

Lower Cambrian acritarchs and the Proterozoic–Cambrian boundary in southern Norway

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Acritarchs are reported from Lower Cambrian sections in the area of Lake Mjøsa in southern Norway that previously yielded poor skeletal faunas. These skeletal faunas constitute in part the grounds for the faunal biozonation of the Lower Cambrian in Baltoscandia. Compared with other previously investigated sections in Baltoscandia and Greenland, the Lake Mjøsa sections produced numerically sparse assemblages of acritarchs. Taxonomically, they are readily comparable to assemblages from the platform areas of eastern Europe in the USSR and Poland which establish the basis for previously defined 'stages' and acritarch biozones. They can also be compared to assemblages from sequences in the remaining fragments of shelf areas of the early Palaeozoic Iapetus Ocean bordering the present-day North Atlantic (e.g. the Scandinavian Caledonides, Spitsbergen, East and North Greenland, and Scotland). In southern Baltoscandia acritarch assemblages comparable to the Talsy 'stage' (= *Skiafia ornata* acritarch zone) were recovered only from Lower Cambrian sequences in areas that during early Cambrian times presumably underwent considerable subsidence along the Teisseyre/Tornquist Lineament. In other areas, including southern Norway, the earliest recovered diagnostic assemblage is consistent with a Vergale 'stage' age (= *Michystridium dissimulare* zone). Acritarch evidence from the Vardal Sandstone Member and the Ringsaker Quartzite Member is poor. However, the virtually barren quartzarenites of the Hardeberga Sandstone in southern Sweden, which are correlated with the Ringsaker Quartzite Member on lithological and ichnofaunal grounds, yielded abundant Talsy 'stage' age-diagnostic acritarchs. A new acritarch species (*Celtiberium ? quadratum* n.sp.) is described from the Bråstad shale. □ *Acritarchs, phytoplankton, Lower Cambrian, Baltoscandia, East European Platform, southern Norway, Iapetus, zonation.*

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Originally explained in terms of a comprehensive hiatus (Darwin 1859), the drastic biotic changes in the fossil record near the Precambrian/Cambrian boundary are more amenable to explanation in terms of emergence and diversification of metazoans and primary producers (Glaessner 1982). A variety of more or less sophisticated explanations have been invoked to explain the origin and radiation of marine invertebrate phyla (e.g. Brasier 1979, 1982; Glaessner 1982; Lowenstam & Margulis 1980; Runnegar 1982; Sepkoski 1979; Stanley 1976; Towe 1970, 1981).

Our understanding of the patterns of emergence and diversification of late Proterozoic and early Cambrian taxa is influenced by the appreciation of taphonomic factors, biological affinity, food webs (as biotic interdependence in the fossil record), basin development and models of depositional history, and accurate dating of sections

across the Proterozoic/Cambrian transition (or boundary).

Acritarchs are the dominant constituent of late Proterozoic and early Palaeozoic, generally planktonic, photoautotrophs (Downie 1973; Downie et al. 1963; Tappan 1980).

Embodied in a formidable database, available information suggests that the motile and/or encysted life stages of planktonic algal protists accumulated indifferently in a wide range of depositional settings. Individual taxa (as well as specific assemblages of taxa) are geographically widespread and most often cosmopolitan over relatively short spans of geological time. Hence, their biostratigraphic usefulness is becoming increasingly recognized.

Because they constitute the very base of marine trophic regimes the fossil record of acritarchs is significant in the context of metazoan radiation

patterns near the Precambrian/Cambrian boundary. This is particularly true since near the Precambrian/Cambrian boundary the fossil record of phytoplankton encompasses rich assemblages of cyanobacteria and acritarchs composed of diagnostic taxa (Downie 1982; Knoll & Swett 1987; Moczyłowska & Vidal 1986, 1988a; Volkova et al. 1979, 1983) which underwent radiation and extinction (Vidal & Knoll 1983). Hence, while the fossil record of early metazoans is essentially limited to the terminal segment of the Proterozoic and early Cambrian, marine algal protists have long-standing roots in the early Proterozoic (Jankauskas 1979; Zhang Zhongying 1986). Proterozoic marine ecosystems were basically dominated by prokaryotic and eukaryotic primary producers and heterotrophic protists (Knoll & Calder 1983; Knoll 1985; Vidal & Knoll, 1983) which build up simple food webs. In late Vendian (or Ediacaran) and early Cambrian times the rise and radiation of skeletonized marine metazoans considerably extended the short carbon cycle characteristic of early and middle Proterozoic times.

In this paper we report additional evidence for the detailed dating and correlation of the classical Lower Cambrian stratigraphic sections in the Lake Mjøsa region in southern Norway. Our data also generate further evidence concerning the controls acting upon the distribution of early Cambrian taxa.

Geology

Structural and palaeogeographic setting

Traditional type and reference sections and outcrops for Lower Cambrian stratigraphy in southern Norway are located within the Mjøsa district and adjacent areas in the southern part of the classical Sparagmite Region (Fig. 1). Lower Cambrian rocks occur in the uppermost part of the Hedmark Group in the Vangsås Formation and overlying beds attributed informally to the 'Holmia series'. Lower Cambrian strata are present in two tectonostratigraphic settings formed by the allochthonous Osen-Røa Nappe Complex and the autochthonous sedimentary cover overlying penneplained Precambrian basement rocks (Bockelie & Nystuen 1985; Bergström & Gee 1985).

Cambro-Silurian strata within the lower Cale-

donian nappe unit are folded and cut by subordinate thrusts and faults within imbricated fan and duplex structures (Morley 1986). The folded sequence extends from the Lake Mjøsa area southward into the Oslo Region as a decollement thrust sheet with the sole thrust (Osen-Røa Thrust) located within the Middle to Upper Cambrian Alum Shale (Nystuen 1981, 1983). The autochthonous Lower Cambrian strata crop out as flat-lying and nearly undeformed beds within a narrow zone along the eroded nappe front west and east of Lake Mjøsa (Fig. 1).

Palinspastic restorations of the decollement sheet in the Oslo Region suggest that the allochthonous Lower Cambrian in the Osen-Røa Nappe Complex at Mjøsa was deposited 140–150 km to the NNW relative to the autochthonous Lower Cambrian beds at the eroded nappe front (Oftedahl 1943; Nystuen 1981; Morley 1986). However, the Lower Cambrian arenaceous and shaly beds in these two tectonostratigraphic positions were all deposited within the same epicontinental foreland sea that originated east of the Iapetus Ocean and the Caledonian mobile belt (Kumpulainen & Nystuen 1985). This shallow-marine early Cambrian epicontinental sea-way rimmed the NW periphery of the Baltoscandian craton and transgressed the craton from the NW to the SE.

In early Cambrian times an axial land height probably separated areas of epicontinental sea covering NW Baltoscandia from other epicontinental seas that covered SE Baltoscandia (Thorslund 1960; Skjeseth 1963; Martinsson 1974; Bergström 1980). This land barrier terminated towards the SW border zone of Baltoscandia. The two epicontinental seas merged into the Iapetus oceanic sea-way system along the Teisseyre/Tornquist Lineament.

Stratigraphical and sedimentological framework

Lower Cambrian beds in the Lake Mjøsa district formed by progressive onlapping of the Baltoscandian craton from late Proterozoic rift basins on the western Baltoscandian margin (Kumpulainen & Nystuen 1985). The Vangsås Formation originated within the Hedmark Basin during a late rift phase and the following thermal subsidence in Vendian to early Cambrian times. The upper part of the formation was deposited on the crystalline basement outside the Hedmark

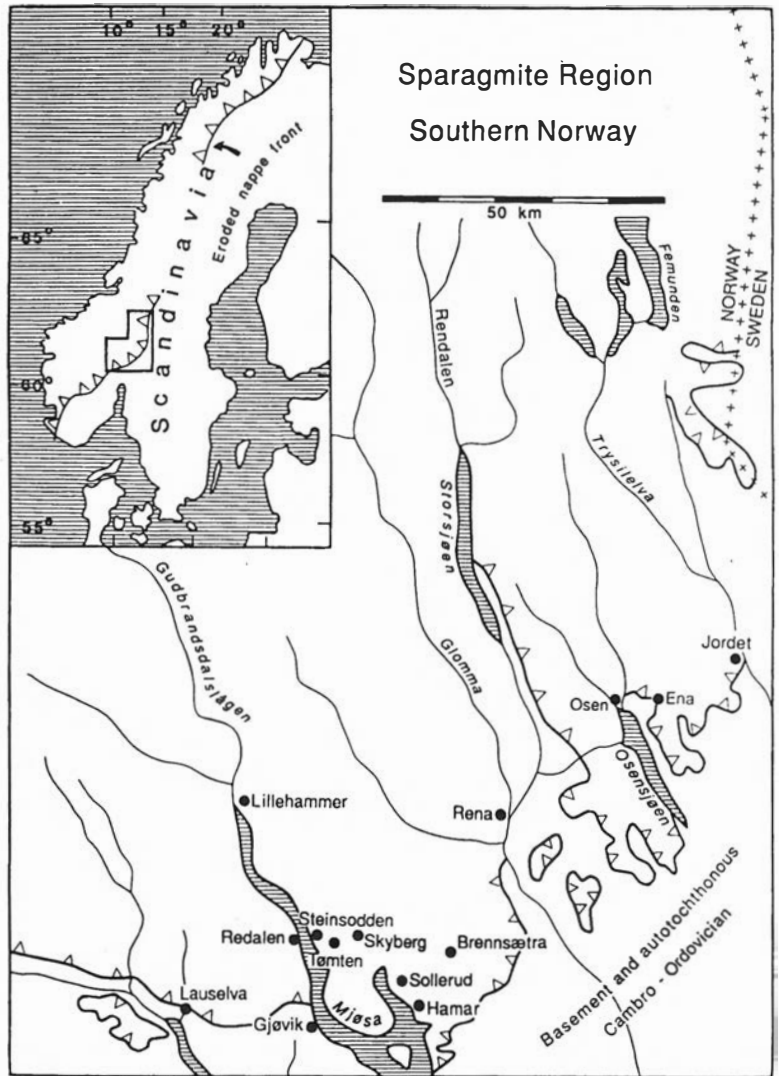


Fig. 1. Sketch map showing geological localities discussed in text.

Basin during the early Cambrian transgressions (Nystuen 1987).

The lower member of the Vangsås Formation, the Vardal Sandstone Member, consists of feldspathic sandstones and conglomerates which in the lower part are deltaic, coarsening upwards into braided-stream facies that laterally and vertically grade into littoral and shallow-marine sandstones (Dreyer 1988). In the Osen–Jordet and Femunden areas (Fig. 1), this lower member is also developed as turbidite sandstones grading into black shales (Nystuen 1982).

The shallow-marine environment continued

during the deposition of the upper member, the Ringsaker Quartzite Member. This quartzarenite facies was deposited as a transgressive sheet of sand, onlapping the western Baltoscandian craton from the west. Thus, the uppermost part of the Ringsaker Member forms the lowermost autochthonous beds (except for local occurrences of Varangerian glacial beds) east of Lake Storsjøen, wedging out southwards (Nystuen 1982). The Ringsaker Quartzite Member consists of 20–100 cm thick cross-bedded quartzarenite beds. In allochthonous position the uppermost part of the member is developed as pipe-rock facies with

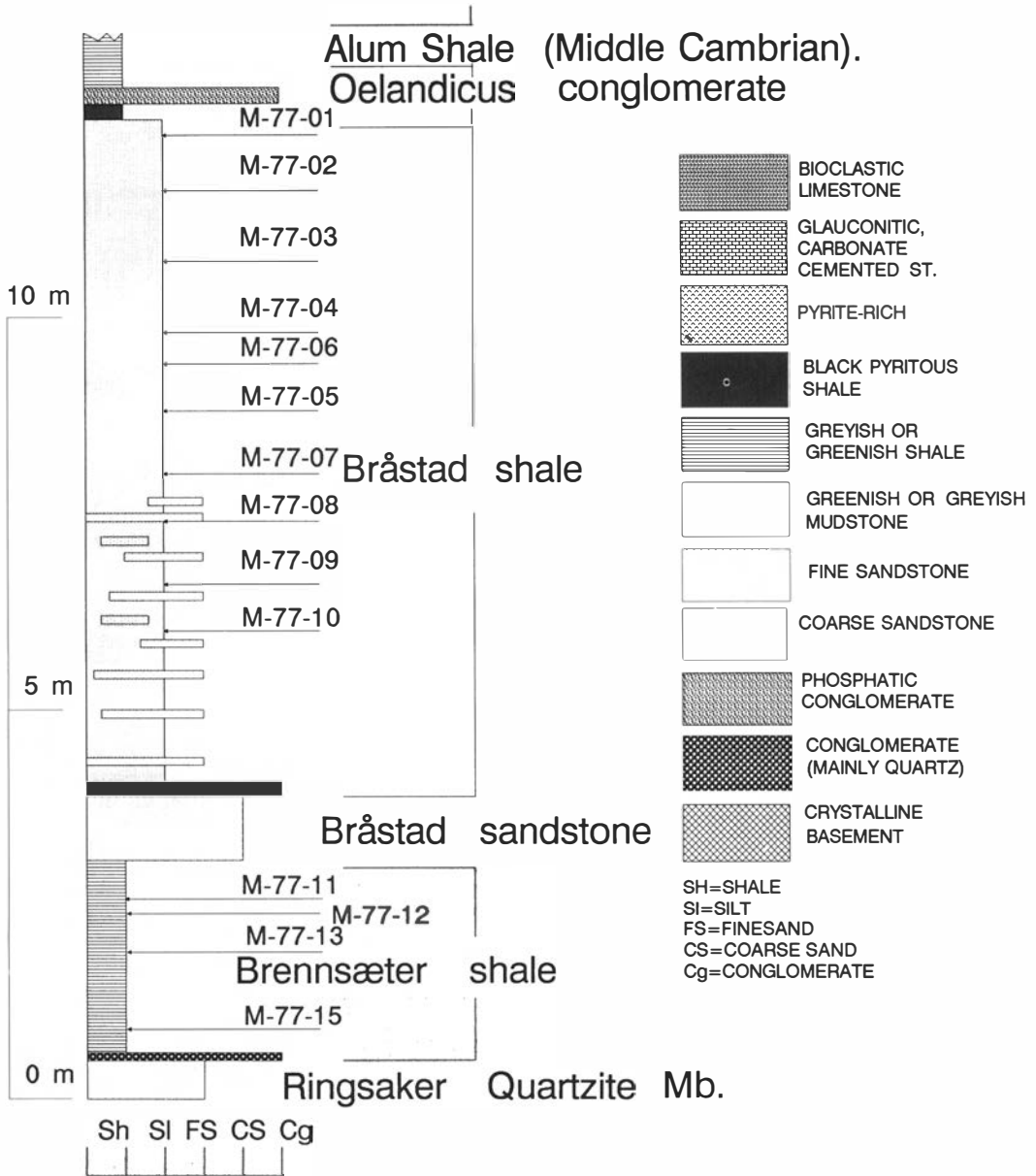


Fig. 2. Schematic geological section of the Lower Cambrian at Flagstadelva, Brennsætersaga (cf. Vogt 1924; Skjeseth 1963; Moczyłowska & Vidal 1986). Lithologic symbols apply to Figs. 2-5.

Skolithos and *Diplocraterion* (Skjeseth 1963). In some localities, as at the sampled locality Sollerud east of Lake Mjøsa, very thin greyish-green discontinuous shale beds occur between the quartzarenite beds (Bryhni et al. 1981). The Ringsaker Quartzite Member was deposited in an open shallow sea under strong influence of waves and

storm-generated currents (Nystuen 1982, 1987; Dreyer 1988). The Ringsaker Quartzite Member is overlain by fine-grained sandstones, mudstones and shales of the 'Holmia series'. The contact is an unconformity with no angularity or with indications of deep subaerial stream erosion. The unconformity is inferred from the presence at

some localities of a quartzite-pebble conglomerate with mudstone clasts. Similar quartzite conglomerates also occur within the Ringsaker Member. At other localities, the typical Ringsaker quartzarenite beds are directly overlain by 'Holmia series' mudstones (Vogt 1924; Skjeseth 1963). The 'Holmia series' was subdivided into formations by Skjeseth (1963) and given names from type localities within the Osen-Røa Nappe Complex. These units were correlated with corresponding autochthonous lithological units. Here we follow the lithostratigraphical subdivision by Skjeseth (1963). However, the units are here treated as having the rank of informal lithostratigraphic units.

