Acritarchs from the Ordovician of the Oslo Region, Norway

CRISTIANA RIBECAI, DAVID L. BRUTON & MARCO TONGIORGI

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Ordovician (Tremadoc–Early Llanvirn age) acritarchs are recorded for the first time from five samples in the Asker–Røyken area, south of the Oslo Region, Norway. Two samples from the Nes–Hamar district in the north were barren. Permian contact metamorphic temperatures of the sampled area are in excess of 300°C and are consistent with the conodont Colour Alteration Index (CAI). This study confirms that suggested previous temperature thresholds (<200°C) for the preservation of reliably identifiable acritarchs are too low. Comparison of the present assemblages with those elsewhere in Baltoscandia, Gondwana and China are consistent with the earliest Arenig age of the base of the Tøyen Formation and the Arenig–Llanvirn age of the succeeding Huk Formation of the Oslo Region.

C. Ribecai, M. Tongiorgi, Department of Earth Sciences, University of Pisa, via S. Maria, 53, IT-56126, Pisa, Italy; D. L. Bruton, Paleontologisk Museum, Sars gate 1, NO-0562, Oslo, Norway

Introduction

This paper documents the presence of identifiable acritarchs in samples of Lower Ordovician rocks collected in the southern (Asker–Røyken) area of the Oslo Region, Norway, where the metamorphic temperature, interpreted from co-occurring conodont elements (the so-called conodont Colour Alteration Index, CAI), has previously been thought to have been too high to enable preservation of structured organic matter (Bergström 1980; Bryhni & Andréasson 1985), though chitinozoans have been recovered from younger rocks (Grahn et al. 1994).

A series of seven samples, five from the Asker–Røyken area and two from the Nes–Hamar area (Fig. 1) were taken (by MT) in 1992 during a visit to Oslo in connection with a meeting of the Working Group of the Ordovician Geology of Baltoscandinavia (WOGOGOB). These were processed in Pisa by the senior author (CR). Only samples from the Asker–Røyken area produced acritarchs.

Standard palynological techniques were used on 80 g of each sample and followed the methods of Bagnoli et al. (1988) and Albani (1989). Neither oxidation nor alkali treatment was used. The macerated residue was centrifuged in zinc bromide solution having D^{20} of 2.5, at 2000 rpm for 10 minutes and at 3000 rpm for 10 minutes. Microfossils from the floating organic fraction were concentrated by sieving, using a polyethylene filter with a mesh size of 10 μm and a stainless steel filter with a mesh size of 50 μm. Acritarchs from both size fractions were mounted separately. On average, 15 to 40 specimens per slide were identified (at least at the generic level) in each fossiliferous sample.

Palynological slides, prefixed CPT, are deposited in the collections of the Museo di Storia Naturale e del Territorio, University of Pisa, Italy.

The conodont biozones used throughout the text are those applied to the Baltoscandian Ordovician succession by Bagnoli & Stouge (1997).

Geological setting

The Oslo Region (Størmer 1953), includes 11 districts in a NNE–SSW trending belt of southern Norway some 220 km long and 40–70 km wide (Fig. 1). Its present lateral limits are essentially those of a Permian graben (Dons & Larsen 1978), but during the early Palaeozoic it was a cratonic basin in which approximately 1250 m Cambro-Silurian marine sediments and a similar thickness of late Silurian, mainly non-marine sediments, were deposited.

These rocks are preserved within the various districts of the Oslo Region along with Precambrian gneisses and Permian igneous rocks, the latter causing extensive contact metamorphism (Fig. 1). In the areas of Oslo, Bærum, Asker and Røyken, the Lower Palaeozoic rocks show varying degrees of Caledonian folding and faulting, and are parautochthonous with décollement zones situated at the base or within the Cambrian Alum shales. At the northern end, in the Mjøsa area, the whole succession has been thrust southwards at least 150 km, and forms part of the Osen–Røa Nappe Complex (Nystuen 1981; Bockelie & Nystuen 1985).

