processes are of regular length and thickness, tubular in shape. The tips of the processes are blunt.

*Dimensions.* – Diameter of central body 9–12 µm; length of processes 3–4 µm.

*Remarks.* – The species differs from other species of *Comasphaeridium* by the extremely regular shape of the processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone.

## *Comasphaeridium molliculum* Moczydłowska & Vidal, 1988

Pl. 2A–D, F

*Synonymy.* – □non 1959 *Archaeohystrichosphaeridium papillosum* sp.n. – Timofeev, p. 20, Pl. 2:10, 13. □1968 *Baltisphaeridium papillosum* (Timofeev) Volkova comb. nov. – Volkova, p. 20, Pl. 2:10. □1979 *Baltisphaeridium papillosum* (Timofeev, 1959) Volkova, 1968 – Volkova *et al.*, p. 11, Pl. 13:13. □1986 *Comasphaeridium* sp. 2 – Moczydłowska & Vidal, p. 217, Fig. 11A. □1988 *Comasphaeridium molliculum* sp. nov. – Moczydłowska & Vidal, 1988b, pp. 2–3, Pl. 1:1, 2.

*Material.* – 28 well-preserved specimens.

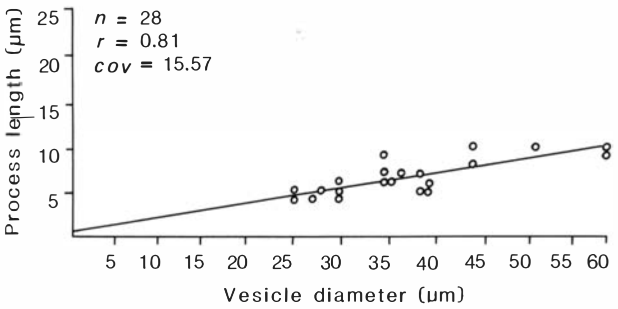

*Fig. 18.* Bivariate plot of size distribution of *Comasphaeridium molliculum* Moczydłowska & Vidal in the Lower Cambrian of the Lublin Slope.

*Description.* – Central spherical vesicle having circular to subcircular outline (after compression) with smooth outer surface covered by numerous, closely arranged filiform and flexible processes. Excystment apparently by median split.

*Dimensions.* – $N$=28. Diameter of vesicle 20–60 µm, $\bar{x}=35.64\pm1.85$ µm, $\sigma=9.81$ µm; length of processes 4–10 µm, $\bar{x}=6.14\pm0.36$ µm, $\sigma=1.94$ µm (Fig. 18).

*Remarks.* – *Comasphaeridium molliculum* Moczydłowska & Vidal differs from *C. strigosum* (Jankauskas) Downie by its thin and clearly defined processes. It differs as well from *C. brachyspinosum* (Kirjanov) Moczydłowska & Vidal by the regular circular outline of the vesicle and by the lack of proximal thickening of the processes. *C. molliculum* differs from *C. velvetum* Moczydłowska by its hair-like, well-defined, longer and not agglutinated processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Parczew IG-10 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Talsy horizon (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, $1a\alpha_1$–$1a\alpha_2$ beds and $1a\beta$ bed: Lower Cambrian, *Holmia* B and C zone, respectively (Moczydłowska & Vidal 1986). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Moczydłowska & Vidal 1986).

## *Comasphaeridium strigosum* (Jankauskas) Downie, 1982

Pl. 1N–O

*Synonymy.* – □1969 *Baltisphaeridium* sp. 2 – Volkova, 1969b, p. 226, Pl. 49:21, Pl. 51:38. □1976 *Baltisphaeridium* ? *strigosum* Jankauskas, sp. nov. – Jankauskas & Posti, pp. 146–147, Figs. 8, 14. □1979 *Baltisphaeridium* ? *strigosum* Jankauskas, 1976 – Volkova *et al.*, p. 12, Pl. 10:16–18. □1979 *Baltisphaeridium* ? *strigosum* Yankauskas, 1976 – Vidal, 1979b, p. 18, Pl. 1a. □1982 *Comasphaeridium strigosum* (Jankauskas) comb. nov. – Downie, p. 260, Fig. 6j–l. □1987 *Comasphaeridium strigosum* (Jankauskas) Downie, 1982 – Knoll & Swett, p. 916, Fig. 7.5.

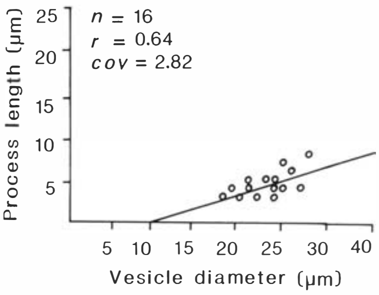

*Fig. 19.* Bivariate plot of size distribution of *Comasphaeridium strigosum* (Jankauskas) Downie in the Lower Cambrian of the Lublin Slope.

*Material.* – 16 fairly well-preserved specimens.

*Description.* – Vesicles circular to oval in outline, possessing abundant and very closely arranged processes. The processes are solid, simple, of equal length, slightly widened proximally and sharp-pointed distally.

*Dimensions.* – $N$=16. Diameter of central body 18–28 µm, $\bar{x}=22.94\pm0.73$ µm, $\sigma=2.93$ µm; length of processes 3–8 µm, $\bar{x}=4.44\pm0.37$ µm, $\sigma=1.50$ µm (Fig. 19).

*Remarks.* – *Comasphaeridium strigosum* (Jankauskas) Downie differs from *C. velvetum* Moczydłowska by having free-standing, longer and uniform processes. It differs from *C. agglutinatum* Moczydłowska by its larger ratio between vesicle diameter and process length, and by having much longer processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Parczew IG-10 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcore Parczew IG-10, upper part of the Mazowsze Formation: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1, Kaplonosy Formation: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Baltic Syneclise, drillcores Kościerzyna IG-1 and Prabuty IG-1: Lower Cambrian, *Schmidtiellus* Zone (= *Mobergella*) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy horizon and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Brantevik Sandstone and Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Vidal 1981b; Moczydłowska & Vidal, 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, $1a\alpha_1$–$1a\alpha_2$ beds: Lower Cambrian, *Holmia* B zone, $1a\beta$ and $1b\alpha$–$1b\beta$ beds: Lower Cambrian, *Holmia* C zone (Vidal 1981b; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation:

Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation and Ella Island Formation: Lower Cambrian (Vidal 1979b; Downie 1982; Moczydłowska & Vidal 1986); North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

### *Comasphaeridium velvetum* Moczydłowska, 1988

Pl. 1P–R

*Synonymy.* – □1986 *Comasphaeridium* n.sp. 4 – Moczydłowska & Vidal, Fig. 8A. □1988 *Comasphaeridium velvetum* n.sp. – Moczydłowska, 1988a, pp. 6–7, Pl. 1:2, 3; Fig. 3.

*Material.* – 93 specimens, most of them well-preserved.

*Description.* – Vesicles circular in outline. The surface is covered by abundant, short processes of equal length. The processes are densely packed and attached to each other proximally, with widened bases and tips ranging from acuminate to blunt.

*Dimensions.* – *N*=30. Diameter of vesicle 15–30 µm, $\bar{x}$=23.76±0.69 µm, $\sigma$=3.77 µm; length of processes 2–4 µm, $\bar{x}$=3.16±0.13 µm, $\sigma$=0.75 µm (Fig. 20).

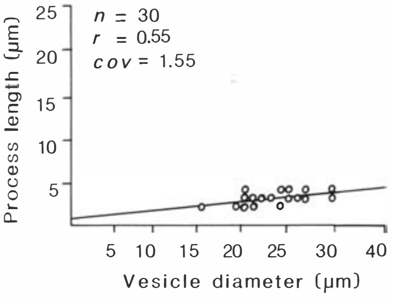

*Fig. 20.* Bivariate plot of size distribution of *Comasphaeridium velvetum* Moczydłowska in the Lower Cambrian of the Lublin Slope.

*Remarks.* – The species differs from *Comasphaeridium agglutinatum* Moczydłowska by having shorter processes, by their equal length and the more slender bases of the processes. From *C. strigosum* (Jankauskas) Downie it differs by the widened processes bases and by their denser arrangement.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone.

## Genus *Cymatiosphaera* O.Wetzel ex Deflandre, 1954

*Type species.* – *Cymatiosphaera radiata* O. Wetzel, 1933, p. 73.

### *Cymatiosphaera postii* (Jankauskas, 1976) Jankauskas, 1979

Pl. 9H–I

*Synonymy.* – □1976 *Cymatiosphaera radiata* Jankauskas, sp. nov. – Jankauskas & Posti, pp. 148–149, Figs. 2, 3. □1979 *Cymatiosphaera postii* Jankauskas, nom. nov. – Volkova *et al.*, p. 26, Pl. 14:1–3. □1982 *Cymatiosphaera postii* Jankauskas 1979 – Downie, p. 264, Fig. 9h.

*Material.* – 17 well-preserved specimens.

*Description.* – Vesicles oval in outline. The spherical central body possesses high ridges which divide its surface into pentagonal and hexagonal fields. Six to eight ridges are usually observed on the outline of the central body.

*Dimensions.* – *N*=17. Diameter of vesicle 22–45 µm, $\bar{x}$=31.82±1.85 µm, $\sigma$=7.62 µm; diameter of central body 14–25 µm, $\bar{x}$=18.94±0.96 µm, $\sigma$=3.96 µm; diameter of polygonal fields 7–15 µm; height of ridges 7–14 µm, $\bar{x}$=11.29±0.59 µm, $\sigma$=2.44 µm (Fig. 21).

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons; Middle Cambrian, Kibartai horizon; Izhora beds: Lower Ordovician (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, $1a\alpha_1$–$1a\alpha_2$ beds: Lower Cambrian, *Holmia* B zone (Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982).

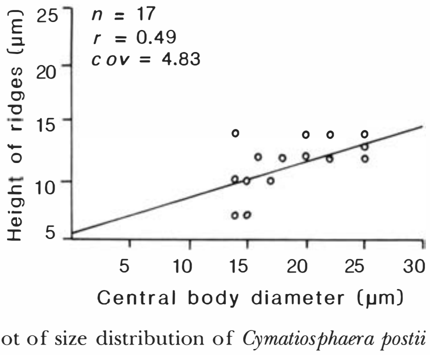

*Fig. 21.* Bivariate plot of size distribution of *Cymatiosphaera postii* (Jankauskas) Jankauskas in the Lower Cambrian of the Lublin Slope.

### *Cymatiosphaera* sp.

Pl. 9J

*Material.* – 18 generally well-preserved specimens.

*Description.* – Vesicles circular to oval in outline. Numerous ridges subdivide the spherical central body into irregularly shaped polygonal fields.

*Dimensions.* – *N*=18. Overall diameter 25–50 µm; diameter of central body 11–40 µm; diameter of polygonal fields 10–12 µm; height of ridges 3–5 µm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcores Parczew IG-10 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcores Łopiennik IG-1 and Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

## Genus *Estiastra* Eisenack, 1959

*Type species.* – *Estiastra magna* Eisenack, 1959, pp. 201–202, Pl. 16:17–20.

## *Estiastra minima* Volkova, 1969

Pl. 9A–G

*Synonymy.* – □1969 *Estiastra minima* Volkova sp. nov. – Volkova, 1969b, pp. 230–321, Pl. 50:32–36. □1979 *Estiastra minima* Volkova, 1969 – Volkova *et al.*, p. 18, Pl. 10:8–14. □1987 *Estiastra minima* Volkova, 1969 – Knoll & Swett, p. 916, Fig. 8.13.

*Material.* – 171 generally well-preserved specimens.

*Description.* – Vesicles polygonal in outline. The irregular central body possesses 4–9 conical processes with wide bases and sharp-pointed tips. The cavity of the central body does not communicate with the processes cavity.

*Dimensions.* – *N*=30. Diameter of central body 5–10 µm, $\bar{x}$=7.23±0.37 µm, σ=2.02 µm; length of processes 5–12 µm, $\bar{x}$=7.36±0.42 µm, σ=2.31 µm; width of basal part of processes 3–7 µm, $x$=4.36±0.23 µm, σ=1.27 µm (Fig. 22).

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Podlasie Depression, drillcores Biała Podlaska 1 and Podborowisko 1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons; Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Svalbard, East Spitsbergen, South Tokammane, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987).

## Genus *Fimbriaglomerella* Loeblich & Drugg, 1968

*Type species.* – *Fimbriaglomerella* divisa Loeblich & Drugg, 1968, pp. 136–137, Pl. 4:1–6.

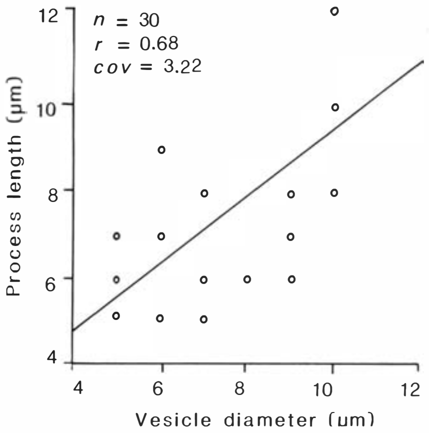

*Fig. 22.* Bivariate plot of size distribution of *Estiastra minima* Volkova in the Lower Cambrian of the Lublin Slope.

## *Fimbriaglomerella membranacea* (Kirjanov, 1974) Moczydłowska & Vidal, 1988

Pl. 3G

*Synonymy.* – □1974 *Cymatiosphaera ? membranacea* Kirjanov, sp. nov. – Kirjanov, p. 121, Pl. 7:2, 3. □1979 *Cymatiosphaera ? membranacea* Kirjanov, 1974 – Volkova *et al.*, p. 25, Pl. 16:1, 2. □non 1986 *Cymatiosphaera ? membranacea* Kirjanov – Moczydłowska & Vidal, Fig. 10A–B. □1988 *Fimbriaglomerella membranacea* (Kirjanov 1974) comb. nov. – Moczydłowska & Vidal, 1988b, pp. 3–4, Pl. 1:5–9.

*Material.* – Three fairly well-preserved specimens.

*Description.* – Spherical or ovoidal, double walled vesicles. The wall of the inner body is robust, thus contrasting with the more translucent and much thinner outer membrane to which it is attached by means of straight filmy muri. These define small, irregularly polygonal luminae at the contact with the surface of the outer membrane. Excystment probably by median split.

*Dimensions.* – *N*=3. Diameter of vesicle 35–39 µm; diameter of inner body 18–25 µm; height of filmy muri 5–10 µm.

*Remarks.* – *Fimbriaglomerella membranacea* (Kirjanov) Moczydłowska & Vidal differs from *F. minuta* (Jankauskas) Moczydłowska & Vidal by having a robust-walled inner body, much more numerous filmy muri, and narrower surface luminae.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Talsy horizon; Siberian Platform: Lower Cambrian, Tommotian Stage, *Dokidocyathus regularis* Zone (Volkova *et al.* 1979; Rudavskaya & Vassileva 1984); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986, 1988b).

Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986, 1988b). Norway, Lake Mjøsa region, 1aβ beds: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986, 1988b). East Greenland, Ella Ø, Bastion Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Fimbriaglomerella minuta* (Jankauskas, 1979) Moczydłowska & Vidal, 1988

Pl. 3H

*Synonymy.* – □1979 *Cymatiosphaera minuta* Jankauskas, sp. nov. – Volkova *et al.*, p. 26, Pl. 14:10–12. □1986 *Cymatiosphaera minuta* Jankauskas – Moczydłowska & Vidal, Fig. 10D, E. □1986 *Cymatiosphaera ? membranacea* Kirjanov – Moczydłowska & Vidal, p. 214, Fig. 10A, B. □1988 *Fimbriaglomerella minuta* (Jankauskas 1979) comb. nov. – Moczydłowska & Vidal, 1988b, pp. 4–6, Pl. 2:8–17.

*Material.* – Two poorly preserved specimens.

*Description.* – Spherical, double-walled vesicles. The wall of the inner body is thin and enclosed by an outer thin membrane. Straight filmy muri rise radially from the inner body and define small polygonal luminae at the contact with the surface of the outer membrane. Excystment not observed.

*Dimensions.* – *N*=2. Diameter of inner body 15–20 µm; height of filmy muri 3 µm.

*Remarks.* – The species differs from *F. membranacea* (Kirjanov) Moczydłowska & Vidal by having a thin-walled inner body, smaller number of filmy muri and wider luminae reflecting the intersection of the outer membrane with the radially arranged muri.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, upper part of the Mazowsze Formation: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – Poland, Baltic Syneclise, drillcores Kościerzyna IG-1 and Prabuty IG-1, Zawiszyn Formation: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy horizon (Volkova *et al.* 1979). Sweden, Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Vidal 1981c; Moczydłowska & Vidal 1986, 1988b). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981c; Moczydłowska & Vidal 1986, 1988b).

## Genus *Globosphaeridium* n. gen.

*Type species.* – *Globosphaeridium cerinum* (Volkova, 1968) comb. nov. [= *Baltisphaeridium cerinum* Volkova, 1968, pp. 17–18, Pls. 1:1–7; 11:5].

*Diagnosis.* – Organic-walled microfossils consisting of spherical to ovoidal vesicles. The central body is single-walled with smooth surface and possesses numerous, distinctly separated and solid processes. The processes are simple, of equal width or widened at the base, and tapering towards the tips. They are slender or stiff resembling long spines. Their length is substantially smaller than the diameter of central body. Excystment not observed.

*Derivation of name.* – From Latin *globus*, sphere, making reference to the overall shape of the specimens (a conspicuous central body and short processes).

*Remarks.* – *Globosphaeridium* n.gen. differs from *Comasphaeridium* Staplin, Jansonius & Pocock, 1965, by clearly separated and less numerous processes. It differs from *Asteridium* n.gen. by definitely larger dimensions of the vesicle.

## *Globosphaeridium cerinum* (Volkova, 1968) comb. nov.

Pl. 4H–J

*Synonymy.* – □1968 *Baltisphaeridium cerinum* Volkova sp. nov. – Volkova, pp. 17–18, Pls. 1:1–7; 11:5. □1978 *Elektoriskos cerinus* (Volkova, 1968) Vanguestaine 1978 nov. comb. – Vanguestaine, p. 271. □1979 *Baltisphaeridium cerinum* Volkova, 1968 – Volkova *et al.*, p. 8, Pl. 1:4–10. □non 1982 *Baltisphaeridium cerinum* Volkova 1968 – Downie, p. 259, Figs. 5, 6e–g. □1986 *Baltisphaeridium cerinum* (Volkova) Downie 1982 – Moczydłowska & Vidal, Fig. 11B. □1990 *Elektroriskos cerinus* (Volkova) Vanguestaine 1978 – Eklund, p. 36, Fig. 8C, D.

*Material.* – Nine very well-preserved specimens.

*Description.* – Spherical to ovoidal vesicles with numerous evenly distributed processes. The processes are solid and thorn-shaped, being slightly thicker at the base and sharp-pointed.

*Dimensions.* – *N*=9. Diameter of central body 20–35 µm, $\bar{x}$=25.77±1.98 µm, σ=5.93 µm; length of processes 2–3 µm, $\bar{x}$=2.44±0.17 µm, σ=0.52 µm (Fig. 23).

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Parczew IG-10 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Baltic Syneclise, drillcore Prabuty IG-1: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy and Vergale horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Brantevik Sandstone and Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone and Norretorp Formation: Lower Cambrian, *Holmia* B zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986); Östergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, Vergale Stage (Eklund 1990). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa

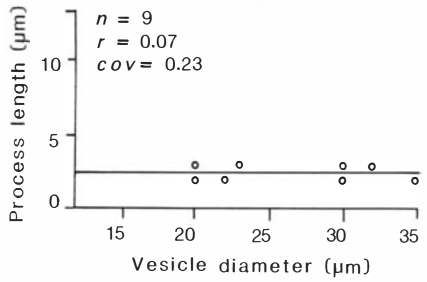

*Fig. 23.* Bivariate plot of size distribution of *Globosphaeridium cerinum* (Volkova) comb.nov. in the Lower Cambrian of the Lublin Slope.

region, 1aβ and 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Belgium, Massif de Rocroi, Devillien: Lower Cambrian (Vanguestaine 1978). East Greenland, Ella Ø, Bastion Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Globosphaeridium* sp.

*Material.* – 31 poorly preserved specimens.

*Description.* – Vesicles circular to oval in outline, possessing slender solid processes. The processes are equal in thickness and sharp-pointed.

*Dimensions.* – *N*=31. Diameter of central body 25–30 µm, $\bar{x}$=27.35±0.36 µm, σ=2.00 µm; length of processes 5–7 µm, $\bar{x}$=5.64±0.13 µm, σ=0.75 µm (Fig. 24).

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

## Genus *Goniosphaeridium* Eisenack, 1969, emend. Kjellström, 1971

*Type species.* – *Goniosphaeridium* (*Baltisphaeridium*) *polygonale* Eisenack, 1931, *in* Eisenack, 1959, p. 199, Pl. 16:8.

## *Goniosphaeridium implicatum* (Fridrichsone, 1971) Downie, 1982

Pl. 10A

*Synonymy.* – □1969 *Baltisphaeridium* sp. 1 – Volkova, 1969b, p. 226, Pl. 49:20. □1971 *Baltisphaeridium implicatum* Fridrichsone sp. nov. – Fridrichsone, pp. 11–12, Pl. 3:7–14. □1982 *Goniosphaeridium implicatum* (Fridrichsone 1971) comb. nov. – Downie, p. 278, *non* Fig. 10v–x. □1987 *Baltisphaeridium implicatum* Fridrichsone, 1971 – Knoll & Swett, p. 915, Fig. 7.7.

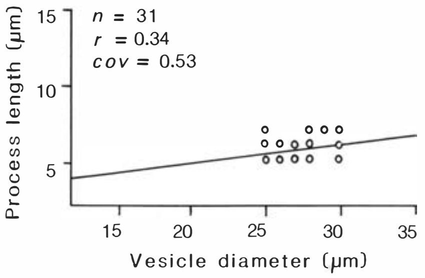

*Fig. 24.* Bivariate plot of size distribution of *Globosphaeridium* sp. in the Lower Cambrian of the Lublin Slope.

*Material.* – Five poorly preserved specimens.

*Description.* – Spherical vesicles, irregular in outline, consisting of a massive central body and thin, slender and transparent processes. The processes have widened bases and sharp tips. The central body is opaque. The cavity of the central body communicates freely with the processes.

*Dimensions.* – *N*=5. Diameter of central body 16–38 µm; length of processes 6–10 µm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones (Volkova 1969a, b; Moczydłowska, 1981). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons; Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, Lingulid Sandstone Member: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987).

## *Goniosphaeridium varium* (Volkova, 1969) Downie, 1982

Pl. 10B

*Synonymy.* – □1969 *Baltisphaeridium varium* Volkova sp. nov. – Volkova, pp. 225–226, Pls. 50:4–8; 51:13, 14. □1979 *Baltisphaeridium varium* Volkova, 1969 – Volkova *et al.*, p. 13, Pl. 6:1–5. □1982 *Goniosphaeridium varium* (Volkova 1969) comb. nov. – Downie, p. 278, Fig. 11a, b, g.

*Material.* – 26 well and fairly well preserved specimens.

*Description.* – Microfossils oval in outline consisting of a central opaque body covered by transparent, heteromorphic processes. These are conical in shape; wide at the bases and tapering at the distal part. The cavity of the central body communicates with the inner cavity of the processes.

*Dimensions.* – *N*=26. Diameter of central body 17–39 µm, $\bar{x}$=27.88±1.20 µm, σ=6.12 µm; length of processes 5–16 µm, $\bar{x}$=8.46±0.56 µm, σ=2.85 µm; Width of basal part of processes 3–5 µm (Fig. 25).

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcores Łopiennik IG-1, Parczew IG-10 and Radzyń IG-1, Kaplonosy

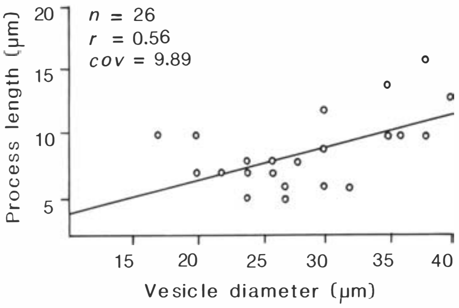

*Fig. 25.* Bivariate plot of size distribution of *Goniosphaeridium varium* (Volkova) Downie in the Lower Cambrian of the Lublin Slope.

and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcores Biała Podlaska 1, Podborowisko 1 and Okuniew IG-1: Lower Cambrian, *Holmia* zone (s.l.), drillcore Okuniew IG-1: Lower Cambrian, *Protolenus* zone (Volkova 1969a, b; Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons and Middle Cambrian, Kibartai and Deimenos horizons (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, Lingulid Sandstone Member: Lower Cambrian, *Holmia* C zone (Vidal 1981b; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982; Moczydłowska & Vidal 1986) and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

### *Goniosphaeridium* sp.

*Material.* – Three poorly preserved specimens.

*Description.* – Microfossils oval in outline consisting of central body with scattered long conical processes. The cavity of the central body communicates freely with the inner cavity of the processes.

*Dimensions.* – *N*=3. Diameter of central body 35–47 µm; length of processes 9–20 µm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Łopiennik IG-1, upper part of Mazowsze Formation: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

## Genus *Granomarginata* Naumova, 1960

*Type species.* – *Granomarginata prima* Naumova, 1960, p. 114, Pl. 3:10.

### *Granomarginata prima* Naumova, 1960

Pl. 3C

*Synonymy.* – □1960 *Granomarginata prima* sp. nov. – Naumova, p. 114, Pl. 3:10. □1968 *Granomarginata prima* Naumova – Volkova, p. 25, Pls. 4:10–13; 10:6. □1979 *Granomarginata prima* Naumova, 1960 – Volkova *et al.*, p. 19, Pl. 18:1–4. □1986 *Granomarginata prima* Naumova – Moczydłowska & Vidal, Fig. 8J. □1987 *Granomarginata prima* Naumova, 1960 – Knoll & Swett, pp. 916–917, Figs. 8.10, 8.14.

*Material.* – 17 well-preserved specimens.

*Description.* – Lensoidal vesicles having the central body surrounded by a spongy extension which forms a narrow rim.

*Dimensions.* – *N*=17. Diameter of vesicle 24–40 µm, $\bar{x}$=31.35±1.17 µm, σ=4.84 µm; diameter of central body 20–30 µm, $\bar{x}$=23.82±0.92 µm, σ=3.81 µm; width of spongy rim 2–5 µm, $\bar{x}$=4.00±0.27 µm, σ=1.11 µm (Fig. 26).

*Remarks.* – The species differs from *Granomarginata squamacea* Volkova by having a narrower and more compacted rim.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcores Parczew IG-10 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcores Radzyń IG-1 and Kaplonosy IG-1: Lower Cambrian, *Platysolenites* Zone; Podlasie Depression, drillcores Biała Podlaska 1, Mielnik IG-1 and Podborowisko 1: Lower Cambrian, *Platysolenites* Zone (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Lontova and Talsy horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Chulakta Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Moczydłowska & Vidal 1986).

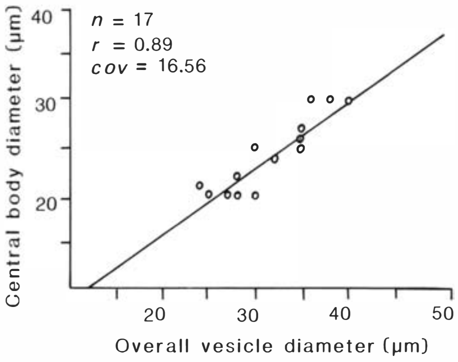

*Fig. 26.* Bivariate plot of size distribution of *Granomarginata prima* Naumova in the Lower Cambrian of the Lublin Slope.