The lowermost fossiliferous beds of the 'Holmia series' are recorded at Brennsætersaga in the River Flagstadelva (Figs. 1, 2). Here the Ringsaker Quartzite Member with *Monocraterion* at the top is overlain by about 2 m thick greenish-grey shale with thin fine-grained sandstone laminae. This unit, originally called Brennsæter Limestone by Skjeseth (1963) (also termed $1a\alpha_1$) is here named Brennsæter shale since shale is the dominant lithology and limestone has not been observed in our studies. This unit has yielded the trilobite *Holmia cf. mobergi* (Ahlberg et al. 1986; Bergström 1980, 1981). The Brennsæter shale is overlain by the 1.3 m thick Bråstad sandstone ($1a\alpha_2$, Skjeseth 1963), which forms an upward coarsening unit terminating in a phosphorite-bearing quartz-granule conglomerate. The quartzarenite beds are in turn overlain by a grey, laminated arenaceous mudstone (Bråstad shale, $1a\beta$, Skjeseth 1963) which yielded *Volborthella tenuis* (Skjeseth 1963). At Brennsætra, the 9.5 m thick Bråstad shale is eroded and overlain by the 'oelandicus' phosphorite conglomerate of Middle Cambrian age (Skjeseth 1963).

At the localities Redalen and Steinsodden (Fig. 1) on the western and eastern shores of Lake Mjøsa, respectively, the 'Holmia series' commences with a 1.0–2.5 m thin-bedded and fine-grained quartzarenite unit. This facies probably corresponds to the Bråstad sandstone. It is overlain by a 25–30 m thick barren, grey arenaceous mudstone of the Bråstad shale facies.

At the localities Skyberg and Tømten (Figs. 1, 5) the Bråstad shale (mudstone) is succeeded by a greenish-grey shale attributed to the *Holmia* shale ($1b\alpha$, Skjeseth 1963). The *Holmia* shale contains a mixed trilobite fauna consisting of olenellids and ellipsocephalids (Kiær 1917;

Ahlberg 1985) and is overlain by a bioclastic limestone, the Evjevika limestone ($1b\beta$, Skjeseth 1963). This latter unit forms the top of the Lower Cambrian in the Lake Mjøsa area and has yielded a trilobite fauna pertaining to the *Proampyx linnarssoni* Zone.

The Lower Cambrian autochthonous sequences at the River Lauselva (Skjeseth 1963) and Ena (Nystuen 1969) (Fig. 1) consist of arenaceous and conglomeratic basal beds overlying Precambrian granite and gneisses, followed by greenish-grey mudstone. At both localities *Cruziana* occurs along with horizontal and vertical trace fossils. The lower arenaceous beds at Ena have yielded *Torella* (Nystuen 1969) and the upper mudstone at Lauselva *Volborthella* and the trilobite *Callavia* (Skjeseth 1963), the latter renamed *Holmia inusitata* Ahlberg and Bergström (in Ahlberg et al. 1986). These autochthonous sequences contain several unconformities that, in the case of the locality at Ena, are marked by thin conglomerate lenses carrying small dolomite and phosphorite clasts (Nystuen 1969). Skjeseth (1963) correlated the arenaceous basal beds with the Brennsæter shale and the Bråstad sandstone and the overlying grey mudstone with the Bråstad shale.

The Lower Cambrian 'Holmia series' is a 10–30 m thick foreland sequence that contains several minor unconformities that represent hiatuses of unknown duration. The lower arenaceous basal beds represent shoreline and shallow-marine facies. Marked lateral changes in facies and thickness (Vogt 1924) are considered to relate to variations in relief of underlying rocks and local pattern of coastal currents. The grey arenaceous mudstone (Bråstad shale) and the greenish-grey *Holmia* shale represent a sequence of increasing water depth.

In terms of modern sequence stratigraphy (Van Wagoner et al. 1988), the overall transgressive Lower Cambrian succession in the Mjøsa district can be considered a major genetic sequence that can be subdivided into several parasequences separated by unconformities and marine-flooding surfaces. Hence, a major marine-flooding surface underlies the Bråstad shale, whereas beds enriched in carbonate bioclastic detritus, as the Evjevika limestone, represent subaqueous condensed sections that formed during events of regional transgressions. Further progress in understanding the dynamics of the Lower Cambrian transgression in Baltoscandia is, however,

dependent on better knowledge of biostratigraphy and palaeoecology. This also relates to the discussion of the Precambrian–Cambrian boundary in this sequence.

Material and methods

Extensive stratigraphic sections through the Lower Cambrian strata in the Mjøsa area are relatively rare. For this study, fresh rock samples were collected from several sections and outcrops keeping in mind structural simplicity and availability of potentially fossiliferous fine detrital rocks. Investigated localities are shown on the map in Fig. 1 and locations in appendix 1 give the name of 1:50 000 map sheets of the topographical map of Norway followed by UTM coordinates.

Whenever possible, rock samples were collected at even intervals in continuously or partially exposed sections. This is the case with sections at Brennsætersaga (Figs. 1, 2; LØTEN 614500/6753750) in Flagstadelva (Skjeseth 1963; Moczyłowska & Vidal 1986), Steinsodden (GJØVIK 590900/6754200; Skjeseth 1963), Lauselve River (Fig. 3; EINA 573450/6733300; Skjeseth 1963), Sollerud (Fig. 4; HAMAR, PN 068 492; Bryhni *et al.* 1981) and Skyberg (Fig. 5; HAMAR 597000/6755700).

Localities at Redalen (GJØVIK 590450/6753400), Tømten (HAMAR 593900/6754750; Vogt 1924), Ena (Vidal 1981a; JORDET 653000/6799300) consist of exposures which comprise limited stratigraphic intervals. At Redalen mudstone beds overlying the Ringsaker Quartzite Member and lithologically equivalent to beds at Steinsodden were found barren. At Tømten fossiliferous greyish shales were collected as spot samples (M-77-28, 29, 30). Investigated samples can be seen in appendix 1 and in Figs. 2–9. About 50 g of fresh rock of each sample was processed according to the method fully described by Vidal (1988). The organic-walled microfossils recovered are poorly preserved, usually being strongly compressed and displaying a considerable thermal alteration. The latter can be inferred from the colour of acritarchs, which ranges from light-brown for the small acritarchs (hue 10YR 5/6) to dark-brown (hue 10YR 3/2) for the larger and thicker-walled specimens (Pearson 1984). This corresponds to TAI 3+ to 4– (AMC 5+ to 6 in Rovnina 1981), which may indicate palaeo-

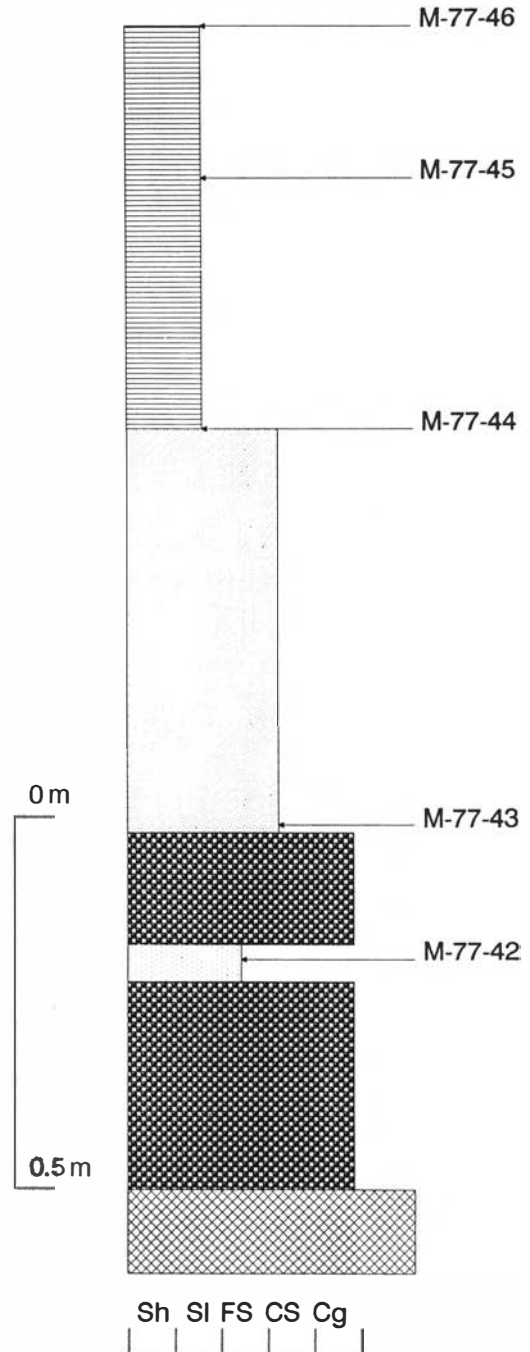


Fig. 3. Schematic geological section of the Lower Cambrian at Lauselve River (see Skjeseth 1963). For lithologic symbols see Fig. 2.

temperatures in the order of 175–<200°C (Rovnina 1981).

Samples of micaceous, greyish mudstone

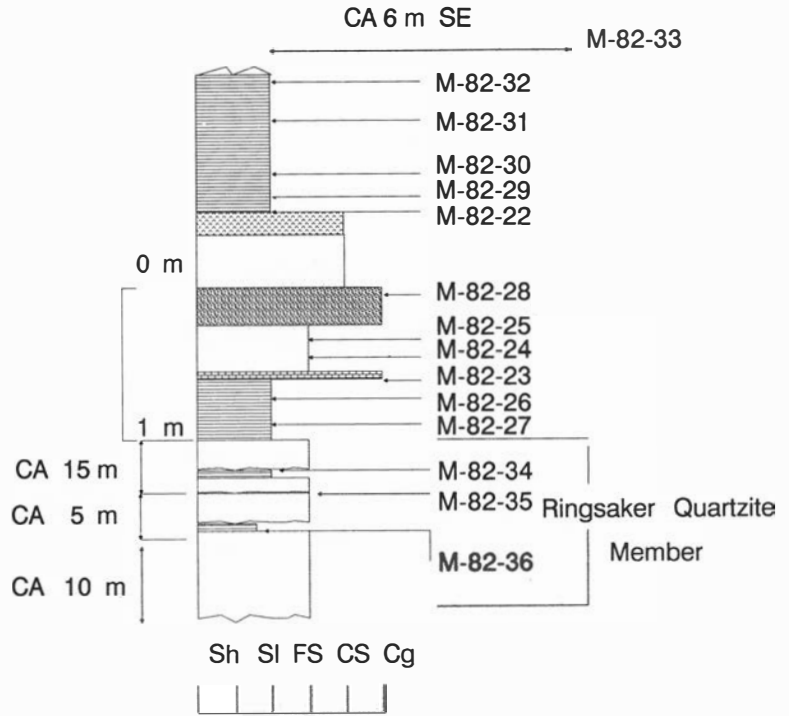


Fig. 4. Schematic geological section of the Lower Cambrian at Sollerud (Bryhni et al. 1981:68). For lithologic symbols see Fig. 2.

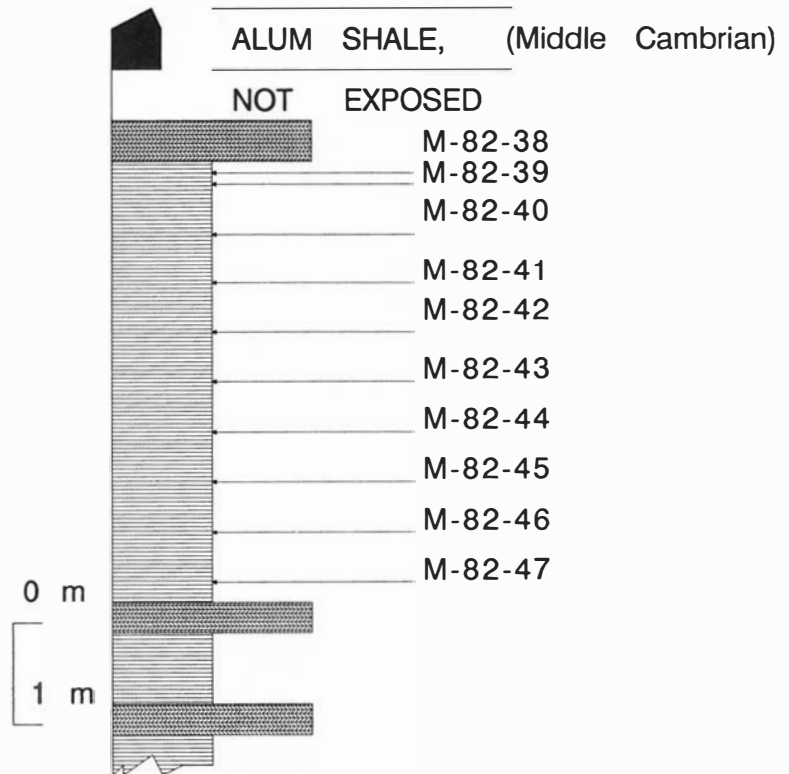


Fig. 5. Schematic geological section of the Lower Cambrian at Skyberg. For lithologic symbols see Fig. 2.

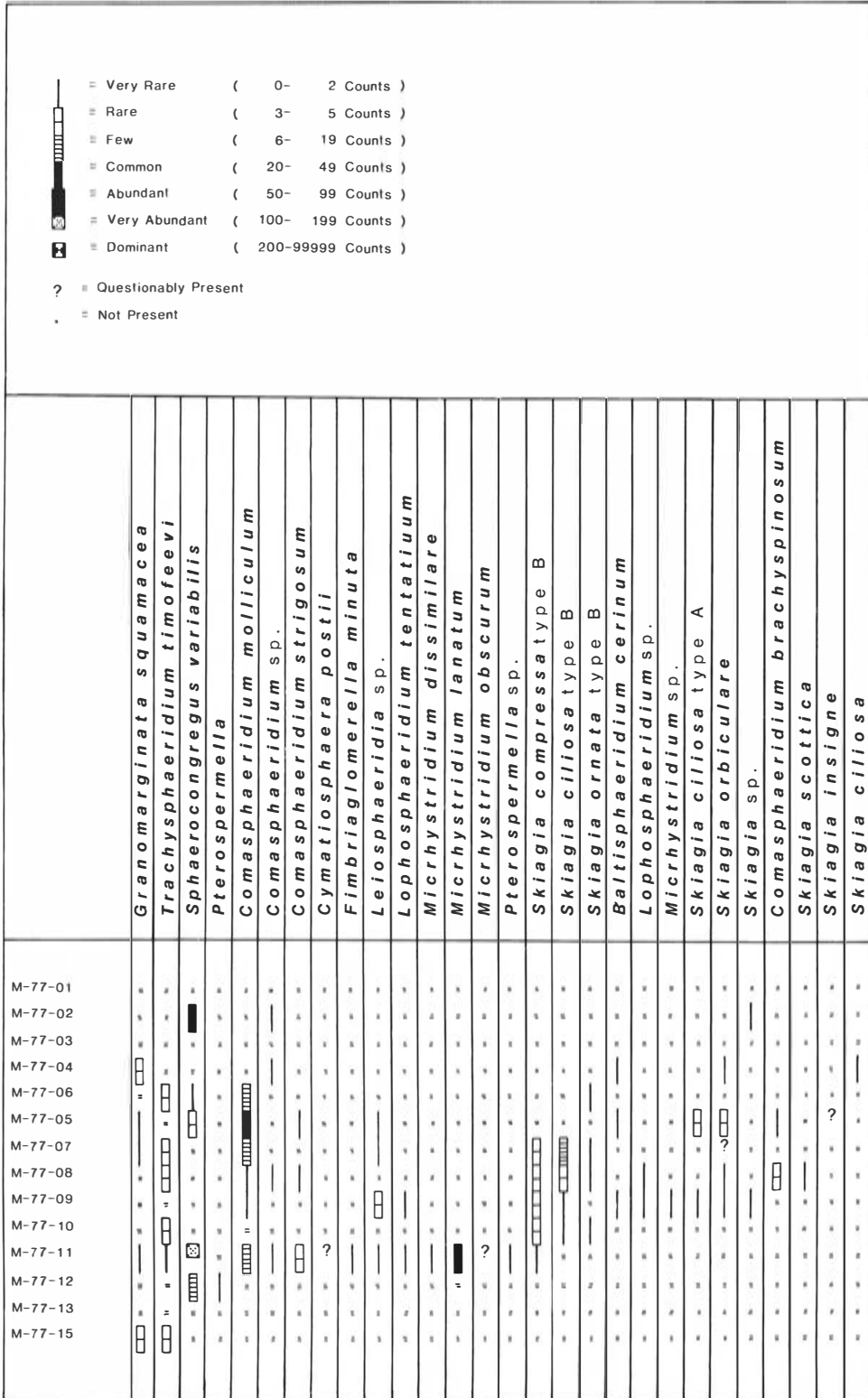


Fig. 6. Numeric occurrence of acritarch taxa in samples from section through Lower Cambrian at Flagstadelva, Brennsætersåga.