The Ordovician rocks of the Oslo Region largely comprise alternating dark grey to black shale (or mudstones) and limestone units (see Bjørlykke 1973, 1974a, 1974b; Henningsmoen 1974; Möller & Kvingen 1988, for discussions of the possible origin of the limestones). Sandstones are rare, except in the uppermost Ordovician, and volcanic rocks are restricted to bentonite horizons

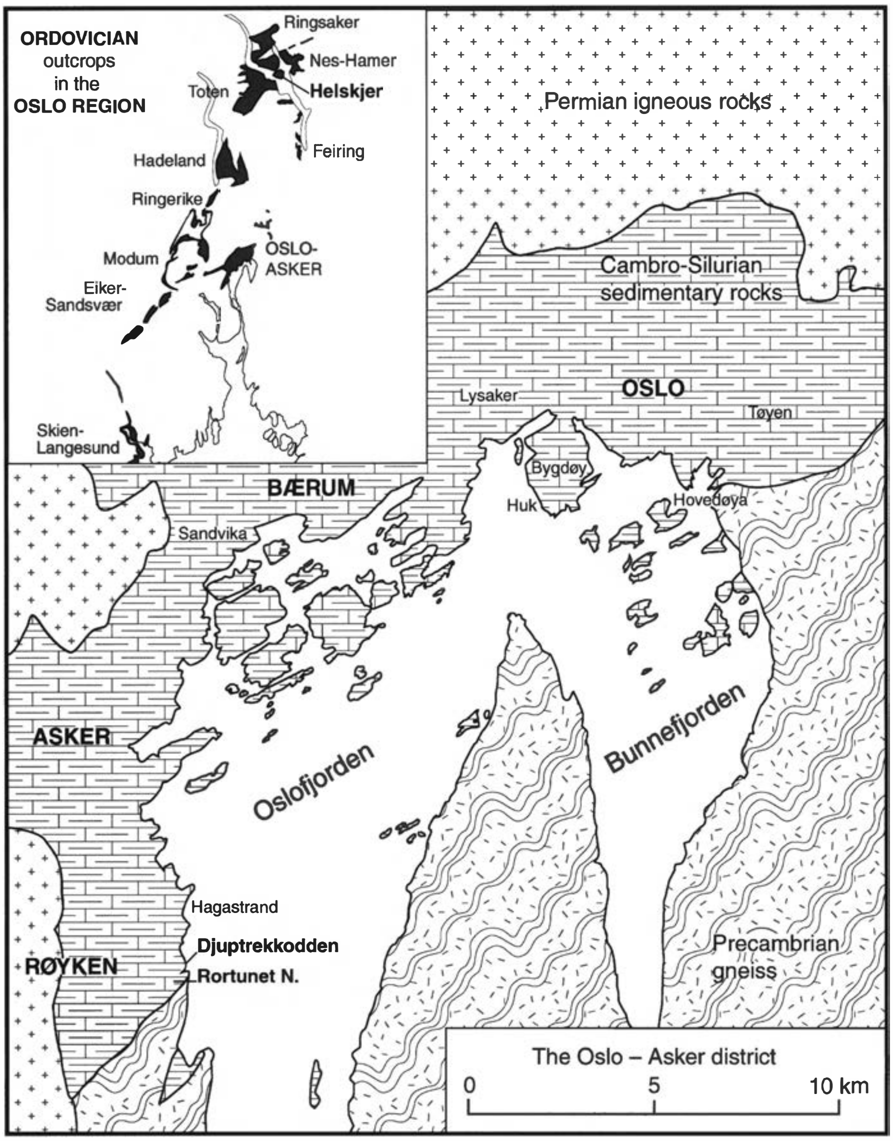


Fig. 1. Map of the Oslo–Asker district with locations of the Rortunet N and Djuptrekkodden localities. The inset map shows the Ordovician outcrops in the districts of the Oslo Region (Størmer 1953) and the Helskjer locality of the Nes-Hamar district. Modified from Owen et al. 1990.

(Bergström et al. 1995) in the Middle Ordovician of Oslo–Asker (Fig. 1). Here the Ordovician rocks are weakly folded and thrust, and have also been subjected to the contact metamorphic effects of the Drammen granite and other Permian intrusive rocks (Grorud 1991). It is estimated that the grade of metamorphism does not to exceed greenschist facies as a result of Caledonian burial and deformation (Bryhni & Andréasson 1985), but the later Permian contact metamorphism in the Oslo graben resulted in minimum temperatures as high as 390°C at distances 2 km from the intrusion (Svensen & Jamtveit 1998).