### *Granomarginata squamacea* Volkova, 1968

Pl. 3D–F

*Synonymy.* – □1968 *Granomarginata squamacea* Volkova, sp. nov. – Volkova, p. 25, Pls. 4:14–19; 10:4, 5; 11:11. □1969 *Granomarginata squamacea* Volkova – Volkova, 1969b, p. 231, Pls. 47:5, 17; 49:12. □1978 *Granomarginata squamacea* – Tynni, p. 48, Pl. 6:47, 48. □1978 *Annulum difeminatum* Fombella 1978, n.sp. – Fombella, pp. 249–250, Pl. 3:18, 19. □1979 *Granomarginata squamacea* Volkova, 1968 – Volkova *et al.*, p. 19, Pl. 18:5–9. □1979 *Granomarginata squamacea* Volkova, 1968 – Fombella, Pls. 1:2, 3; 3:40. □1980 *Granomarginata squamacea* Volkova, 1968 – Moczydłowska, p. 472, Pl. 2:5–7. □1981 *Granomarginata squamacea* Volk. – Moczydłowska, Fig. 5J, L. □1982 *Granomarginata squamacea* Volkova, 1968 – Downie, p. 279, Fig. 11k. □1983 *Annulum squamaceum* (Volkova, 1968) comb.n. – Martin & Dean, pp. 359–360, Pl. 43.1, Figs. 4, 7–12. □1983 *Granomarginata squamacea* Volkova, 1968 – Vanguestaine & Van Looy, Pl. 1:10. □1986 *Granomarginata squamacea* Volkova – Moczydłowska & Vidal, Fig. 8G. □1987 *Granomarginata squamacea* Volkova, 1968 – Knoll & Swett, p. 917, Fig. 8.18., *non* Fig. 8.11.

*Material.* – 735 specimens, most of them well-preserved.

*Description.* – Lensoidal vesicles, circular or oval in outline, having a spongy wall which forms a wide extension or rim surrounding the central body in the equatorial part. The spongy structure of the wall appears as irregular 'filaments' on the outline of the equatorial zone.

*Dimensions.* – *N*=50. Size 20–55 µm, $\bar{x}$=34.92±1.23 µm, σ=8.75 µm; diameter of central body 13–37 µm, $\bar{x}$= 23.18±1.02 µm, σ=7.21 µm; thickness of wall in equatorial zone 5–12 µm, $\bar{x}$=6.86±0.28 µm, σ=1.99 µm (Fig. 27).

*Remarks.* – *Granomarginata squamacea* differs from *G. prima* Naumova by having a thicker spongy rim and by more fluffy character of the vesicle wall.

Some of the features described in the emended diagnosis for the conspecific taxon *Annulum squamaceum* (Volkova, 1968) comb.n. proposed by Martin & Dean (1983) were established on examination of well-preserved material under the scanning electron microscope. There is no reason to transfer the species to a new genus on the evidence of supplementary, more detailed morphological observations. In my view these are a complement to the original diagnosis of the genus *Granomarginata* established by Naumova, 1960. The genus *Annulum* Fombella, 1978, is a junior synonym of *Granomarginata* Naumova, 1960.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Łopiennik IG-1 and Parczew IG-10, upper part of Włodawa Formation and drillcores Terebiń IG-5, Łopiennik IG-1, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcores Łopiennik IG-1 and Parczew IG-10, upper part of the Mazowsze Formation: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

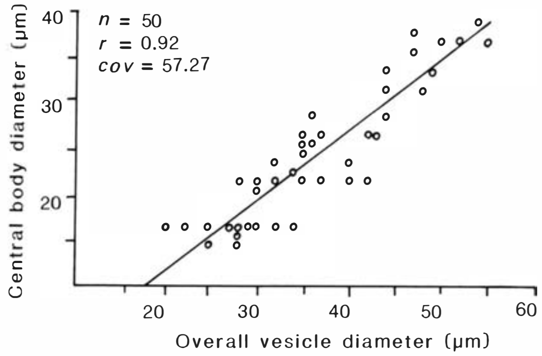

*Fig. 27.* Bivariate plot of size distribution of *Granomarginata squamacea* Volkova in the Lower Cambrian of the Lublin Slope.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Kaplonosy IG-1: Lower Cambrian, *Platysolenites* Zone and drillcore Radzyń IG-1: Lower Cambrian, *Platysolenites* Zone, *Holmia* and *Protolenus* zones (s.l.); Podlasie Depression, drillcores Biała Podlaska 1, Mielnik IG-1, Okuniew IG-1 and Podborowisko 1: Lower Cambrian, *Protolenus* and *Holmia* zones (s.l.); drillcore Okuniew IG-1: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*); Baltic Syneclise, drillcores Kościerzyna IG-1 and Prabuty IG-1: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova 1969a, b; Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Lontova, Talsy, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Chulakta and Shabakty Formations: Lower Cambrian (Ogurtsova 1985). Finland, region Söderfjärden: Lower Cambrian (Tynni 1978). Sweden, Scania, Brantevik Sandstone and Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Norretorp Formation: Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1a$\alpha_1$–1a$\alpha_2$ and 1a$\beta$ beds: Lower Cambrian, *Holmia* B and C zones, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Belgium, Massif de Rocroi and Massif de Stavelot, Devillian: Lower Cambrian (Vanguestaine 1978). Spain Cantabrian Mts, Oville Formation: Middle and Upper Cambrian, Ordovician, Tremadocian (Fombella 1978, 1979). Canada, Alberta, Gog Formation: Lower Cambrian (Downie 1982); Newfoundland, Burin Peninsula: Lower Cambrian (Downie 1982) and Manuels River, Brigus Formation and Chamberlains Brook Formation: Lower and Middle Cambrian, respectively (Martin & Dean 1983). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation (Downie, 1982; Moczydłowska & Vidal 1986) and Ella Island Formation: Lower Cambrian (Moczydłowska & Vidal 1986). Morocco, High Atlas Mts., Tacheddirt Valley: Middle Cambrian (Vanguestaine & Van Looy 1983).

## Genus *Heliosphaeridium* n.gen.

*Type species.* – *Heliosphaeridium dissimilare* (Volkova, 1969) comb. nov. (=*Micrhystridium dissimilare* Volkova, 1969), Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy formation, Lower Cambrian, *Protolenus* Zone. Volkova, 1969, p. 227, Pl. 50:12, 13, 19, 20.

*Diagnosis.* – Organic-walled microfossils with spherical to oval, thin-walled, single layered vesicle. The central body bears variable number of processes which are hollow and communicate with the central body cavity, but closed at the tips. The wall and processes have the same appearance. The bases of the processes have variable shapes and are generally widened. The process tips are simple or branching. The processes are homeomorphic but occasionally a few of them may differ in shape. Excystment not observed.

*Derivation of name.* – From Greek, *helios*, sun, referring to the radial processes arising from the central body.

*Species* included. –, *Heliosphaeridium coniferum* (Downie, 1982) comb. nov., *Heliosphaeridium dissimilare* (Volkova, 1969) comb. nov., *Heliosphaeridium longum* (Moczydłowska, 1988) comb. nov., *Heliosphaeridium lubomlense* (Kirjanov, 1974) comb. nov., *Heliosphaeridium notatum* (Volkova, 1969) comb. nov. (=*Micrhystridium notatum* Volkova sp. nov. – Volkova 1969b, p. 228, Pl. 51:16–19, Poland, drillcore Radzyń IG-1, depth 1044.5 m, Kostrzyń Formation, Middle Cambrian), *Heliosphaeridium obscurum* (Volkova, 1969) comb. nov., *Heliosphaeridium radzynicum* (Volkova, 1979) comb. nov.

### *Heliosphaeridium coniferum* (Downie, 1982) comb. nov.

Pl. 8B–D

*Synonymy.* – □1982 *Micrhystridium coniferum* n.sp. – Downie, p. 260, Figs. 4, 6q–t. □1987 *Micrhystridium* cf. *M. minutum* Downie, 1982 – Knoll & Swett, p. 919, Fig. 8.3.

*Material.* – Nine well-preserved specimens.

*Description.* – Vesicles circular in outline. The central body bears numerous, evenly distributed processes. Processes are equal in length with conical and widened, but clearly separated bases. The tips of the processes are blunt. The cavities of central body and processes communicate.

*Dimensions.* – $N$=9. Diameter of central body 5–10 µm, $\bar{x}$=7.44±0.65 µm, $\sigma$=1.94 µm; length of processes 2–7 µm, $\bar{x}$=4.44±0.47 µm, $\sigma$=1.42 µm (Fig. 28).

*Remarks.* – The species differs from *Asteridium spinosum* (Volkova, 1969) comb. nov. by having hollow processes and by its wider bases and blunt tips.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

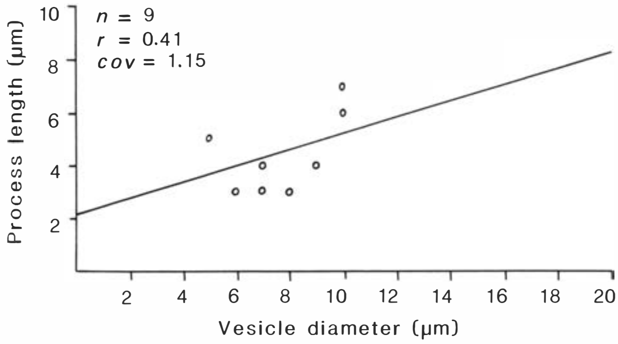

*Fig. 28.* Bivariate plot of size distribution of *Heliosphaeridium coniferum* (Downie) comb.nov. in the Lower Cambrian of the Lublin Slope.

*Occurrence and stratigraphic range.* – Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Canada, Alberta, Gog Formation: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987).

### *Heliosphaeridium dissimilare* (Volkova, 1969) comb. nov.

Pl. 8A, E–J

*Synonymy.* – □1969 *Micrhystridium dissimilare* Volkova sp. nov. – Volkova, 1969b, p. 227, Pl. 50:12, 13, 19, 20. □1979 *Micrhystridium dissimilare* Volkova, 1969 – Volkova *et al.*, p. 14, Pl. 8:1–4. □1982 *Micrhystridium dissimilare* Volkova 1969 – Downie, pp. 260–261, Fig. 6u. □1982 *Micrhystridium ordensis* sp. nov. – Downie, p. 262, Fig. 6ff, gg, hh. □1987 *Micrhystridium dissimilare* Volkova, 1969 – Knoll & Swett, pp. 917, 919, Fig. 8.15; *non* 8.12.

*Material.* – 1147 well-preserved specimens and additional large number of poorly preserved specimens.

*Description.* – Vesicle circular to oval in outline, possessing numerous long and evenly distributed processes. The bases of the processes are slightly widened and the tips are sharp-pointed. The processes are often irregularly curved. The vesicle cavity communicates with the processes.

*Dimensions.* – $N$=50. Diameter of central body 10–18 µm, $\bar{x}$=14.30±0.33 µm, $\sigma$=2.33 µm; length of processes 4–10 µm, $\bar{x}$=5.64±0.22 µm, $\sigma$=1.57 µm (Fig. 29).

*Remarks.* – The species differs from *H. lubomlense* (Kirjanov, 1974) comb. nov. by having a regular vesicle outline and slightly widened bases of processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcores Łopiennik IG-1 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Platysolenites* Zone, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus*

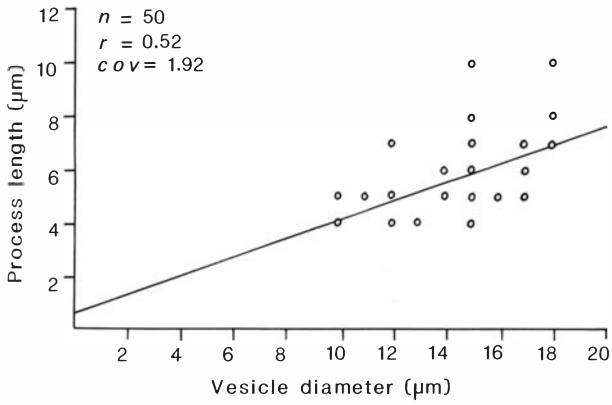

*Fig. 29.* Bivariate plot of size distribution of *Heliosphaeridium dissimilare* (Volkova) comb.nov. in the Lower Cambrian of the Lublin Slope.

Zones; Podlasie Depression, drillcores Biała Podlaska 1 and Podborowisko 1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, Lingulid Sandstone Member: Lower Cambrian, *Holmia* C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, $1a\alpha_1$–$1a\alpha_2$ and $1b\alpha$–$1b\beta$ beds: Lower Cambrian, *Holmia* B and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Canada, Alberta, Mt Eisenhower, Gog Formation and Mt Whyte Formation: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982; Moczydłowska & Vidal 1986) and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1987; Vidal & Peel 1988).

## *Heliosphaeridium longum* (Moczydłowska, 1988) comb. nov.

Pl. 8P–Q

*Synonymy.* – □1988 *Micrhystridium longum* n.sp. – Moczydłowska, pp. 7–8, Pl. 1:5, 6; Fig. 3.

*Material.* – Five poorly preserved specimens. The central body is usually deformed by the growth of pyrite crystals.

*Description.* – Vesicle oval in the outline, consisting of a central body and processes. The processes are slender and long in relation to the diameter of the central body. The inner cavity of processes communicates with the vesicle cavity. The bases of the processes are conical and elongated. The tips of the processes vary from acute to slightly rounded.

*Dimensions.* – *N*=5. Diameter of central body 7–12 µm, $\bar{x}$=10.00±0.70 µm, σ=1.58 µm; length of processes 5–16 µm, $\bar{x}$=10.60±1.60 µm, σ=3.57 µm.

*Remarks.* – The species differs from other heliosphaerids by having much longer processes in relation to diameter of the central body.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

## *Heliosphaeridium lubomlense* (Kirjanov, 1974) comb. nov.

Pl. 8K–N

*Synonymy.* – □1974 *Micrhystridium lubomlense* Kirjanov, sp. nov. – Kirjanov, pp. 125–126, Pl. 8:1, 2. □1979 *Micrhystridium lubomlense* Kirjanov, 1974 – Volkova *et al.*, p. 15, Pl. 8:12–14. □1987 *Micrhystridium dissimilare* Volkova, 1969 – Knoll & Swett, Fig. 8.12.

*Material.* – 48 well-preserved specimens.

*Description.* – Vesicles irregularly circular or oval in outline, consisting of central body and processes. Numerous long processes are equally distributed on the central body. The processes have wide conical bases and the tips are sharp-pointed or slightly widened funnel-like. The conical bases of processes form a wavy outline of the central body. There is free communication between the cavity of the central body and processes.

*Dimensions.* – *N*=48. Diameter of central body 10–20 µm, $\bar{x}$=15.27±0.39 µm, σ=2.71 µm; length of processes 5–11 µm, $\bar{x}$=6.73±0.23 µm, σ=1.61 µm (Fig. 30).

*Remarks.* – The species differs from *H. dissimilare* (Volkova, 1969) comb. nov. by the wider conical bases of the processes and the wavy outline of the central body.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Ka-

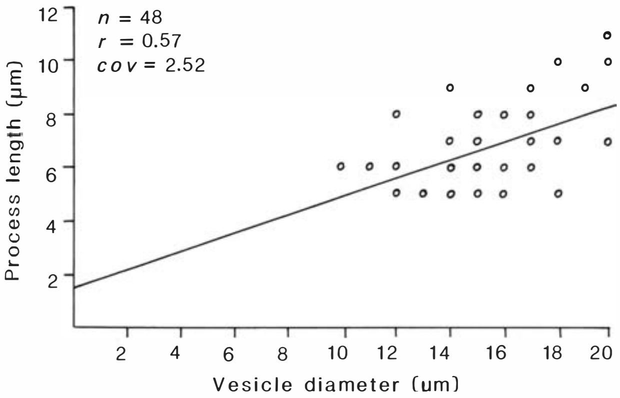

*Fig. 30.* Bivariate plot of size distribution of *Heliosphaeridium lubomlense* (Kirjanov) comb.nov. in the Lower Cambrian of the Lublin Slope.

plonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons, and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Svalbard, East Spitsbergen, Topiggane, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987).

## *Heliosphaeridium obscurum* (Volkova, 1969) comb. nov.

Pl. 8O

*Synonymy.* – □1969 *Micrhystridium obscurum* Volkova sp. nov. – Volkova, 1969b, p. 228, Pl. 51:21–32. □1971 *Micrhystridium obscurum* Volkova, 1969b – Gardiner & Vanguestaine, p. 187, Pl. 1:5–6. □1971 *Micrhystridium dissimilare* Volkova, 1969 – Gardiner & Vanguestaine, Pl. 1:1, 2, 4. □1978 *Micrhystridium dissimilare* Volkova, 1969 – Vanguestaine, Pl. 2:38–40. □1979 *Micrhystridium obscurum* Volkova, 1969 – Volkova *et al.*, p. 15, Pl. 9:5–7, 11. □1981 *Micrhystridium obscurum* Volkova – Erkmen & Bozdoğan, Pl. 1:9. □1981 *Micrhystridium dissimilare* Volkova – Erkmen & Bozdoğan, Pl. 1:11. □1982 *Micrhystridium ellipticum* sp. nov. – Downie, p. 261, Fig. 6v, w.

*Material.* – Twelve well-preserved specimens.

*Description.* – Vesicles oval in outline, possessing a central body evenly covered by a small number of short processes. The processes are of variable width and have slightly widened bases with blunt or tapering ends. The cavities of central body and process communicate.

*Dimensions.* – *N*=12. Diameter of central body 10–16 µm, x̄=13.33±0.64 µm, σ=2.23 µm; length of processes 2–5 µm, x̄=3.50±0.31 µm, σ=1.08 µm (Fig. 31).

*Remarks.* – The species differs from *Asteridium spinosum* (Volkova, 1969) comb. nov. by having few processes, in which the inner cavity communicates with the central body cavity, and additionally by having widened process bases.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Protolenus* zone (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons; Middle Cambrian, Kibartai and Deimenos horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Västergötland, File Haidar Formation, Lingulid Sandstone Member: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986). Ireland, Bray Group, Thulla Formation and Ribband Group, Booley Bay Formation: Lower and Middle Cambrian (Gardiner & Vanguestaine 1971). Belgium, Massif de Stavelot, Revinien Inferior: Middle Cambrian (Vanguestaine 1978). Canada, Alberta, Mt Eisenhower, Gog Formation: Lower Cambrian (Downie 1982). Turkey, region Merdin–Derik, Sosink Formation: Cambrian (Erkmen & Bozdoğan 1981).

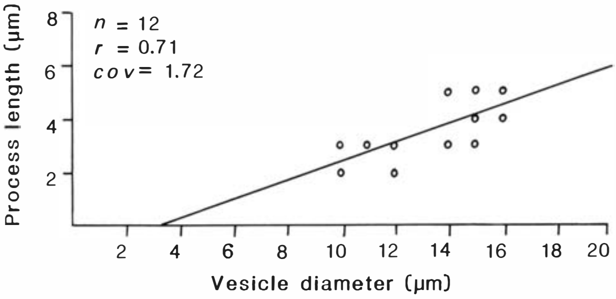

*Fig. 31.* Bivariate plot of size distribution of *Heliosphaeridium obscurum* (Volkova) comb.nov. in the Lower Cambrian of the Lublin Slope.

## *Heliosphaeridium radzynicum* (Volkova, 1979) comb. nov.

Pl. 8R–S

*Synonymy* – □1969 *Micrhystridium parvum* Volkova sp. nov. – Volkova, 1969b, p. 229, Pl. 50:21–26. □1979 *Micrhystridium radzynicum* Volkova nom. nov. – Volkova *et al.*, p. 16, Pl. 9:12, 13.

*Material.* – Three well-preserved specimens.

*Description.* – Vesicle irregularly polygonal in outline, possessing scattered processes. The bases of the processes are slightly widened and the tips sharp-pointed. The cavities of processes and central body communicate.

*Dimensions.* – *N*=3. Diameter of central body 5–6 µm; length of processes 2–3 µm.

*Remarks.* – The species differs from other heliosphaerids by the polygonal outline of the central body and by its extremely small size.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons (Volkova *et al.* 1979).

## *Heliosphaeridium* sp.

*Material.* – 16 poorly preserved specimens.

*Description.* – Vesicle circular to oval in outline consisting of a central body and processes. The central body cavity communicates with the cavity of the processes. The processes are widened at the proximal part, tapering or blunt at the distal ends.

*Dimensions*. – *N*=16. Diameter of central body 10–18 µm; length of processes 4–8 µm.

*Present record*. – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Łopiennik IG-1 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

## Genus *Leiosphaeridia* Eisenack, 1958, emend. Downie & Sarjeant, 1963

*Type species*. – *Leiosphaeridia baltica* Eisenack, 1958, p. 8, Pl. 2:5.

### *Leiosphaeridia* sp.

Pl. 12A–H, 13A–J, 14A–F, 15C

*Material*. – More than 23 000 specimens, most of them well-preserved.

*Description*. – Circular to oval vesicles with smooth surface.The wall of vesicle is thin and delicate, or solid and thick (up to 1 µm in thickness). Compression folds are small, irregular or wide roll-like, and are irregularly distributed. Excystment by median split.

*Dimensions*. – *N*=100. Diameter of vesicle 15–330 µm, $\bar{x}$=55.38±5.39 µm, σ=53.90 µm. Additional specimens occurring in clusters are usually smaller, with diameters at about 10 µm.

*Remarks*. – Specimens belonging to the genus *Leiosphaeridia* in the investigated material are not identified to the species level. The morphological differences are restricted to vesicle diameter and wall thickness, which determine the shape of the compression folds formed during compaction. Pylomes are not observed in the present material. Median split seems to be random and not predetermined by any special structure of the wall (Pls. 12G; 13I, J). The accumulation of organic matter in the cavity of certain specimens (Pl. 13C, 15C) may be the result of the condensation of cytoplasm (Volkova 1964; Awramik *et al.* 1972; Hofmann 1976; Lindgren 1982a).

Two types of leiospheres are observed, namely thin-walled, transparent, with delicate compression folds (Pl. 12A, D, G), and thick-walled, with roll-like compression folds (Pl. 12E, F, H, Pl. 13B, D). Previously, these morphotypes were referred to as 'type A' and 'type B' (Volkova 1864) or 'sp. 1' and 'sp. 2' (Moczydłowska & Vidal 1986). There is a full array of transitional forms between the two main types (cf. Pl. 12, 13, 14A–F), and there are no adequate and objective criteria for a subdivision at the specific level. I consider previous such attempts (e.g. Kirjanov 1974; Jankauskas 1976; Aseeva 1976, 1983; Paškevičienė 1980) unconvincing.

*Occurrence and stratigraphic range*. – *Leiosphaeridia* spp. is the most common and abundant form taxon of microphytoplankton in Vendian and Cambrian strata in Poland (the EEP, the Holy Cross Mts., Upper Silesia), Sweden, Denmark, Norway, Greenland, Svalbard, Great Britain, Belgium, France, Spain, USSR (the EEP and the Siberian Platform, the Urals), U.S.A., Canada and China. The genus is known to occur from late Proterozoic to Tertiary (Downie & Sarjeant 1964; Tappan 1980; Lindgren 1982a, b).

## Genus *Liepaina* Jankauskas & Volkova, 1979

*Type species*. – *Liepaina plana* Jankauskas & Volkova, 1979, *in* Volkova *et al.*, pp. 28–29, Pls. 20:1–6; 21:1, 2.

### *Liepaina plana* Jankauskas & Volkova, 1979

Pl. 10C–D

*Synonymy*. – □1979 *Liepaina plana* Jankauskas et Volkova sp. nov. – Volkova *et al.*, pp. 28–29, Pls. 20:1–6; 21:1, 2.

*Material*. – 26 fairly well-preserved specimens.

*Description*. – Vesicle polygonal in outline. Spoke-like and wide elements, 7–12 in number, project radially from the equatorial margin of the central body. The spokes support a surrounding brim-like membrane. Both the central body and the membrane have smooth surfaces.

*Dimensions*. – *N*=26. Diameter of vesicle 38–65 µm, $\bar{x}$= 56.19±1.58 µm, σ=8.08 µm; diameter of central body 20–34 µm, $\bar{x}$=27.92±0.78 µm, σ=3.98 µm; membrane width 9–18 µm, $\bar{x}$=14.42±0.59 µm, σ=3.00 µm (Fig. 32).

*Remarks*. – The marginal part of the brim-like membrane is often poorly preserved.

*Present record*. – Poland, Lublin Slope of the EEP, drillcores Łopiennik IG-1 and Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range*. – USSR, the EEP: Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Norway, Lake Mjøsa region, 1aβ bed: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986).

## Genus *Lophosphaeridium* Timofeev, 1959, ex Downie, 1963, emend. Lister, 1970

*Type species*. – *Lophosphaeridium* rarum Timofeev ex Downie, 1963, p. 630 [=*Lophosphaeridium* rarum Timofeev, 1959, p. 29, Pls. 2:5; 24:2].

### *Lophosphaeridium dubium* (Volkova, 1968) comb. nov.

Pl. 3A

*Synonymy*. – □1968 *Baltisphaeridium dubium* Volkova, sp. nov. – Volkova, p. 18, Pls. 1:8, 9; 11:6. □1979 *Baltisphaeridium dubium* Volkova, 1968 – Volkova *et al.*, p. 9, Pl. 5:3, 4. □1986 *Baltisphaeridium dubium* Volkova – Moczydłowska & Vidal, Fig. 11E–F.

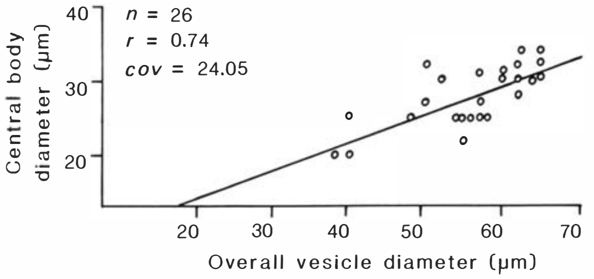

*Fig. 32.* Bivariate plot of size distribution of *Liepaina plana* Jankauskas & Volkova in the Lower Cambrian of the Lublin Slope.

*Material.* – Two well-preserved specimens.

*Description.* – Vesicle oval in outline and covered by numerous sculptural elements evenly distributed on the surface. Sculptural elements short and solid, resembling thorns with rounded distal tips.

*Dimensions.* – *N*=2. Diameter of vesicle 35–38 μm; length of sculpture elements 1–2 μm.

*Remarks.* – The species differs from *Lophosphaeridium truncatum* Volkova by having thorn-like sculpture elements.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.); Baltic Syneclise, drillcore Prabuty IG-1, Zawiszyn Formation: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy and Vergale horizons (Volkova *et al.* 1979). Sweden, Scania, Norretorp Formation: Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B-C and *Holmia* C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). East Greenland, Ella Ø, Bastion Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Lophosphaeridium tentativum* Volkova, 1968

Pl. 2G–I

*Synonymy.* – □1968 *Lophosphaeridium tentativum* Volkova, sp. nov. – Volkova, p. 24, Pls. 3:4, 5; 11:7. □1974 *Lophosphaeridium tentativum* Volkova, 1968 – Vanguestaine, Pl. 1:6. □1978 *Lophosphaeridium tentativum* Volkova, 1968 – Vanguestaine, Pl. 1:20–25. □1978 *Lophosphaeridium tentativum* – Tynni, Pl. 7:61. □1979 *Lophosphaeridium tentativum* Volkova, 1968 – Volkova *et al.*, p. 22, Pl. 13:4–9. □1982 *Lophosphaeridium tentativum* Volkova, 1968 – Downie, p. 279, Fig. 11n. □1986 *Lophosphaeridium tentativum* Volkova – Moczydłowska & Vidal, Fig. 8H.

*Material.* – 84 well preserved specimens.