Key to Symbols																								
/	=	Very Rare	(0–	2 Counts)																			
X	=	Rare	(3–	5 Counts)																			
O	=	Few	(6–	19 Counts)																			
●	=	Common	(20–	49 Counts)																			
?	=	Questionably Present																						
□	=	Not Present																						
SAMPLES	<i>Comasphaeridium</i> sp.	<i>Pterospermella</i> sp.	<i>Baltisphaeridium dubium</i>	<i>Leiosphaeridia</i> sp.	<i>Skiagia ciliosa</i> type A	<i>Dictyotidium priscum</i>	<i>Globulus gossipinus</i>	<i>Lophosphaeridium</i> sp.	<i>Comasphaeridium strigosum</i>	<i>Baltisphaeridium cerinum</i>	<i>Comasphaeridium molliculum</i>	<i>Skiagia compressa</i>	<i>Skiagia scottica</i>	<i>Skiagia</i> sp.	<i>Trachysphaeridium timofeevi</i>	<i>Cymatiosphaera</i> sp.	<i>Tasmanites bobrowskae</i>	<i>Gonosphaeridium primarium</i>	<i>Michrystridium dissimulare</i>	<i>Skiagia ciliosa</i> type 2	<i>Michrystridium obscurum</i>	<i>Tasmanites tenellus</i>	SAMPLES	Locality / Stratigraphy
M-77-28	/		/	●	/			/	/	/					/								M-77-28	Tømten, <i>Holmia kjerulfi</i> Zone
M-77-29		X		O		X					O	X						O	/	/			M-77-29	Tømten, <i>Holmia kjerulfi</i> Zone
M-77-30			X	/		X									X	/							M-77-30	Tømten, <i>Holmia kjerulfi</i> Zone
M-77-31			X											/									M-77-31	Skyberg
M-77-42			X											/									M-77-42	Lauselva
M-77-44														/									M-77-44	Lauselva
M-77-45			X								/	X		X									M-77-45	Lauselva
M-77-46			X									X		X									M-77-46	Lauselva
M-77-112			X	X	/	/	/	X	/	X	/	X		X									M-77-112	Ena,
M-82-01								/	/														M-82-01	Ø. Abu
M-82-09								/	/														M-82-09	Ø. Abu
M-82-37						/																	M-82-37	Skyberg
M-82-39			O	/																			M-82-39	Sollerud
M-82-40			X	/	/																		M-82-40	Skyberg
M-82-44		/	●	/																			M-82-44	Skyberg
M-82-45	/																						M-82-45	Skyberg
M-82-47	/																						M-82-47	Skyberg

Fig. 7. Numeric occurrence of acritarch taxa in samples from sections through Lower Cambrian at Tømten (M-77-28-30), Skyberg (M-77-31, M-82-37, 39, 40, 44, 45, 47), Ø. Åbu (M-82-01, 09), Lauselva (M-77-42, 44, 45, 46), Ena (M-77-112).

interbeds in the Ringsaker Quartzite at Sollerud (Fig. 4) were examined. Although all yielded dark-grey organic detritus, only one sample (M-82-34) yielded two specimens of poorly preserved acritarchs attributed to *Comasphaeridium* sp.

Shale samples from the Brennsæter shale (unit 1a₁) collected at Brennsætersaga (in Flagstadelva Figs. 1, 2; Skjeseth 1963; Moczyłowska

& Vidal 1986) and Ena yielded abundant well-preserved acritarchs (Vidal 1981a; Fig. 6), while samples from Redalen and Steinsodden (Skjeseth 1963) are generally virtually barren (Fig. 7).

Shale samples from the Bråstad shale (unit 1a₁) collected at Brennsætersaga (Skjeseth 1963; Moczyłowska & Vidal 1986; Fig. 2; see above), Lauselva River (Fig. 3; Skjeseth 1963) and Sol-

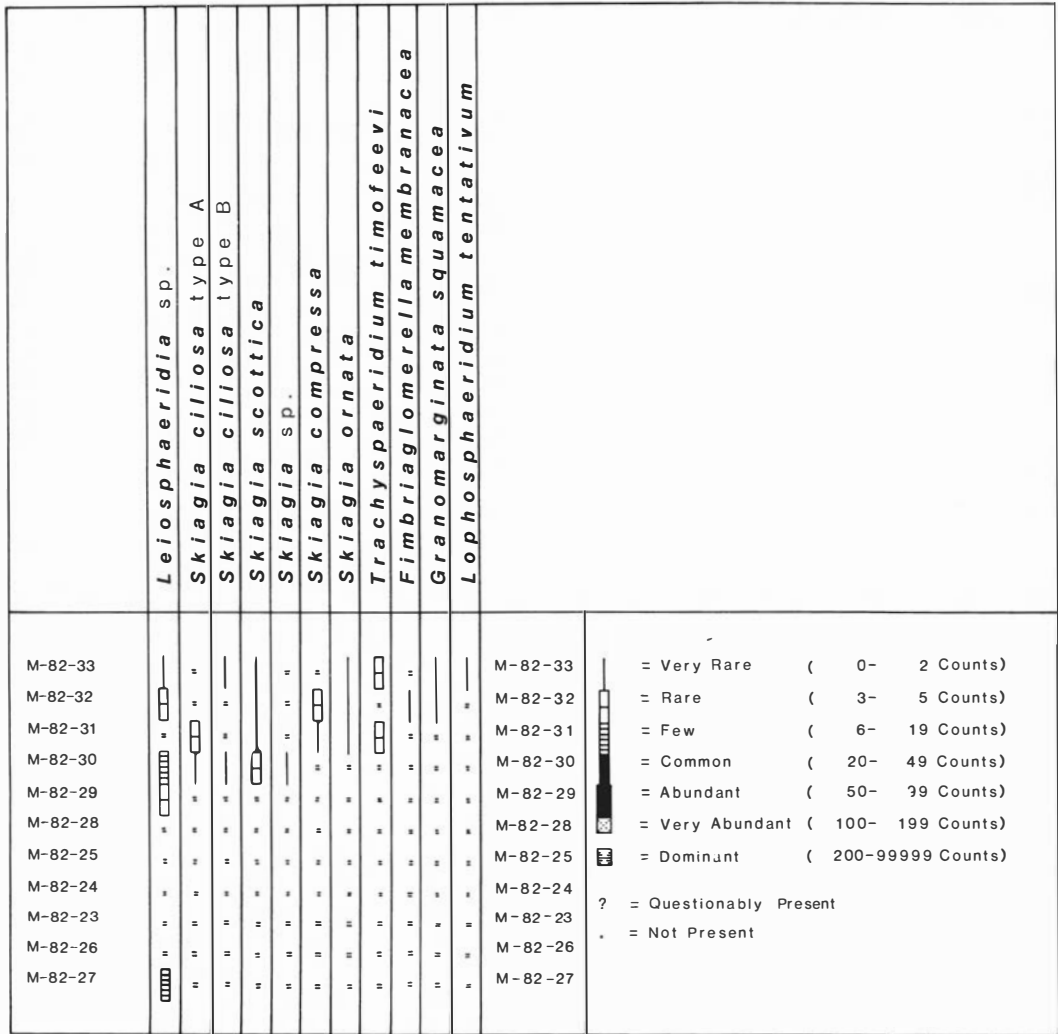


Fig. 8. Numeric occurrence of acritarch taxa in samples from section through Lower Cambrian at Sollerud (Bryhni et al. 1981:68).

lerud (Fig. 4; Bryhni et al. 1981:68) yielded relatively abundant acritarchs (Vidal 1981a).

Greenish shales of the Evjevik limestone (unit 1bβ) were collected at Tømten and Skyberg (Fig. 5). Samples from Tømten yielded extremely abundant acritarchs (Vidal 1981a), while only a few from Skyberg yielded scattered acritarchs (Fig. 8).

Taxonomy

The algal affinity of most acritarchs seems unquestionably established and is generally accepted, as

it is the idea that they may represent the abandoned organic envelopes of encysted and/or motile stages of prasinophycean green algae, dinoflagellates, or similar groups now extinct (Dale 1977; Tappan 1980). Until quite recently the generally accepted view was that Precambrian acritarchs consisted largely of smooth, morphologically simple forms lacking any form of diagnostic features (Downie 1973). Thus, lavishly ornamented spinous acritarchs were for a time regarded as unique to Phanerozoic strata (Brasier 1977). Assemblages of complex, characteristically ornamented acritarchs have been reported from numerous, geographically widely distributed late

Proterozoic and early Cambrian siliciclastic and carbonate sequences in most continents (see Vidal & Knoll 1983 for a review). Among them, Lower Cambrian acritarch assemblages display a remarkable homogeneity in taxonomic composition (Urbanek & Rozanov 1983). Diagnostically ornamented acanthomorphic (displaying simple and conical, and complex membrane-bound processes) and polygonomorphic late Proterozoic acritarchs were first reported by Timofeev et al. (1976) and Vidal (1976). But recent restudy of *Papillomembrana compta* (Vidal 1990) from the late Proterozoic Biskopåsen Conglomerate in the Hedmark Basins (Spjeldnæs 1963) suggests that this may in fact be the earliest report of Proterozoic acanthomorphic acritarchs (Vidal 1990). Subsequent work has demonstrated that complex acritarchs are relatively common in the late Proterozoic (Vidal 1981c; Knoll & Calder 1983; Knoll 1984; Vidal & Ford 1985; Yin Leiming 1985; Awramik et al. 1985; Pjatiletov & Rudavskaya 1985; Butterfield et al. 1988; Zang & Walter 1989; Knoll & Ohta 1988). A resemblance between giant Proterozoic process-bearing acritarchs and certain early Palaeozoic acanthomorphic acritarch taxa was indicated by Yin Leiming (1985) and Zang & Walter (1989). However, this refers only to a similarity of general gross morphological features between the late Proterozoic giants (most often one degree of magnitude larger than early Cambrian taxa and displaying a different wall structure) and certain early Palaeozoic taxa. In fact, some forms from the terminal Proterozoic Pertatataka Formation in Central Australia (Zang & Walter 1989) appear to have been lens-shaped rather than spheroidal, thus being very different indeed from any early Palaeozoic taxa. Thus, while the morphology of most 'spinous' early Palaeozoic acritarchs leads us towards comparisons with endocysts, the Proterozoic 'spinous' giants bear a closer resemblance to the cysts of certain prasinophycean green algae. This might be a palaeobiologically interesting parallel since the cysts of prasinophycean green algae, which are the likely living counterparts of *Leiosphaeridia*, *Tasmanites*, *Cymatiosphaera* and most Proterozoic acritarch taxa, are initially about 10 µm in diameter. However, the mature cyst may be as much as 100–175 µm in diameter (Tappan 1980).

In general, acritarchs have a limited array of diagnostic features, such as the general shape of the vesicle, its surface ornamentation and the

shape and ornamentation of processes and excystment mechanism (Al-Ameri 1986; Tappan 1980). Deficient descriptions, often too imprecise and accompanied by poor illustrations, have probably contributed to the erroneous generic attribution of some Proterozoic acritarchs to early Palaeozoic genera. Nevertheless, allowing that taxonomic attributions were correct, generic as well as supra-generic entities of acritarchs are purely arbitrary (Loeblich 1974) and in 90 out of 100 cases lack any biological implication whatsoever. They may contribute, however, to the erroneous image that species grouped under the same generic combination may have been biologically closely related. Generic attributions may have additional undesired effects when reviewing the stratigraphic ranges of acritarch taxa as they may contribute to the impression of extremely long-lived genera. Thus, supposed diachronous occurrences of discrete 'Talsy'-type acritarchs stem from a basic misunderstanding of documented occurrences of morphologically complex acritarchs (acanthomorphs, polygonomorphs, etc.) in clearly pre-Phanerozoic strata, some of which were attributed to early Palaeozoic genera (e.g. Yin Leiming 1985). Although casual inspection shows that these acritarchs have a grade of morphological complexity once thought to be restricted to Phanerozoic fossils, very few of them belong to genera found principally in younger rocks and almost none are species found in the Cambrian. Insofar as acritarch zones are based on species assemblages the presence of complex acritarchs in the Proterozoic does no more to compromise Cambrian biostratigraphy than the discovery of a Carboniferous ammonite would to invalidate the *Pleuroceras spinatum* Zone of the Jurassic. A potentially important and possibly neglected fact is that the very specific and apparently diverse (Zang & Walter 1989) terminal Proterozoic, late Riphean and Ediacaran, gigantic acritarchs are more common than previously imagined and that this increases their potential significance for refined biostratigraphy (Butterfield et al. 1988).

In this paper, only brief descriptions and discussions of previous taxa are included in the interests of brevity. Certain taxa are extremely rare in the present material, being represented by poorly preserved specimens that do not allow proper illustration in acceptable micrographs.

Complete synonymies and taxonomic treatments can be found in Downie (1982), Hagenfeldt (1989), Knoll & Swett (1987), Moczyłowska &

Bergström 1981; Mens et al. 1987 After Eklund 1990			This paper		After Moczydłowska 1989			
East European Scandinavia		S. Sweden	Southern Norway	East European Platform	S. Norway	Poland	USSR	Poland
Platform		Östergötland	Lake Mjøsa	Platform	Mjøsa	Biozones	acritach "horizons"	Lublin Slope
Lower Cambrian	<i>E. oelandicus</i>	<i>Oelandicus</i> glauconite st.	limestone, shale conglomerate	Kibartai	Hawke Bay regression	<i>E. oelandicus</i>	Kibartai	Kostrzyń Fm
	<i>Proampyxinnassoni</i>	Lingulid Sandstone	?	Rausve	Evjevik Lst.	<i>Protolenus</i>	Rausve	Radzyń & Kaplonosy Fms
	<i>Holmia kjerulfi</i> group <i>Holmia husitata</i>	U. Vergale (Luboni)	<i>Holmiersh.</i> Bråstad st & sh Brennisaeter sh.	Vergale	<i>Holmia</i> Sh. Bråstad Sh.	<i>Holmia</i>	Vergale	
	<i>Mobergella</i> <i>Schmidtella</i> <i>Rusophycus</i>	Dominopol Talsy	Ringsaker Quartzite Mbr. Vardal Sandstone Mbr.	Talsy	Bråstad St. Brennisaeter Fm. Ringsaker Q.	<i>Schmidtella</i>	Talsy	
	<i>Platysolenites antiquissimus</i>	Lontova	?	Lontova	Vardal St.	<i>Platysolenites</i>	Lontova	Mazowsze Fm
P.C.	<i>Sabellites cambriensis</i>	Rovno	Ekre Shale	Rovno "Kotlin"	?	<i>Sabellites</i> - <i>Vendotaenia</i>	Rovno	Wlodawa Fm Lublin Fm

Fig. 9. Correlation chart of the Lower Cambrian in the Lake Mjøsa area, southern Sweden (left; according to Eklund, in press) and the Lublin Slope of the East European Platform in Poland (right; according to Moczydłowska 1989).