The samples

The samples are discussed in stratigraphical rather than numerical order. The following localities (Fig. 1) were sampled in the Slemmestad area of Asker–Røyen (Asker sheet 1814 I, 1976). Rortunet N (NM 835 280): for section, see Lindholm (1991, text-fig. 1, loc. 1); for stratigraphy, see Hoel (1999a, b). Djuptrekkodden (NM 844 296): for section and stratigraphy see Nielsen (1995, text-figs. 26–28, 30). Map references refer to Topografisk Kart 1:50 000 M711 series.

Sample 1

Rortunet N. Black shale of the Tøyen Formation, Hagstrand Member, *Tetragraptus phyllograptoides* graptolite Zone, Latorp Stage, Hunneberg Substage, earliest Arenig.

The acritarchs in this sample are poorly preserved, black in colour, deeply corroded, with thinned-out and often truncated processes, or even reduced to a very faint, lacunose graphite framework. No reliable species identifications are possible, and at the generic level determinations are difficult.

The better material may be tentatively referred to the following species: ?*Athabascaella playfordii* Martin, 1984 emend. Martin & Yin, 1988 (Fig. 2.1), ?*A. rossii* Martin, 1984 emend. Martin & Yin, 1988, ?*Cymatiogalea deunffii* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974 (Fig. 2.4)), ?*C. messaoudensis* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974, *Peteinosphaeridium* spp. (Fig. 3.10–12).

Discussion

C. deunffii and *C. messaoudensis* are two distinctive elements of the '*messaoudensis-trifidum* assemblage', an association of typical taxa known from the northern margin of Gondwana, at high southern latitudes, during the Tremadoc–Arenig transition (Servais & Molyneux 1997). From the Baltic area, these species have been observed by Paalits (in Servais & Molyneux 1997) in the Hunneberg of Estonia and the Moscow Basin. Recently, both species were recorded by Raevskaya (1999) in her assemblage I from the St. Petersburg region which is referred to the Hunneberg Substage of the Latorp Stage, upper *P. proteus* conodont Zone, *T. phyllograptoides* graptolite Zone.

A. playfordii and *A. rossii* are indicative of upper Tremadoc to lowermost Arenig levels in middle to low latitudes (Martin & Yin 1988; Martin 1992; Yin 1995; Brocke 1997; Brocke & Fatka 1999; Mette & Servais 1999). From Baltoscandia these species have been recorded from the Upper Tremadoc of Öland, Sweden (Tongiorgi in Bagnoli et al. 1988), and Estonia (Volkova 1995). They also occur in Raevskaya's assemblage II of the St. Petersburg region (Hunneberg Substage, uppermost *Paroistodus proteus-Prionodus elegans* conodont Zones, uppermost *T. phyllograptoides* graptolite Zone) together with many taxa, including a *Peteinosphaeridium* species.

The latter genus is believed by Paalits & Erdtmann (1993) to appear in the Hunneberg (*P. proteus* conodont Zone, upper part of the *Hunnegraptus-Araneograptus* to the *T. phyllograptoides* graptolite Zones) of the East European Platform.

The palynomorphs recorded from the early Arenig at Rortunet N seem to correspond with Late Tremadoc–earliest Arenig palynofloras recorded elsewhere.

Sample 2

Rortunet N. Dark grey, calcareous shale of the Huk Formation, Lysaker Member (see Owen et al. 1990, fig. 8; Rasmussen 1991), uppermost *Didymograptus hirundo* graptolite Zone, *Lenodus* sp. A conodont Zone, Kunda Stage, Hunderum Substage, latest Arenig.

The acritarch preservation in this sample allows the following forms to be identified: *Baltisphaeridium* spp., *Dasydorus cirritus* Playford & Martin, 1984, *Liliosphaeridium intermedium* (Eisenack, 1976) emend. Playford, Ribecai & Tongiorgi, 1995 (Fig. 2.7), *L. kaljoi* Uutela & Tynni, 1991 emend. Playford, Ribecai & Tongiorgi, 1995 (Fig. 2.9), *Micrhystridium* spp., *Multiplicisphaeridium* spp., *Peteinosphaeridium dissimile* Górka, 1969 (Figs. 3.1, 2), *P.* sp. cf. *P. eximium* Playford, Ribecai & Tongiorgi, 1995, *P. velatum* Kjellström, 1971 emend. Playford, Ribecai & Tongiorgi, 1995 (Fig. 3.7–9), *P.*? *hystrichoreticulatum* (Eisenack, 1938) Eisenack, Cramer & Díez, 1973 (Fig. 3.5), '*P. macropylum* Form Group' *sensu* Tongiorgi et al. 1998 (Fig. 3.6), *Polygonium* spp.