*Description.* – Vesicle circular to oval in outline, thin-walled and covered by small granulae which constitute the surface sculpture.

*Dimensions.* – *N*=50. Diameter of vesicle 15–50 μm, $\bar{x}$= 31.50±1.14 μm, σ=8.09 μm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, upper part of Włodawa Formation and drillcores Terebiń IG-5, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcore Łopiennik IG-1, upper part of the Mazowsze Formation and drillcores Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Łopiennik IG-1, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.); Podlasie Depression, drillcore Okuniew IG-1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova 1969a; Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Talsy and Vergale horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Finland, region Söderfjärden: Lower Cambrian (Tynni 1978). Sweden, Scania, Brantevik Sandstone and Norretorp Formation: Lower Cambrian, *Holmia* A and B zone, respectively; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B–C and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, Balka Sandstone and 'Green Shales': Lower Cambrian, *Holmia* A and B zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1a$\alpha_1$–1a$\alpha_2$ and 1aβ beds: Lower Cambrian, *Holmia* B and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Belgium, Massif de Rocroi and Massif de Stavelot (drillcore Grand-Halleux), Lower Revinien–Middle Cambrian (Vanguestaine 1974, 1978). Canada, Alberta, Mt Eisenhower, Gog Formation: Lower Cambrian (Downie 1982). East Greenland, Ella Ø, Bastion Formation: Lower Cambrian (Downie 1982; Moczydłowska & Vidal 1986) and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Lophosphaeridium truncatum* Volkova, 1969

Pl. 3B

*Synonymy.* – □1969 *Lophosphaeridium truncatum* sp. nov. – Volkova, 1969b, p. 233, Pl. 50:9, 10. □1969 *Lophosphaeridium* sp. 1 – Volkova, 1969b, p. 233, Pl. 51:39. □1979 *Lophosphaeridium truncatum* Volkova, 1969 – Volkova *et al.*, p. 22, Pl. 4:6, 7. □1987 *Lophosphaeridium truncatum* Volkova, 1969 – Knoll & Swett, p. 917, Figs. 7.14, 7.15.

*Material.* – 24 fairly well-preserved specimens.

*Description.* – Vesicle oval in outline and covered by irregularly distributed surface sculpture elements consisting of clavate coarse grains and discrete granulae.

*Dimensions.* – *N*=24. Diameter of vesicle 25–80 μm, $\bar{x}$=45.75±2.54 μm, σ=12.45 μm; height of sculpture elements 1–2 μm.

*Remarks.* – Volkova (1969b) described two acritarch species, *Lophosphaeridium truncatum* and *Lophosphaeridium* sp. 1, which differ in dimensions and in their stratigraphic ranges. *L. truncatum* was described from Lower Cambrian rocks, while *Lophosphaeridium* sp. 1 was reported from the Middle Cambrian. Later, *L. truncatum* was also recorded in Middle Cambrian strata (Volkova *et al.* 1979). In the Lublin Slope of the EEP, specimens of *Lophosphaeridium* with a larger diameter and coarse tubercular sculpture (*Lophosphaeridium* sp. 1 according to Volkova 1969b) occur in the Lower Cambrian. Thus the morphologies and ranges overlap, and there is no sound criterion to recognize two separate species.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcore Okuniew IG-1: Middle Cambrian, *Eccaparadoxides oelandicus* Zone (Volkova 1969a, b; Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Talsy, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Svalbard, East Spitsbergen, South Tokammane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987).

## *Lophosphaeridium* sp.

*Material.* – Two poorly preserved specimens.

*Description.* – Vesicle oval in outline covered by tightly arranged small, denticle-like sculptural elements.

*Dimensions.* – *N*=2. Diameter of vesicle 45–75 and 100–110 μm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Łopiennik IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone and drillcore Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

## Genus *Multiplicisphaeridium* Staplin, 1961, emend. Staplin, Jansonius & Pocock, 1963, emend. Eisenack, 1969

*Type species.* – *Multiplicisphaeridium ramispinosum* Staplin, 1961, p. 411, Pl. 48:24.

## *Multiplicisphaeridium dendroideum* (Jankauskas, 1976) Jankauskas & Kirjanov, 1979

Pl. 9L

*Synonymy.* – ☐1976 *Baltisphaeridium dendroideum* Jankauskas, sp. nov. – Jankauskas, p. 189, Pl. 25:19. ☐1977 *Multiplicisphaeridium xianum* Fombella n.sp. – Fombella, p. 119, Pl. 1:13. ☐1978 *Multiplicisphaeridium xianum* Fombella 1977 – Fombella, Pl. 3:5. ☐1979 *Multiplicisphaeridium dendroideum* (Jankauskas, 1976) Jankauskas et Kirjanov, comb. nov. – Volkova *et al.*, p. 17, Pl. 3:1–7. ☐1982 *Multiplicisphaeridium dendroideum* (Jankauskas 1976) Volkova *et al.* 1979 – Downie, p. 262, Fig. 7k–l.

*Material.* – One well-preserved specimen.

*Description.* – Vesicle oval in outline and consisting of a central body bearing long processes. The processes are wide in the proximal part, gradually thinning towards the distal part. The ends of the processes are heteromorphic, simple and branching into two or three branches. The central body cavity is connected with the inner cavity of the processes.

*Dimensions.* – Diameter of central body 20 μm; length of processes 15 μm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). England, Hollybrush Sandstone and Wales, Hells Mouth Grit: Lower Cambrian (Downie 1982). Spain, Cantabrian Mts., Oville Formation: Middle Cambrian (Fombella 1977, 1978, 1979). East Greenland, Ella O, Bastion Formation: Lower Cambrian (Downie 1982).

## Genus *Pterospermella* Eisenack, 1972

*Type species.* – *Pterospermella* aureolata (Cookson & Eisenack) Eisenack, 1972, p. 597, text-Figs. 1–3 [=*Pterospermopsis aureolata* Cookson & Eisenack, 1958, p. 49, Pl. 9:10–12].

## *Pterospermella solida* (Volkova, 1969) Volkova, 1979

Pl. 4F–G

*Synonymy.* – ☐1969 *Pterospermopsis solida* Volkova sp. nov. – Volkova, pp. 234–235, Pl. 49:15, 16. ☐1979 *Pterospermella solida* (Volkova, 1969) Volkova, comb. nov. – Volkova *et al.*,

p. 29, Pl. 17:3, 6. ☐1987 *Pterospermella* cf. *P. solida* (Volkova) Volkova, 1979 – Knoll & Swett, p. 915, Fig. 7.8.

*Material.* – 49 well-preserved specimens.

*Description.* – Vesicle circular or oval in outline. The inner body is spherical or ovoidal, surrounded in the equatorial part by a thin membrane which is stretched on radial, irregularly distributed elements. The supporting rod-like elements vary in length and the outline of the membrane is irregular.

*Dimensions.* – $N$=20. Size of vesicle 28–50 µm, $\bar{x}$= 35.55±1.40 µm, $\sigma$=6.27 µm; diameter of inner body 14–25 µm, $\bar{x}$=19.55±0.74 µm, $\sigma$=3.31 µm; width of membrane 5–15 µm, $\bar{x}$=9.15±0.57 µm, $\sigma$=2.58 µm (Fig. 33).

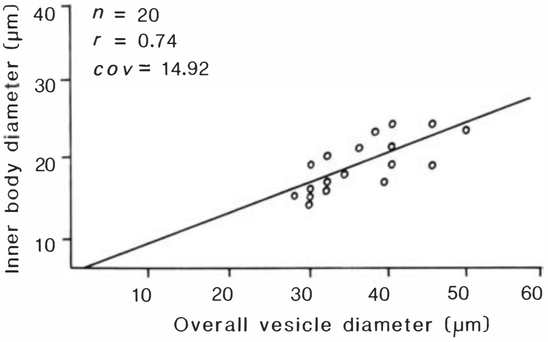

*Fig. 33.* Bivariate plot of size distribution of *Pterospermella solida* (Volkova) Volkova in the Lower Cambrian of the Lublin Slope.

*Remarks.* – The species differs from *Pterospermella vitalis* Jankauskas by the variable length of the supporting elements and their irregular distribution.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Łopiennik IG-1 and Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, Lingulid Sandstone Member: Lower Cambrian, *Holmia* C zone (Vidal 1981b; Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987).

## *Pterospermella velata* Moczydłowska, 1988

Pl. 4A–D

*Synonymy.* – ☐1986 *Pterospermella* n.sp. 1 – Moczydłowska & Vidal, Fig. 8I. ☐1987 *Granomarginata squamacea* Volkova, 1968 – Knoll & Swett, Fig. 8.11. ☐1988 *Pterospermella velata* n.sp. – Moczydłowska, 1988a, p. 7, Pl. 1:7, 8; Fig. 3. ☐non 1989 *Pterospermella velata* Moczydłowska 1988 – Hagenfeldt, 1989a, p. 101–103, Pl. 4:9.

*Material.* – 273 specimens, most of them well-preserved. Some of them display damaged marginal parts of the membrane.

*Description.* – Vesicle circular to oval in outline. The inner body is spherical, solid and surrounded by an outer membrane. The membrane is delicate, transparent and often slightly wrinkled. The margin of the membrane is irregular.

*Dimensions.* – $N$=100. Diameter of vesicle 25–65 µm (holotype 55–60 µm), $\bar{x}$=44.83±0.85 µm, $\sigma$=8.55 µm; diameter of inner body 15–35 µ$\bar{x}$=25.06±0.43 µm, $\sigma$=4.46 µm; width of membrane 3–16 µm, $\bar{x}$=10.36±0.24 µm, $\sigma$=2.38 µm (Fig. 34).

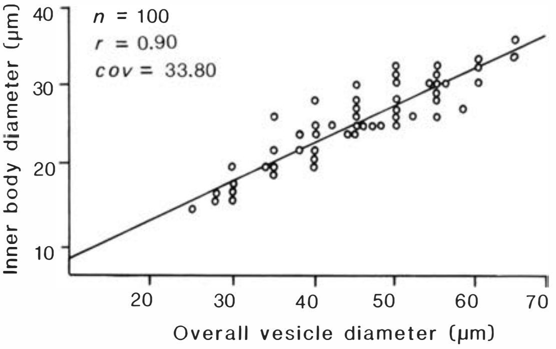

*Fig. 34.* Bivariate plot of size distribution of *Pterospermella velata* Moczydłowska in the Lower Cambrian of the Lublin Slope.

*Remarks.* – The species differs from *Pterospermella solida* (Volkova) Volkova by the lack of radially supported elements (rods) in the outer membrane, and from *Pterospermella vitalis* Jankauskas by the irregular outline of the membrane and lack of radial elements. From *Pterospermella vitrea* (Volkova) Volkova it differs by having a very clearly defined inner body. It additionally differs from *Granomarginata squamacea* Volkova by having thin and single-layered surrounding membrane contrary to spongy wall of *G. squamacea*.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Łopiennik IG-1, Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone.

*Occurrence and stratigraphic range.* – Svalbard, East Spitsbergen, Andromedafjellet: Lower Cambrian (Knoll & Swett 1987).

## *Pterospermella vitalis* Jankauskas, 1979

Pl. 4E

*Synonymy.* – ☐1979 *Pterospermella vitalis* Jankauskas sp. nov. – Volkova *et al.*, p. 29, Pl. 17:4, 5.

*Material.* – Two well-preserved specimens.

*Description.* – Vesicle oval in outline and consisting of the solid inner body surrounded in the equatorial plane by a smooth and transparent membrane. The membrane is stretched over stiff, regular and radial rod-like elements which are of almost equal length.

*Dimensions.* – *N*=2. Size 21–41 µm; diameter of inner body 16–26 µm; width of membrane 4–8 µm.

*Remarks.* – The species differs from *Pterospermella solida* (Volkova) Volkova by its regular and uniform supporting elements of the membrane.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcore Łopiennik IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Baltic Syneclise, drillcore Prabuty IG-1, Zawiszyn Formation: Lower Cambrian, *Schmidtiellus* Zone (=*Mobergella*) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Talsy and Vergale horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979).

### *Pterospermella* sp.

*Material.* – Twelve poorly preserved specimens.

*Description.* – Vesicle oval in outline. The inner body is circular or oval and surrounded at the equatorial plane by a membrane without supporting elements.

*Dimensions.* – *N*=12. Vesicle size 50–66 µm; diameter of inner body 17–30 µm; width of membrane 10–22 µm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcores Łopiennik IG-1 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

## Genus *Skiagia* Downie, 1982, emend.

*Type species.* – *Skiagia scottica* Downie, 1982, p. 264, Figs. 5, 8k–l, 9.

*Emended diagnosis.* – Spherical or slightly ellipsoidal vesicle bearing processes which are hollow but do not communicate with the central body cavity. The processes may be simply attached to the wall of the central body, but in some forms they have widened bases with proximal plugs. The processes are widened distally in the shape of a funnel with closed terminations. The excystment is by median split.

*Remarks.* – Downie (1982, p. 263) comments that the funnel terminations of the processes are opened distally. This feature could imply a similarity with acritarchs attributed to the genus *Hystrichosphaeridium* Deflandre, 1937, emend. Eisenack, 1958, emend. Davey & Williams, 1966. In the present material abundant specimens occur of almost all known species of *Skiagia* (except one). Specimens with distally opened processes were not observed in the present collection from the Lublin Slope, nor in collections from Scandinavia, Greenland (G. Vidal, University of Lund), and the EEP in the USSR (N.A. Volkova, Geological Institute of the USSR Academy of Sciences, Moscow).

Several species of *Skiagia* have been distinguished on the basis of major diagnostic character, i.e. the shape of processes. A study of numerous collections revealed a great variability in this particular feature within discrete species or between the nearest similar species. In morphotype-based form-taxonomy, the distinction of form-species can be done by convenience, choosing subjectively established limits. The intra- and interspecific variability sometimes renders the specific assignation difficult. Gradual morphological changes are particularly notable between acritarchs attributed to *S. orbiculare* and *S. ornata*, and between different morphotypes of *S. ciliosa*.

The stratigraphic ranges of *S. orbiculare* and *S. ornata* are identical, and morphotypes of *S. ciliosa* co-occur within its range. A possible explanation for the co-existence of these morphotypes may be that they are encysted or vegetative cells of a single biological species that presents a wide intraspecific variability (e.g., *S. ciliosa* with its morphological types A and B). Alternatively, they may belong to different species which could have produced morphologically overlapping encysted or motile cells (e.g., *S. orbiculare* and *S. ornata*, or *S. compressa* and *S. ciliosa*). In this case the intermediate morphotypes between separate form-species could also be the result of hybridization between biological species. However, as is the case among living chromophytes, changes in the local environment, such as salinity, nutrient availability and water temperature may have possibly resulted in one single taxon producing morphologically different encysted or motile cells (Dale 1988).

### *Skiagia ciliosa* (Volkova, 1969) Downie, 1982

Pl. 7A–F

*Synonymy.* – □1969 *Baltisphaeridium ciliosum* Volkova sp. nov. – Volkova, 1969b, pp. 224–225, Pls. 50:1–3; 51:11, 12. □1971 *Baltisphaeridium tuberculatum* Fridrichsone, sp.n. – Fridrichsone, pp. 10–11, Pl. 3:1–6. □1979 *Baltisphaeridium ciliosum* Volkova, 1969 – Volkova *et al.*, p. 8, Pl. 2:1–5. □1979 *Baltisphaeridium compressum* Volkova, 1968 – Vidal, 1979b, p. 17, Pl. 1b, d, f. □1979 *Baltisphaeridium orbiculare* Volkova, 1968 – Vidal, 1979b, pp. 17–18, Pl. 1c, e. □1982 *Skiagia ciliosa* (Volkova, 1969) comb. nov. – Downie, p. 263, Figs. 5, 7p–q. □1982 *Baltisphaeridium cerinum* Volkova 1968 – Downie, Fig. 6e, f, g. □1982 *Skiagia orbiculare* (Volkova) – Downie, Fig. 8g. □1986 *Skiagia ciliosa* (Volkova) Downie, 1982 – Moczydłowska & Vidal, Fig. 13A–F. □1987 *Skiagia ciliosa* (Volkova) Downie, 1982 – Knoll & Swett, p. 921, Figs. 9.3, 9.6–9.8, 9.14, 9.15, 10.2, 10.4, 10.7. □1987 *Baltisphaeridium cerinum* Volkova, 1968 – Knoll & Swett, p. 915, Figs. 7.2, 7.3. □1987 *Skiagia compressa* (Volkova) Downie, 1982 –

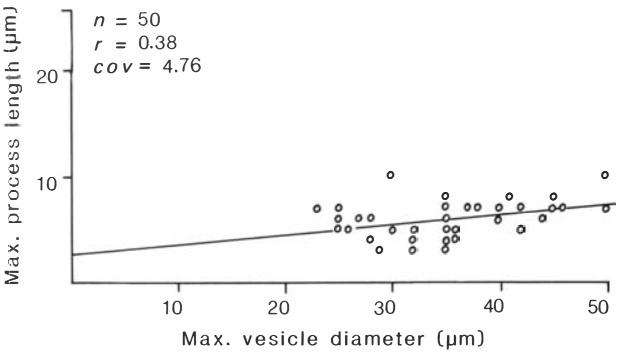

*Fig. 35.* Bivariate plot of size distribution of *Skiagia ciliosa* (Volkova) Downie in the Lower Cambrian of the Lublin Slope.

Knoll & Swett, Fig. 9.10. □1987 *Skiagia orbiculare* (Volkova) Downie, 1982 – Knoll & Swett, Fig. 10.6.

*Material.* – 720 well and fairly well-preserved specimens and additional abundant specimens in poor state of preservation.

*Description.* – The vesicle is circular to oval in outline and consists of a central body possessing numerous cylindrical processes of medium length. The processes are hollow, but separated from the central body cavity by a plug. The bases of the processes are conical, the ends being funnel-shaped.

*Dimensions.* – *N*=50. Diameter of central body 20–50 μm, x̄=34.68±1.00 μm, σ=7.13 μm; length of processes 3–10 μm, x̄=6.04±0.24 μm, σ=1.74 μm (Fig. 35).

*Remarks.* – Two morphotypes are observed among specimens attributed to *Skiagia ciliosa* (Volkova) Downie. *S. ciliosa* type A (Pl. 7A–C) has poorly developed process bases and thin slender processes which are separated from the central body by thin plugs. *S. ciliosa* type B (Pl. 7D–F) possesses wide conical process bases having thick plugs. The processes of specimens of morphotype B are wider and longer and possess larger funnel-shaped terminations. Specimens of both morphotypes co-occur in discrete samples and their relative frequency is unrelated to stratigraphic occurrence. This circumstance is shown on frequency counts of both morphotypes produced for different samples from discrete sequences (Fig. 36). The species appears in the *Heliosphaeridium–Skiagia* Zone, and the relationship between the frequency of morphotype A and morphotype B is variable. The sequences sampled at the drilling sites Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1 represent a more proximal location in the basin as compared to the sequences penetrated by the drillholes Terebiń IG-5 and Łopiennik IG-1. Morphotypes A and B have random distribution at different stratigraphic levels in all investigated drillcores, and this indicates that their occurrence is related neither to stratigraphic nor to depositional features.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcores Łopiennik IG-1, Parczew IG-10 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.), Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcores Biała Podlaska 1, Podborowisko 1 and Okuniew IG-1: Lower Cambrian, *Holmia* zone (s.l.) and drillcore Okuniew IG-1: Lower Cambrian, *Protolenus* zone (s.l.) (Volkova 1969a, b; Volkova et al. 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons, Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Forma-

| DRILLHOLE | TEREBIŃ | ŁOPIENNIK | PARCZEW | RADZYŃ | KAPLONOSY |
|---|---|---|---|---|---|
| | OFF-SHORE ZONE | | NEAR-SHORE ZONE | | |
| **Volkovia - Liepaina** Zone | [DEPTH m] [NUMBER] | 4742.1<br>4766.7 } – 13 34<br>4775.9 – – 2 | 1689.5 – 8 –<br>1694.5 7 10 11 | 1128.0 – 7<br>1140.0 11 3 | [DEPTH m] [NUMBER] |
| **Heliosphae-ridium - Skiagia** Zone | 3515.5 41 2 | 4799.0<br>4805.6 } – – 21<br>4810.0<br>4827.2 } – 19 18<br>4832.0 – – 5<br>4836.0 1 1 15 | | 1188.0 11 85<br>1195.5 3 51 | 982.0 – – 2<br>1079.0 50 – –<br>1124.0 265 2 54 |
| Skiagia ciliosa TYPE | A B | A A–B B | A A–B B | A B | A A–B B |

*Fig. 36.* Distribution and frequency of specimens of *Skiagia ciliosa* (Volkova) Downie in the Lower Cambrian sequence in the Lublin Slope.

tion: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Gislöv Formation: Lower Cambrian, *Holmia* C zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B–C and *Holmia* C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981b; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1aβ and 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Vidal 1981b; Moczydłowska & Vidal 1986). England, Purley Shales: Lower Cambrian; Wales, Hells Mouth Grit: Lower Cambrian and Lower Cared Mudstones: Middle Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation (Downie 1982) and Ella Island Formation (Vidal 1979b; Moczydłowska & Vidal 1986). North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Skiagia compressa* (Volkova, 1968) Downie, 1982

Pl. 5A

*Synonymy.* – □1968 *Baltisphaeridium compressum* Volkova, sp. nov. – Volkova, p. 19, Pl. 2:6–9, 12. □1979 *Baltisphaeridium compressum* Volkova, 1968 – Volkova *et al.*, p. 9, Pl. 2:6–10. □1982 *Skiagia compressa* (Volkova 1968) comb. nov. – Downie, p. 263, Fig. 7r–u. □1982 *Skiagia ornata* (Volkova) – Downie, Fig. 8h, i. □1986 *Skiagia compressa* (Volkova) Downie, 1982 – Moczydłowska & Vidal, Fig. 9C–F. □1987 *Skiagia compressa* (Volkova) Downie, 1982 – Knoll & Swett, p. 921, Figs. 9.4, 9.5; non 9.10.

*Material.* – 75 well and fairly well preserved specimens.

*Description.* – The vesicle is oval in outline and consists of a central body bearing numerous processes. The processes have wide conical bases (a feature reflected into a wavy outline of the central body) and funnel-like widened ends. The inner cavity of the processes is separated from the cavity of the central body by a thin wall.

*Dimensions.* – $N$=40. Diameter of central body 25–35 μm, $\bar{x}$=30.30±0.47 μm, σ=2.98 μm; length of processes 5–10 μm, $\bar{x}$=7.45±0.23 μm, σ=1.48 μm (Fig. 37).

*Remarks.* – *Skiagia compressa* (Volkova) Downie differs from other species of *Skiagia* by the wavy outline on the central body.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) and Middle Cambrian, *Eccaparadoxides oelandicus* and *Paradoxides paradoxissimus* Zones; Podlasie Depression, drillcores Biała Podlaska 1, Okuniew IG-1 and Podborowisko 1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova 1969a, b; Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Talsy, Vergale and Rausve horizons (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B–C and *Holmia* C zones, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, $1a\alpha_1$–$1a\alpha_2$ beds: Lower Cambrian, *Holmia* B zone, and 1aβ and 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Belgium, Massif de Rocroi and Massif de Stavelot, Devillien: Lower Cambrian (Vanguestaine 1978). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation (Downie 1982) and Ella Island Formation: Lower Cambrian (Vidal 1979b; Moczydłowska & Vidal 1986); North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

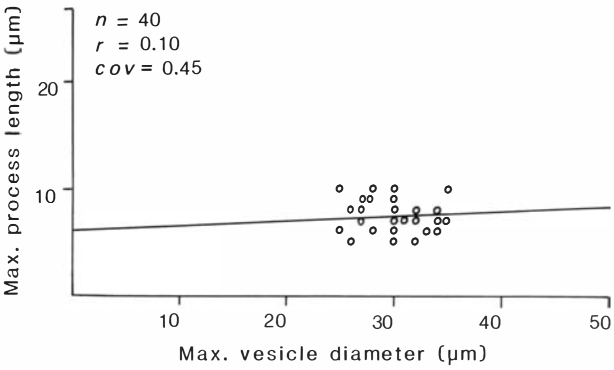

*Fig. 37.* Bivariate plot of size distribution of *Skiagia compressa* (Volkova) Downie in the Lower Cambrian of the Lublin Slope.

## *Skiagia* cf. *insigne* (Fridrichsone, 1971) Downie, 1982

Pl. 7I

*Synonymy.*– □1971 *Hystrichosphaeridium* (?) *insigne* Fridrichsone, sp. nov. – Fridrichsone, pp. 14–16, Pl. 2:10–22. □1974 *Baltisphaeridium insigne* (Fridrichsone) comb. nov. – Volkova, p. 195, Pl. 27:5–7. □1978 *Hystrichosphaeridium insigne*– Tynni, Pl. 7:69. □1979 *Baltisphaeridium insigne* (Fridrichsone, 1971) Volkova, 1974 – Volkova *et al.*, p. 10, Pl. 4:1–5. □1982 *Skiagia insigne* (Fridrichsone, 1971) comb. nov. – Downie, pp. 263–264.

*Material.* – Three fairly well-preserved specimens.

*Description.* – The vesicle is oval in outline and consists of a central body covered by numerous thick, robust, cylindrical processes. The process bases are wide, shaped as truncated cones, and are separated by a septum from the process inner cavity and by a plug from the cavity of the central body. The terminations of the processes are shaped as wide, flat funnels, closed distally and divided on several parts.

*Dimensions.* – *N*=3. Diameter of central body 33–38 µm; length of processes 4–5 µm.

*Remarks.* – Specimens described here differ from *Skiagia insigne* (Fridrichsone) Downie by having numerous processes with less well-developed basal parts. They differ from *Skiagia ciliosa* (Volkova) Downie by having processes with divided ends. The specimens attributed to *Skiagia* cf. *insigne* (Fridrichsone, 1971) Downie, 1982, presented by Downie (1982, Figs. 5 and 8a, b, c) have neither the divided terminations of the processes, nor the conical process base with a septum characteristic for *S. insigne.* Therefore they are not included in the synonymy list above.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Łopiennik IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Podlasie Depression, drillcore Biała Podlaska 1: Lower Cambrian, *Holmia* zone (s.l.) (Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Finland, region Söderfjärden: Lower Cambrian (Tynni 1978).

## *Skiagia orbiculare* (Volkova, 1968) Downie, 1982

Pl. 5B–D

*Synonymy.* – □1968 *Baltisphaeridium orbiculare* Volkova sp. nov. – Volkova, p. 19, Pls. 2:1–5; 11:3. □1979 *Baltisphaeridium orbiculare* Volkova, 1968 – Volkova *et al.*, p. 10, Pl. 1:1–3. □1982 *Skiagia orbiculare* (Volkova 1968) comb. nov. – Downie, p. 264, *non* Fig. 8d–g. □1987 *Skiagia orbiculare* (Volkova) Downie, 1982 – Knoll & Swett, p. 921, Fig. 10.8, *non* 10.6.

*Material.* – 18 well-preserved specimens.

*Description.* – The vesicle is circular to oval in outline and consists of a central body covered by numerous processes of medium length. The processes are slender and delicate, having an inner cavity that is separated from the central body. The widened proximal part of the processes tapers towards the distal portion. The ends of the processes are funnel-like.

*Dimensions.* – *N*=18. Diameter of central body 20–45 µm, $\bar{x}$=32.27±1.51 µm, $\sigma$=6.40 µm; length of processes 5–10 µm, $\bar{x}$=7.39±0.45 µm, $\sigma$=1.91 µm (Fig. 38).

*Remarks.* – The species differs from *Skiagia ornata* (Volkova) Downie by having shorter and thinner processes with conical bases and smaller funnel-shaped ends. Additionally, it differs from *S. ciliosa* (Volkova) Downie by the gradual widening of the processes from the base towards the distal part. The specimens illustrated by Downie (1982, Fig. 8e, f) under the name *S. orbiculare* (Volkova) Downie possess more robust processes with wide funnel ends, a feature characteristic for *S. pura* Moczydłowska.