Vidal (1988a) and Moczydłowska (in press), Volkova (1968, 1981a, 1981b), Volkova et al. (1983).

A composite stratigraphic range chart is shown in Fig. 10, which includes ranges in the USSR and Polish parts of the East European Platform and Scandinavia, according to a recent revision by Moczydłowska (1989, in press).

Details of geographic and stratigraphic distribution can be found in Downie (1982), Eklund (1990), Hagenfeldt (1989), Knoll & Swett (1987), Moczydłowska (1989, in press), Moczydłowska & Vidal (1986), Vidal, (1981a), Volkova (1968, 1981a, 1981b), Volkova et al. (1979, 1983).

LO specimen numbers refer to the collections of the Geological Institute, University of Lund. England Finder coordinates are given at the right of the colon following the slide number. Slide labels are oriented to the left of the microscope stage.

A number of microfossils recovered were identified as belonging to prasinophycean green alga. They are attributed to the genus *Cymatiosphaera* O. Wetzell, ex Deflandre, 1954, *Cymatiosphaera postii* (Jankauskas 1976) Jankauskas, 1979 and *Pterospermella* Eisenack, 1972.

Fossils attributed to *Cymatiosphaera* sp. (Fig. 11A–B) consist of compressed spheroidal vesicles with high crests which divide the surface into polygonal-shaped fields (campi). Four recovered specimens from sample M-77-30 of the *H. kjerulfi* shales indicate an overall diameter of 36–45 µm.

Cymatiosphaera postii (Jankauskas 1976) Jankauskas, 1979 is represented by one uncertainly identified specimen recovered from sample M-77-11. The microfossil is 34 µm in diameter and its oval vesicle possesses high ridges which divide the

surface of the central body into pentagonal and hexagonal fields. Six to eight ridges are generally observed in this taxon.

Microfossils with circular or oval vesicles consisting of an inner spherical or ovoidal body equatorially surrounded by a thin irregularly shaped membrane with irregularly distributed supporting rods are here attributed to *Pterospermella* sp. Specimens recovered from samples M-77-11 and M-77-12 are oval-shaped with vesicles ranging from 35 to 40 µm across and with membranes of variable width (1–2 µm). However, one single specimen from sample M-82-44 has a solid vesicle of comparable diameter and a slightly wider membrane (2–3 µm).

Microfossils here attributed to the prasinophycean TASMANITACEAE belong to the genus *Tasmanites* Newton, 1875. The fossils were identified as *Tasmanites bobrowskae* Wazynska, 1967 and *Tasmanites tenellus* Volkova, 1968. One single specimen of *Tasmanites bobrowskae* Wazynska was recorded in sample M-77-30 of the *Holmia kjerulfi* shales. It possesses a thick, smooth wall with numerous conspicuous pores. It also lacks the narrow grooved connections observed in specimens of *T. volkovae* Kirjanov, 1974 (not recorded in the present material). *Tasmanites bobrowskae* Wazynska is a species abundantly represented in the Lower Cambrian of Scandinavia (Vidal 1981a; Moczydłowska & Vidal 1986; Moczydłowska 1989).

Tasmanites tenellus Volkova, 1968 is represented also by one single occurrence from sample M-77-28 from the *H. kjerulfi* shales. It has a spherical, thin to moderately thick vesicle (113 µm in diameter) provided with extremely small widely

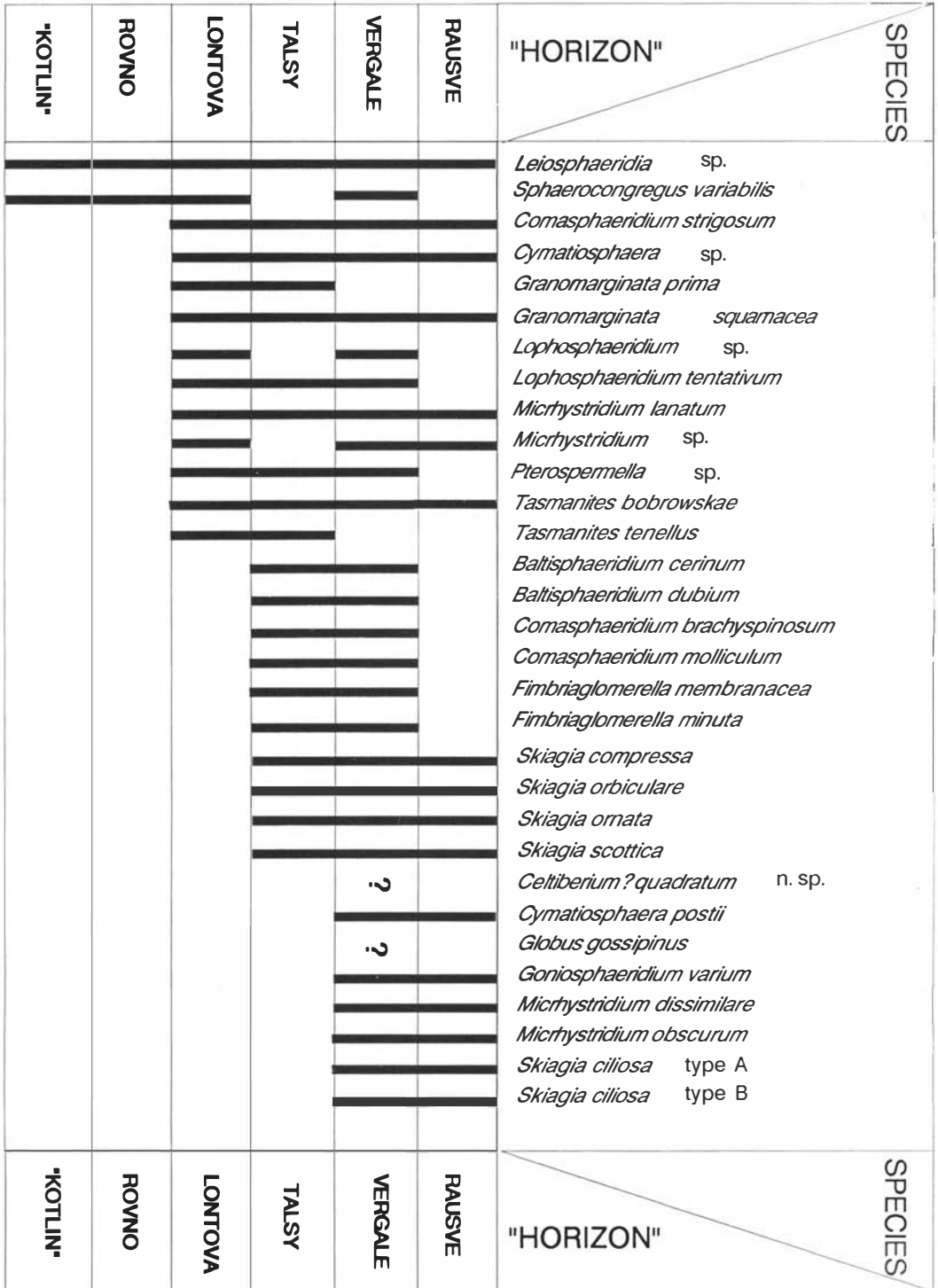


Fig. 10. Stratigraphic ranges of selected acritarch taxa in the Lower Cambrian and Upper Proterozoic in the East European Platform with corrected ranges for Scandinavia (after Moczydlowska 1989).

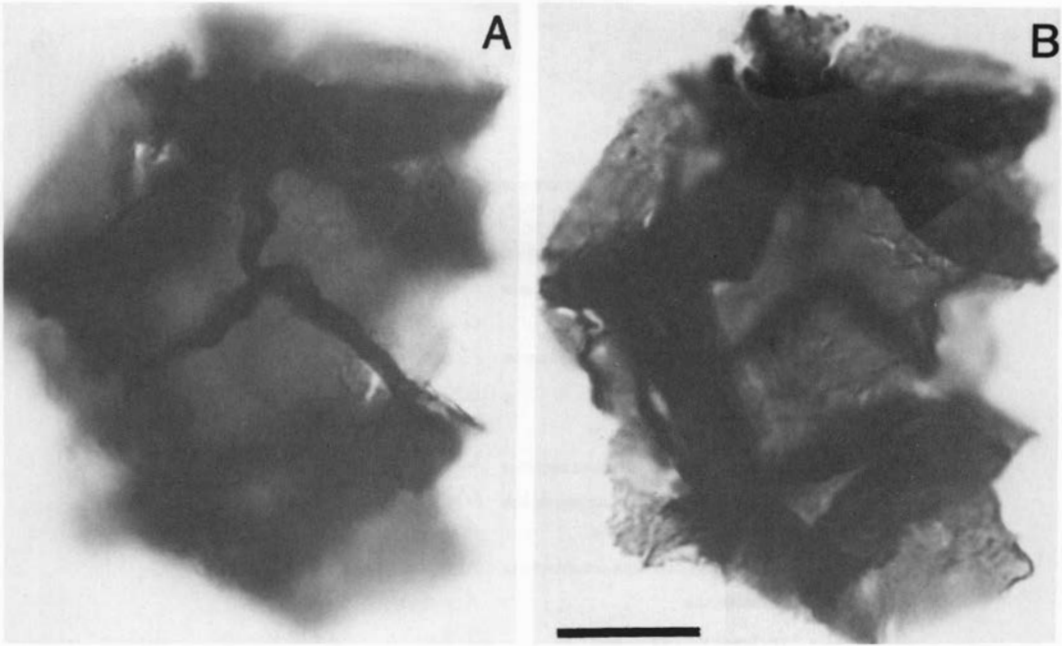


Fig. 11. A–B. *Cymatiosphaera* sp., upper and lower focus levels. Specimen LO 6060, slide M-77-30A(1): N/32-3. Oil immersion transmitted light. From sample M-77-30. Lower Cambrian *Holmia* shale at locality Tømten. Length of bar at B 10 μm .

spaced pores. In general, the species differs from *Tasmanites bobrowskae* Wazynska through its thin vesicle wall and small pores. The rarity of this, in other instances, generally common species may be explainable as a result of misidentification with large dark and thick-walled 'leiosphaerids'. This is because the dark colour imposed by thermal alteration on thick-walled spheromorphs renders the tiny pores diagnostic of this taxon invisible.

Several microfossil taxa are here attributed to the Group ACRITARCHA Evitt, 1963. Microfossils identified as *Baltisphaeridium cerinum* Volkova, 1968 (Fig. 12E) are rare in the Lower Cambrian of the Mjøsa area (one single specimen in sample M-77-28 and five specimens in sample M-77-112). The vesicle diameter ranges from 30 to 35 μm and the process length of processes is 3–5 μm .

Baltisphaeridium dubium Volkova, 1968 is represented by five specimens in sample M-77-28 and one single specimen in sample M-82-44 from the *Holmia kjerulfi* shales. The spheroidal vesicle, covered by numerous evenly distributed short and solid conical processes with rounded distal ends, is 35–50 μm in diameter and the processes range from 1 to 2 μm in length.

Rare specimens of acritarchs from samples M-77-05 and M-77-08 from the Bråstad shale are attributed to *Comasphaeridium brachyspinosum* (Kirjanov, 1974) Moczyłowska & Vidal, 1988a (Fig. 12A; for complete synonymy see Moczyłowska & Vidal, 1988a and Moczyłowska, in press). Recovered specimens have diameters ranging from 46 to 50 μm , while process length is 3–4 μm .

The population of *Comasphaeridium molliculum* Moczyłowska & Vidal, 1988a (Fig. 12B–C) in the present material is rich. The spheroidal vesicle has a smooth outer surface covered by numerous closely arranged filiform processes; ranges 37–72 μm . The processes range from 6 to 10 μm ($\bar{x} = 45$, $N = 30$). Excystment is by median split (Moczyłowska & Vidal 1988a), a feature never seen in the present material. It differs from *C. strigosum* (Jankauskas) Downie, 1982 by its slender, clearly defined and evident processes, differing from *C. brachyspinosum* (Kirjanov) Moczyłowska & Vidal, 1988a through the regular circular outline of the vesicle and through the absence of any thickening in the proximal portion of the processes. From *C. velvetum* Moczyłowska, 1988 it differs through its hair-like and well-defined, much longer discrete (not agglutin-

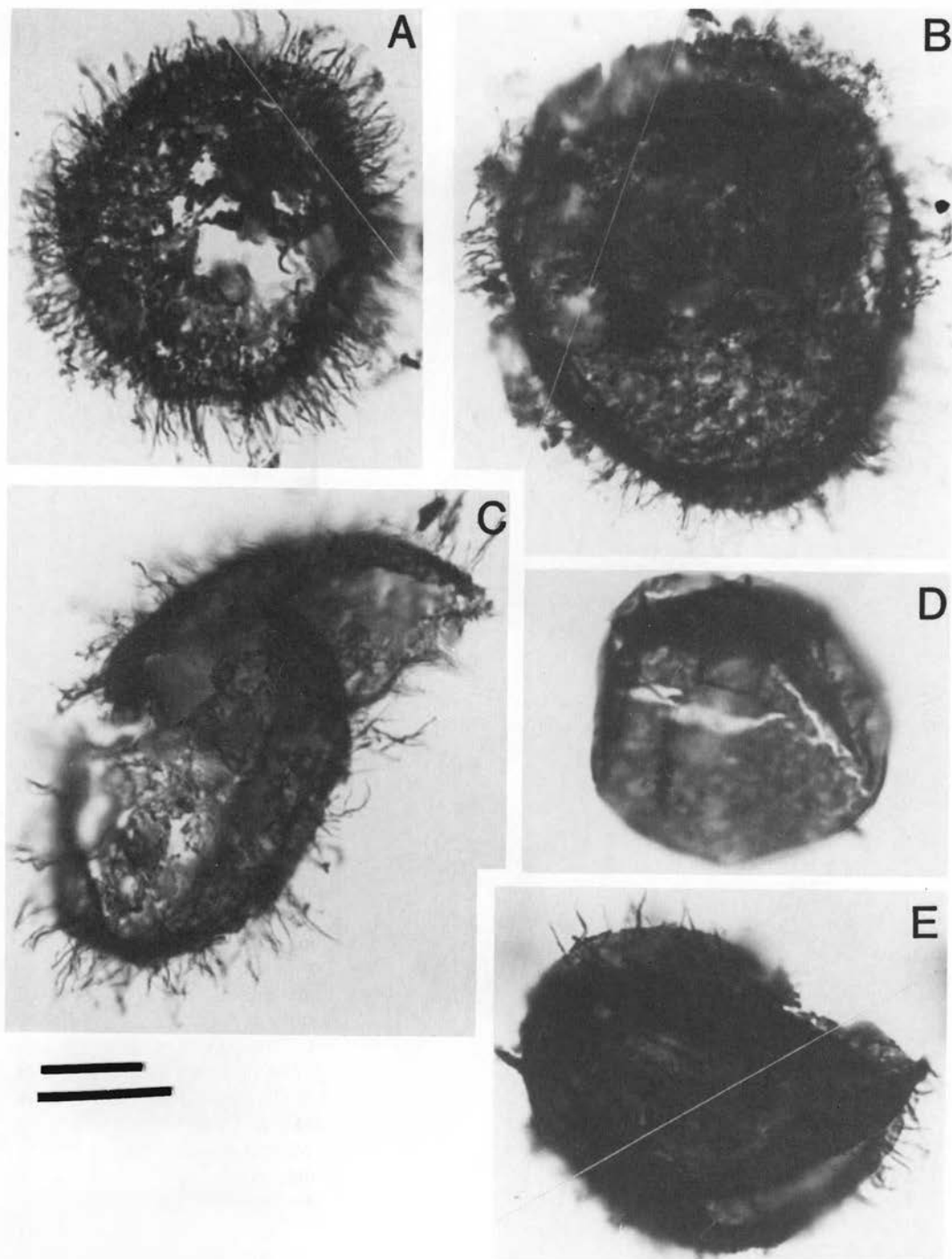


Fig. 12. A. *Comasphaeridium brachyspinosum* (Kirjanov 1974) Moczyłowska & Vidal, 1988, specimen LO 6061, slide M-77-05(01): W/30-3. B, C. *Comasphaeridium molliculum* Moczyłowska & Vidal, 1988, specimen LO 6062, slides M-77-05(02): Y/34 and M-77-07(A)1: V/36-4, respectively. D. *Leiosphaeridia* sp., specimen LO 6063, slide M-77-07(01): Z/50. *Baltisphaeridium cerinum* Volkova, specimen LO 6062, slide M-77-05(02): O/45. Specimens at A, B, E from sample M-77-05 from the Lower Cambrian Bråstad shale (unit 1a β) at Flagstadelva, Brennsætersaga. Specimens at C, D from sample M-77-07 (same unit and locality). Oil immersion transmitted light. Length of upper bar below C 10 μ m for A, B, E and lower bar 10 μ m for C, D.