Discussion

P.? *hystrichoreticulatum* has been recorded from Baltoscandia and China, where it seems to be restricted to the uppermost Arenig. In fact, the association of *P.*? *hystrichoreticulatum* with *L. kaljoi* and *P. dissimile* [but without *L. hypertrophicum* (Eisenack, 1976) emend. Playford, Ribecai & Tongiorgi, 1995] is present on Öland, Sweden, in the Upper Arenig; i.e., from the uppermost Volkhov Stage, Langevoja substage to lowermost Kunda Stage, Hunderum Substage (Stouge et al. 1995; Ribecai & Tongiorgi 1997). In South China, Tongiorgi et al. (1998) recorded *L. kaljoi, P. dissimile* and *P.*? *hystrichoreticulatum*, together with *P. velatum*, from the upper Arenig, Darriwilian (*Undulograptus austrodentatus* graptolite Zone).

The already known stratigraphic distribution of the acritarchs yielded by this sample is consistent with the latest Arenig age attributed to the sampling level (Owen et al. 1990).

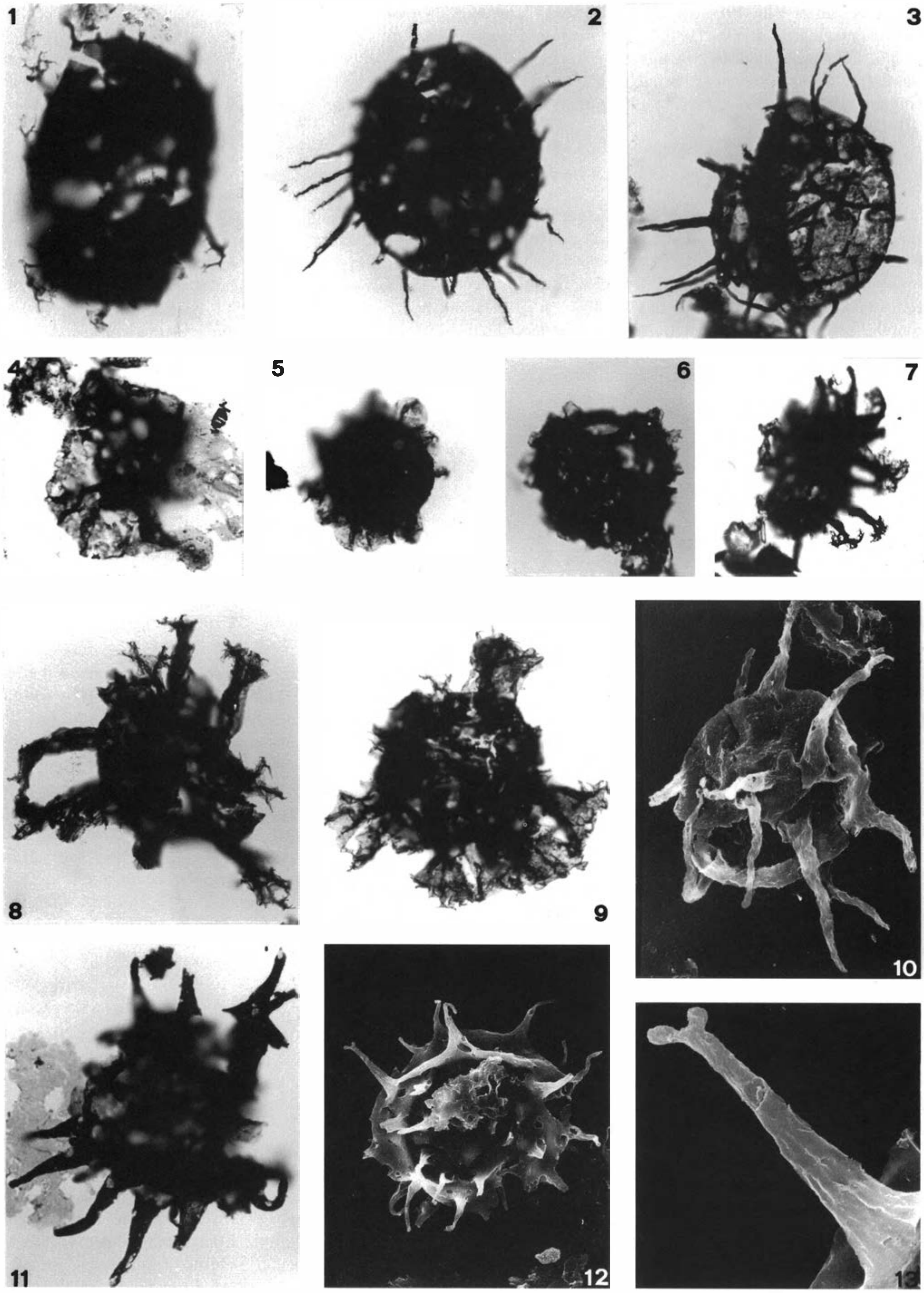
Sample 4

Djuptrekkodden. Dark grey, nodular limestone of the Huk Formation, Lysaker Member, *Asaphus expansus* trilobite Zone, Volkhov–Kunda boundary, latest Arenig.

Although specimens are quite rare in this sample, their preservation allows recognition of the following taxa: *Baltisphaeridium* spp. (Fig. 2.2), *Cycloposphaeridium auriculatum* Uutela & Tynni, 1991 emend. Playford, Ribecai & Tongiorgi, 1995 (Fig. 2.5), *Liliosphaeridium hypertrophicum* (Fig. 2.8), *Micrhystridium* spp., *Multiplicisphaeridium* spp., *Pachysphaeridium* spp. (Fig. 2.11), *Peteinosphaeridium dissimile* (Fig. 3.3), *P. eximium* (Fig. 3.4), *P.* sp. cf. *P. velatum*, '*P. macropylum* Form Group', *Polygonium* sp., *Veryhachium* sp.

Discussion

In Baltoscandia, *C. auriculatum* is known from the ?Volkhov to Aseri stages (uppermost Arenig to middle Llanvirn) of Estonia (Uutela & Tynni 1991), and from the Kunda Stage (?lowermost Llanvirn) of Öland, Sweden (Ribecai & Tongiorgi 1995; Playford et al. 1995). On Öland, Sweden, *L. hypertrophicum* (Ribecai & Tongiorgi 