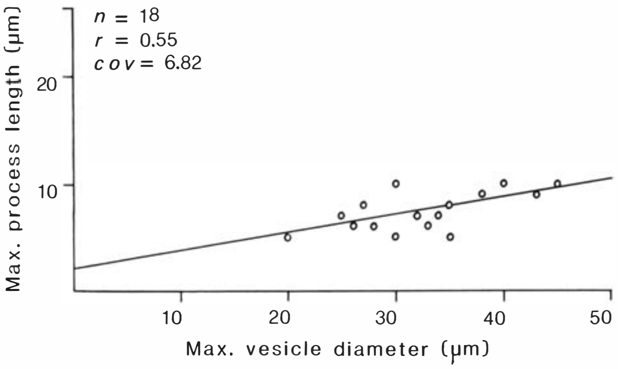

*Fig. 38.* Bivariate plot of size distribution of *Skiagia orbiculare* (Volkova) Downie in the Lower Cambrian of the Lublin Slope.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Radzyń IG-1 and KaplonosyIG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone and *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Talsy, Vergale and Rausve horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Norretorp Formation: Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B–C and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1aβ bed: Lower Cambrian, *Holmia* C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation and Ella Island Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Skiagia ornata* (Volkova, 1968) Downie, 1982

Pl. 5E–F, 6A–D

*Synonymy.*– □1968 *Baltisphaeridium ornatum* Volkova, sp. nov. – Volkova, pp. 18–19, Pls. 1:10–14; 11:1. □1979 *Baltisphaeridium ornatum* Volkova, 1968 – Volkova *et al.*, p. 11, Pl. 4:9–11. □1982 *Skiagia ornata* (Volkova 1968) comb. nov. – Downie, p. 264, *non* Fig. 8h–i. □1986 *Skiagia ornata* (Volkova) Downie, 1982 – Moczydłowska & Vidal, Fig. 11C–D. □1987 *Skiagia ornata* (Volkova) Downie, 1982 – Knoll & Swett, p. 922, Figs. 10.1, 10.3, 10.5.

*Material.* – 230 well and fairly well-preserved specimens.

*Description.* – The vesicle is circular to oval in outline and possesses a central body covered by numerous, long and cylindrical processes. The processes are slightly wider in the proximal part. The ends of the processes are funnel-like. The processes have an inner cavity separated from the

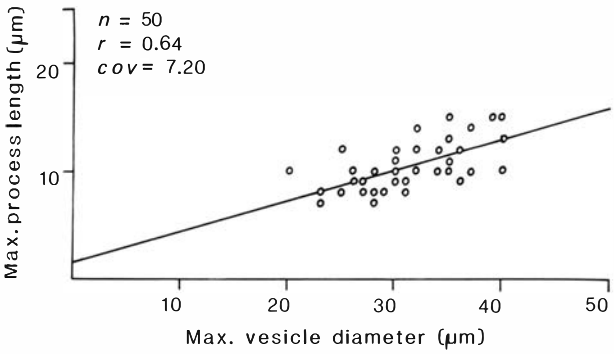

*Fig. 39.* Bivariate plot of size distribution of *Skiagia ornata* (Volkova) Downie in the Lower Cambrian of the Lublin Slope.

central body by the vesicle wall. Despite the large number of processes and their close proximity the distal ends are separated.

*Dimensions.* – *N*=50. Diameter of central body 20–40 μm, $\bar{x}$=31.86±0.70 μm, σ=5.00 μm; length of processes 7–15 μm, $\bar{x}$=10.74±0.31 μm, σ=2.22 μm (Fig. 39).

*Remarks.* – The species differs from *Skiagia orbiculare* (Volkova) Downie by having longer processes and more developed funnel-like process tips. It differs from *S. scottica* Downie by the isolated distal ends of the processes.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Terebiń IG-5, Łopiennik IG-1, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Talsy, Vergale and Rausve horizons (Volkova *et al.* 1979); Kazakhstan, Maly Karatau, Shabakty Formation: Lower Cambrian (Ogurtsova 1985). Sweden, Scania, Norretorp Formation: Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1a$\alpha_1$–1a$\alpha_2$ beds and 1aβ bed: Lower Cambrian, *Holmia* B and C zone, respectively (Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Skiagia pura* Moczydłowska, 1988

Pl. 7G–H

*Synonymy.* – ☐1988 *Skiagia pura* n.sp. – Moczydłowska, 1988a, pp. 8–9, Pl. 2:1, 2; Fig. 3.

*Material.* – Four fairly well-preserved specimens.

*Description.* – The vesicle is oval in outline and possesses a central body bearing numerous evenly distributed processes that do not display basal attachments with the central body. The processes have distal funnel-shaped parts that are generally in contact.

*Dimensions.* – *N*=4. Diameter of central body 26–45 μm; length of processes 5–10 μm.

*Remarks.* – The species differs from *Skiagia insigne* (Fridrichsone) Downie by the funnel-like tips of the processes and by lacking septa between the cavity of the central body and the processes, and by the lack of conical bases. It differs from *S. scottica* Downie by having thicker and shorter processes in relation to the vesicle diameter and less flattened distal process tips.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Parczew IG-10, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

## *Skiagia scottica* Downie, 1982

Pl. 6E–F

*Synonymy.* – ☐1982 *Skiagia scottica* sp. nov. – Downie, p. 264, Figs. 8k–l, 9a–f. ☐1982 *Skiagia orbiculare* (Volkova) – Downie, Fig. 8f. ☐1987 *Skiagia scottica* Downie, 1982 – Knoll & Swett, p. 922, Figs. 9.9, 9.12.

*Material.* – 15 well-preserved specimens.

*Description.* – The vesicle is circular to oval in outline and consists of a central body covered by abundant processes. The processes are long, evenly wide, cylindrical, and they are only slightly widened in the proximal part. The distal ends of the processes are wide and flat, funnel-like, and often attached to each other. The inner cavity of the processes is separated from the cavity of the central body by the vesicle wall.

*Dimensions.* – *N*=15. Diameter of central body 20–35 μm, $\bar{x}$=30.60±1.01 μm, σ=3.92 μm; length of processes 5–12 μm, $\bar{x}$=9.60±0.59 μm, σ=2.29 μm (Fig. 40).

*Remarks.* – *Skiagia scottica* Downie differs from other species of the genus by the tightly arranged processes that are often joined at the distal parts.

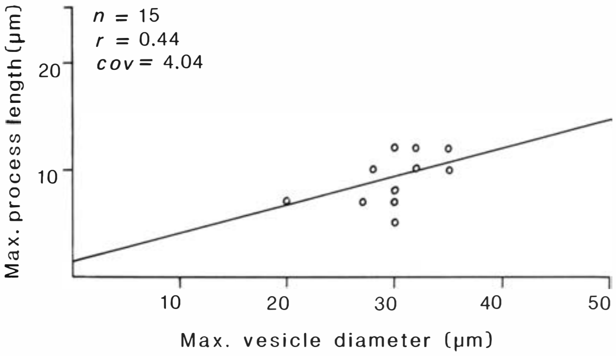

*Fig. 40.* Bivariate plot of size distribution of *Skiagia scottica* Downie in the Lower Cambrian of the Lublin Slope.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Parczew IG-10 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcores Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone; drillcore Łopiennik IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Sweden, Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1aβ and 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986) and Tømten quarry: Lower Cambrian, *Holmia* Shales (Downie 1982). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation (Downie 1982) and Ella Island Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## Genus *Tasmanites* Newton, 1875

*Type species.* – *Tasmanites punctatus* Newton, 1875, p. 341.

### *Tasmanites bobrowskae* Ważyńska, 1967

Pl. 10F–G, 11C–E

*Synonymy.* – □1967 *Tasmanites bobrowskii* sp. nov. – Ważyńska, p. 14, Pls. 3:23–27; 4:28. □1968 *Tasmanites variabilis* Volkova sp. nov. – Volkova, p. 29, Pls. 5:9–12; 11:9. □1978 *Tasmanites bobrowskae* Ważyńska, 1967 – Vanguestaine, p. 272. □1978 *Tasmanites bobrowskii* – Tynni, Pl. 4:29, 30. □1979 *Tasmanites variabilis* Volkova, 1968 – Vidal, 1979b, p. 23, Pl. 2c–d. □1979 *Tasmanites bobrowskii* Wazynska, 1967 – Volkova *et al.*, p. 33, Pl. 23:3–5. □1980 *Tasmanites bobrowskae* Ważyńska, 1967 – Moczydłowska, p. 475, Pl. 4:1. □1982 *Tasmanites bobrowskii* Wazynska 1967 – Downie, p. 280, Fig. 9k. □1986 *Tasmanites bobrowskae* Wazyńska – Moczydłowska & Vidal, Figs. 8N, 12A. □1987 *Tasmanites bobrowskii* Ważyńska, 1967 – Knoll & Swett, p. 913, Figs. 5.11–5.16.

*Material.* – 417 well-preserved specimens.

*Description.* – Vesicles circular to oval in outline. The vesicle wall is thick and perforated by irregularly distributed large pores.

*Dimensions.* – $N$=50. Diameter of vesicle 50–90 μm (but real dimensions were larger because the specimens are folded), $\bar{x}$=80.22±1.03 μm, $\sigma$=7.29 μm; distance between pores 2–3 μm (Fig. 41).

*Remarks.* – According to the *International Code of Botanical Nomenclature* (1983), the specific epithets of plant fossils formed from the feminine gender ought to have the suffix *-ae*. This applies to *T. bobrowskae* (Vanguestaine 1978; Moczydłowska 1980). *T. bobrowskae* Ważyńska differs from *T. tenellus* Volkova by having larger pores and thicker vesicle wall.

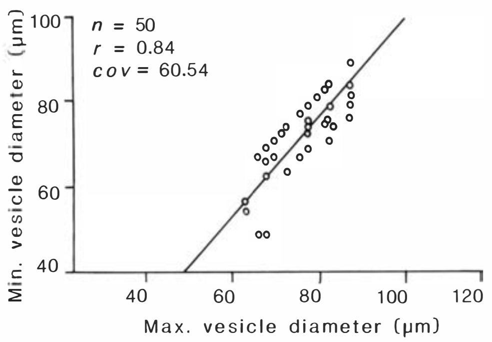

*Fig. 41.* Bivariate plot of size distribution of *Tasmanites bobrowskae* Ważyńska in the Lower Cambrian of the Lublin Slope.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Parczew IG-10 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcores Parczew IG-10, Radzyń IG-1 and Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone; drillcore Kaplonosy IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Heliosphaeridium–Skiagia* Zone.

*Occurrence and stratigraphic range.* – Poland, Podlasie Depression, drillcores Iwanki–Rohozy 3 and Podborowisko 1: Lower Cambrian (Ważyńska 1967), drillcores Biała Podlaska 1 and Okuniew IG-1: Lower Cambrian, *Holmia* zone (s.l.); Lublin Slope, drillcore Radzyń IG-1: Lower Cambrian, *Holmia* and *Protolenus* zones (s.l.) (Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Lontova, Talsy, Vergale and Rausve horizons (Volkova *et al.* 1979). Finland, region Söderfjärden: Lower Cambrian (Tynni 1978). Sweden, Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982). Belgium, Massif de Rocroi and Massif de Stavelot, Devillien: Lower Cambrian and Revinien: Middle and Upper Cambrian (Vanguestaine 1978). Canada, Alberta, Mt Eisenhower, Gog Formation: Lower Cambrian (Downie 1982). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation and Ella Island Formation and North Greenland, Buen Formation: Lower Cambrian (Vidal 1979b; Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Tasmanites tenellus* Volkova, 1968

Pl. 11A–B

*Synonymy.* – □1968 *Tasmanites tenellus* Volkova sp. nov. – Volkova, p. 29, Pls. 6:1–5; 10:1. □1979 *Tasmanites tenellus* Volkova, 1968 – Volkova *et al.*, p. 33, Pls. 23:1, 2; 24:1. □1986 *Tasmanites tenellus* Volkova – Moczydłowska & Vidal, Fig. 12E–F. □1987 *Tasmanites tenellus* Volkova, 1968 – Knoll & Swett, p. 913, Fig. 5.8.

*Material.* – 77 well and fairly well preserved specimens.

*Description.* – Vesicles circular to oval in outline. The vesicle wall is thin and perforated by small, irregularly distributed pores.

*Dimensions.* – *N*=30. Diameter of vesicle 50–120 µm (but real dimensions were larger since the vesicles are folded), $\bar{x}$=95±2.78 µm, σ=15.25 µm; distance between pores 2–3 m m (Fig. 42).

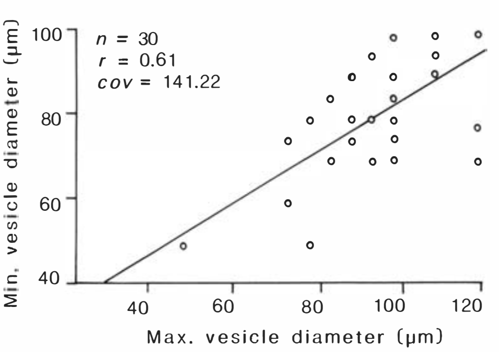

*Fig. 42.* Bivariate plot of size distribution of *Tasmanites tenellus* Volkova in the Lower Cambrian of the Lublin Slope.

*Remarks.* – The species differs from *Tasmanites bobrowskae* Ważyńska by having thinner wall and small pores.

*Present record.* – Poland, Lublin Slope of the EEP, drillcores Parczew IG-10 and Kaplonosy IG-1, Mazowsze Formation: Lower Cambrian, *Asteridium–Comasphaeridium* Zone; drillcores Parczew IG-10 and Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcores Radzyń IG-1 and Kaplonosy IG-1; Podlasie Depression, drillcores Biała Podlaska 1, Mielnik IG-1, Okuniew IG-1 and Podborowisko 1: Lower Cambrian, *Platysolenites* Zone (Volkova 1969a, b; Volkova *et al.* 1979; Moczydłowska 1981). USSR, the EEP: Lower Cambrian, Lontova and Talsy horizons; Siberian Platform, Olenek Uplift: Lower Cambrian, Tommotian Stage (Volkova *et al.* 1979). Sweden, Scania, Hardeberga Sandstone: Lower Cambrian, *Holmia* A zone; Kalmarsund region, '*Mobergella* Sandstone': Lower Cambrian, *Holmia* B zone; Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member: Lower Cambrian, *Holmia* B–C zone (Vidal 1981b, c; Moczydłowska & Vidal 1986). Denmark, Bornholm, 'Green Shales': Lower Cambrian, *Holmia* B zone (Vidal 1981c; Moczydłowska & Vidal 1986). Norway, Lake Mjøsa region, 1bα–1bβ beds: Lower Cambrian, *Holmia* C zone (Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). East Greenland, Ella Ø, Bastion Formation and North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## *Tasmanites volkovae* Kirjanov, 1974

Pl. 10E, E$^1$

*Synonymy.* – □1969 *Tasmanites* sp. – Volkova, 1969b, p. 236, Pl. 49:10, 11. □1974 *Tasmanites volkovae* Kirjanov, sp. nov. – Kirjanov, pp. 128–129, Pl. 8:11–13. □1979 *Tasmanites volkovae* Kirjanov, 1974 – Volkova *et al.*, p. 34, Pl. 25:1–3. □1986 *Tasmanites volkovae* Kirjanov – Moczydłowska & Vidal, Fig. 12C–D. □1987 *Tasmanites volkovae* Kirjanov, 1974 – Knoll & Swett, p. 913, Figs. 5.9, 5.10.

*Material.* – One well-preserved specimen.

*Description.* – Vesicle circular to oval in outline with a thick wall perforated by abundant, evenly distributed pores. The pores are placed in funnel-like depressions of the wall, a feature that gives rise to wavy vesicle outline.

*Dimensions.* – *N*=1. Diameter of vesicle 100×150 µm.

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – USSR, the EEP: Lower Cambrian, Talsy, Vergale and Rausve horizons and Middle Cambrian, Kibartai horizon (Volkova *et al.* 1979). Sweden, Västergötland, File Haidar Formation, *Mickwitzia* Sandstone Member and Lingulid Sandstone Member: Lower Cambrian, *Holmia* B–C and C zone, respectively (Vidal 1981b, c; Moczydłowska & Vidal 1986). Svalbard, East Spitsbergen, South Tokammane, Topiggane and Andromedafjellet, Tokammane Formation: Lower Cambrian (Knoll & Swett 1987). North Greenland, Buen Formation: Lower Cambrian (Moczydłowska & Vidal 1986; Vidal & Peel 1988).

## Genus *Volkovia* Downie, 1982

*Type species.* – *Volkovia dentifera* (Volkova, 1969) comb. nov., Downie, 1982, pp. 265, 278, Fig. 10o–p [=*Deunffia dentifera* Volkova, 1969, p. 234, Pl. 50:29–31].

## *Volkovia dentifera* (Volkova, 1969) Downie, 1982

Pl. 9K, K$^1$

*Synonymy.* – □1969 *Deunffia dentifera* Volkova sp. nov. – Volkova, 1969b, p. 234, Pl. 50:29–31. □1979 *Deunffia dentifera* Volkova, 1969 – Volkova *et al.*, p. 23, Pl. 10:1–3. □1982 *Volkovia dentifera* (Volkova 1969) comb. nov. – Downie, pp. 265, 278, Fig. 10o–p.

*Material.* – One well-preserved specimen.

*Description.* – Ellipsoidal vesicle possessing one single, long process that is slightly widened in the proximal part and sharp-pointed in the distal end. An circular opening (pylome?) is located opposite to the only process.

*Dimensions.* – *N*=1. Diameter of vesicle 8×20 µm; length of process 26 µm.

*Remarks.* – Specimens of *Volkovia dentifera* (Volkova) Downie are very rare. One single specimen was recovered in the Łopiennik IG-1 drillcore among all investigated samples. Previously, the species was also recorded in the drillcore Radzyń IG-1 (Volkova 1969a, b; Volkova *et al.* 1979), at the depth of 1138.9–1144.2 m (Volkova 1969a, b).

*Present record.* – Poland, Lublin Slope of the EEP, drillcore Łopiennik IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Volkovia–Liepaina* Zone.

*Occurrence and stratigraphic range.* – Poland, Lublin Slope, drillcore Radzyń IG-1, Kaplonosy and Radzyń formations: Lower Cambrian, *Protolenus* zone (s.l.) (Volkova 1969a, b; Volkova *et al.* 1979). USSR, the EEP: Lower Cambrian, Rausve horizon (Volkova *et al.* 1979). Scotland, Fucoid Beds: Lower Cambrian (Downie 1982).

# Conclusions

The present investigation has demonstrated the abundant occurrence of acritarchs and cyanobacterial microfossils in the Upper Vendian and Lower Cambrian sequence of five drillcores in the Lublin Slope of the East European Platform in Poland. This study leads to the following conclusions:

1. Organic-walled microfossils are generally well preserved. The thermal alteration of organic matter corresponds to the diagenesis, proto- and mesokatagenesis stages of lithogenesis. The thermal alteration affecting the rock units is reflected in certain differences in the state of preservation and colour of organic matter recovered from discrete formations. The recorded higher thermal alteration of organic matter in the Upper Vendian deposits (Białopole, Lublin and Włodawa Formations) is probably the result of higher heat flow reaching the sedimentary cover during the late Vendian times as result of the inferred opening of an aborted rift.

2. The taxonomic diversity and stratigraphic distribution of the continuous succession of microfossils allow to distinguish six microfossil assemblages established on the basis of the earliest appearance of taxa. Assemblages 1–2 are late Vendian in age while 3–6 are early Cambrian.

3. Variations in the specific composition of the assemblages seem independent of palaeoenvironmental conditions and facies changes and are here interpreted as evolutionarily controlled microbiotic changes through time.

4. The acritarch assemblages *Asteridium tornatum – Comasphaeridium velvetum*, *Skiagia ornata – Fimbriaglomerella membranacea*, *Heliosphaeridium dissimilare – Skiagia ciliosa*, and *Volkovia dentifera – Liepaina plana* determine the proposed formal Assemblage-zones of the Lower Cambrian in the Lublin Slope.

5. A conspicuous radiation of acritarchs at the top of the Włodawa Formation and within the Mazowsze Formation resulted in the appearance of a distinctively Cambrian assemblage of acritarch taxa that define the *Asteridium tornatum – Comasphaeridium velvetum* Assemblage-zone. This zone is here regarded to mark the base of the Cambrian System in the Lublin region. The distinctive radiation of phytoplankton is probably synchronous over the investigated area and is parallelled by a nearly contemporaneous emergence of shelly fossils and a new assemblage of trace fossils.

6. The Kaplonosy IG-1 drillcore is the proposed reference section for the Precambrian–Cambrian boundary in the Lublin Slope. The boundary is placed at the depth of 1342.5 m within the upper part of the Włodawa Formation.

7. The continuous Precambrian–Cambrian sequence underlying the Lublin Slope is proposed as a supplementary reference section for defining the stratotype of the Precambrian–Cambrian boundary.

8. Rocks of the uppermost Mazowsze Formation, and the Kaplonosy and Radzyń formations, are attributed to the *Skiagia ornata – Fimbriaglomerella membranacea*, *Heliosphaeridium dissimilare – Skiagia ciliosa*, and *Volkovia dentifera – Liepaina plana* Assemblage-zones.

9. The acritarch assemblages and the concurrent zones defined by the stratigraphic ranges of their taxa allow correlation of Lower Cambrian strata irrespective of lithofacies development and presence or absence of macrofauna.

10. According to analysis of the Lower Cambrian faunal record in relation to micropalaeontologic data from the Lublin area, the Lublin Formation and most of the Włodawa Formation are referred to the proposed *Sabellidites–Vendotaenia* Interval-zone and regarded as late Vendian in age. The base of the zone is marked by the first appearance of vendotaenids. The top of the zone is limited by the lowermost appearance of *Platysolenites* fauna, defining the succeeding zone. The *Sabellidites–Vendotaenia* Interval-zone is defined by *Vendotaenia* and *Sabellidites* in part of their ranges below the occurrence of *Platysolenites*. However, both taxa have ranges overlapping within the *Platysolenites antiquissimus* Interval-zone.

11. Deposits of the upper part of the Włodawa Formation and the bulk of the Mazowsze Formation are attributed to the here revised *Platysolenites antiquissimus* Interval-zone. Its lower boundary embrace the strata with the first occurrence of *Platysolenites antiquissimus*. The upper boundary of the zone is limited by the appearance of *Schmidtiellus mickwitzi*, the index taxon of the succeeding zone. The total occurrence range of *Platysolenites antiquissimus* is wider then the *Platysolenites antiquissimus* Interval-zone, and it overlaps with the *Schmidtiellus mickwitzi* Range-zone and the lower part of the *Holmia kjerulfi* Assemblage-zone. The Precambr-

ian–Cambrian boundary coincides with the base of the *Platysolenites antiquissimus* Interval-zone.

12. The *Mobergella* Zone in Poland seems to be contemporaneous with the *Schmidtiellus mickwitzi* and/or *Holmia kjerulfi* trilobite Zones. The stratigraphic range of the *Mobergella* fauna in Scandinavia overlaps with the range of *Platysolenites antiquissimus* and *Holmia mobergi*. Thus, the *Mobergella* Zone introduced in Poland is considered superfluous and is here rejected.

13. As previously proposed, the Klimontovian Stage comprised strata referred to pre-trilobite Cambrian strata in Poland, including the *Sabellidites*, *Platysolenites* and *Mobergella* Zones. The *Sabellidites* Zone is late Vendian in age, whereas strata attributed to the *Mobergella* Zone are contemporaneous with the earliest trilobites zone. On these grounds the Klimontovian Stage is rejected.

14. The sedimentologically continuous sequence referred to the uppermost Mazowsze Formation, and the Kaplonosy and Radzyń formations, is here regarded as time equivalent to strata elsewhere attributed to the *Schmidtiellus mickwitzi* Range-zone, the here recognized *Holmia kjerulfi* Assemblage-zone, and the still informal *Protolenus* zone.

15. The Precambrian–Cambrian boundary in the USSR part of the EEP is within the upper part of the Rovno Formation in Ukraine and the southern slope of the Fennoscandian Shield.

16. The previously proposed Precambrian–Cambrian boundary at the base of the Tommotian Stage in the Siberian Platform is challenged by acritarch evidence suggesting that part of the underlying Yudomian Stage including Nemakit–Daldyn horizon and the Moty Formation may belong to the Cambrian System. Furthermore, deposits referred to the Tommotian Stage, previously defined as a pre-trilobite unit in the Siberian Platform, are partly time equivalent to the trilobite-bearing Talsy horizon in the EEP and the *Schmidtiellus mickwitzi* Zone in parts of the EEP and Baltoscandia. This indicates the coexistence in time of some 'Tommotian' shelly metazoans with well-developed trilobite faunas. Thus, models dealing with the radiation of metazoans and the rise of skeletonization that rely largely on evidence from the Tommotian of Siberia demand substantial revision.

17. The acritarch record derived from rocks of the Yu'anshan Member of the Qiongzhusi Formation in Yunnan Province in the South China Platform suggests that the *Eoredlichia–Wutingaspis* trilobite Zone is time equivalent with the *Holmia kjerulfi* Assemblage-zone in Poland and the *Holmia inusitata/ Holmia kjerulfi* Zones in Baltoscandia. This implies that the zone with *Eoredlichia–Wutingaspis* and *Eoredlichia–Parabadiella* is not the oldest trilobite zone, except locally. Consequently, the upper part of the Meishucunian Stage, previously regarded to precede the oldest trilobites may be time equivalent with the *Schmidtiellus mickwitzi* Zone.

18. Acritarch-based correlation of the Lower Cambrian strata within the Baltoscandian Platform suggests that the 'Green Shales' in the island of Bornholm biostratigraphically embrace the *Skiagia–Fimbriaglomerella* and *Heliosphaeridium–Skiagia* acritarch Zones in the Lublin Slope corresponding to the *Schmidtiellus mickwitzi* Zone and the *Holmia inusitata/ Holmia kjerulfi* Zones in Baltoscandia.

19. *Mobergella*-bearing beds and the *Mickwitzia* Sandstone Member, both units of the lower part of the File Haidar Formation, are contemporaneous with the *Heliosphaeridium–Skiagia* acritarch Zone in the Lublin Slope that seems to correspond to the *Holmia inusitata/ Holmia kjerulfi* Zones in Baltoscandia. Hence, the lower biostratigraphic range of the File Haidar Formation cannot be older than the *Holmia inusitata/ Holmia kjerulfi* Zones. The *Mobergella* fauna has a stratigraphic range overlapping with the range of these zones.

20. The Bråstad Sandstone and the Brennsæter Shale in the Lake Mjøsa area are attributed to the *Heliosphaeridium–Skiagia* acritarch Zone which corresponds to the *Holmia inusitata/ Holmia kjerulfi* Zones. If correct, this implies that *Holmia mobergi* Bergström, formerly recorded to co-occur with *Schmidtiellus mickwitzi* (Schmidt), may have a stratigraphic range overlapping with the range of *Holmia inusitata* Ahlberg & Bergström.