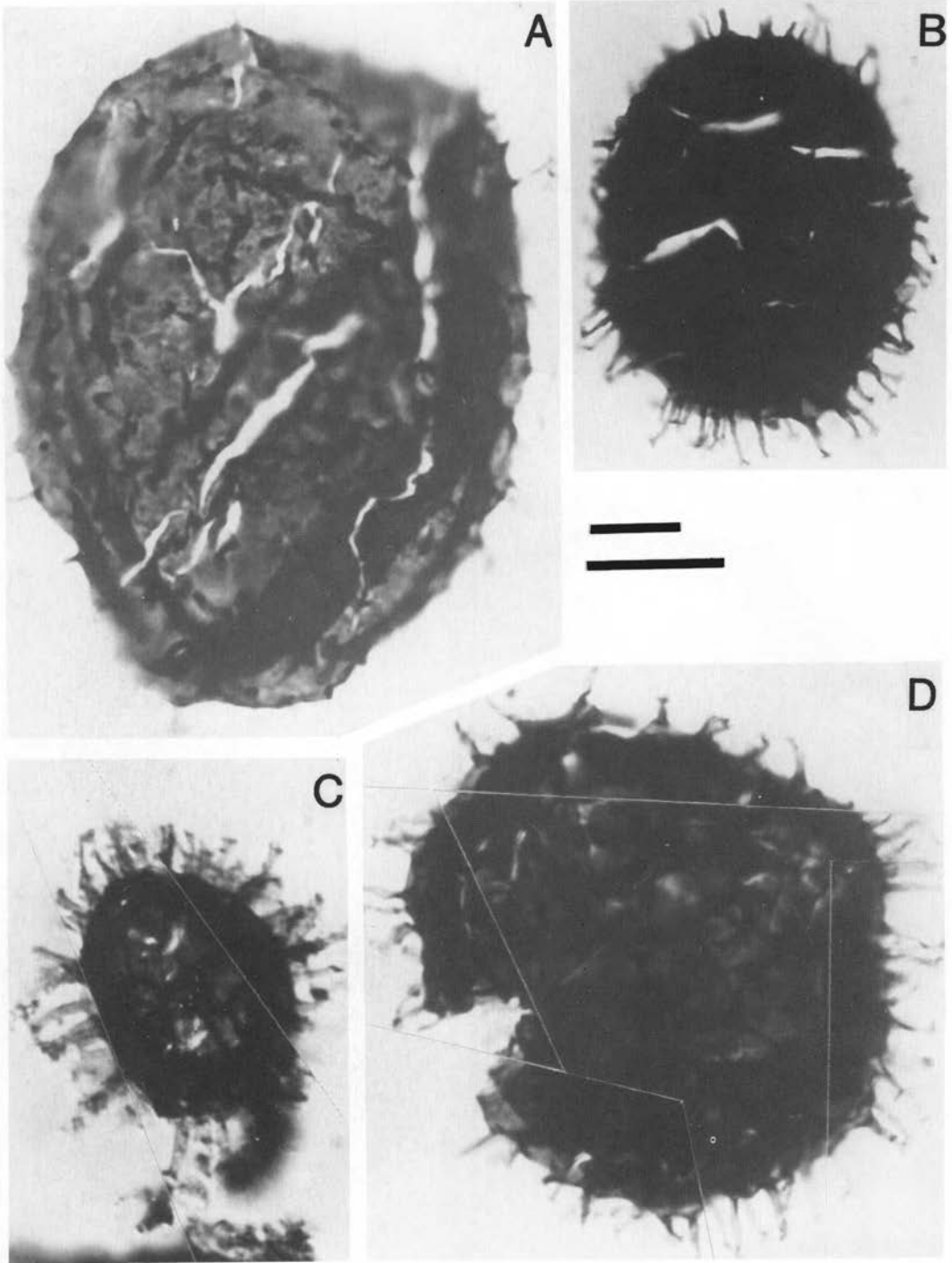


Fig. 13. A. *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 (type A), specimen LO 6065, slide M-77-08(01): G/47. B-D. *S. ciliosa* (Volkova, 1969) Downie, 1982, specimens LO 6066, LO 6065, slides M-77-29(01): O/49-1, M-77-29(01): G/38-2, M-77-08(01): X/39, respectively. From sample M-77-08 from the Bråstad shale at Flagstadelva, Brennsætersaga and M-77-29 of the *Holmia* shale at Tømten. Length of upper bar under B is 10 µm for A and B. Lower bar is 10 µm for C and D.

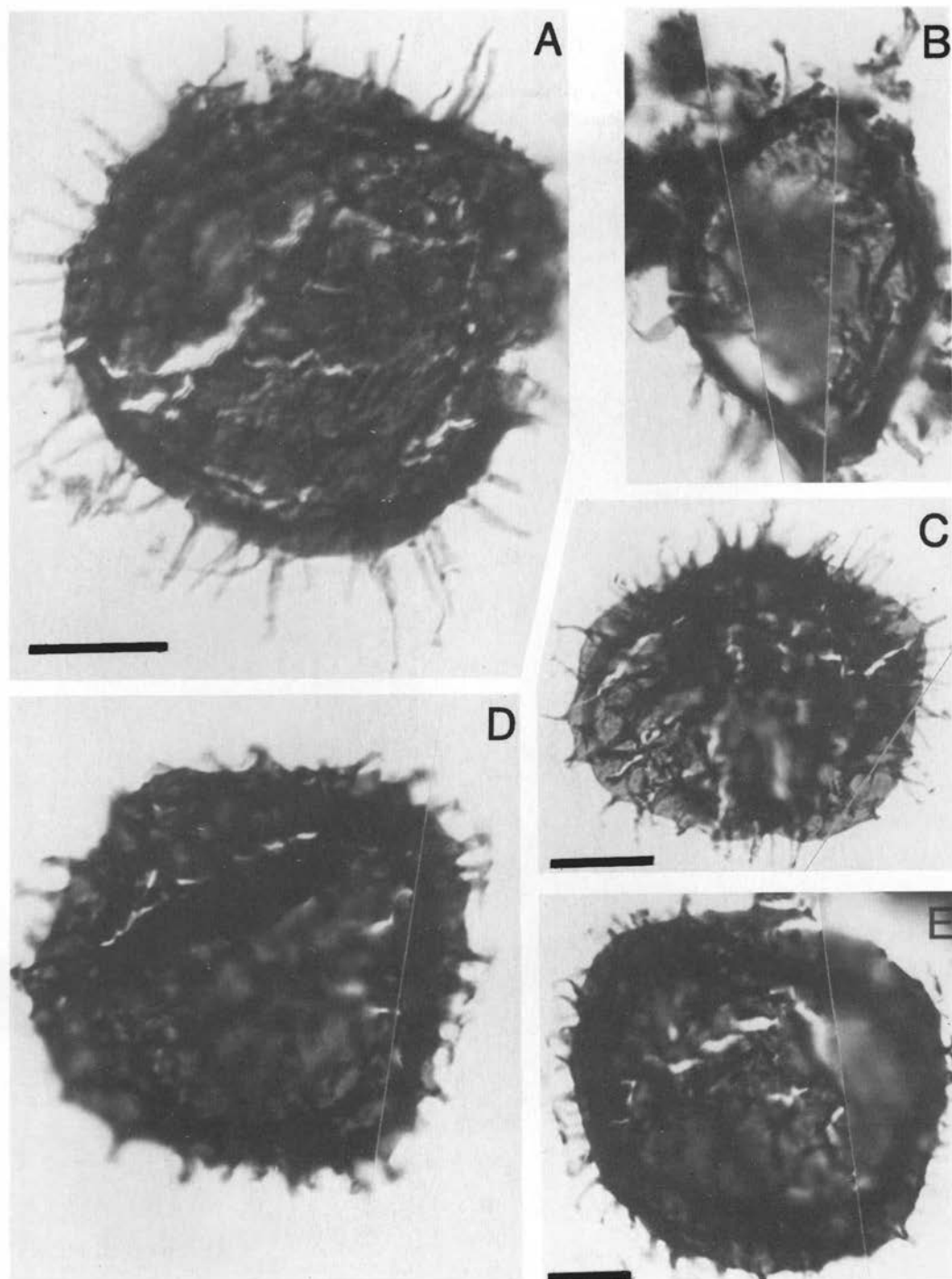


Fig. 14. A, B, D, E. *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 (type B), specimens LO 6067, LO 6072, LO 6066, slides M-77-28(01): K/46, M-77-04(01): W/50, M-77-29(01): D/32, M-77-29(01): G/50-1, respectively. C. *S. ciliosa* (type A), specimen LO 6066, slide M-77-29(01): W/50. From sample M-77-28, M-77-29 from the *Holmia* shale at Tømten and M-77-04 from the Bråstad shale at Flagstadelva, Brennsætersaga. Length of bar under A 10 μ m for A and D. Bar under C represents 10 μ m for B and C. Bar under E is 10 μ m for E.

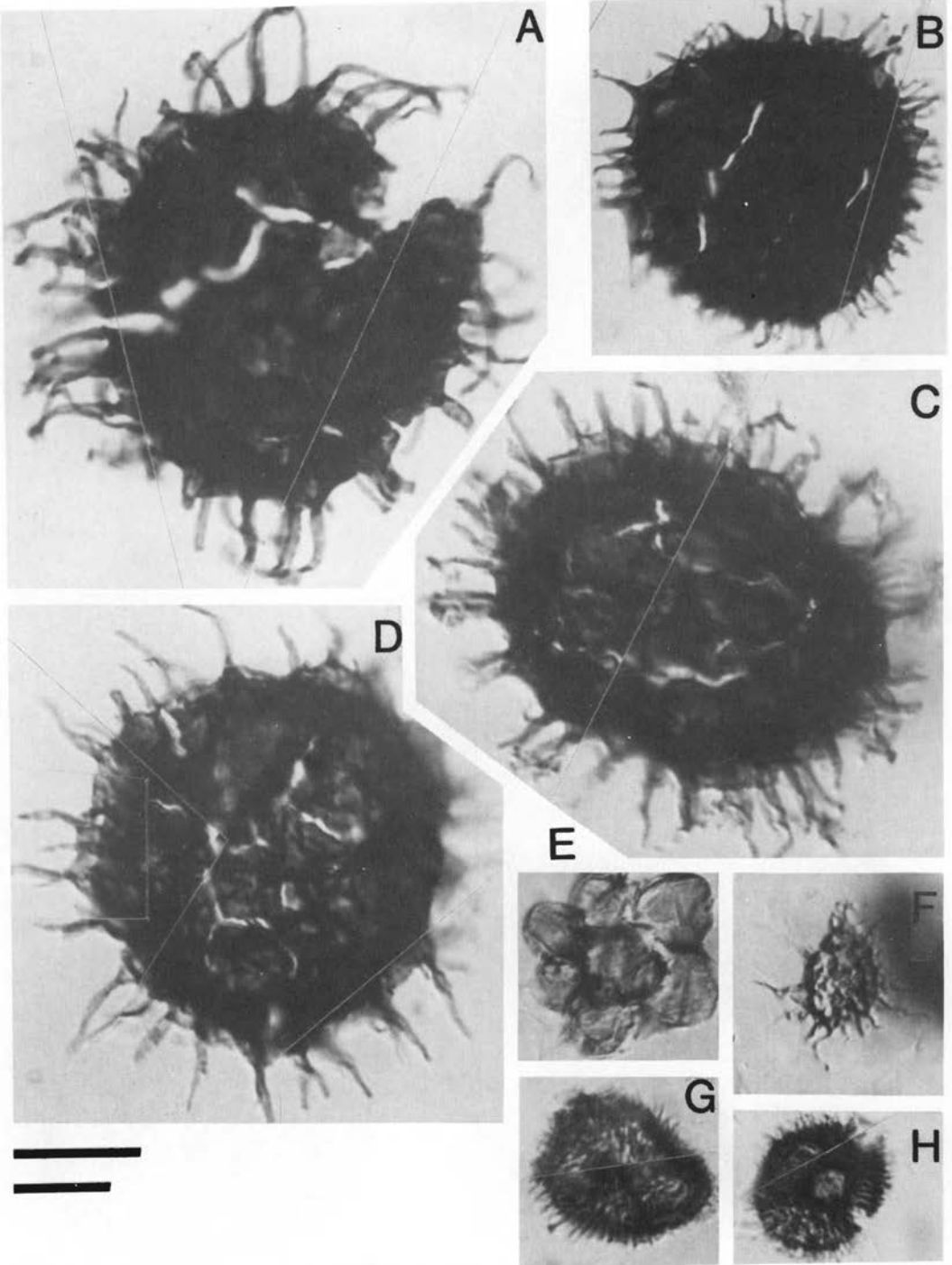


Fig. 15. A–D. *Skiagia compressa* (Volkova, 1968) Downie, 1982, specimens LO 6066 and LO 6067, slides M-77-29(01): S/37-1, M-77-29(01): C/40-4, M-77-28(01): Z/46-3, M-77-28(01): X/30. E. Unnamed coenobial cell cluster, specimen LO 6068, slide M-77-11(01)G: Y/27. F. *Micrhystridium dissimilare* Volkova, 1969, specimen LO 6068, slide M-77-11(01)G: N/26-1/3. G, H. *Micrhystridium lanatum* Volkova, 1969, specimen LO 6068, M-77-11(01)G: S/29-1 and M-77-11(01)G: S/46-4. From samples M-77-28, 29 of the *Holmia* shale at Tømten and M-77-11 from the Brennsæter shale at Flagstadelva, Brennsætersaga. Upper bar under D represents 10 µm for A–D. Lower bar represents 10 µm for E–H.