1995, 1997; Playford et al. 1995) is characteristic of the lower to middle Kunda (Hunderum to Valaste substages) or uppermost Arenig to lower Llanvirn, and has been recorded recently from the Llanvirn of the peri-Gondwana margin in Belgium and Tunisia (Tongiorgi & Di Milia 1999). The co-occurrence of *C. auriculatum, L. hypertrophicum* and *P. eximium* (but without *C. oelandica*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Eisenack, 1974) is considered to be indicative of the uppermost Arenig–lowermost Llanvirn (lower Kunda Stage, Hunderum Substage) on Öland (Ribecai & Tongiorgi 1997).

Based on the co-occurrence of *P. dissimile* and *L. hypertrophicum*, the age of the present sample could be very latest Arenig and thus the top of the Lysaker Member could be slightly younger that previously thought (Owen et al. 1990).

Sample 3

Rortunet N. Dark grey limestone of the Huk Formation, Svartodden Member, nodular limestone horizon immediately below the top of the formation, *Didymograptus artus* graptolite Zone, Kunda Stage, Valaste Substage, Early Llanvirn.

Discussion

This sample yielded only poorly preserved specimens of *Micrhystridium* spp., *Multiplicisphaeridium* spp. and fragments of *Baltisphaeridium.* These do not help in further confirming the age that has been previously attributed to the sampling level.

Sample 2/2

Djuptrekkodden. Dark limestones of the Elnes Formation, *Didymograptus murchisoni* graptolite Zone, Early Llanvirn.

Although poorly preserved, the following taxa have been identified: *Baltisphaeridium* spp. (Fig. 2.3), ?*Cycloposphaeridium* sp. (Fig. 2.6)), *Dasydorus cirritus, Micrhystridium* spp., *Multiplicisphaeridium* spp., *Pachysphaeridium* spp. (Fig. 2.10, 12, 13), *Peteinosphaeridium* sp., *Polygonium* spp., *Veryhachium* sp.

Discussion

D. cirritus is a cosmopolitan species known from rocks of Lower to Middle Ordovician age. Thus, this species and the associated taxa do not provide further chronological information about the age of the sampling level.