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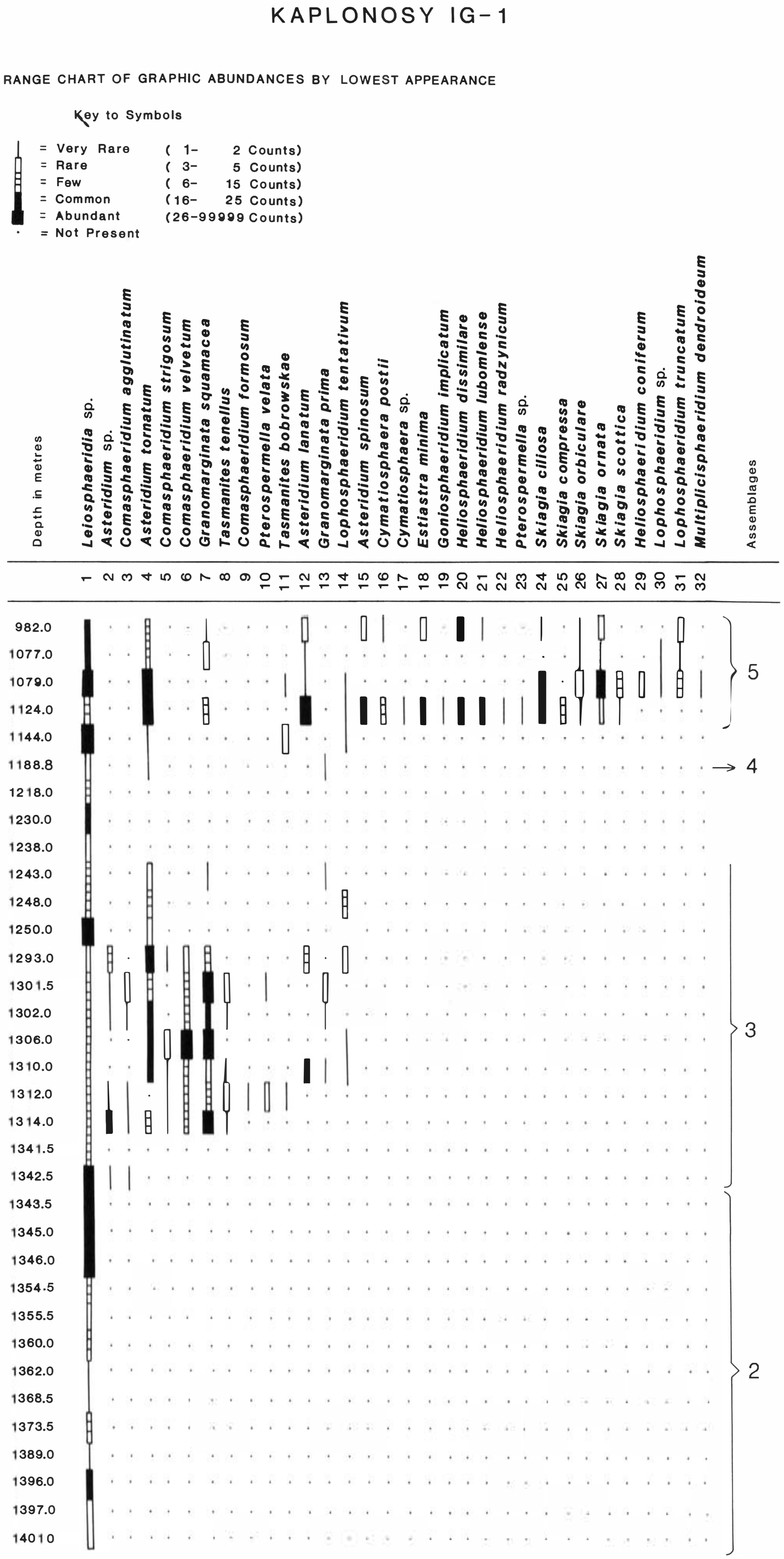
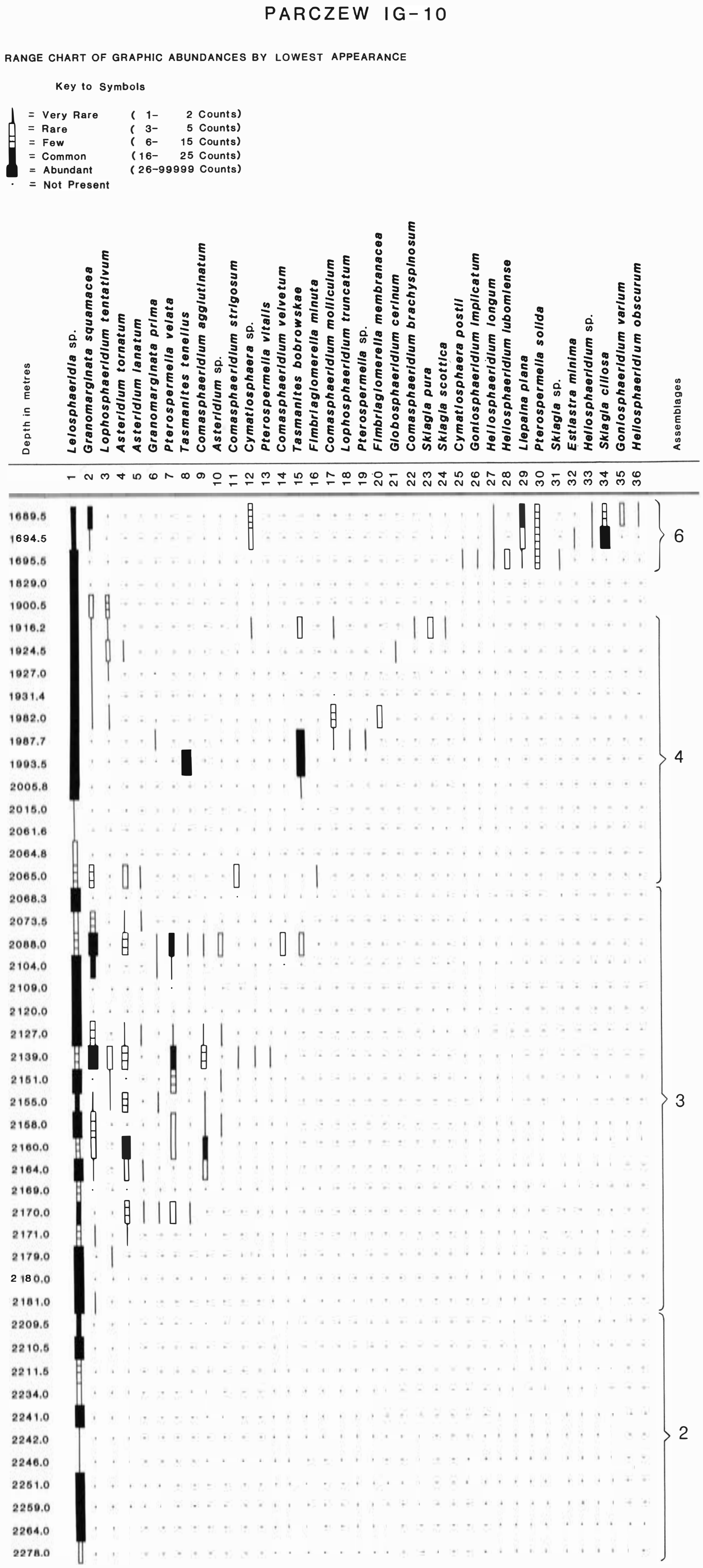
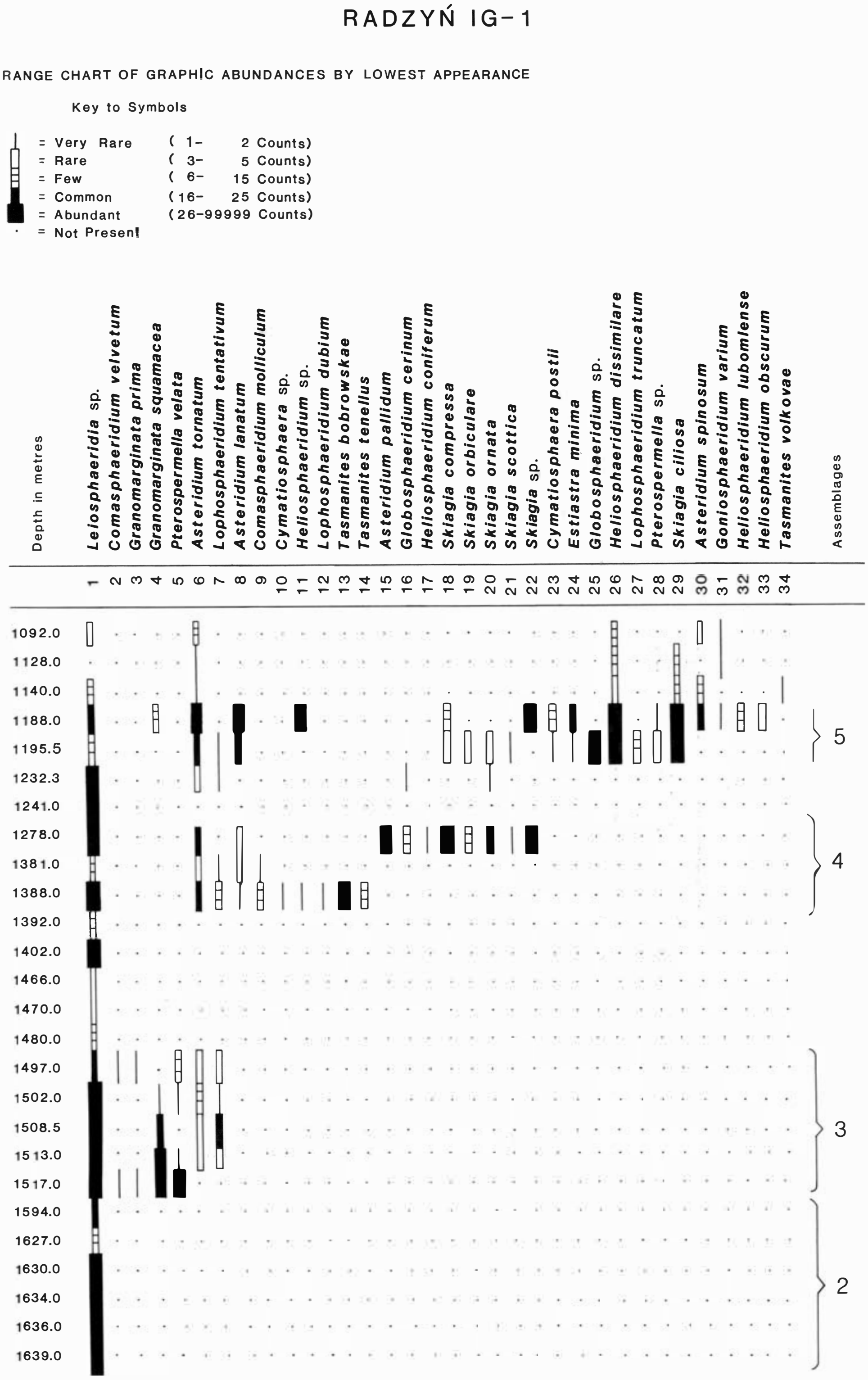


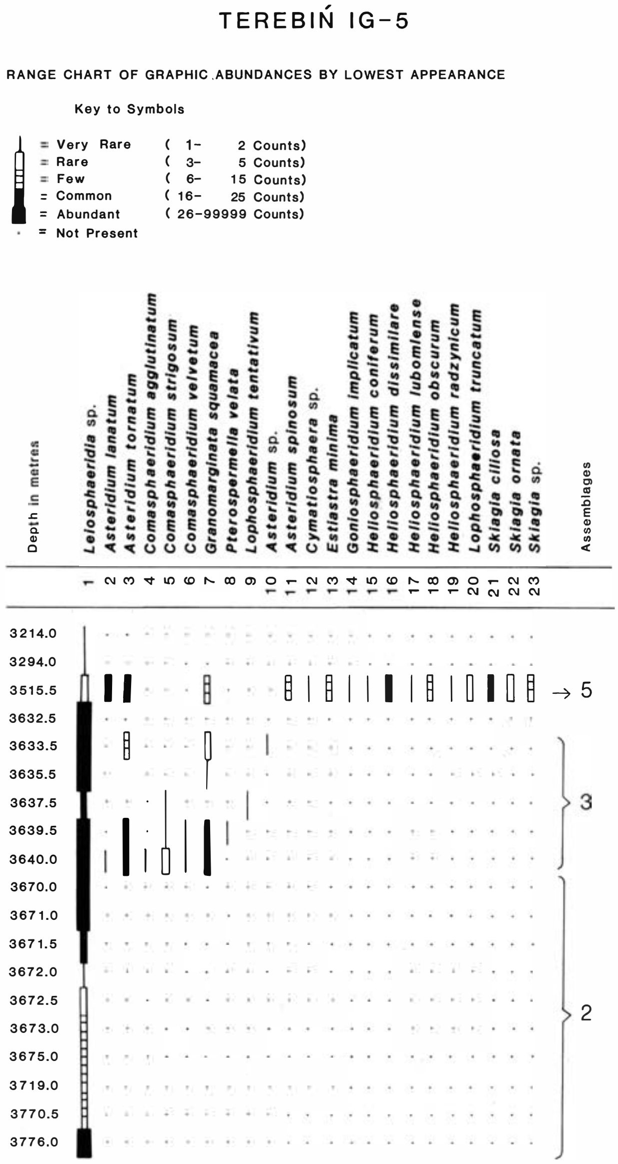
*Appendix 1.* Range chart of acritarch species in the Kaplonosy IG-1 drillcore.



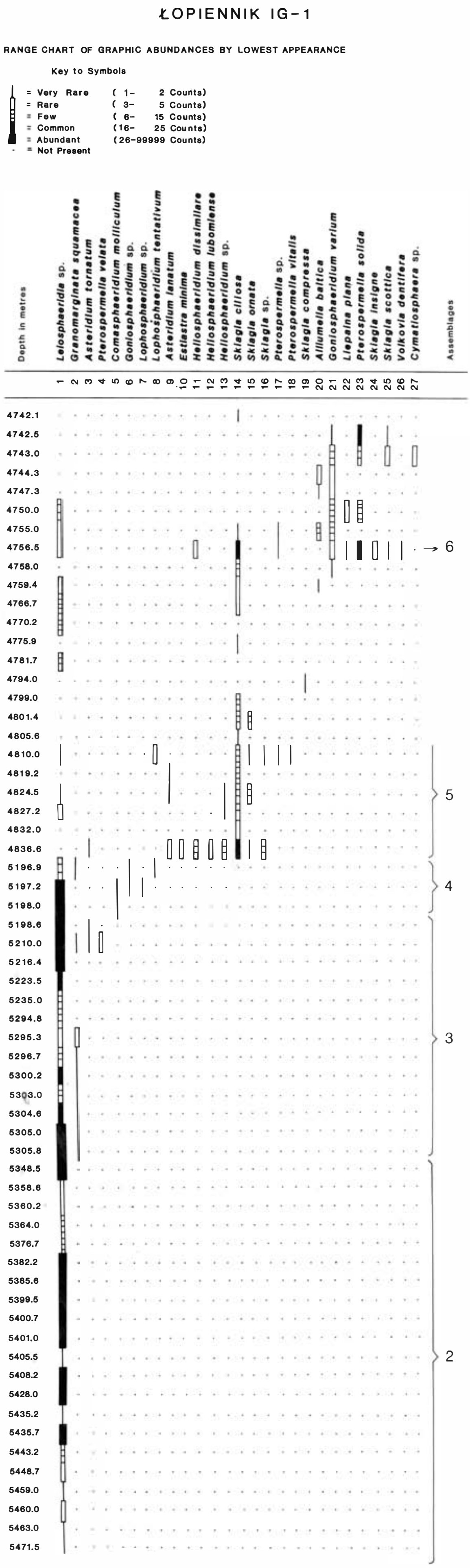
*Appendix 2.* Range chart of acritarch species in the Parczew IG-10 drillcore.



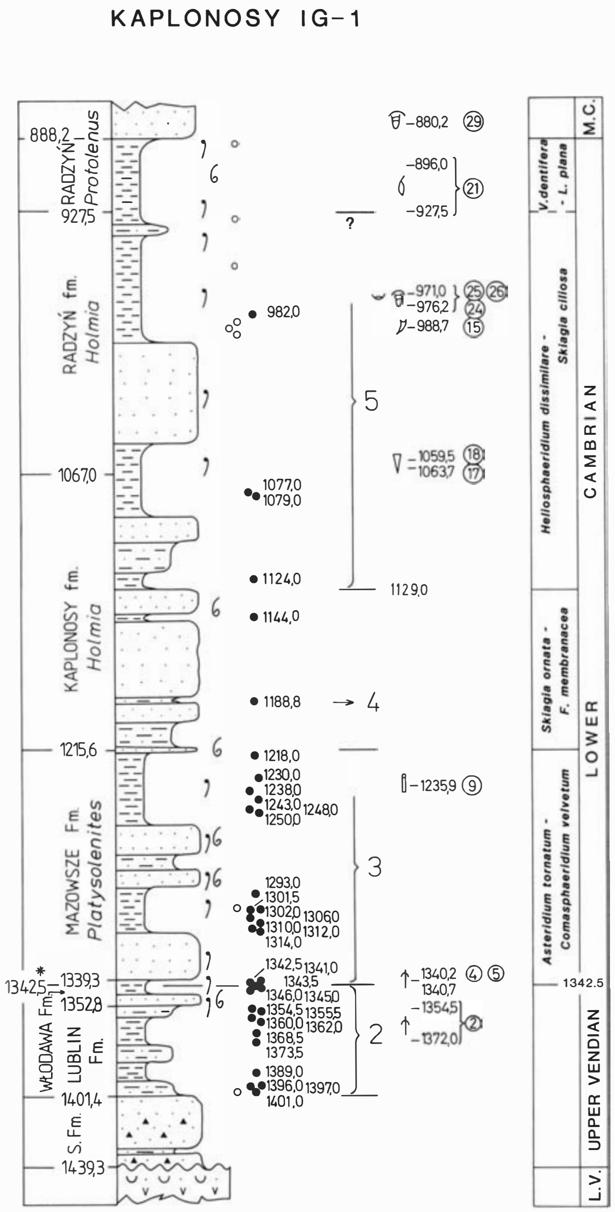
*Appendix 3.* Range chart of acritarch species in the Radzyń IG-1 drillcore.



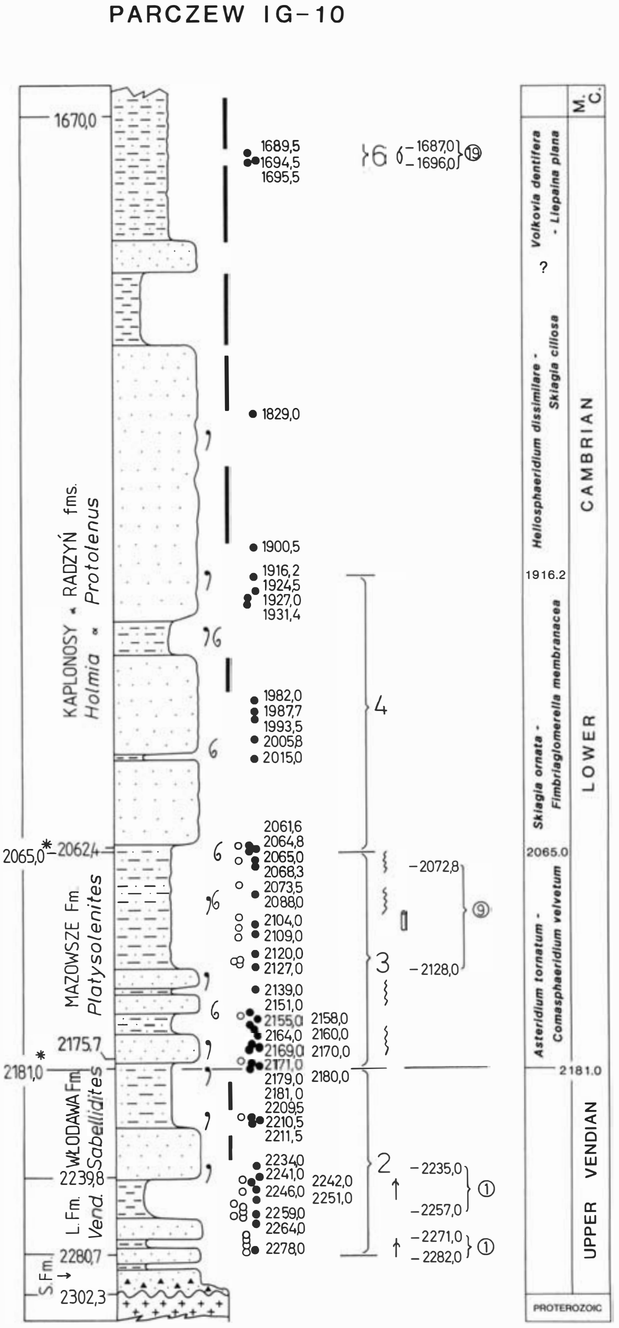
*Appendix 4.* Range chart of acritarch species in the Terebiń IG-5 drillcore.



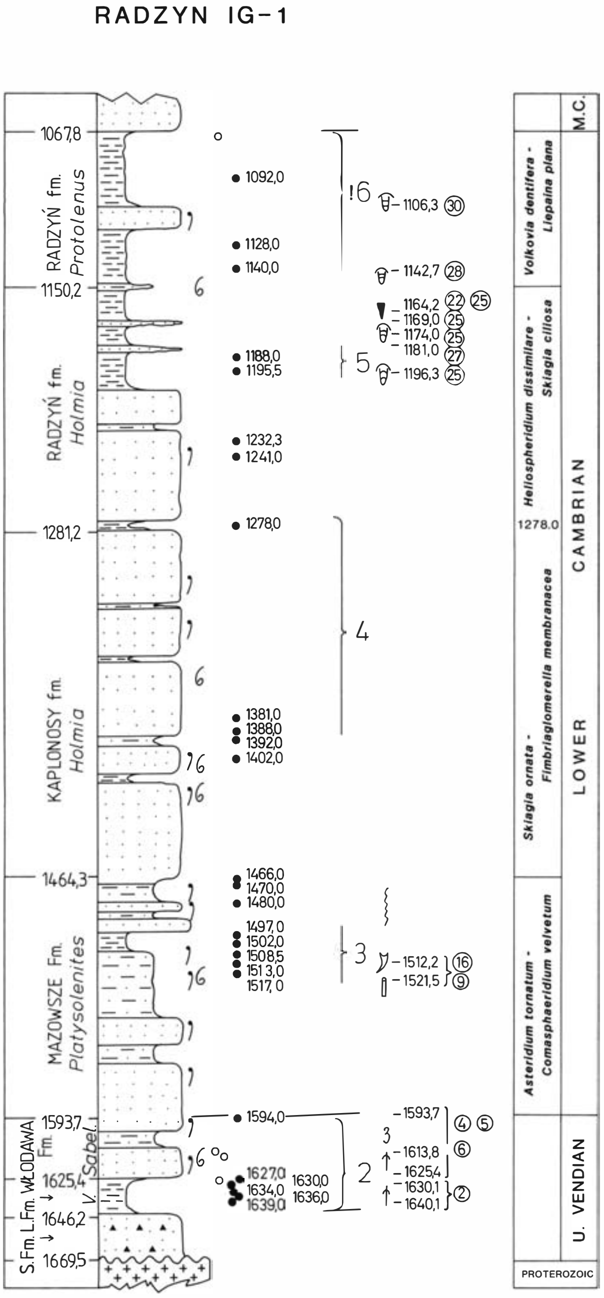
*Appendix 5.* Range chart of acritarch species in the Łopiennik IG-1 drillcore.



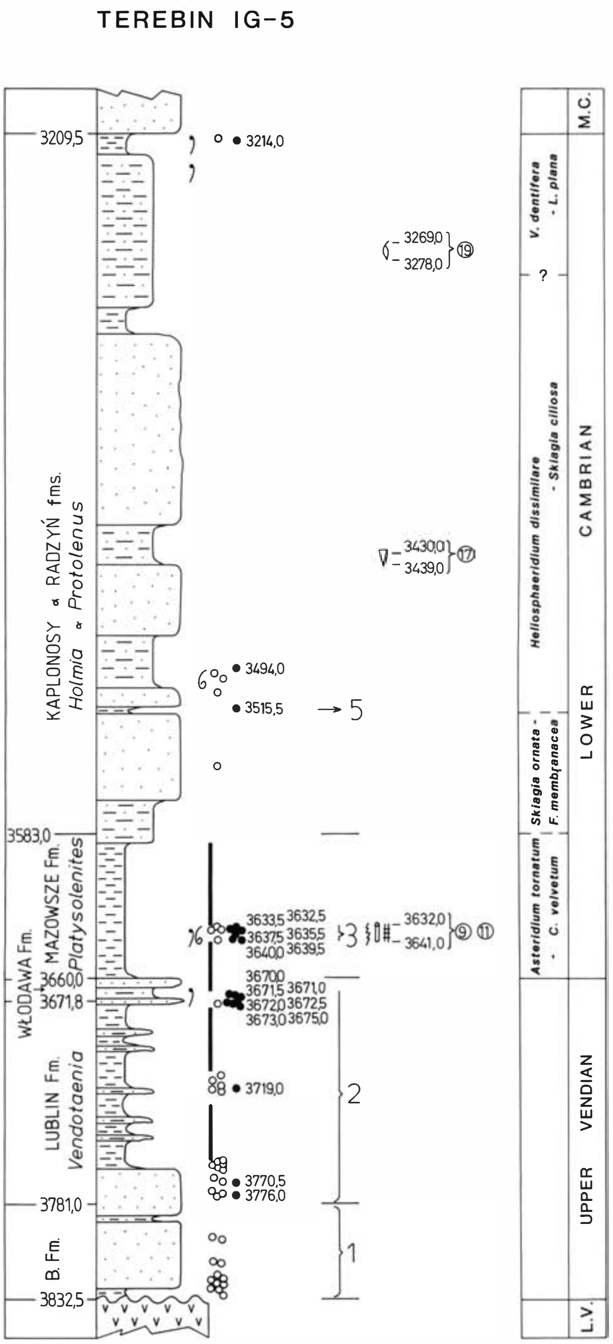
*Appendix 6.* Stratigraphic section of the Upper Vendian and Lower Cambrian sequence in the Kaplonosy IG-1 drillcore. Lithostratigraphic subdivision and faunal zones according to Lendzion (1972a, 1983a, b) and Areń & Lendzion (1978). Occurrence of macrofossils after Lendzion (1972a, 1983c), Gnilovskaya (1979a) and Fuglewicz [unpublished data, personal communication, 1987, concerning *Westonia wimani* (Walcott) and *W. bottnica* (Wiman)]. The Precambrian–Cambrian boundary (at the depth of 1342.5 m*) according to Moczydłowska (1988a, 1989). For additional explanations see Appendix 11.