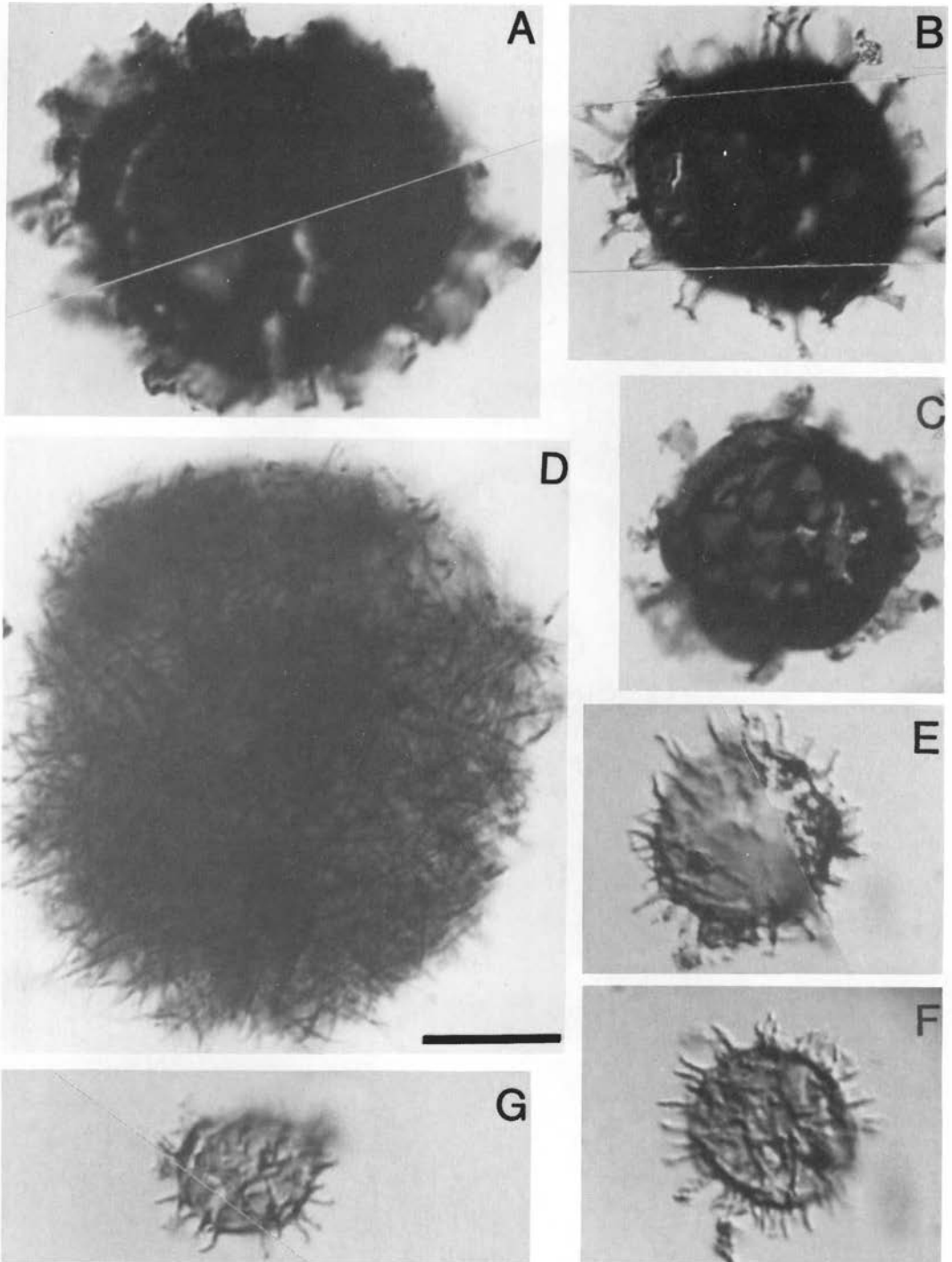


Fig. 16. A. *Celtiberium* ? *quadratum* n. sp., Holotype, specimen LO 6069, slide M-77-09(01): Z/48. B-C. *Skiagia* cf. *insigne* (Fridrichsone, 1971) Downie, 1982, specimens LO 6064 and LO 6062, slides M-77-07(01)A: D/38-2, M-77-05(02): Z/28-3. D. *Globus gossipinus* Vidal, 1988, specimen LO 6060, slide M-77-30(01)A: N/32-4. E-F. *Micrhystridium dissimilare* Volkova, 1969, specimen LO 6067, slide M-77-28(01): V/30, M-77-28(01): V/29. G. *Micrhystridium obscurum* Volkova, 1969, specimen LO 6067, slide M-77-28(01): P/41. From samples M-77-09, M-77-07, M-77-05 from the Bråstad shale at Flagstadelva, Brennsætersaga and M-77-28, M-77-30 from the *Holmia* shales and Evjevik limestone at Tømten and Skyberg, respectively. Bar under D represents 10 μ m for all specimens.

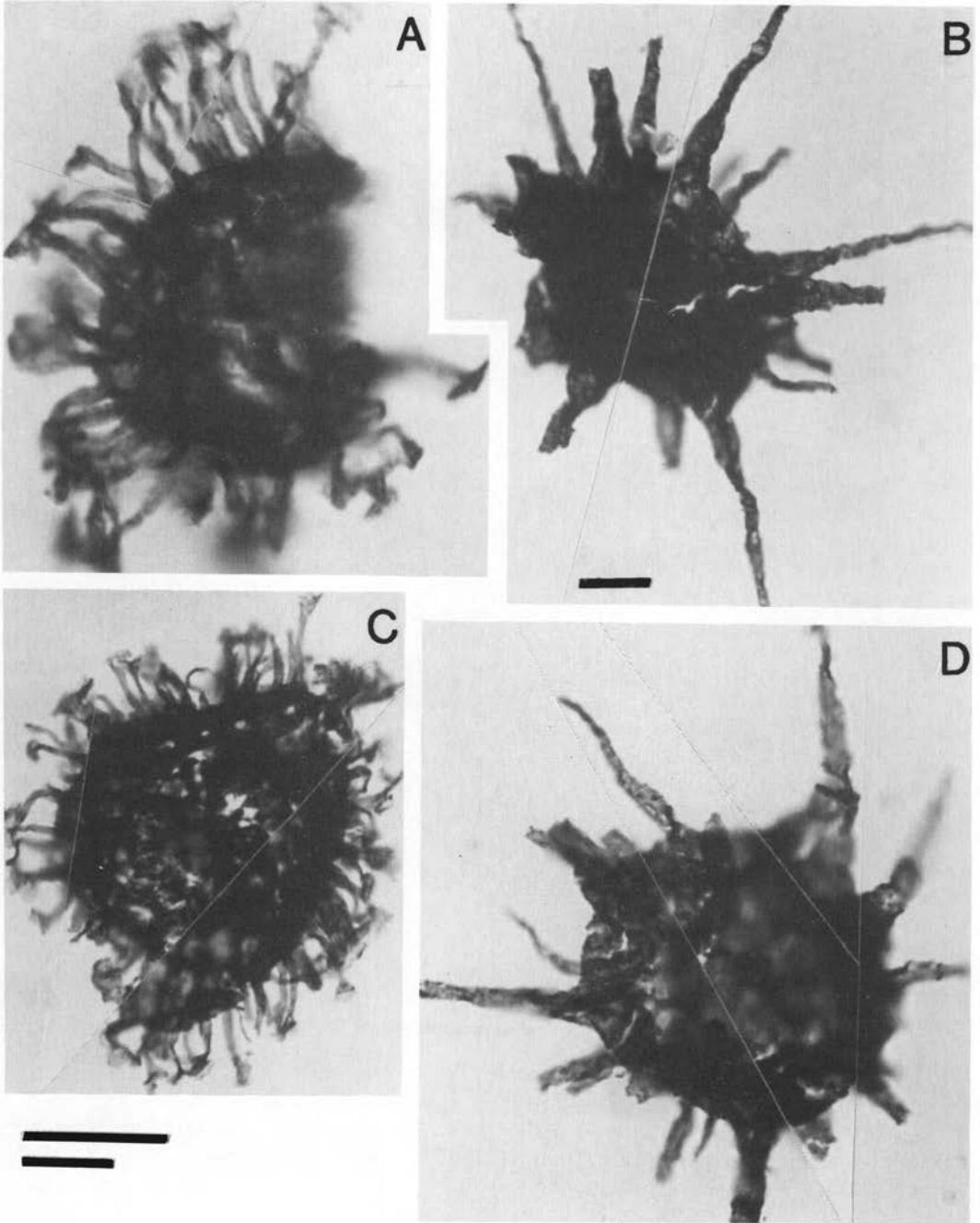


Fig. 17. A, C. *Skiagia ornata* (Volkova, 1968) Downie, 1982, Specimens LO 6070, LO 6071, slides M-82-32(01)A: K/37-3, M-77-06(01): U/28. B, D. *Goniosphaeridium primarium* (Jankauskas) Downie, 1982, specimen LO 6066, slide M-77-29(01): J/40-1, M-77-29(01): C/34. From samples M-82-32 of the *Holmia* shales at Sollerud, M-77-06 from the Bråstad shale at Flagstadelva, Brennsætersaga, M-77-29 from the *Holmia* shales at Tømten. Bar at B represents 10 µm for B. Upper bar under C represents 10 µm for A and lower bar 10 µm for C and D.

ated processes). *C. molliculum* is rather abundant in samples of the Brennsæter shale and Bråstad shale and occurs additionally in sample M-77-29 of the *Holmia kjerulfi* shales and M-77-112 of unit 1a α .

Comasphaeridium strigosum (Jankauskas) Downie, 1982 has a circular to oval vesicle possessing abundant and very closely attached processes that are filiform, of equal length and slightly widened proximally. The species is represented by single specimen occurrences in samples M-77-05, 08, 11, 112 of the Bråstad and Brennsæter shales, M-77-28 of the *H. kjerulfi* shales.

Individual occurrences of *Dictyotidium* Eisenack, 1955, emend. Staplin, 1961 in samples M-77-28 and M-82-40 display vesicle diameters ranging from 35 to 40 μm .

Fimbriaglomerella membranacea (Kirjanov, 1974) Moczydłowska & Vidal, 1988a has a spherical or ovoidal, double-walled vesicle with a robust-walled inner body and thinner surrounding membrane with straight filmy muri defining small, polygonal lumina. The species occurs as rare specimens in sample M-82-32. A closely related species, *Fimbriaglomerella minuta* (Jankauskas, 1979) Moczydłowska & Vidal, 1988a, has a spherical double-walled vesicle that, like in the former species, has an inner body enclosed by the outer thin membrane. Straight filmy muri rise radially from the inner body and define very small polygonal lumina. Two specimens recorded in sample M-77-11 of the Brennsæter shale are 21 μm in diameter.

Globus gossipinus Vidal 1988 (Fig. 16D) consists of spherical aggregates of submicron wide filaments irregularly protruding along the periphery. Rare specimens occur in samples M-77-29, M-77-30, M-82-37 from the *H. kjerulfi* shales and in sample M-77-112.

Goniosphaeridium primarium (Jankauskas) Downie, 1982 (Fig. 17B–D) has an oval-shaped, irregular, sturdy vesicle with conical-shaped processes with wide proximal portion which gradually taper towards the sharp-pointed distal part. The cavity of the vesicle is in open communication with the processes. Seven specimens found in sample M-77-28 and six from sample M-77-29 of the *Holmia kjerulfi* shales show vesicle diameters ranging from 27 to 60 μm and process 13–30 μm in length.

Granomarginata squamacea Volkova, 1968 consists of circular or oval vesicles having a 'sponge-like' wall which forms a wide corona

equatorially around the central body. The diameter of the inner body is 15–17 μm , while the width of the corona is 9–10 μm . It occurs in samples M-82-32, 33 at Sollerud (Figs. 4, 8), M-77-04, 05, 07 of the Bråstad shale and M-77-11, 15 of the Brennsæter shale (Figs. 2, 6).

Acritarchs attributed to *Leiosphaeridia* sp. (Fig. 12D) are solitary (usually compressed and displaying irregular folds), moderately robust and smooth vesicles in different states of degradation that occur in generally small numbers in the investigated samples (Figs. 6–8) and lack diagnostic features. Recovered specimens range from 21 to 35 μm in diameter.

Samples M-77-08, 09 yield specimens obviously attributable to *Lophosphaeridium* Timofeev, 1959, ex Downie, 1963, emend. Lister, 1970 which are otherwise too poorly preserved to allow completely certain identification. However, they could belong among *Lophosphaeridium tentativum* Volkova, 1968 and consist of thin-walled, circular to oval vesicles with a faint tightly arranged granular sculpture. The observed vesicle diameter in sample M-77-09, 11, M-82-33 is 36–58 μm .

Rare small acritarchs in sample M-77-09 of the Bråstad shale were uncertainly identified as *Micrhystridium* sp. Closer identification is not possible due to poor preservation. However, they cannot be compared with either *M. tornatum* or with *M. lanatum*. Most likely they represent poorly preserved specimens of *Micrhystridium dissimilare* Volkova, 1969 (Figs. 15F, E, G). They have a vesicle circular to oval in outline possessing numerous evenly distributed conical-shaped processes with widened proximal attachments and sharp-pointed, often twisted and elongated distal portions. The processes appear to freely communicate with the vesicle cavity. Specimens from M-77-11 have vesicles 10–12 μm in diameter and processes 3–4 μm in length, while slightly larger dimensions are observed in these from M-77-28, 29 (vesicle diameter 13–15 μm , process length 4–5 μm). A few specimens occur in sample M-77-11 of the Brennsæter shale and more abundantly in samples M-77-28, 29 from the *H. kjerulfi* shales (Figs. 6, 7).

Acritarchs here attributed to *Micrhystridium lanatum* Volkova, 1969 (Fig. 15G–H) have ovoidal to spheroidal vesicles covered by numerous uniformly distributed ciliar-shaped, slender processes of uniform length which are slightly widened basally in the shape of a grain.

Distally the processes are sharp-pointed. The vesicle is 10–22 µm in diameter and the length of processes is 2–4 µm. The species is abundant in sample M-77-11 of the Brennsæter shale (Fig. 6).

Michrystidium obscurum Volkova, 1969 (Fig. 16F) is represented by acritarchs with vesicles oval in outline and possessing an evenly distributed small number of short, sturdy, thorn-shaped processes which are slightly widened proximally and blunt or slightly tapering distally. The vesicle cavity communicates with the processes. The vesicle diameter is 10–12 µm, while the process length is 2–3 µm. Two specimens were identified in sample M-77-28 of the *H. kjerulfi* shales and an uncertainly identified specimen in sample M-77-11 of the Brennsæter shale (Figs. 6, 7).

Acritarchs attributed to the Genus *Skiagia* Downie, 1982 consist of specimens identifiable with *Skiagia* but not allowing further specific identification; these occur in samples M-77-02, 09, 31, 44, 45, 46, 112, M-82-30.

Acritarchs identified as *Skiagia ciliosa* (Volkova, 1969) Downie, 1982 (Figs. 13A–D, 14A–E) have circular to ovoidal vesicles possessing numerous cylindrical processes. The processes appear generally hollow but this feature is difficult to ascertain in many instances. The processes are isolated from the vesicle cavity by a plug. Proximally, the processes are generally conical, while apically they are funnel-shaped. In specimens from various samples the diameter of the vesicle is 27–45 µm and the length of the processes 5–10 µm. The species occurs in samples M-77-05, 07-10 of the Bråstad shale and M-77-28-30, M-82-39, 40, 44 of the *H. kjerulfi* shale and M-77-112. Two distinctive morphotypes of *S. ciliosa*, informally called *S. ciliosa* type A and *S. ciliosa* type B can be discerned in various Lower Cambrian sequences (cf. Moczyłowska & Vidal 1986). Type A (Fig. 13A, Fig. 14C) displays poorly developed process bases and the processes are thin and slender. *Skiagia ciliosa* type B (Fig. 13B–D, Fig. 14A, B, D, E) has wide conical process bases which are wider and as a rule also longer (Fig. 14A) and funnel-shaped terminally. Both morphotypes occur together in numerous samples from various Lower Cambrian sequences in numerous locations and their numeric relations are variable, a feature which defies explanation in terms of discernible environmental control.

Skiagia compressa (Volkova, 1968) Downie 1982 (Fig. 15A–D) possesses an oval-shaped ves-

icle that bears numerous proximally wide and conical-shaped processes, thus resulting in a diagnostically 'crenulated' periphery. Distally, the processes are funnel-shaped. The vesicle is 28–50 µm in diameter, while the length of processes is 5–10 µm. It occurs in M-77-07-11 from Brennsæter and Bråstad shale and samples M-77-32, 33, 29, 45, 112.

Single acritarch specimens from sample M-77-05, 07 of the Bråstad shale are identified as *Skiagia* cf. *insigne* (Fridrichsone, 1971) Downie, 1982 (Fig. 16B–C). They have an ovoidal to spheroidal vesicle with few, disperse robust and cylindrical processes that proximally are wide and in the shape of a truncated cone that is separated by a septum from the process stem. The distal ends are wide and funnel-shaped (in fact tulip-shaped). The vesicle is 22–24 µm and the processes are 3–4 µm in length.

Skiagia orbiculare (Volkova, 1968) Downie, 1982 refers to acritarchs with ovoidal to spheroidal vesicles with numerous medium-length processes that are slender, tapering along their length from the proximal part and distally, where they terminate in a funnel shape. Their vesicle is 20–35 µm in diameter, while the process length is 5–10 µm.