Two additional samples were treated from the locality of Helskjer on the island of Helgøya, in the Nes–Hamar district, north of the Oslo Region (Fig. 1; see also Owen et al. 1990, fig. 8). Both samples were barren. These were sample 5, Svartodden Member, 70 cm above the base and sample 6, Helskjer Member, 11 m above the top of the Tøyen Formation (for section, see Owen et al. 1990, fig. 10).

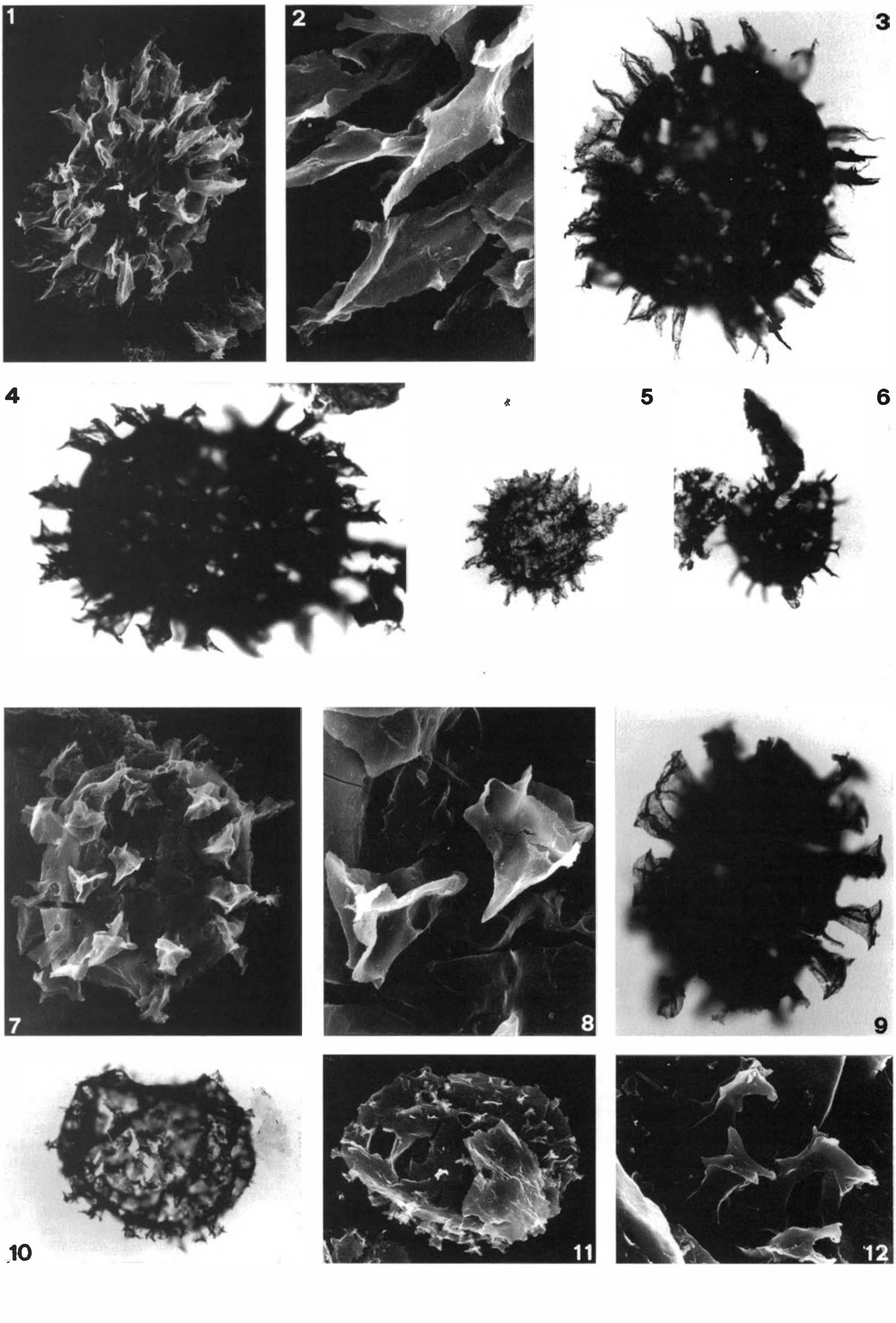
The preservation potential of palynomorphs

In terms of organic molecular structures in sedimentary rocks, it is had been thought that these would be destroyed with increasing metamorphism, and that only graphite would remain at or beyond, the upper greenschist facies (Smith & Saunders 1970; Hayes et al. 1983). Cramer & Diez de Cramer (1975) have suggested that smoothening out of the sculptural elements, separation of processes from the body and other similar damage should make species identification difficult at about 160°C. At about 165°C, shearing and fracturing was believed to start, and by about 200°C, identification was expected to become difficult even at generic level. Between 250°C and 300°C, an increasing mosaic shattering was expected, until total destruction took place.