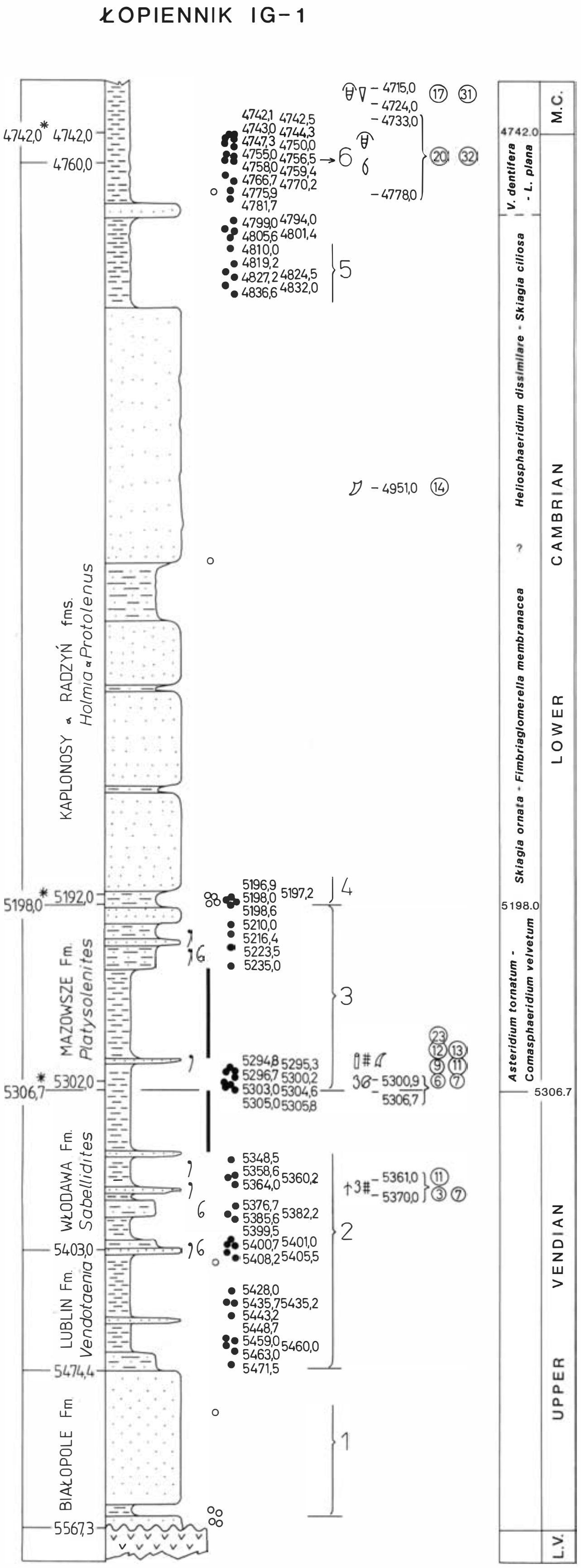
*Appendix 7.* Stratigraphic section of the Upper Vendian and Lower Cambrian sequence in the Parczew IG-10 drillcore. Lithostratigraphic subdivision, faunal zones and occurrence of macrofossils according to Areń & Lendzion (1978). Occurrence of trace fossils after Pacześna (1986). The Precambrian–Cambrian boundary (at the depth of 2181.0 m*) and upper limit of the *Platysolenites antiquissimus* Interval-zone (at the depth of 2065.0 m*) according to acritarch zonation. For explanations see Appendix 11.



*Appendix 8.* Stratigraphic section of the Upper Vendian and Lower Cambrian sequence in the Radzyń IG-1 drillcore. Lithostratigraphic subdivision, faunal zonation and occurrence of macrofossils according to Lendzion (1972a) and Areń & Lendzion (1978). Occurrence of trace fossils after Paczeŝna (1986). For explanations see Appendix 11.



*Appendix 9.* Stratigraphic section of the Upper Vendian and Lower Cambrian sequence in the Terebiń IG-5 drillcore. Lithostratigraphic subdivision, faunal zonation and occurrence of macrofossils according to Areń & Lendzion (1977, unpublished documentation of the research drillhole Terebiń IG-5, Archive of the Geological Institute, Warsaw). Occurrence of trace fossils after Paczeŝna (1986). For explanations see Appendix 11.



*Appendix 10.* Stratigraphic section of the Upper Vendian and Lower Cambrian sequence in the Łopiennik IG-1 drillcore. Lithostratigraphic subdivision and faunal zonation according to Areń & Lendzion (1976, unpublished documentation of the research drillhole Łopiennik IG-1, Archive of the Geological Institute, Warsaw). Occurrence of macrofossils after Lendzion (1977b, and personal communication 1987), Lendzion & Postii (1983), and trace fossils after Pacześna (1986). For explanations see Appendix 11.

Shales and mudstones

Alternating shales and sandstones

Sandstones

Arkosic sandstones

Tuffs and volcanic agglomerates

Basalts

Crystalline basement

Glauconite

Phosphorite

▮ Uncored intervals

S. Fm. Siemiatycze Formation

B. Fm. Białopole Formation

L. Fm. Lublin Formation

***V.*** / ***Vend.*** } ***Vendotaenia*** Zone

***Sabel.*** ***Sabellidites*** Zone

1342.5* Proposed acritarch-zone boundaries

1 – 6 Acritarch assemblages according to Fig. 5 and Appendices 1–5

! 6 Acritarch assemblage recognized according to data by Volkova, 1969a

● Samples yielding acritarchs

○ Samples yielding only cyanobacteria

Previous fossil record:

⑬ ***Anabarella*** sp.

⑫ ***Aldanella attleborensis***

⑪ ***Onuphionella agglutinata***

⑩ ***Onuphionella*** sp.

⑨ ***Platysolenites antiquissimus***

⑧ ***Platysolenites*** sp.

⑦ ***Sabellidites cambriensis***

⑥ ***Sabellidites*** sp.

⑤ ***Tyrasotaenia tungusica***

④ ***Tyrasotaenia podolica***

③ ***Tyrasotaenia*** sp.

② ***Vendotaenia antiqua***

① ***Vendotaenia*** sp.

Trace-fossils: ***Phycodes, Monocraterion, Planolites, Bergaueria, Gyrolithes, Neonereites, Treptichnus, Teichichnus, Bilinichnus, Mammilichnis***

㉜ Trilobite fragments

㉛ ***Eccaparadoxides*** cf. ***oelandicus***
***Eccaparadoxides insularis***

㉚ ***Kingaspis (Kingaspis) borealis***

㉙ ***Ellipsocephalus*** cf. ***polytomus***

㉘ ***Ellipsocephalus*** cf. ***hoffi***

㉗ ***Ellipsocephalus*** cf. ***gripi***

㉖ cf. ***Holmia kjerulfi***

㉕ ***Strenuaeva primaeva***

㉔ ***Indiana*** sp.

㉓ ***Fomitchella*** sp.

㉒ ***Volborthella*** cf. ***tenuis***

㉑ ***Westonia bottnica, W. wimani***

⑳ ***Lingulella ferruginae***

⑲ ***Lingulella*** sp.

⑱ ***Hyolithellus*** cf. ***micans***

⑰ ***Hyolithida***

⑯ ***Coleolella billingsi***

⑮ ***Torellella*** cf. ***laevigata***

⑭ ***Torellella*** sp.

*Appendix 11.* Explanations of graphic symbols used in Appendices 6–10.

# Plate 1

## A–C. *Asteridium tornatum* (Volkova) comb.nov.

A. Terebiń IG-5 drillcore, depth 3640.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6110 t (G/41/1–3).

B. Parczew IG-10 drillcore, depth 2170.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6111 t (P/30/2).

C. Parczew IG-10 drillcore, depth 2160.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6112 t (O/30/1–2).

## D–F. *Asteridium lanatum* (Volkova) comb.nov.

D. Parczew IG-10 drillcore, depth 2127.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6113 t (M/40/1).

E–F. Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. E. Specimen LO 6114 t (Z/39/2). F. Specimen LO 6115 t (W/43/3).

## G–H. *Asteridium spinosum* (Volkova) comb.nov.

G. Radzyń IG-1 drillcore, depth 1388.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6116 t (H/39/2).

H. Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6117 t (G/45/3).

## I–J. *Asteridium pallidum* (Volkova) comb.nov.

I. Radzyń IG-1 drillcore, depth 1278.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6118 t (O/31/4).

J. Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6119 t (R/39/4).

## K–L. *Comasphaeridium agglutinatum* Moczydłowska

K. Kaplonosy IG-1 drillcore, depth 1312.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6120 T (U/31/1).

L. Kaplonosy IG-1 drillcore, depth 1302.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6121 t (P/40/3).

## M. *Comasphaeridium formosum* Moczydłowska

Kaplonosy IG-1 drillcore, depth 1312.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6122 T (V/39).

## N–O. *Comasphaeridium strigosum* (Jankauskas) Downie

Kaplonosy IG-1 drillcore, depth 1314.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. N. Specimen LO 6123 t (N/39/1). O. Specimen LO 6124 t (Q/43/1).

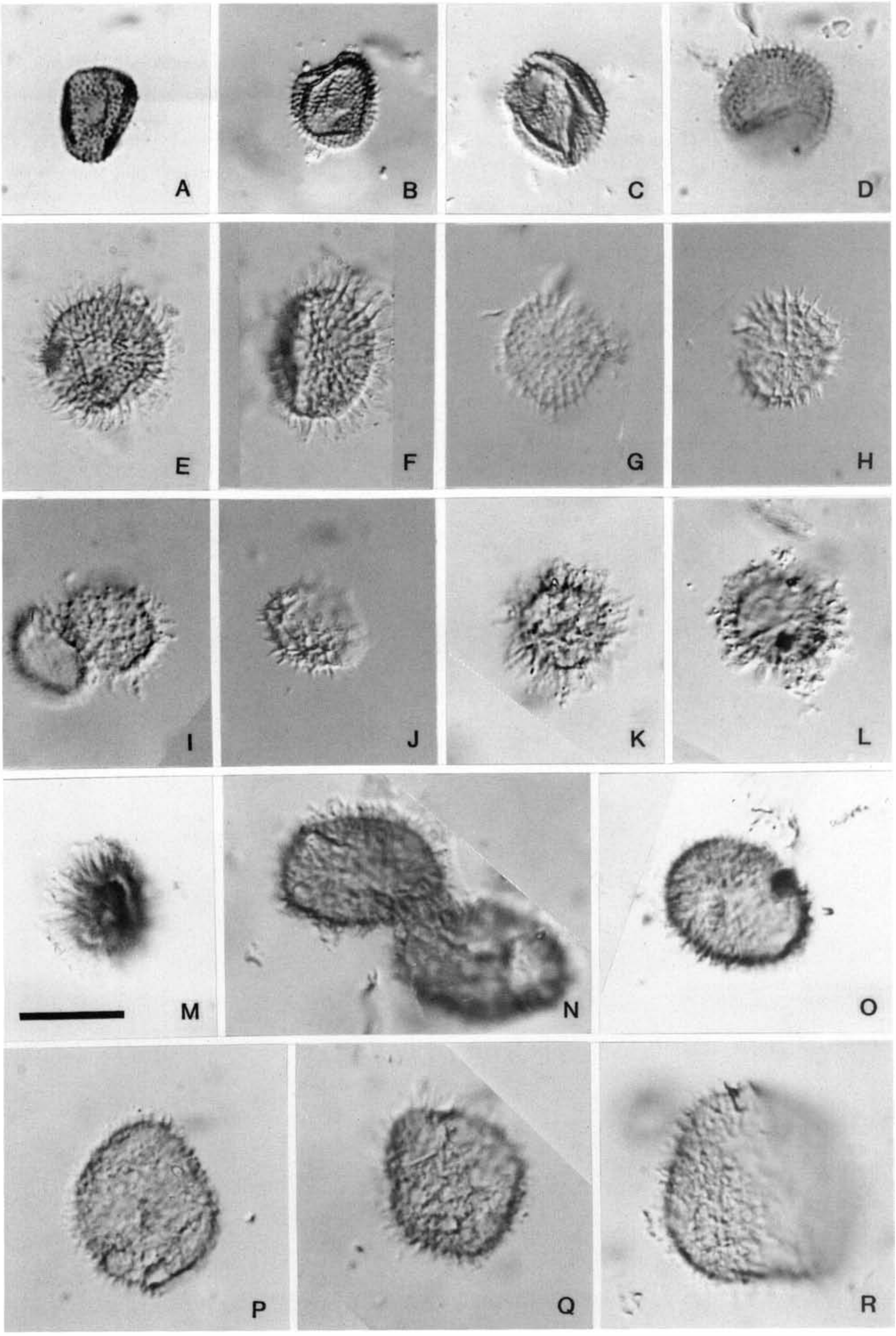
## P–R. *Comasphaeridium velvetum* Moczydłowska

P. Kaplonosy IG-1 drillcore, depth 1312.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6125 T (S/46/2–4).

Q–R. Kaplonosy IG-1 drillcore, depth 1314.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Q. Specimen LO 6126 t (G/42). R. Specimen LO 6127 t (P/33/2).

Scale bar at M equals 15 μm for all micrographs.

All micrographs transmitted light, oil immersion, interference contrast. England Finder coordinates given in brackets following specimen number referring to the collections of Geology Department, Lund University. Abbreviation ‘t’ after the number refers to type specimens and ‘T’ to holotypes.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# Plate 2

## A–D, F. *Comasphaeridium molliculum* Moczydłowska & Vidal

A, C, D. Radzyń IG-1 drillcore, depth 1388.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. A. Specimen LO 6128 t (U/43/4). C. Specimen LO 6130 t (X/36/2). D. Specimen LO 6131 t (G/45/1). B. Radzyń IG-1 drillcore, depth 1381.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6129 t (Q/43/4).

F. Parczew IG-10 drillcore, depth 1982.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6132 t (T/50).

## E. *Comasphaeridium brachyspinosum* (Kirjanov) Moczydłowska & Vidal

Parczew IG-10 drillcore, depth 1916.2 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6133 t (T/37).

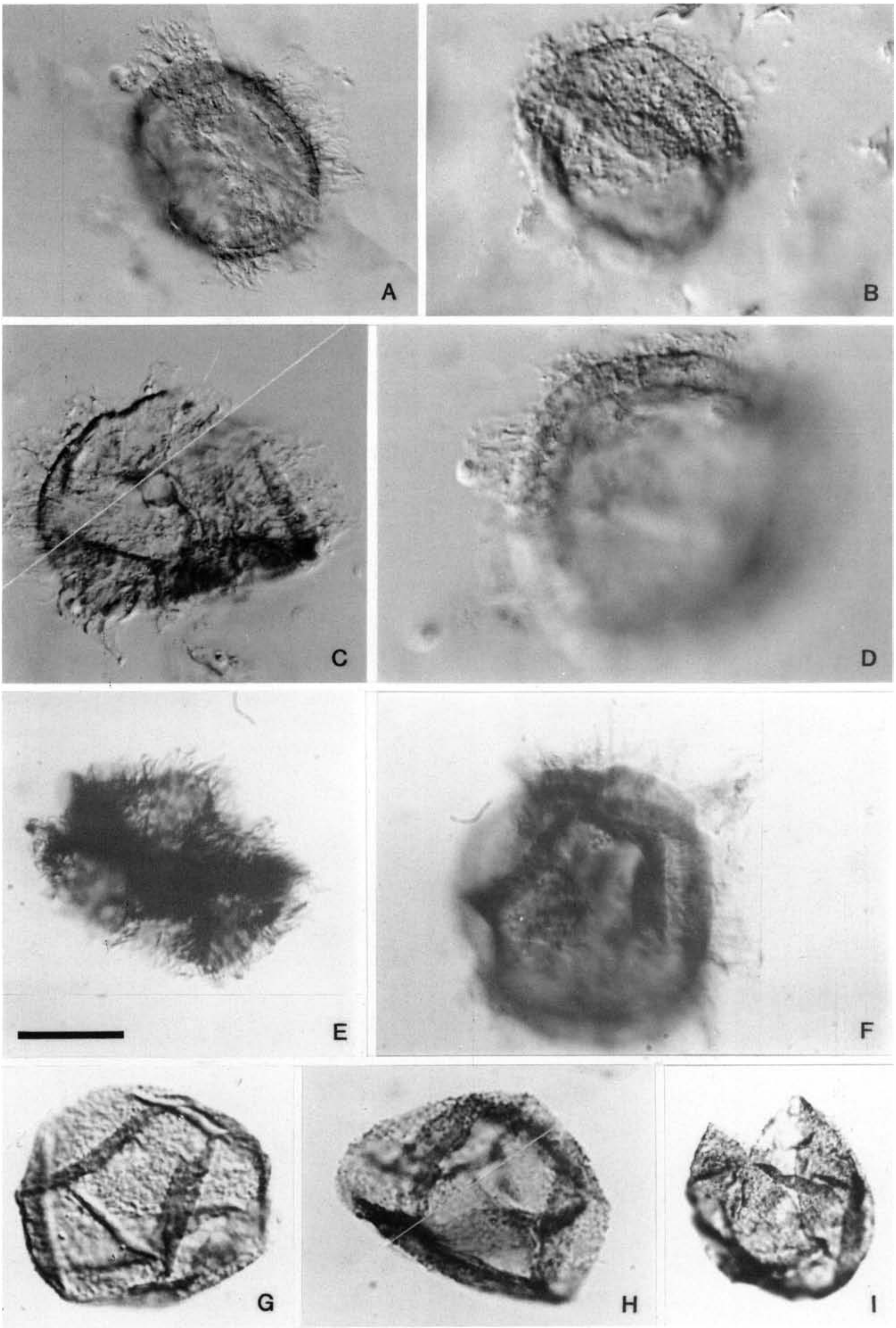
## G–I. *Lophosphaeridium tentativum* Volkova

G. Parczew IG-10 drillcore, depth 2179.0 m, upper part of the Włodawa Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6134 t (S/31/4).

H. Terebiń IG-5 drillcore, depth 3637.5 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6135 t (H/28/2).

I. Parczew IG-10 drillcore, depth 1924.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6136 t (K/47/3).

Scale bar at E equals 15 µm for all micrographs.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# Plate 3

## A. *Lophosphaeridium dubium* (Volkova) comb.nov.

Radzyń IG-1 drillcore, depth 1388.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6137 t (E/32).

## B. *Lophosphaeridium truncatum* Volkova

Radzyń IG-1 drillcore, depth 1195.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6138 t (S/39).

## C. *Granomarginata prima* Naumova

Parczew IG-10 drillcore, depth 2088.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6139 t (K/47/3).

## D–F. *Granomarginata squamacea* Volkova

D. E. Parczew IG-10 drillcore, depth 2139.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. D. Specimen LO 6140 t (G/41/4). E. Specimen LO 6141 t (K/36/4). F. Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6142 t (H/38/4).

## G. *Fimbriaglomerella membranacea* (Kirjanov) Moczydłowska & Vidal

Parczew IG-10 drillcore, depth 1982.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6143 t (U/34/2).

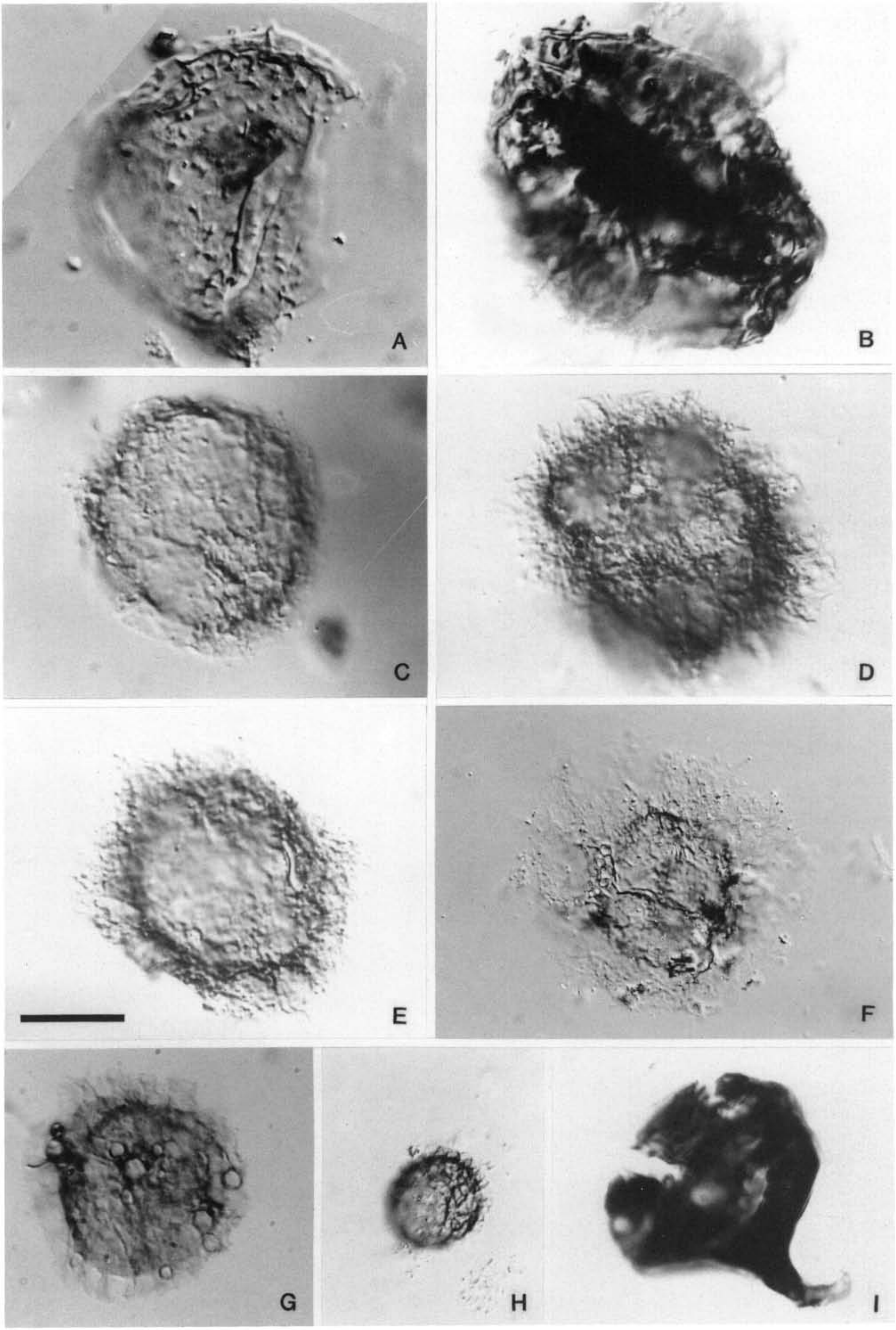
## H. *Fimbriaglomerella minuta* (Jankauskas) Moczydłowska & Vidal

Parczew IG-10 drillcore, depth 2065.0 m, upper part of the Mazowsze Formation, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6144 t (Q/47/3–4).

## I. *Alliumella baltica* Vanderflit

Łopiennik IG-1 drillcore, depth 4755.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6145 t (L/45/3).

Scale bar at E equals 15 µm for A, B, G; 12 µm for C; 10 µm for I; and 20 µm for D, E, F, H.


A
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I

# Plate 4

## A–D. *Pterospermella velata* Moczydłowska

A, C–D. Radzyń IG-1 drillcore, depth 1517.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. A. Specimen LO 6146 T (T/50). C. Specimen LO 6148 t (V/44/1). D. Specimen LO 6149 t (S/33/1).

B. Kaplonosy IG-1 drillcore, depth 1312.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6147 t (Y/32).

## E. *Pterospermella vitalis* Jankauskas

Parczew IG-10 drillcore, depth 2139.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6150 t (G/34/2).

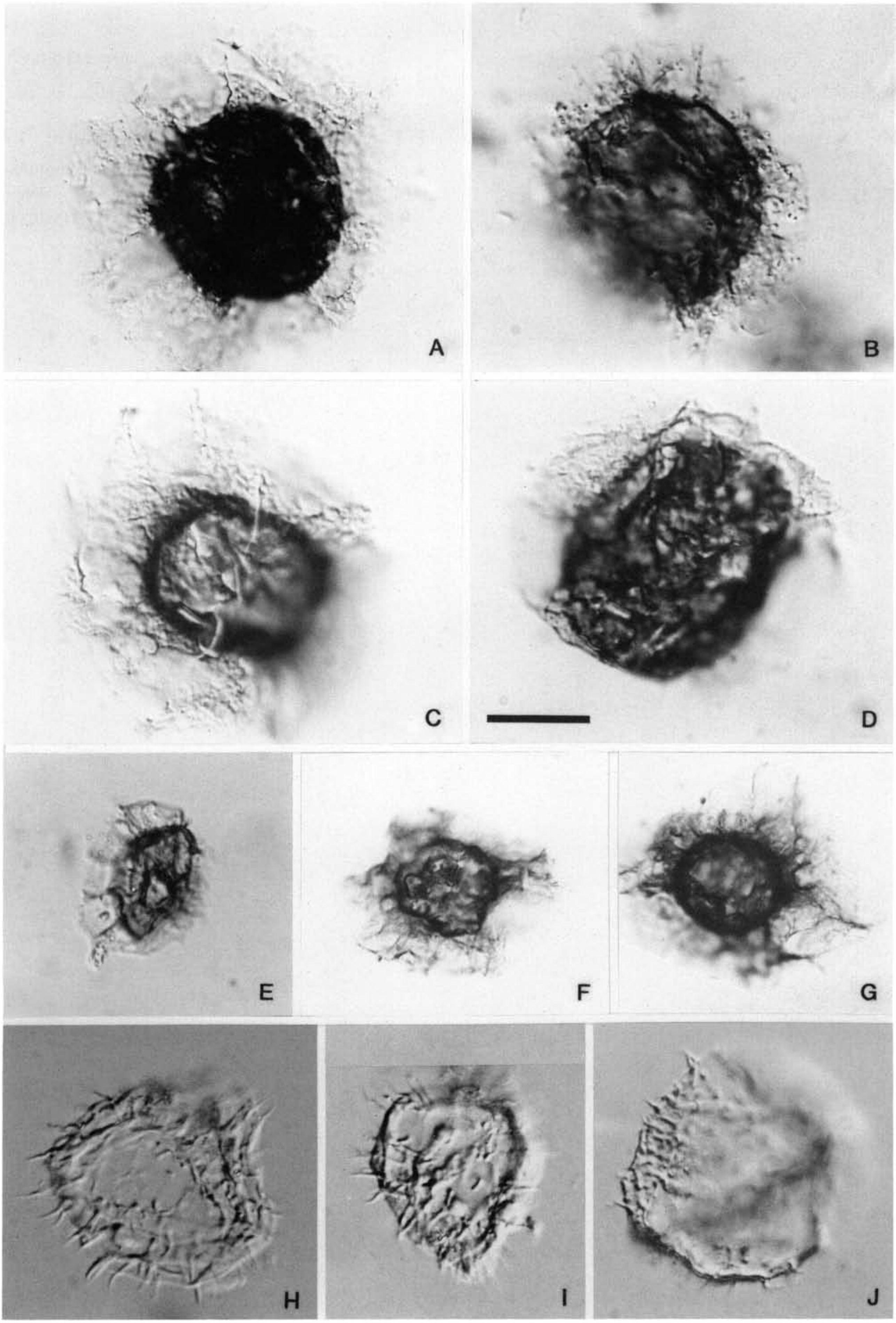
## F–G. *Pterospermella solida* (Volkova) Volkova

Parczew IG-10 drillcore, depth 1689.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. F. Specimen LO 6151 t (F/40/2–4). G. Specimen LO6152 t (K/49).

## H–J. *Globosphaeridium cerinum* (Volkova) comb.nov.

Radzyń IG-1 drillcore, depth 1278.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. H. Specimen LO 6153 t (I/32/1). I. Specimen LO 6154 t (T/33/4). J. Specimen LO 6155 t (Y/38).

Scale bar at D equals 20 μm for A, E, F, G; 15 μm for B, C, D, H, I, J.


A
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I
J

# Plate 5

## A. *Skiagia compressa* (Volkova) Downie

Radzyń IG-1 drillcore, depth 1278.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6156 t (O/45/2).