Skiagia ornata (Volkova, 1968) Downie, 1982 (Fig. 17A, C) has a spheroidal vesicle carrying numerous, long cylindrical processes that are widened proximally and distally (funnel-shaped). The vesicle is 27–40 µm, while the length of the processes is 10–12 µm. Two morphotypes denominated *S. ornata* type 1 and type 2 (Moczyłowska and Vidal 1986) have been distinguished. Type 1 (Fig. 11C–D in Moczyłowska and Vidal 1986; later described as *Elektoriscos flexuosus* sp. nov., although misspelt *Elektoriscos*, by Eklund, 1990) has numerous slender, often irregularly twisted processes that attach proximally by a bouton-shaped structure. Only type 2 occurs in the present material from southern Norway, in samples M-82-30-33, M-77-06-08, 10 of the Bråstad shale.

Skiagia scottica Downie, 1982 is a species with spheroidal to ovoidal vesicle with numerous processes that are long, slender and cylindrical, proximally slightly widened and distally open into a wide funnel shape, being often attached one to the other. The vesicle is 20–36 µm in diameter, the process length being 6–15 µm. It occurs as rare poorly preserved examples in samples M-77-08 of the Bråstad shale, M-82-30, 31, 32, 33 and M-77-112.

Sphaerocongregus variabilis Moorman, 1974 is represented by colonial cell aggregates about 20 µm in diameter consisting of discrete spheroidal cells 1–2 µm in diameter possibly related to Chroococcalean (Manusy & Vidal 1983) or pleurocapsalean (Knoll & Swett 1985) cyanobacteria. This taxon was reported by Knoll et al. (1981), Knoll & Swett (1985), Mansuy (1983), Palacios Medrano (1989), Vidal (1976) and Vidal & Nystuen (1990).

Trachysphaeridium timofeevi Vidal, 1976 reveals ovoidal to ellipsoidal, thick-walled and scabrate sculptured vesicles 58–65 µm × 20–32 µm. It occurs in sample M-77-28 and more abundantly in samples M-77-06, 07, 08, 10, 11, 15, M-82-31, 33.

Genus *Celtiberium* Fombella, 1977, emend. Fombella, 1978

Celtiberium ?quadratum Vidal n. sp.

Fig. 16A

Liepaina? n. sp., Vidal, 1981a, p. 190, Fig. 3A–B.

Derivation of name. – Latin quadratum, square; relating to the square outline of the processes.

Diagnosis. – Spheroidal compressed vesicle with tightly arranged rectangular-shaped processes with end bluntly on the distal portion. The processes appear imbedded in a membrane like tissue.

Holotype. – Fig. 16A. Specimen LO 6069, slide M-77-09(1): Z/48. Lower Cambrian Bråstad shale, Flagstadelva at Brennsætersaga, southern Norway (Figs. 1, 2).

Dimensions. – Vesicle diameter 25 µm, process length 3–5 µm.

Material. – Two specimens.

Remarks. – This species is known from sample M-77-09 from the Bråstad shale.

Unfortunately attempts at obtaining additional material were fruitless. The species has, however, a very diagnostic morphology and this motivates the formal description as a new species despite its extreme rarity.

Occurrence. – Bråstad shale, southern Norway.

Biostratigraphy

Lower Cambrian acritarch biostratigraphy emanates from extensive work in the Soviet part of the East European Platform (Jankauskas 1975; Jankauskas & Posti 1976; Volkova 1968, 1973, 1981b; Volkova et al. 1979, 1983; see also Keller & Rozanov 1979 for additional references), and in Poland (Moczyłowska 1988, 1989; Moczyłowska & Vidal 1986; Volkova 1981a) and has resulted in establishing a number of Upper Proterozoic and Lower Cambrian ‘horizons’ (Russian

gorizont). Although translated as ‘stage’ (Mens 1981) or as ‘regional stage’ (Mens et al. 1987), here the usage of ‘stage’ is preferred following Eklund (1990), who also included a comprehensive discussion upon the origin and usage of the units (see also Moczyłowska, in press).

Modern attempts at a biozonation of the mainly siliciclastic Lower Cambrian sequences in Baltoscandia resulted in distinguishing seven biozones based on generally sparse shelly fossils and trilobites (Ahlberg 1985; Ahlberg et al. 1986). The zone fossils of the two lower zones (*Sabellidites cambriensis* and *Platysolenites antiquissimus*) have demonstrably exceedingly long stratigraphic ranges (Bergström 1981; Vidal 1981b; Moczyłowska & Vidal 1986). Moreover, attention should be directed to the often overlooked fact that most (if not all) index taxa of shelly fossils in the ‘Tommotian’ Lower Cambrian have substantially longer stratigraphic ranges than suggested by the biozones which they are supposed to define (cf. Moczyłowska & Vidal 1986; Moczyłowska, in press). Moczyłowska & Vidal (1988b) indicated that shelly fossils regarded as Tommotian ‘index taxa’ have been reported in co-occurrence with trilobites defining the first recognized trilobite zone in the vast area of the East European Platform, the Fennoscandian Shield, the Scandinavian Caledonides and the Avalon Platform. Furthermore, it has been demonstrated (Bergström 1981) that faunal occurrences correlate with facies development and taphonomy. They represent in our view sporadic occurrences within the total time-range of the taxa concerned. This also may explain the irregular geographic distribution of certain taxa. Hence, in southern Baltoscandia, *Platysolenites* was recorded only in the Lake Mjøsa region (Vogt 1924; Føyn & Glaessner 1979), while *Sabellidites* is only reported from northern Norway (Føyn & Glaessner 1979). This raises doubts about the recognition of these zones in southern Baltoscandia (Vidal 1981b; Ahlberg 1985). Recently, Moczyłowska & Vidal (1986) and Moczyłowska (in press) attempted correlating these lower shelly fossil biozones with biozones established for the East European Platform underlying southeastern Poland.

Previous acritarch work in the Lower Cambrian of southern Norway is rather limited. Downie (1982), Vidal (1981a) and Moczyłowska & Vidal (1986, 1988b) listed occurrences of acritarchs in the *Holmia* shales in southern Norway and dis-

cussed their possible biostratigraphic implications for regional correlations.

Acritarch evidence from the Vangsås Formation is meagre, being restricted to the recovery of two specimens of the early Cambrian age diagnostic acritarch *Fimbrianglomerella minuta* from the top of the Vardal Sandstone Member (Vidal & Nystuen 1990) and two poorly preserved acritarch specimens from a shale interbed in the Ringsaker Quartzite Member. Undoubtedly the presently available data are insufficient. However, added to the generally accepted lithostratigraphic similarity and ichnofossil evidence (Skjeseth 1963), these findings are consistent with generally accepted long-distance correlations suggesting time equivalence between the Ringsaker Quartzite Member and the Hardeberga Sandstone. On the basis of acritarch evidence the Hardeberga Sandstone in southern Sweden was regarded as of early Cambrian *Holmia* age (Vidal 1981a). Recovered acritarch taxa were previously reported from the Lontova and Talsy 'stages' in the Baltic region of the East European Platform. The Talsy 'stage' encompasses the Lükati Formation in Estonia and time equivalent units in Poland which yielded a trilobite fauna attributable to the *Schmidtiellus mickwitzi* Zone (Mens et al. 1987). Among decidedly Talsy diagnostic acritarch taxa, the Hardeberga Sandstone yielded only four acritarch taxa reported from the Mazowsze Formation (corresponding to the *Platysolenites antiquissimus* Zone) in the Lublin Slope in southeastern Poland (Moczyłowska & Vidal 1986; Moczyłowska 1988b, 1989) and these have relatively long stratigraphic ranges. Moczyłowska (1989) incorporated the basal quartzarenites in southern Sweden (Hardeberga Sandstone in Scania and Bornholm) and southern Norway (Ringsaker Quartzite Member) in the *Schmidtiellus mickwitzi* Zone (the lowermost trilobite zone in Baltoscandia and the East European Platform).

Based on a single find of a trilobite attributed to *Holmia* cf. *mobergi* (Ahlberg et al. 1986), the shales of unit 1a α_1 (= Brennsæter shale) were correlated with rocks in southern Sweden (Norretorp Sandstone) considered as part of the *S. mickwitzi* Zone (Bergström 1981) and later (Mens et al. 1987) correlated with the upper Dominopol' (= Talsy) 'stage' in the USSR. Based on previous and present acritarch evidence, the age of the Brennsæter shale (1a α_1) and the overlying Bråstad sandstone (1a α_2), successively on top of the

Ringsaker Quartzite Member, is ambiguous. This is because sampled levels immediately above the Ringsaker Quartzite Member did not yield any time-diagnostic acritarch taxa to allow comparison with other sequences. At the most complete section, at Flagstadelva (Brennsætersaga), time diagnostic acritarchs appear first about 2 m above the top of the Ringsaker Quartzite (sample M-77-11; Fig. 6). Most taxa have considerable ranges. However, the abundant occurrence of *Micrhystridium dissimulare* (Fig. 6) is in agreement with a Vergale age (Volkova et al. 1983).

Bergström (1981), Ahlberg et al. (1986) and Mens et al. (1987) considered the Mickwitzia Sandstone in Västergötland as belonging to the *Schmidtiellus mickwitzi/Mobergella* Zone and thus, time equivalent to the Brennsæter shale. The unit yielded an acritarch assemblage consisting of Talsy and Vergale age-diagnostic acritarchs (Moczyłowska & Vidal 1986) interpreted by Eklund (1990) as of early and late Vergale age and suggesting time equivalence with the Bråstad shale and overlying units of the Lower Cambrian in the Mjøsa area.

The Bråstad shale (unit 1a β) yielded the trilobite *Holmia inusitata* which defines the *Holmia inusitata* Zone (Ahlberg et al. 1986) which is correlated with the lower portion of the Vergale 'stage' in the USSR. *Volborthella tenuis* occurs in the unit (Vogt 1924) which also yielded a single fragmentary specimen of *Platysolenites antiquissimus* (Vogt 1924) from Stensviken (= Steinsodden; see appendix). Probably through a misinterpretation, this occurrence of *P. antiquissimus* was subsequently placed in the Brennsæter formation (= unit 1a α_1) by Skjeseth (1963; cf. Føyn & Glaessner 1979).

In the investigated section at Flagstadelva, Brennsætersaga (see appendix), *Skiagia ciliosa* (type B), a Vergale age-diagnostic taxon (Figs. 12, 13), appears first in unit 1a β (= Bråstad shale) at a level about 5.5 m above the Ringsaker Quartzite Member (sample M-77-10) and *S. ciliosa* (type A) occurs in overlying beds (Fig. 6). The questionable occurrence of *Skiagia* cf. *insigne* in samples M-77-05 and M-77-07 is of certain interest. This Vergale 'stage'-diagnostic species was reported by Hagenfeldt (1989) from units at several drillhole locations in the Baltic area to which Vergale and younger ages were attributed. However, the questionably identified specimens represent the second recorded occurrence (the species definitively occurs in the upper Broens

Odde member, also known as 'Green Shales' of the Læså formation on the Island of Bornholm; Moczyłowska and Vidal, unpublished data) in Scandinavia.

Rocks in localities Tømten and Skyberg are attributed to the *Holmia kjerulfi* and *Proampyx linnarssoni* trilobite zones. Several acritarch taxa recovered from the units, such as *Skiagia ciliosa*, *Dictyotidium priscum*, *Micrhystridium obscurum* and *Goniosphaeridium primum*, have their first appearances in the Vergale 'stage' (Volkova et al. 1983). Additionally, *Skiagia scottica*, inferred to indicate a Vergale age (Downie 1982) occurs in two samples from the section at Skyberg. In all, acritarchs from the investigated samples are in agreement with a Vergale age or younger. However, no single taxa diagnostic of the uppermost Cambrian Rausve 'stage' was recorded. The same applies to the scarce assemblage recovered from rocks at locality Sollerud (Fig. 9).

Acritarch based correlations of Lower Cambrian sections in areas within the margins of the Iapetus Ocean were attempted by Downie (1974, 1982), Knoll & Swett (1987), Moczyłowska & Vidal (1986), Vidal (1979). Downie (1974) and Vidal (1979) noted that the Bastion Formation in East Greenland contains a diverse assemblage of Talsy and Vergale age-diagnostic acritarchs and subsequently Moczyłowska & Vidal (1986) showed that the assemblages from the Lower and Upper Bastion Formations have much in common with the assemblage recovered from the Brennsæter and Bråstad shales. Acritarchs from the basalmost Bastion Formation yielded an acritarch complex consistent with a Vergale age (Vidal, unpublished data) and it seems reasonable to assume that it correlates with most of the Topiggane Shale in Spitsbergen (Knoll & Swett 1987). Thus, the almost barren quartzarenites of the Ringsaker Quartzite Member and the poor acritarch assemblage of the Brennsæter shale in southern Norway appear to have counterparts in the totally barren quartzarenites of the Blåevbreen Sandstone Member at the base of the Tokammane Formation and in the depauperate Lontova-like assemblage from the base of the overlying Topiggane Member (cf. Knoll & Swett 1987). In the North Atlantic realm (including the Tokammane Formation in Spitsbergen; Knoll & Swett 1987, the Fucoïd Beds in Scotland; Downie 1982 and the Bastion and Ella Island Formations in East Greenland; Downie 1974, 1982; Moczyłowska & Vidal 1986, Vidal 1979 and unpublished

data) the condensed Lower Cambrian sequences lack the acritarch assemblage diagnostic of the Talsy 'stage'.

The first occurrences of *S. ciliosa* and *M. dissimilare* are significant for recognizing *Micrhystridium dissimilare* acritarch zones (= Vergale acritarch horizon; Moczyłowska 1989). Downie (1982) did not record *S. ciliosa* from the Fucoïd Beds in Scotland, but a species described by him under the name *Skiagia brevispinosa* Downie (1982) is undoubtedly the same as *S. ciliosa* type A, and *Micrhystridium flexispinosum* Downie (1982) is evidently conspecific with *M. dissimilare*.

The shallow marine arenaceous and argillaceous (cf. Mens et al. 1987) rocks of the Lontova Formation in eastern Estonia, eastern Latvia, Lithuania and northern Byelorussia yielded a poorly differentiated acritarch assemblage characterizing the Lontova 'stage'. In the western parts of the East European Platform in the Lublin Slope in Poland, sandy and silty correlatives are part of the Mazowsze Formation, which is generally thicker and perhaps deposited under more open marine conditions. Initially, additional to obvious faunal similarities with the Lontova Formation (Moczyłowska & Vidal 1986; Moczyłowska 1989), Volkova (1972) detected the depauperate acritarch assemblage diagnostic of the Lontova 'stage' in the Mazowsze Formation in drillhole Radzyn (Moczyłowska & Vidal 1986:212). More recently, a definitively more diverse assemblage of 'comasphaerids', 'micrhystrids', *Pterosperrmella* and *Granomarginata* was recovered from drillhole Radzyn, and several additional drillholes (Moczyłowska 1988, 1989), and unequivocally defines a biostratigraphic assemblage zone (*Micrhystridium tornatum/Comasphaeridium velvetum* acritarch zone; Moczyłowska 1989, in press) obviously preceding a taxonomically more diverse and formerly recognized Talsy 'stage' assemblage (= *Skiagia ornata* acritarch zone; Moczyłowska 1989). There seem to be two possible explanations for this discrepancy in phytoplankton contents between the Lontova Formation in the USSR part of the East European Platform and its obvious counterpart in southeastern Poland (Mazowsze Formation): (a) the Mazowsze acritarch assemblage has escaped detection in former investigations of the Lontova Formation, alternatively, (b) in the Polish part of the East European Platform, the Mazowsze assemblage formed during conditions of accumulation representing more open marine

or offshore conditions (presumably therefore being more diverse) than these affecting the Lontova 'stage' assemblage in the USSR part of the East European Platform. In any event the Lontova and Mazowsze assemblages are replaced by the distinctive Talsy (= *Skiagia ornata* acritarch zone; Moczyłowska 1989, in press) assemblage. This has a simple explanation in the USSR part of the East European Platform, where the Lükati Formation rests transgressively (and separated by a conglomerate) on the Soru Formation and the Lontova Formation (Mens et al. 1987). Hence (as might appear to be the case with the Ringsaker Quartzite Member and overlying *Holmia* shales) a hiatus can be inferred. On the other hand, in SE Poland, sedimentologic evidence by Jaworowski (1980) indicates continuous deposition across the junction between the Mazowsze and Kaplonosy Formations (Lendzion 1983). Nevertheless, Lendzion (1983) postulated a hiatus between the Mazowsze and Kaplonosy Formations (units attributed to the *Platysolenites* Zone and the *Schmidtellus* Zone, respectively) referring to the negative evidence provided by the absence of *Mobergella* in the Lublin Slope (cf. Moczyłowska (1988 and in press for a detailed review) as compared to its previously recorded occurrence in drillholes in the Baltic Syncline and Podlasie Depression. However, continuity (or lack thereof) ought to be defined on sedimentological criteria. Detailed studies of numerous continuously cored drillholes from the Lublin Slope (Moczyłowska & Vidal 1986; Moczyłowska 1989, in press) failed to reveal a break between the units in question and are thus in agreement with the independently presented results by Jaworowski (1978, 1980). This suggests that during late Proterozoic and early Cambrian times the Lublin Slope of the East European Platform was part of a passive margin and that (contrary to what seems to be the case with southern Baltoscandia) sedimentation might have been essentially continuous across the Precambrian/Cambrian boundary.