Recent work has shown that these figures are too low and need modification. Thus Di Milia (1991) obtained fully identifiable species of acritarchs from metapelitic rock samples collected from the Solanas Sandstone Formation of Central Sardinia, where the metamorphic temperature has been estimated to have reached about 350–370°C (Sassi in Di Milia et al. 1993). Nevertheless, only about 20% of the processed Sardinian samples were suitable for palaeontological and stratigraphical studies, since the microfossils had been destroyed as a result of tectonic deformation, reducing them to a mosaic of minute graphitic fragments. In most cases, standard palynological techniques could not be used, and the fossils were studied in thin sections cut parallel to the main rock foliation (cf. Burmann 1968, 1969, 1970; Kalvacheva 1978; Tongiorgi et al. 1984; Kalvacheva et al. 1986). Thus, it is concluded that both rock deformation and metamorphism can cause the destruction of palynomorphs.

Deformation of the rocks in the Asker–Røyen district is generally low for the horizons sampled, but this can vary from locality to locality and evidence for a cleavage can be found in shales, together with strain-distorted fossils.

Fig. 2. 1: ?*Athabascaella playfordii* Martin, 1984, emend. Martin & Yin, 1988. Tøyen Fm., Hagastrand Mbr., locality Rortunet N. Sample 1, OSLO1/TOT-1, CPT110001-01, E.F. X28/2, × 600. 2: *Baltisphaeridium* sp. 1. Huk Fm., Lysaker Mbr., locality Djuptrekkodden. Sample 4, OSLO4/50-3, CPT110005-06, E.F. Q51/3, ×600. 3: *Baltisphaeridium* sp. 2. Elnes Fm., locality Djuptrekkodden, Sample 2/2, OSLO2bis/TOT-2, CPT110003-02, E.F. F41/3, ×600. 4: ?*Cymatiogalea deunffii* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974. Tøyen Fm., Hagastrand Mbr., locality Rortunet N. Sample 1, OSLO1/TOT-3, CPT110001-03, E.F. P28, ×600. 5: *Cycloposphaeridium auriculatum* Uutela & Tynni, 1991, emend. Playford, Ribecai & Tongiorgi, 1995. Huk Fm., Lysaker Mbr., locality Djuptrekkodden. Sample 4, OSLO4/10-3, CPT110005-03, E.F. G43, ×600. 6: *Cycloposphaeridium*? sp. Elnes Fm., locality Djuptrekkodden, Sample 2/2, OSLO2bis/TOT-1, CPT110003-01, E.F. W46, ×600. 7: *Liliosphaeridium intermedium* (Eisenack, 1976) emend. Playford, Ribecai & Tongiorgi, 1995. Huk Fm., Lysaker Mbr., locality Rortunet N. Sample 2, OSLO2/10-1, CPT110002-01, E.F. U32/1, ×600. 8: *L. hypertrophicum* (Eisenack, 1976) emend. Playford, Ribecai & Tongiorgi, 1995. Huk Fm., Lysaker Mbr., locality Djuptrekkodden Sample 4, OSLO4/50-3, CPT110005-06, E.F. U44/4, ×600. 9: *L. kaljoi* Uutela & Tynni, 1991, emend. Playford, Ribecai & Tongiorgi, 1995. Huk Fm., Lysaker Mbr., locality Rortunet N. Sample 2, OSLO2/50-1, CPT110002-04, E.F. D24, ×600. 10: *Pachysphaeridium* sp. 1. Elnes Fm., locality Djuptrekkodden. Sample 2/2, OSLO2bis/Stub-2, CPT110003-05, E.F. Q40/3, ×600. 11: *Pachysphaeridium* sp. 2. Huk Fm., Lysaker Mbr., locality Djuptrekkodden, Sample 4, OSLO4/50-3, CPT110005-06, E.F. V40/1-V40/2, ×600. 12, 13 *Pachysphaeridium* sp. 3. 12: Elnes Fm., locality Djuptrekkodden. Sample 2/2, OSLO2bis/Stub-2, CPT110003-05, E.F. O38, ×600. 13: Detail of the right part of specimen in 12, showing the process features, ×3200.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Bryhni & Andréasson (1985) maintained that Caledonide metamorphism was low grade and probably related to depth of burial and strain (but see Bergström 1980, p. 385), while Svensen & Jamtveit (1998) estimated a minimum temperature of 390°C in Lower Palaeozoic sediments at distances 2 km from a Permian intrusive body north of Oslo. A similar temperature profile was provided by Grorud (1991) for the Drammen granite, with an estimated temperature of 340°C at the same distance. The localities yielding acritarchs are about 3 km away from the Drammen granite, and the conodont Colour Alteration Index (CAI) of 4.5–5 from the Oslo area is consistent with temperatures of 300°C or more (Hamar 1966; Bergström 1980). Similar temperatures have been recorded from the stratigraphically younger Mjøsa Limestone in the Nes–Hamar district (Bergström 1980, p. 390) and it seems likely that our older samples from Helgøya have been subjected to similar or even slightly higher temperatures. Professor Stig Bergström (pers. comm. to DLB 26/11/1999) stated that it seems unlikely that the lack of acritarchs there can be attributed to heating if they survive in Oslo, and so far we have no explanation for our barren samples. Away from the metamorphic aureoles in the Oslo Region, local changes in metamorphic grade can be determined by contact metamorphism associated with Permian dykes and sills. This may explain why CAIs of 5 have been recorded for Ordovician conodonts in the Ringerike area (Bergström 1980, p. 390), while elsewhere, Silurian conodonts indicative of a CAI 3 are associated with both acritarchs and chitinozoans (Dorning & Aldridge 1982; Aldridge 1984).