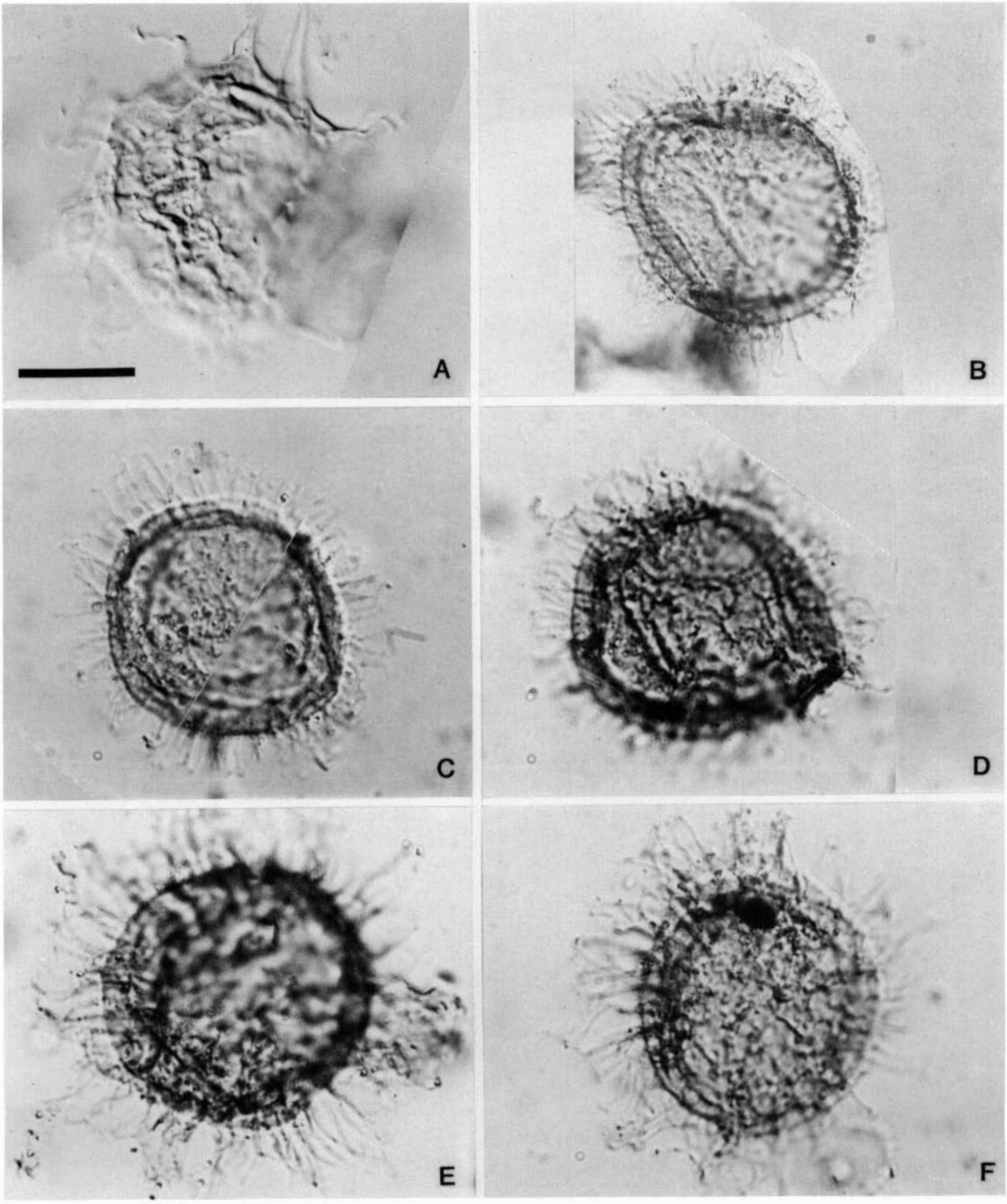
## B–D. *Skiagia orbiculare* (Volkova) Downie

Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. B. Specimen LO 6157 t (Q/44/3). C. Specimen LO 6158 t (W/36/4). D. Specimen LO 6159 t (L/33/1).

## E–F. *Skiagia ornata* (Volkova) Downie

Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. E. Specimen LO 6160 t (T/44). F. Specimen LO 6161 t (T/36/1).

Scale bar at A equals 15 µm for all micrographs.


A
B
C
D
E
F

# Plate 6

## A–D. *Skiagia ornata* (Volkova) Downie

A. B. Radzyń IG-1 drillcore, depth 1278.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. A. Specimen LO 6162 t (S/45/2–4). B. Specimen LO 6163 t (F/47/3).

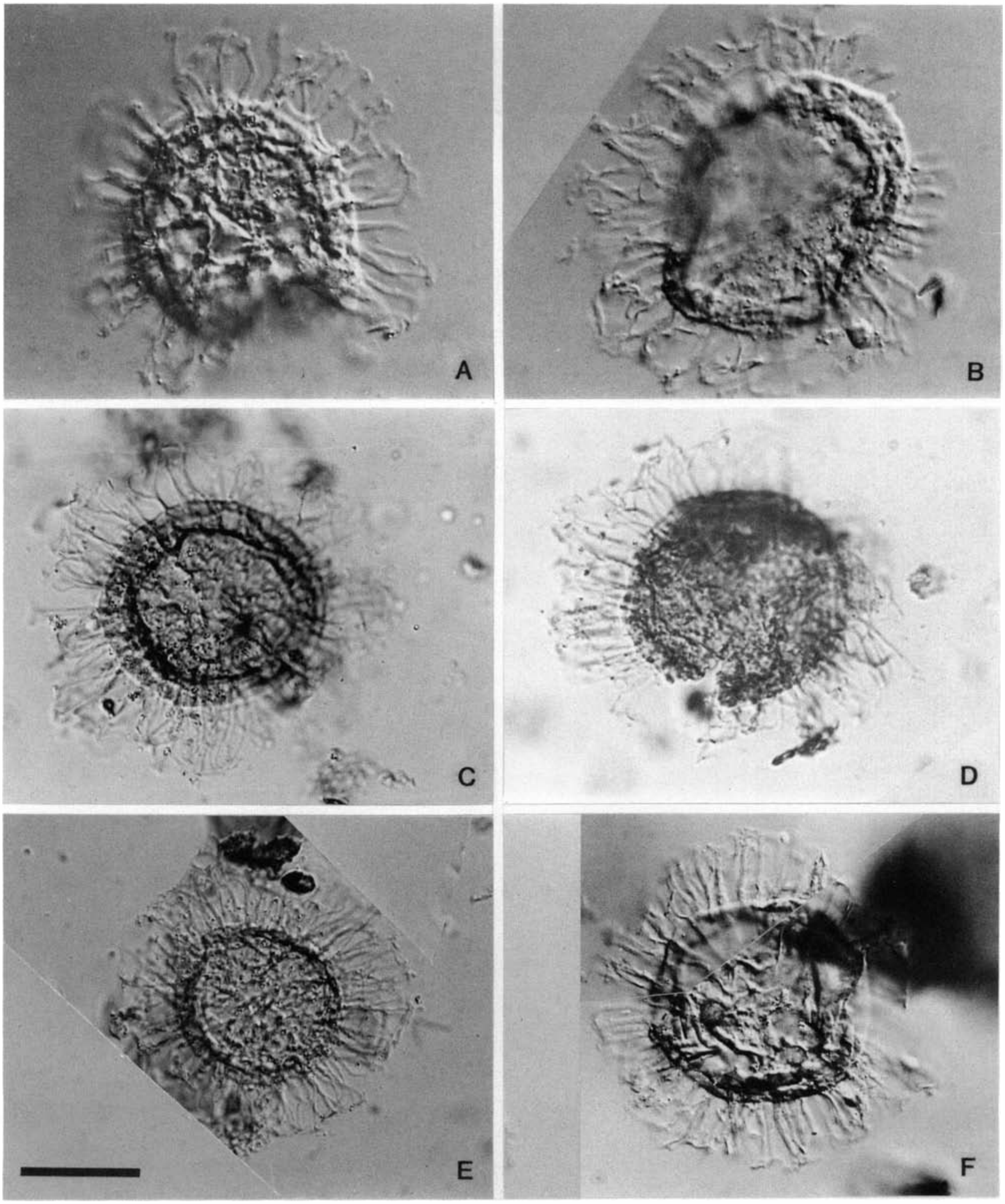
C. D. Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. C. Specimen LO 6164 t (I/46). D. Specimen LO 6165 t (L/30/4).

## E–F. *Skiagia scottica* Downie

E. Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6166 t (Z/44/3).

F. Radzyń IG-1 drillcore, depth 1278.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6167 t (Q/41/4).

Scale bar at E equals 15 μm for all micrographs.


A
B
C
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E
F

# Plate 7

## A–F. *Skiagia ciliosa* (Volkova) Downie

A. B. C. D. F. Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. A. Specimen LO 6168 t (T/37/4). B. Specimen LO 6169 t (P/46/1). C. Specimen LO 6170 t (Y/30/3). D. Specimen LO 6171 t (R/47). F. Specimen LO 6173 t (U/43).

E. Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6172 t (F/49/2).

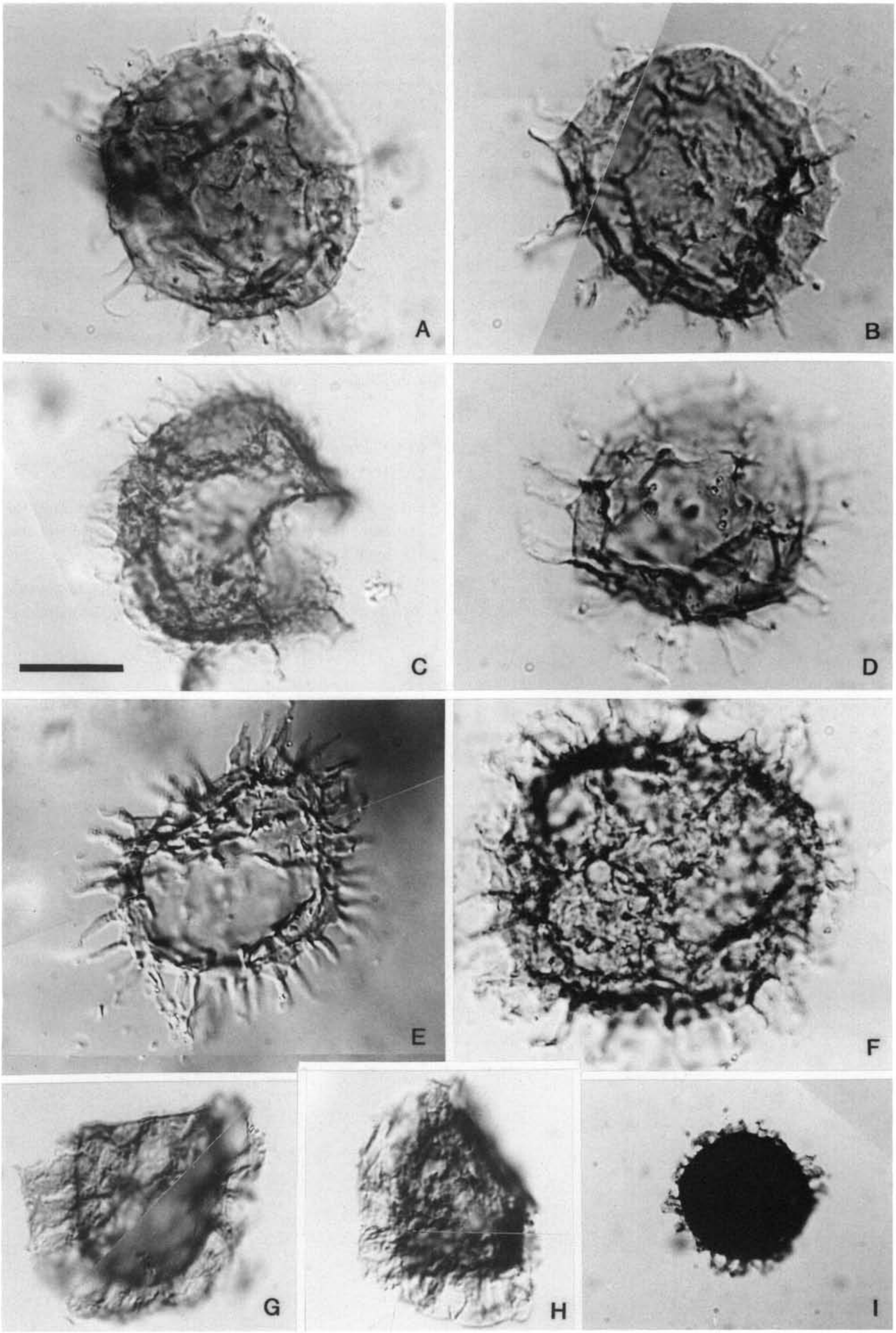
## G–H. *Skiagia pura* Moczydłowska

Parczew IG-10 drillcore, depth 1916.2 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. G. Specimen LO 6174 t (Z/42/3). H. Specimen LO 6175 T (Y/38/1).

## I. *Skiagia* cf. *insigne* (Fridrichsone) Downie

Łopiennik IG-1 drillcore, depth 4756.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6176 t (R/38).

Scale bar at C equals 12 µm for A–F; 15 µm for G–H; 28 µm for I.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# Plate 8

## A, E–J. *Heliosphaeridium dissimilare* (Volkova) comb.nov.

A, E–H. Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. A. Specimen LO 6177 t (U/38/1). E. Specimen LO 6181 t (S/39). F. Specimen LO 6182 t (K/32/2). G. Specimen LO 6183 t (V/48). H. Specimen LO 6184 t (T/37).

I–J. Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. I. Specimen LO 6185 t (S/42). J. Specimen LO 6186 t (H/36).

## B–D. *Heliosphaeridium coniferum* (Downie) comb.nov.

B. Radzyń IG-1 drillcore, depth 1278.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6178 t (I/46/3).

C. Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliospaheridium–Skiagia* Zone. Specimen LO 6179t (H/43/4).

D. Terebiń IG-5 drillcore, depth 3515.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6180 t (Y/39/2).

## K–N. *Heliosphaeridium lubomlense* (Kirjanov) comb.nov.

K. Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6187 t (W/39/2).

L–M. Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. L. Specimen LO 6188 t (G/43/3). M. Specimen LO 6189 t (M/40/4).

N. Parczew IG-10 drillcore, depth 1695.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6190 t (G/38/1).

## O. *Heliosphaeridium obscurum* (Volkova) comb.nov.

Radzyń IG-1 drillcore, depth 1188.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6191 t (M/40/4).

## P–Q. *Heliosphaeridium longum* (Moczydłowska) comb.nov.

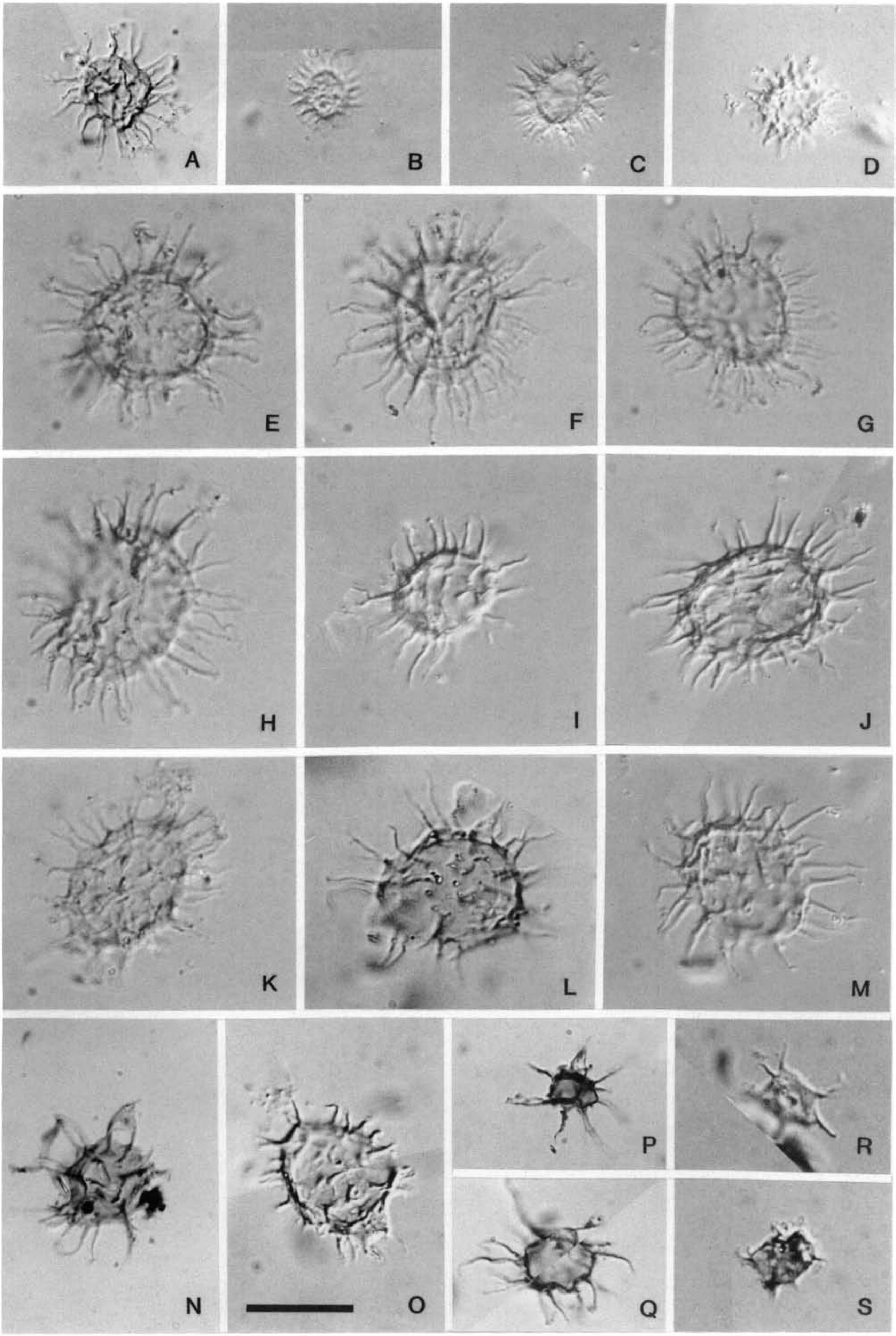
P. Parczew IG-10 drillcore, depth 1695.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6192 t (N/47).

Q. Parczew IG-10 drillcore, depth 1694.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6193 T (F/42).

## R–S. *Heliosphaeridium radzynicum* (Volkova) comb.nov.

Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. R. Specimen LO 6194 t (X/38). S. Specimen LO 6195 t (V/36/2).

Scale bar at O equals 12 µm for E–O, R–S; 15 µm for B–D; 20 µm for A, P–Q.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O
P
R
Q
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# Plate 9

## A–G. *Estiastra minima* Volkova

Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. A. Specimen LO 6196 t (Z/47/1). B. Specimen LO 6197 t (T/41). C. Specimen LO 6198 t (O/38). D. Specimen LO 6199 t (R/46/2). E. Specimen LO 6200 t (R/42/2). F. Specimen LO 6201 t (S/43/1). G. Specimen LO 6202 t (P/42/4).

## H–I. *Cymatiosphaera postii* (Jankauskas) Jankauskas

H. Radzyń IG-1 drillcore, depth 1195.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6203 t (Y/39).

I. Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6204 t (M/38).

## J. *Cymatiosphaera* sp.

Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6405 t (O/41).

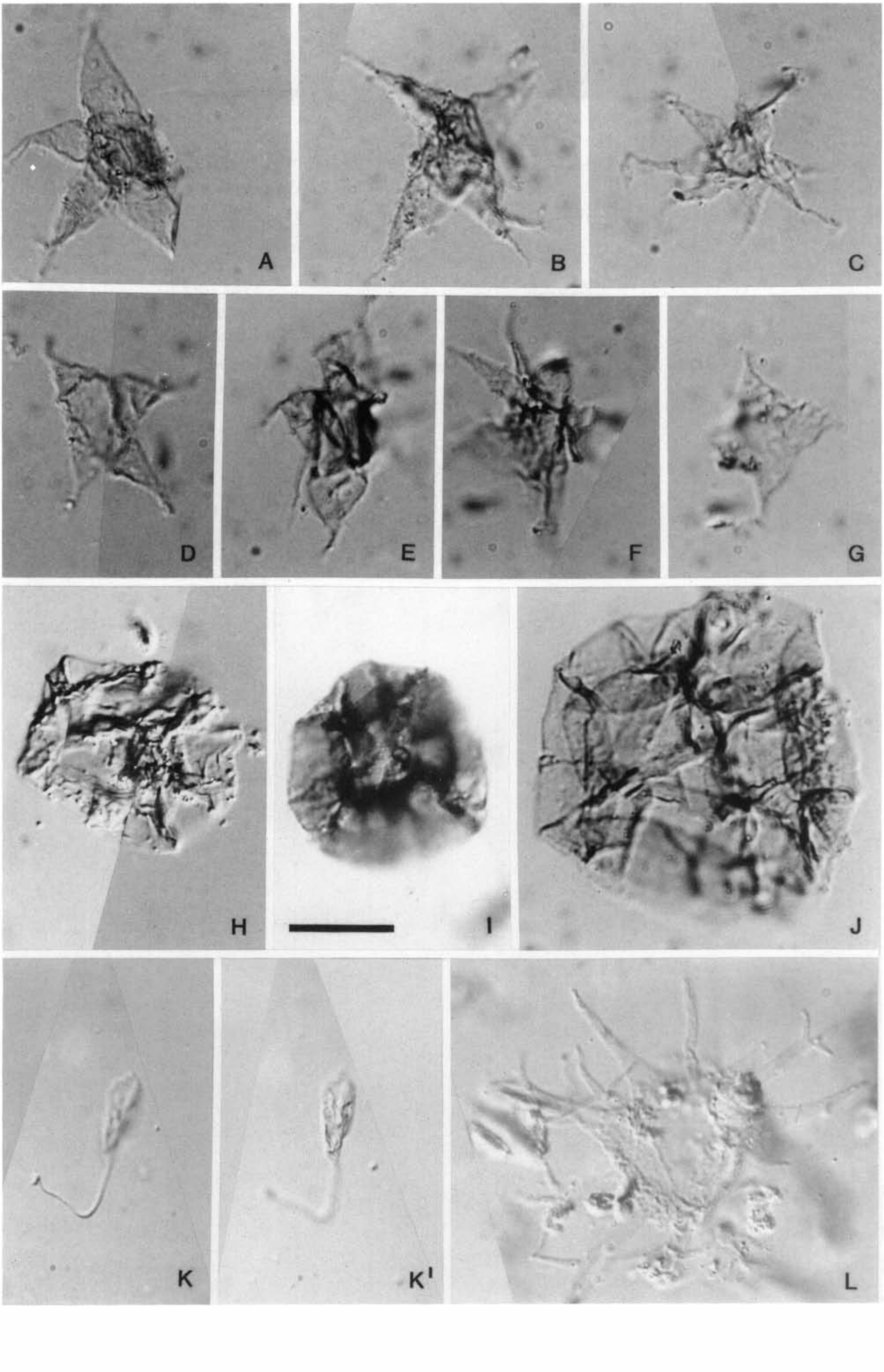
## K–K<sup>l</sup>. *Volkovia dentifera* (Volkova) Downie

Łopiennik IG-1 drillcore, depth 4756.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6206 t (N/36). K, K$^{l}$. The same specimen in different focus.

## L. *Multiplicisphaeridium dendroideum* (Jankauskas) Jankauskas & Kirjanov

Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6207 t (K/34/2).

Scale bar at I equals 10 µm for A–G; 20 µm for H–I; 12 µm for J; 25 µm for K; 15 µm for L.


A
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H
I
J
K
K'
L

# Plate 10

## A. *Goniosphaeridium implicatum* (Fridrichsone) Downie

Kaplonosy IG-1 drillcore, depth 1124.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6208 t (Y/38/3).

## B. *Goniosphaeridium varium* (Volkova) Downie

Łopiennik IG-1 drillcore, depth 4756.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6209 t (U/41/1).

## C–D. *Liepaina plana* Jankauskas & Volkova

C. Parczew IG-10 drillcore, depth 1694.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6210 t (Y/43).

D. Parczew IG-10 drillcore, depth 1695.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6211 t (W/54).

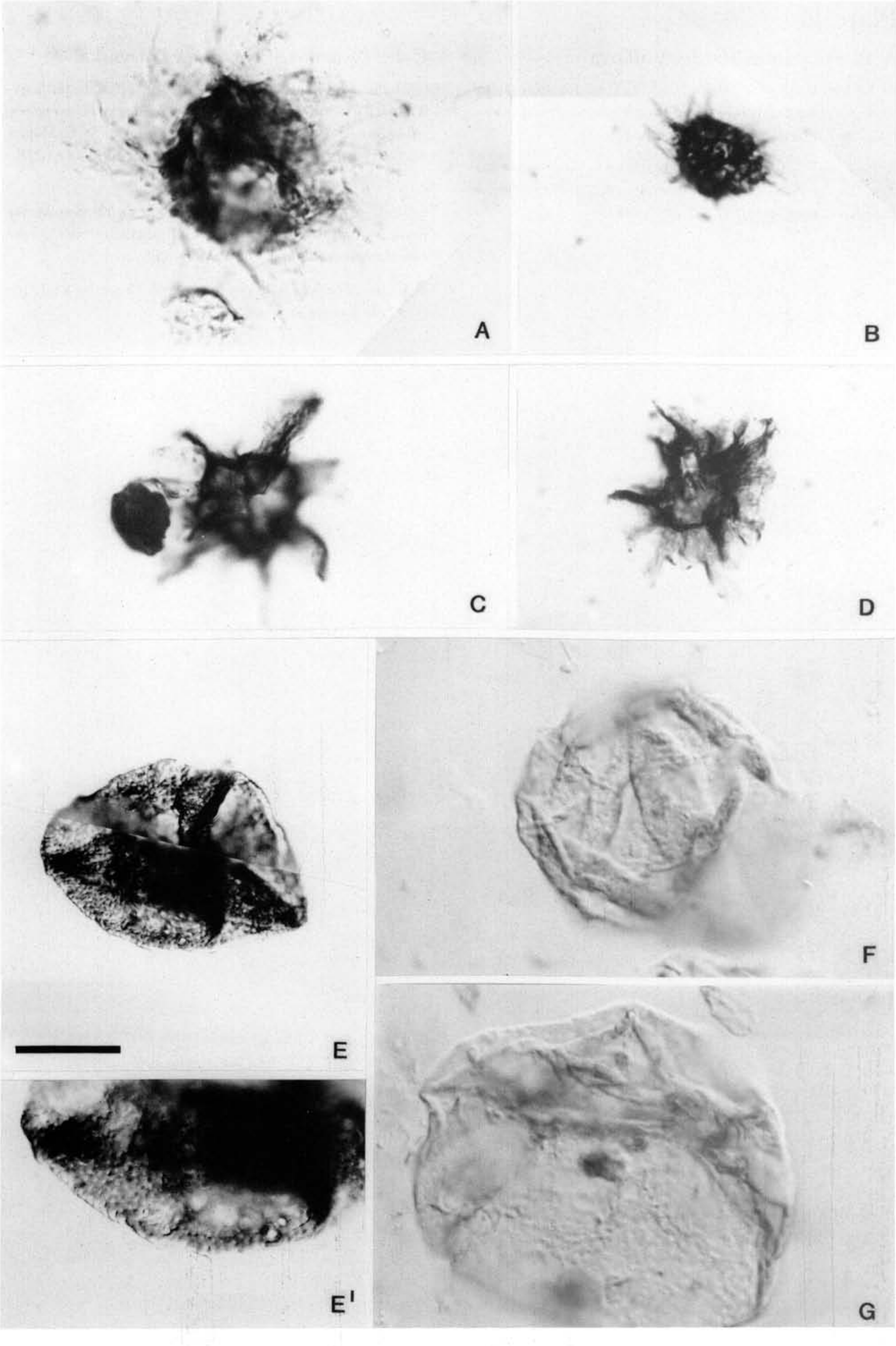
## E–E$^{|}$. *Tasmanites volkovae* Kirjanov

Radzyń IG-1 drillcore, depth 1140.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Volkovia–Liepaina* Zone. Specimen LO 6212 t (U/46). E$^{|}$ magnified part of the specimen from E showing the wavy outline of the vesicle.

## F–G. *Tasmanites bobrowskae* Ważyńska

Radzyń IG-1 drillcore, depth 1388.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. F. Specimen LO 6213 t (X/35). G. Specimen LO 6214 t (V/37/2).

Scale bar at E equals 20 µm for A, G; 30 µm for B; 25 µm for C, D, F; 60 µm for E; 35 µm for E$^{|}$.