Ongoing studies of stable isotopes (C and S) and biomarkers across the proposed boundary interval may shed additional light on the degree of depositional continuity across the Precambrian/Cambrian transition interval. However, published preliminary isotopic curves for the early Cambrian elsewhere might prove of little use in establishing continuity (or lack thereof) in any of the above sections. This is because in the absence

of a demonstrably complete reference curve, isotopic data can only document a stratigraphic discontinuity if the time interval represented by the hiatus was one of major change in ocean water chemistry. Until an isotopic curve is established for unambiguously pre-trilobite Cambrian carbonates, no conclusions about sedimentological completeness can be drawn from Lower Cambrian isotope data.

Because of the large extension of the investigated area of the Lublin Slope, the nearly contemporaneous phytoplankton changes are described by Moczyłowska (1989) from several drillholes across various lithofacies and do not coincide with lithostratigraphic boundaries. A phytoplankton 'shift' occurs at the top of the Włodawa Formation in rocks considered to represent the upper limit of the *Sabellidites* Zone. Hence, it slightly precedes, or roughly coincides, with the appearance of 'Tommotian' faunal components such as *Aldanella polonica* = *Aldanella attleborensis* (Landing 1988), *Anabarella* sp., *Onuphionella agglutinata*, *Platysolenites* sp. and *P. antiquissimus* (for further details see Moczyłowska & Vidal 1986; figs. 3, 4, 6 and Moczyłowska 1988; fig. 1, in press).

On faunal and acritarch evidence (Rudavskaya & Vasilieva 1984; Moczyłowska & Vidal 1988b) the Talsy 'stage' appears roughly time equivalent to the *Dokidocyathus regularis* archaeocyathian Zone of the Tommotian Stage in eastern Siberia.

The absence of pre-Vergale acritarch assemblages in the Lake Mjøsa region is in agreement with a general pattern observed in Baltoscandia. Thus, no assemblage comparable to the characteristic *Michrystidium tornatum*-*Comasphaeridium velvetum* assemblage from the Mazowsze Formation in SE Poland (Moczyłowska 1989, in press) has been detected thus far in a number of sequences in Scandinavia and most rock units investigated to this date appear of Vergale age (Eklund 1990; Hagenfeldt 1989; Moczyłowska & Vidal 1986). Wherever acritarchs were recovered, the basal Cambrian quartzarenites in fragmented areas of the former Iapetus shelf border and the pericratonic Baltoscandian Cambrian basins (southern Norway, southern Sweden and Bornholm) correspond most likely with the Talsy 'stage' (*Skiagia ornata* acritarch zone; Moczyłowska 1989, in press) distinguished in the Lublin Slope of the East European Platform. Hence, paralleling the circumstances in the Lublin Slope, deposits attributable to this second acritarch zone

appear restricted to areas of moderate subsidence along the Teisseyre/Tornquist Lineament (Scania in southern Sweden and the island of Bornholm) and the Caledonides (e.g. Laisvall; Vidal, unpublished data) in the periphery of Baltoscandia, where the occurrence of shale interbeds and phosphorites allow the extraction of relatively abundant phytoplankton (Vidal 1985). Although acritarch data from this study are insufficient, it can be inferred that the absence of Talsy acritarchs (*Skiagia ornata* acritarch zone) depends on the unsuitable facies development dominated by barren quartzarenites.

On the global scale, the Proterozoic-Cambrian sequences in southern Norway have little direct bearing on the problem of the Precambrian-Cambrian boundary. This is because critical portions of the sequence that might straddle the boundary interval are represented in palaeontologically barren units (the generally arenaceous Vangsås Formation). However, these units are overlain by fossiliferous rocks that allow correlation with demonstrably more complete sequences across the boundary interval. Obviously, the present data contribute additional points of observation and strengthen previously suggested correlations between the sequences in Baltoscandia, the East European Platform, the Scandinavian and Greenland Caledonides, the British Isles and North America. Furthermore, this case study demonstrates that studies of fossil phytoplankton from sequences near the Precambrian-Cambrian boundary can contribute substantial understanding to the biotic changes around this important portion of Earth history. Furthermore, increased biostratigraphic resolution contributed by these studies is of importance to the chronologic framing and final understanding of the paramount events in the evolution of the Earth's biota. Near the Precambrian-Cambrian boundary, the explosive radiation of skeletonized metazoans appears as a geologically instantaneous event. However, the first appearance of skeletons in Vendian and Lower Cambrian strata shows that the development of mineralized skeletonization among metazoans was neither instantaneous nor simultaneous in all taxa (Brasier 1982; Lowenstam & Margulis 1980; Stanley 1976). At a pre-skeletonized stage primeval metazoans could have produced agglutinated skeletal parts which post-mortem disaggregation would make unrecognizable in the fossil record (Lowenstam & Margulis 1980). Thus, it may be argued that metazoan

origins could be deeply rooted in the Proterozoic, not being commonly preserved until they eventually became sufficiently numerous (Nicol 1966), or developed mineralized skeletonization (Rhoads & Morse 1971; Lowenstam & Margulis 1980).

Biomineralization is widespread among plant protists. Cyanobacteria-like groups appear deeply rooted in the Proterozoic (Hofmann 1976) and perhaps in the Archean (Awramik et al. 1983; Knoll & Barghoorn 1977). They acquired calcification and appear as calcified fossils (despite a reported but dubious early report suggesting ability to precipitate calcite among possible cyanobacterial microfossils of early Proterozoic, 2.5–2.3 Ga, age; Klein et al. 1987) near the Lower Cambrian boundary (Riding 1984). This feature was attributed to decreased Mg^{2+}/Ca^{2+} ratios (Riding 1982). Differing from an inferred causal connection which seems to link biocalcification in Palaeozoic algae to transgressive events and ensuing extension of epicontinental seas, biocalcification among early Cambrian metazoans does not *per se* follow a suggested increase of habitat following the early Cambrian transgressive event(s) (Riding 1982).

Biomineralization is a feature familiar to many Recent plant protists such as diatoms, chrysophytes, silicoflagellates and calcareous nanoplankton. To judge from its scarce Proterozoic and earliest Cambrian record, biomineralization appears to be exceedingly ancient among various groups of eukaryotic planktonic protists (Allison & Hilgert 1986; Fairchild et al. 1978; Knoll & Vidal 1980; Morad & Vidal 1989). Among possible metazoans, the earliest documented examples of biomineralization in the fossil record derive from the late Proterozoic (late Vendian) in Namibia (Nama Group) and in Spain (Grant 1990).

While the origin of animal clades near to the Precambrian/Cambrian boundary remains obscure, interpretations of their life modes and habitats are useful because they provide the means of analysing possible ecological interactions. Largely based on biomechanical considerations and neontological functional analogies, tube-dwellers are interpreted as infaunal or epifaunal suspension feeders, whereas sclerite-bearing metazoans may in most cases represent benthic deposit-feeders or grazers. Equally significant is analysing the ecological interaction between primary producers and animal grazers.

Thus, predation pressure has been argued to generate patterns of change in the fossil record of phytoplankton (Kitchell 1983). Are there any signals in the early record of planktonic protists which could be connected with an inferred sudden or gradual rise of predation levels? The answer appears to be, yes. The incoming of the earliest Cambrian faunas must have involved a sharp rise in the utilization of organic matter near the water/sediment interface (Bengston 1989). Its appearance in the geologic record can be inferred from the simultaneous appearance of shelly remains and innovative feeding strategies revealed by ichnofossils which are paralleled by a contemporaneous major change among phytoplanktic acritarchs (Moczyłowska & Vidal 1986; Moczyłowska 1989). The correlation of these observed changes with changing productivity levels is demonstrated by at least two studied sequences across the Precambrian–Cambrian boundary (in Newfoundland; Strauss et al. 1990; and in south-eastern Poland; Vidal & Moczyłowska, unpublished data) showing mirroring changes in the $\delta^{13}\text{C}_{\text{org}}$ values of kerogen.

The dominantly arenaceous Lower Cambrian sequences in Baltoscandia are relevant to the above discussion since they illustrate the clear interdependence of the fossil record of metazoans to depositional environments and rock record (Bergström 1981). Invertebrate fossils are generally extremely rare in rocks referred to the lower part of the *Holmia* Series. In fact, several decennia of intermittent, but intensive, search have yielded but a handful of rather fragmentary fossils (see Ahlberg et al. 1986 for a recent review). This does not only apply to the most rare trilobite remains but also to small shelly fossils such as *Mobergella*, *Volborthella* and *Platysolenites*. In fact, hours of intensive search in the greyish shales of unit $1a\beta$ may result in a meagre yield of three or four specimens of *Volborthella*. Despite their rarity, fossils from units $1a\alpha_1$, $1a\alpha_2$ and $1a\beta$ constitute a biota witnessing of an advanced level of faunal differentiation which comprises problematic protozoans and all modern phyla of marine invertebrates with the exception of the bryozoa (Bergström 1989). In fact, outside the Mjøsa area, the probable time-equivalent correlative of the Ringsaker Quartzite Member (Hardeberga Sandstone) in southern Sweden yielded the impression of an indeterminable trilobite (Ahlberg et al. 1986) and numerous ichnofossils, thus suggesting a substantial biotic

complexity at the time of deposition of the basalmost Cambrian quartzites. Dense accumulations of trilobite ‘hash’ are found in condensed bioclastic carbonates referred to the Evjevik limestone (unit $1b\beta$; Skjeseth 1963). Post-mortem concentration and accumulation is probably the mechanism responsible for the formation of these ‘shell-beds’. Thus, the presence or absence of shelly fossils of marine invertebrates in the Lower Cambrian may locally have to do with rates of post-mortem accumulation rather than with selective environmentally controlled biofacies. In this context the numerically advantageous nature of the fossil record of protists in respect of that of marine invertebrates merits special mention (Knoll 1987). In contrast to the above, relatively rich assemblages of acritarchs were recovered from otherwise virtually barren rock units (Vidal 1981a). Despite this, by comparison with other Lower Cambrian units, acritarchs are generally rare in the massive quartzite-dominated basalmost Cambrian units in Baltoscandia (Vidal 1981a). This obviously correlates with the extreme rarity of fine detrital rocks which, whenever present, yield abundant and well-preserved acritarchs (Vidal 1981a; Moczyłowska & Vidal 1986). In the Ringsaker Quartzite Member in southern Norway fine detrital rocks are virtually absent. Two recovered specimens of poorly preserved acritarchs attributed to *Comasphaeridium* sp. constitute the total record from this rock unit.

Conclusions

The Lower Cambrian of the Lake Mjøsa region in southern Norway has come to be a cornerstone in the faunal zonation of the Lower Cambrian of Baltoscandia. Acritarch assemblages can be related to the biozonation of shelly faunas and allow correlation with acritarch biozones in the Polish and USSR parts of the East European Platform, adjacent platform areas in Baltoscandia and the dismembered remains of the shallow shelf areas bordering the early Palaeozoic Iapetus Ocean (Spitsbergen, the Swedish Caledonides, Scotland and East Greenland).

Near the Precambrian–Cambrian boundary the radiation of skeletonized metazoans seems an instantaneous event. Primary producing phytoplankton forms the base of marine trophic regimes and near the Precambrian–Cambrian boundary is profusely represented by rich and diverse acritarch assemblages. Their study, par-

alleled by investigations on the habitats and life modes of early Cambrian infaunal or epifaunal suspension-feeding tube-dwellers and sclerite-bearing benthic deposit-feeders or grazers, is significant for detecting signs of the early ecological interaction between primary producers and animal grazers. Hence, the incoming of the earliest Cambrian faunas must have involved an observable utilization of organic matter near the water/sediment interface which in the geologic record might be inferred from the simultaneous appearance of shelly remains and innovative feeding strategies paralleled by contemporaneous changes in the specific composition of assemblages of phytoplanktic acritarchs. Accurate biostratigraphic subdivision of the Upper Proterozoic and Lower Cambrian is crucial for resolving and 'timing' these palaeobiologically significant events. Planktonic acritarchs evolved rapidly during the terminal Proterozoic and early Cambrian times and provide well-delimited biozones defined by geographically widespread and taxonomically rich acritarch assemblages.

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APPENDIX

Localities

Sollerud, HAMAR, PN 068/492 (Bryhni *et al.* 1981: 68). Folded orthoquartzite of the Ringsaker Quartzite Member displaying major channel structures overlain by impure sandstones and dark-grey silty shales (Fig. 4). Samples M-82-22 to 33.

Flagstadelva, Brennsætersaga, LØTEN 614500/6753750 (Skjeseth 1963, Moczydłowska & Vidal 1986). Section in Fig. 2 through upper part of Ringsaker Quartzite Member and *Holmia* shales (units 1a α_1 , 1a α_2 1a β of Skjeseth 1963). Samples M-77-01 to 15.

Ena, JORDET 653000/6799300. Impure sandstones with ball-and-pillow structures and channelling containing Diplocraterion, arthropod tracks and various trails and Torella belonging to unit 1a α . Sample M-77-112 of thin shale band 100 cm above basal sandstone bed.

Redalen, GJØVIK 590450/6753400. Shore section through steeply dipping thin bedded dark, fine sandstone, occasionally laminated with scattered thin dark muddy layers overlying Ringsaker Quartzite Member. Samples M-77-40 immediately at contact with Ringsaker Quartzite and M-77-41 at 120 cm above top of Ringsaker Quartzite.

Steinsodden, GJØVIK 590900/6754200 (Skjeseth 1963). Shore section through Ringsaker Quartzite Member in sharp contact with overlying sandstone and dark-grey siltstone. Barren samples M-77-17 to 27.

Lauselva River, EINA 573450/6733300 (Skjeseth 1963). River section through gneisses overlain by basal conglomerate overlain by mudstones with *Cruziana*, conglomerate and arenaceous mudstone belonging to unit 1a β . The upper mudstone yielded *Volborthella* and *Callavia* (Skjeseth 1963). The latter identified as *Holmia inusitata* by Ahlberg *et al.* (1986). Samples M-77-42 to 46 (Fig. 3).

Tømten, HAMAR 593900/6754750. Excavated outcrop of greenish-grey shales of unit 1b α with abundant trilobites including *Holmia kjerulfi*. Samples M-77-28 to 30.

Skyberg, HAMAR 597000/6755700. Section on NE side of forest track about 200 m West of farm buildings (Fig. 5) mainly encompassing greenish massive mudstone of unit 1b α -1b β with minor bioclastic brownish weathered limestone (Evjevik Limestone; unit 1b β) with trilobites attributed to the *Proampyx linnarssoni* Zone (Fig. 5). Samples M-82-37 to 47. Sample M-77-31 is from an isolated shale outcrop about 100 m east from the measured section.