A
B
C
D
E
F
E'
G

# Plate 11

## A–B. *Tasmanites tenellus* Volkova

A. Radzyń IG-1 drillcore, depth 1388.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6215 t (O/31).

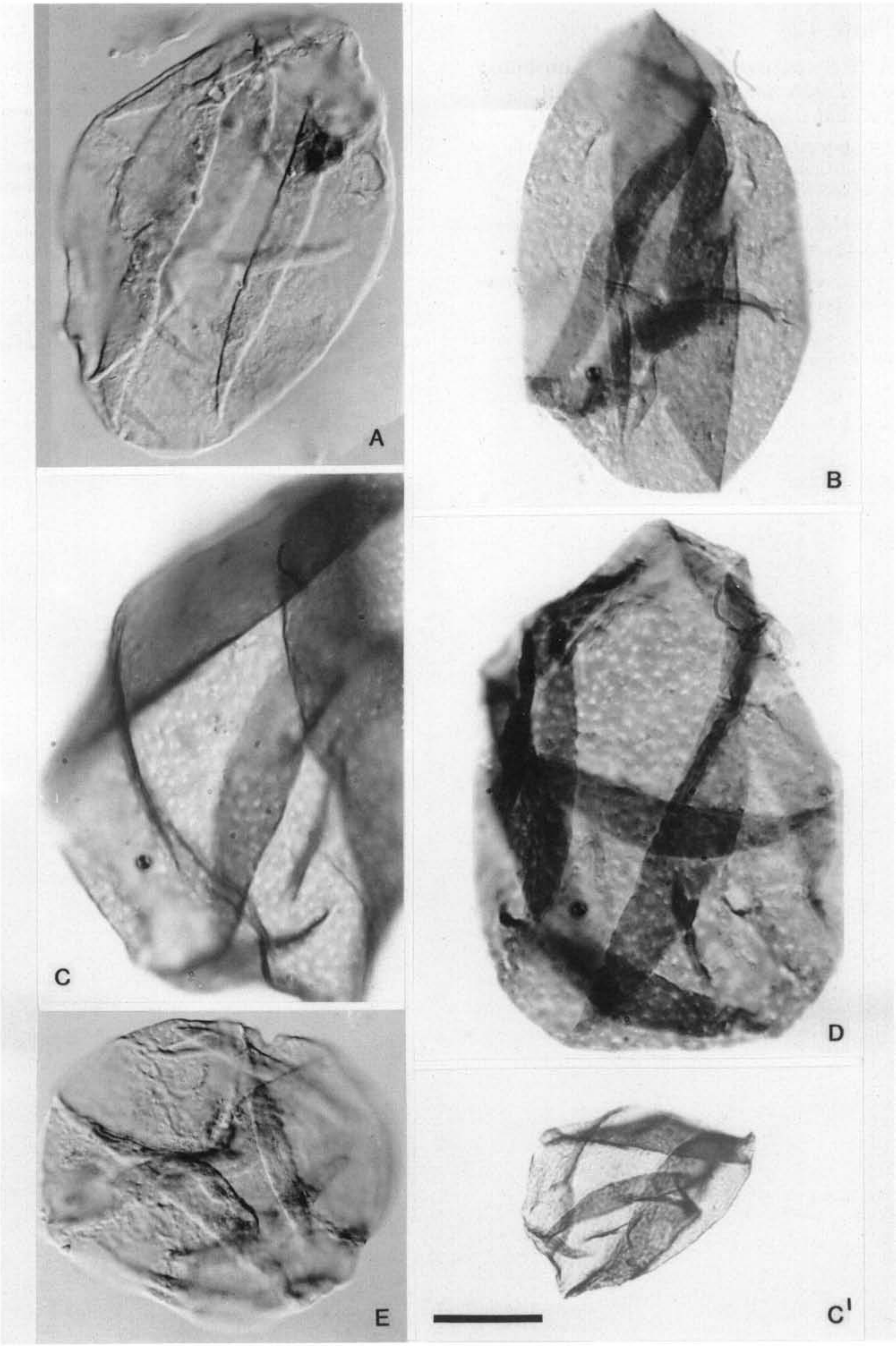
B. Parczew IG-10 drillcore, depth 1993.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6216 t (X/47/3).

## C–E. *Tasmanites bobrowskae* Ważyńska

C–D. Parczew IG-10 drillcore, depth 1993.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. C–C$^1$. Specimen LO 6217 t (E/53/3). C. Magnified part of the specimen in C$^1$. D. Specimen LO 6218 t (T/51/3).

E. Radzyń IG-1 drillcore, depth 1388.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6219 t (X/31).

Scale bar at C$^1$ equals 25 µm for A, B, E; 15 µm for C; 40 µm for C$^1$; 18 µm for D.


A
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C
D
E
C'

# Plate 12

## A–H. Spheromorphic acritarchs attributed to *Leiosphaeridia* sp. from the Upper Vendian.

A–B. Terebiń IG-5 drillcore, depth 3776.0 m, Lublin Formation, Upper Vendian. A. Specimen LO 6220 t (A/34/3). B. Specimen LO 6121 t (K/42/3).

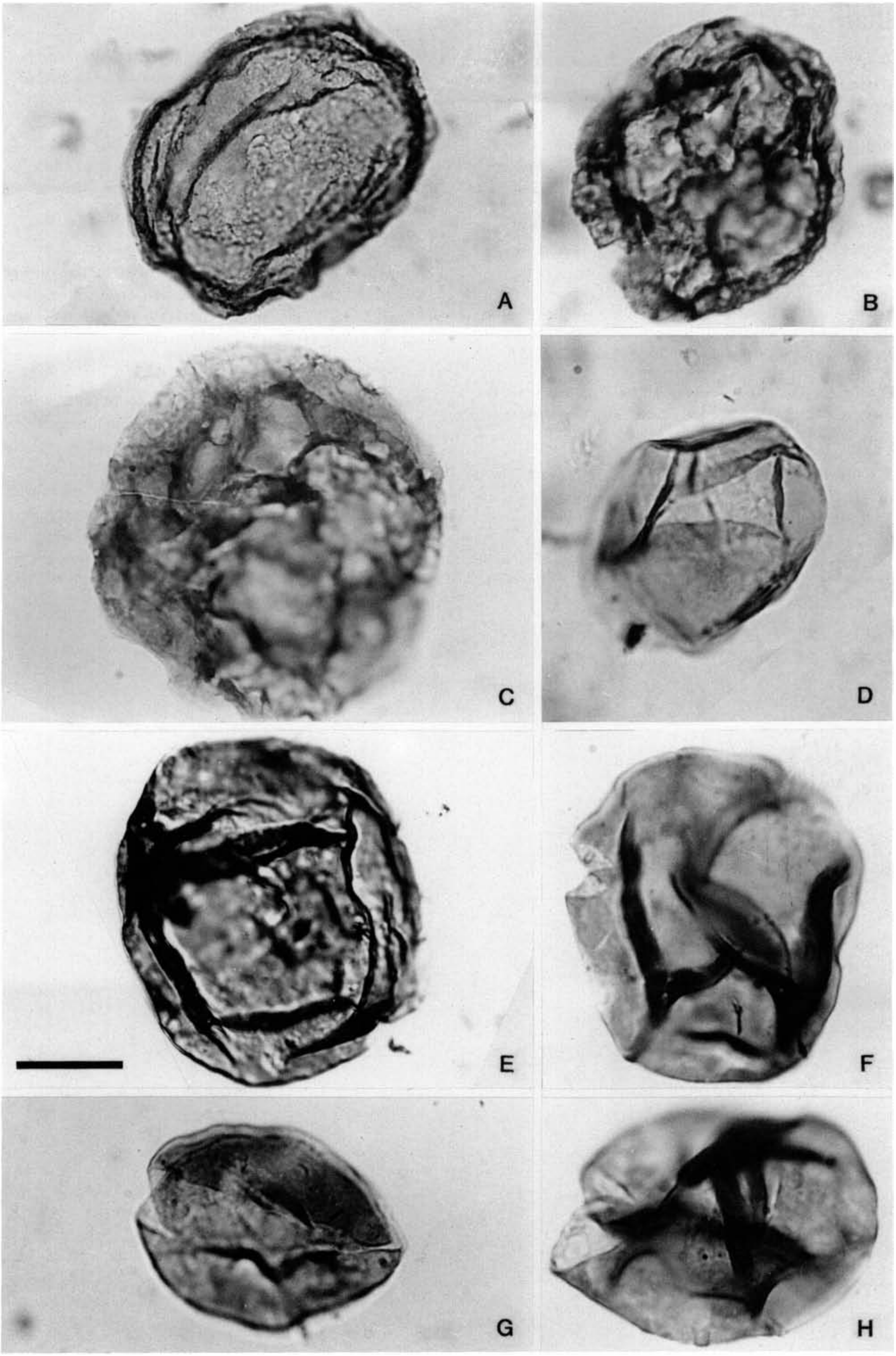
C. Parczew IG-10 drillcore, depth 2278.0 m, Lublin Formation, Upper Vendian. Specimen LO 6222 t (V/38/2).

D. Parczew IG-10 drillcore, depth 2241.0 m, Lublin Formation, Upper Vendian. Specimen LO 6223 t (P/42).

E. Radzyń IG-1 drillcore, depth 1594.0 m, Włodawa Formation, Upper Vendian. Specimen LO 6224 t (X/45/1).

F–H. Parczew IG-10 drillcore, depth 2210.5 m, Włodawa Formation, Upper Vendian. F. Specimen LO 6225 t (F/41/1). G. Specimen LO 6226 t (K/38/1). H. Specimen LO 6227 t (U/47/2).

Different states of preservation are displayed. All show compression folds on the wall. Different appearances depend on the thickness of the vesicle wall and variable degrees of corrosion. A: Strongly corroded, thin-walled vesicle. B, C, E: Strongly corroded thick wall. D, G: Thin-walled vesicles, not correded. F, H: Uncorroded but thick-walled vesicles. B, F, G: Ruptures of the wall caused by compression. G: Possible excystment by the median split. Scale bar at E equals 28 µm for A; 35 µm for B, 18 µm for C; 15 µm for D–H.


A
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# Plate 13

## A–J. Spheromorphic acritarchs attributed to *Leiosphaeridia* sp. from the Lower Cambrian.

A. Radzyń IG-1 drillcore, depth 1517.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6228 t (S/31/1).

B. Parczew IG-10 drillcore, depth 2073.5 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6229 t (P/35/2).

C. Łopienik IG-1 drillcore, depth 5197.2 m, upper part of the Mazowsze Formation, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6230 t (F/35/3).

D. Parczew IG-10 drillcore, depth 2169.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6231 t (P/47/4).

E. Radzyń IG-1 drillcore, depth 1502.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6232 t (Q/46/3).

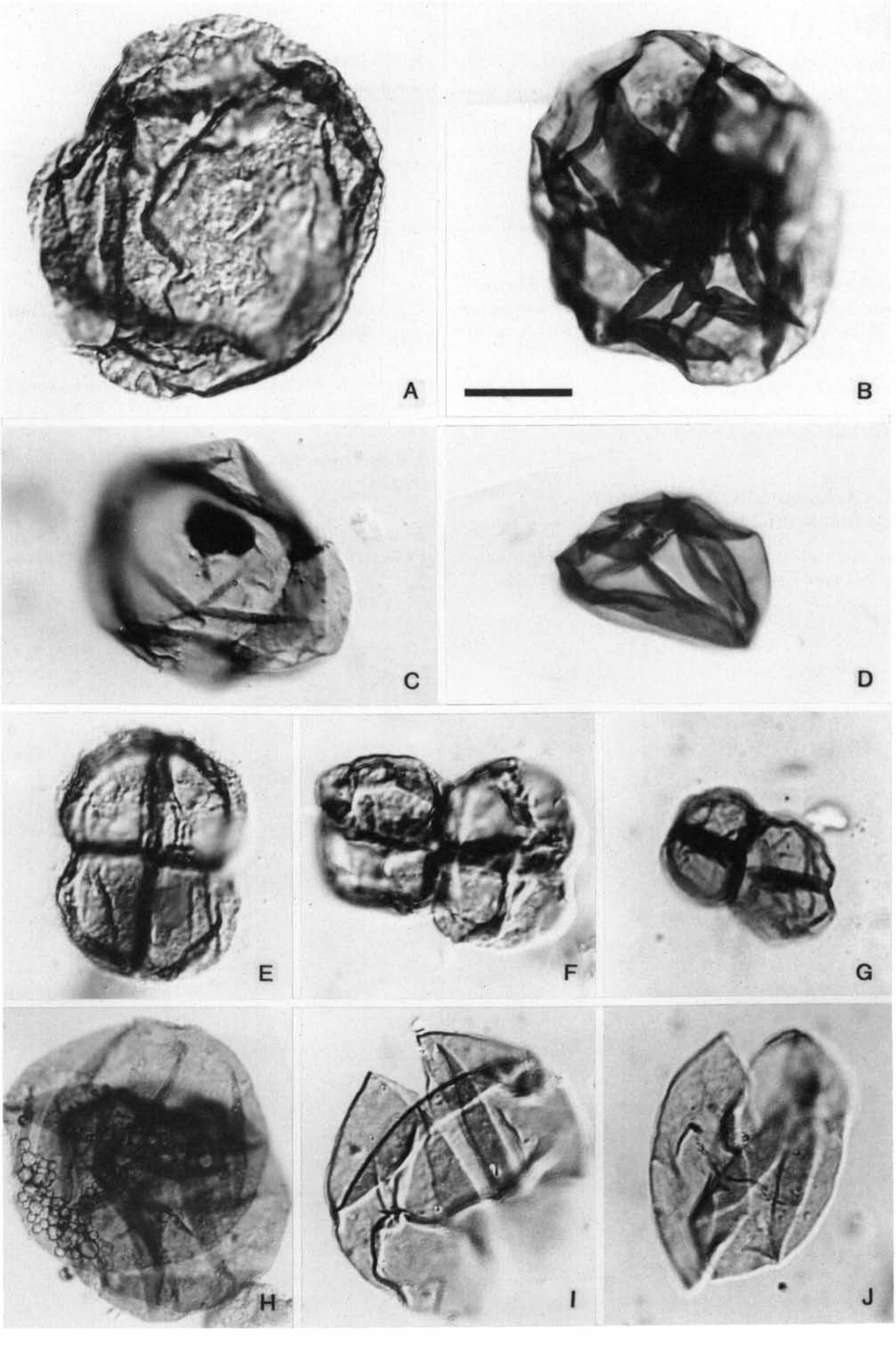
F. Kaplonosy IG-1 drillcore, depth 1250.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6233 t (R/45/4).

G. Parczew IG-10 drillcore, depth 2073.5 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6234 t (T/47/2–4).

H. Parczew IG-10 drillcore, depth 1993.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6235 t (W/49/1–2).

I–J. Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. I. Specimen LO 6236 t (S/36/2). J. Specimen LO 6237 t (K/44).

Figured specimens display different states of preservation. A: Strongly corroded thick vesicle wall. B: Slightly corroded thick vesicle wall with regular compression folds. C: Vesicle with dark internal spot interpreted as coagulated intracellular organic matter. D: Very well preserved vesicle with thick and strongly folded wall. E–G: Spheromorphic acritarchs undergoing cell division. H: Vesicle displaying imprints after growth of pyrite crystals. I–J: Possible excystment by median split. Scale bar at B equals 15 µm for A–C, I–J; 25 µm for D; 10 µm for E–G; 20 µm for H.


A
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# Plate 14

## A–F. *Leiosphaeridia* sp.

A–B. Parczew IG-10 drillcore, depth 1993.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. A. Specimen LO 6238 t (D/50/1–2). B. Specimen LO 6239 t (S/50/3).

C. Kaplonosy IG-1 drillcore, depth 1079.0 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Heliosphaeridium–Skiagia* Zone. Specimen LO 6240 t (H/42).

D–E. Parczew IG-10 drillcore, depth 2005.8 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. D. Specimen LO 6241 t (W/44/1–3). E. Specimen LO 6242 t (B/49).

F. Parczew IG-10 drillcore, depth 1993.5 m, Kaplonosy–Radzyń formations, Lower Cambrian, *Skiagia–Fimbriaglomerella* Zone. Specimen LO 6243 t (Z/50/4).

## G–H. Fragments of filamentous cyanobacterial sheaths.

G. Terebiń IG-5 drillcore, depth 3673.0 m, Lublin Formation, Upper Vendian. Specimen LO 6244 t (X/31/1).

H. Terebiń IG-5 drillcore, depth 3672.0 m, Lublin Formation, Upper Vendian. Specimen LO 6245 t (I/42).

Both specimens display regular annular thickenings on the sheaths, presumably pre-diagenetic feature.

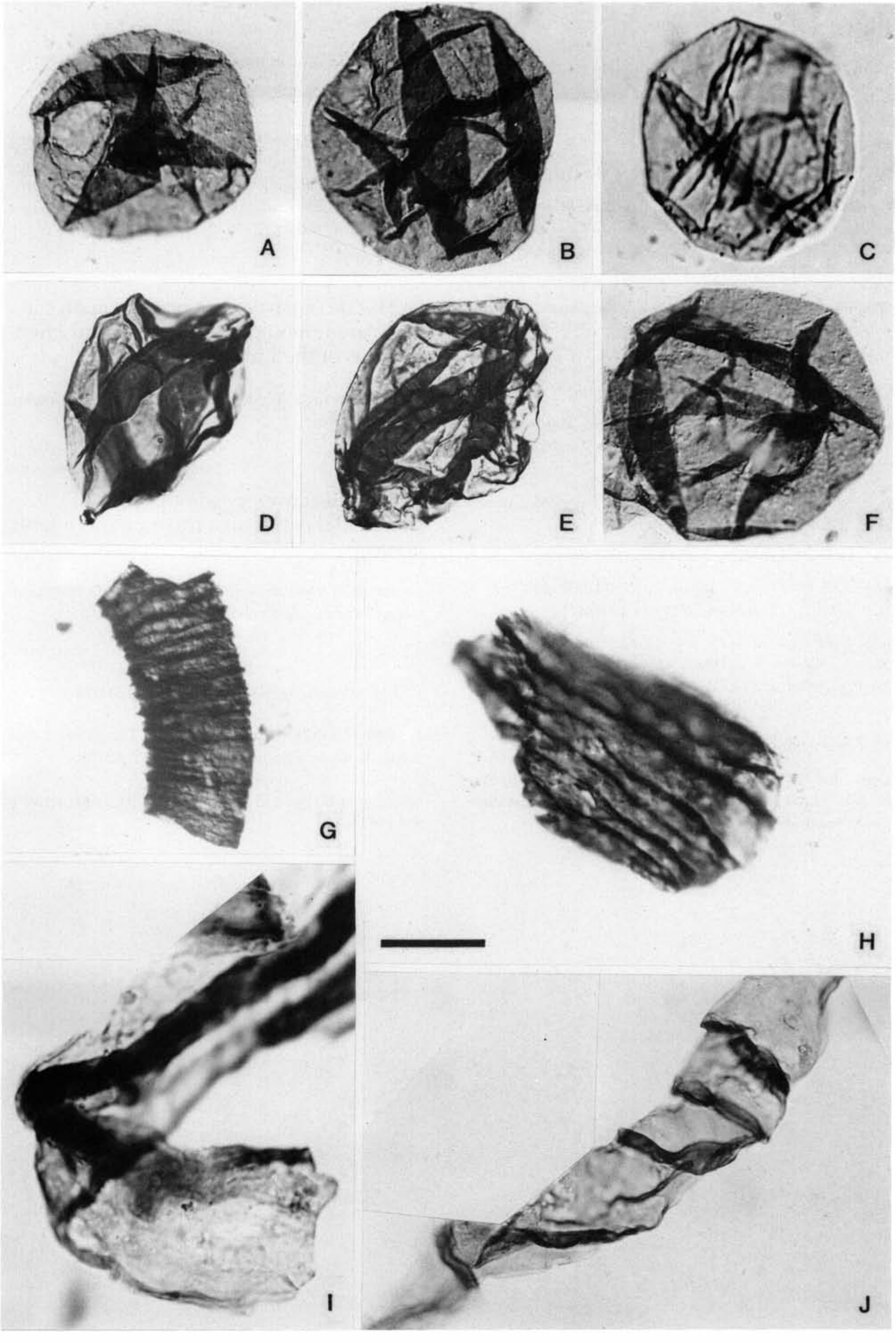
## I–J. Tubular cyanobacterial sheaths.

I. Terebiń IG-5 drillcore, depth 3672.0 m, Lublin Formation, Upper Vendian. Specimen LO 6246 t (R/34/4).

J. Parczew IG-10 drillcore, depth 2278.0 m, Lublin Formation, Upper Vendian, Specimen LO 6247 t (R/36).

Both specimens display compression folds on the smooth sheaths.

Scale bar at H equals 35 µm for A, B; 10 µm for C; 30 µm for D–F; 200 µm for G; 65 µm for H; 25 µm for I; 15 µm for J.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# Plate 15

## Miscellaneous organic remains in the Upper Vendian and Lower Cambrian of the Lublin Slope.

### A–B. Tubular cyanobacterial sheaths.

Łopiennik IG-1 drillcore, depth 5198.6 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. A. Specimen LO 6248 t (K/31/4). B. Specimen LO 6249 t (L/35).

Specimens with coiled thickenings on the sheaths, presumably due to pre-diagenetic morphology.

### C. *Leiosphaeridia* sp.

Łopiennik IG-1 drillcore, depth 5198.6 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6250 t (K/40).

Internal dark spots are interpreted as condensed intracellular organic matter.

### D. Acid-resistant organic, presumably metazoan, remains (Arthropoda?).

Kaplonosy IG-1 drillcore, depth 1302.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6251 t (Q/37).

### E. *Ceratophyton vernicosum* Kirjanov

Łopiennik IG-1 drillcore, depth 5210.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6252 t (E/47/1).

Acid-resistant fossil of unknown affinity.

### F. Unicellular cyanobacterium.

Radzyń IG-1 drillcore, depth 1517.0 m, Mazowsze Formation, Lower Cambrian, *Asteridium–Comasphaeridium* Zone. Specimen LO 6253 t (R/50/2).

### G. Mosaic of particulate organic matter in permanent mount from kerogen-enriched deposits of the Lublin Formation.

Terebiń IG-5 drillcore, depth 3672.5 m, Lublin Formation, Upper Vendian.

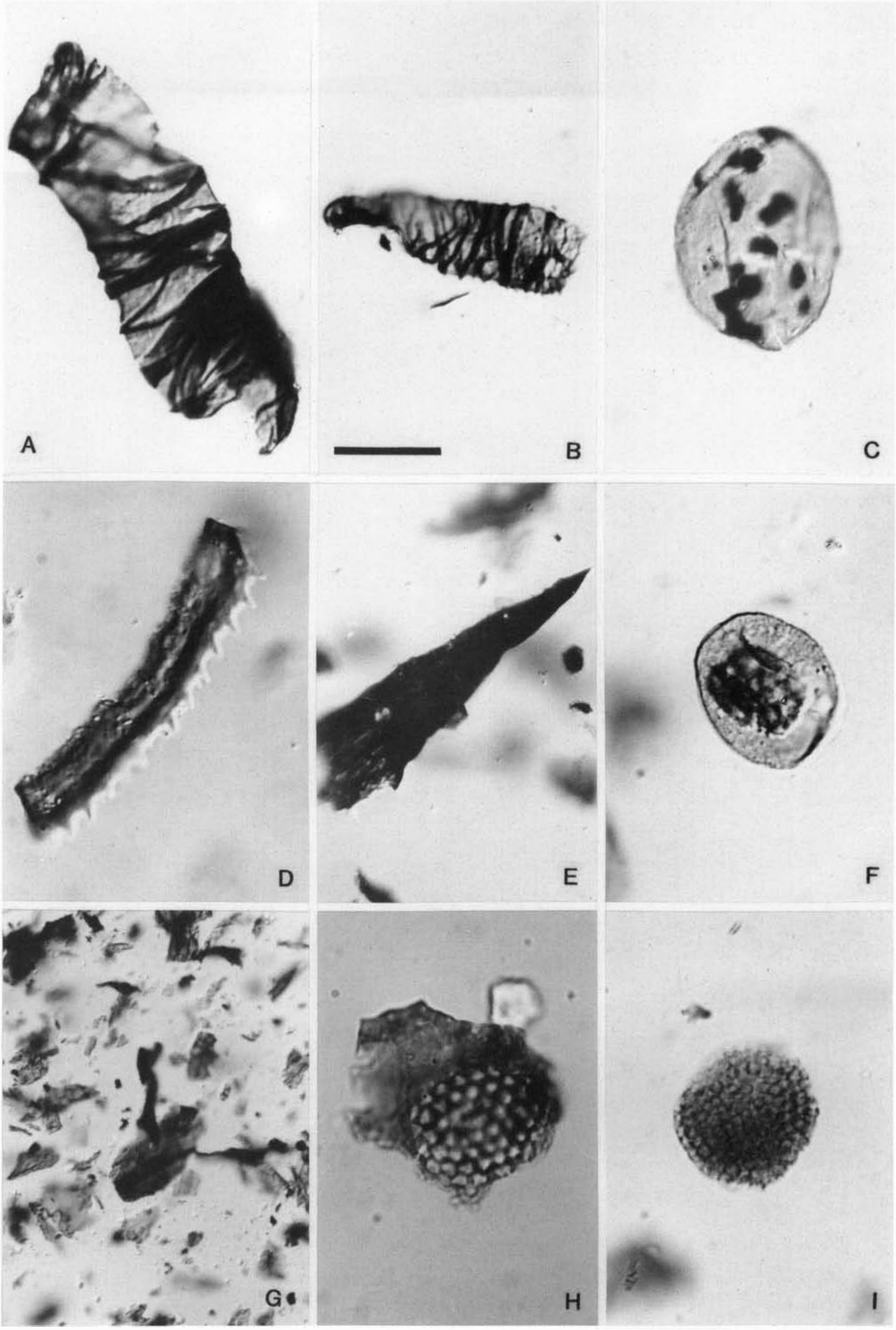
### H. Organic envelope after growth of framboidal pyrite on a fragment of organic matter.

Terebiń IG-5 drillcore, depth 3719.0 m, Lublin Formation, Upper Vendian. Specimen LO 6254 t (W/45/2).

### I. *Sphaerocongregus variabilis* Moorman

Terebiń IG-5 drillcore, depth 3719.0 m, Lublin Formation, Upper Vendian. Specimen LO 6255 t (Y/40/3).

Scale bar at B equals 15 µm for A–D, F, H, I; 40 µm for E; 200 µm for G.


A
B
C
D
E
F
G
H
I

# Instructions to authors

Contact the editor at an early stage regarding suitability of topic, technical requirements, and financing. Final acceptance for publication, however, will not be made until the manuscript has been refereed. Submit the manuscript initially as one paper copy for refereeing and eventually as word-processor text files. Figure and plate originals should not be submitted until the paper has been accepted for publication. After return of the final revised manuscript, the paper will normally be published within 4–6 months. Read galley and page proofs carefully, making only necessary corrections, and return them promptly to the editor. Twenty copies of the publication will be given free of charge to the author(s).

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Use four of fewer grades of heading in the main text: Large size roman (mark this heading with an initial '$2'), smaller size roman ('$3'), smaller size italics ('$4'), and lower case italics flush with the text (followed by a full stop, space, double hyphen, space, and the subsequent text *en suite*). Do not number the headings.

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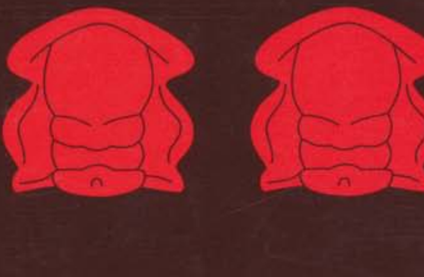

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