Palaeogeographical implications

The acritarchs in Sample 1 from Rortunet N include possibly two species of *Athabascaella,* a widespread genus recorded from the early Arenig of Laurentia, North China and Baltica, but apparently absent from Gondwana (Brocke & Fatka 1999). They occur with other forms (?*C. deunffii* and ?*C. messaoudensis*) which are considered to be typical components of the '*messaoudensis-trifidum* assemblage'. This assemblage has been regarded until now as being restricted to the margins of Gondwana and associated microcontinents at high southern paleolatitudes (Servais & Molyneux 1997), though some components of the same assemblage (but without the eponymous species *Stelliferidium trifidum* (Rasul) Fensome et al., 1990) were recorded from the Hunneberg of Baltica (Tongiorgi & Di Milia 1999).

More definite palaeogeographical affinities are shown by the upper Volkhov–lower Kunda acritarchs from Sample 2 at Rortunet N and Sample 4 from Djuptrekkodden. *Liliosphaeridium hypertrophicum, L. intermedium, L. kaljoi* and *Peteinosphaeridium velatum*, together with representatives of the '*P. macropylum* Form Group', and *Pachysphaeridium* spp. are indicative of the Arenig–Llanvirn Baltic Province, as recently defined by Tongiorgi & Di Milia (1999).

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Fig. 3. 1–3: *Peteinosphaeridium dissimile* Górka, 1969. 1: Huk Fm., Lysaker Mbr., locality Rortunet N, Sample 2, OSLO2/Stub-1, CPT110002-07, E.F. M34/1, ×600. 2: Enlargement of central part of specimen in Fig. 1, showing the process terminations, ×3200. 3: Huk Fm., Lysaker Mbr., locality Djuptrekkodden. Sample 4, OSLO4/50-2, CPT110005-05, E.F. T24/1, ×600. 4: *P. eximium* Playford, Ribecai & Tongiorgi, 1995. Huk Fm., Lysaker Mbr., locality Djuptrekkodden. Sample 4, OSLO4/50-1, CPT110005-04, E.F. K22/4 × 600. 5: *P.*? *hystrichoreticulatum* (Eisenack, 1938) Eisenack, Cramer & Diez, 1973. Huk Fm., Lysaker Mbr., locality Rortunet N. Sample 2, OSLO2/10-2, CPT110002-02, E.F. R43/1, ×600. 6: '*P. macropylum* Form Group' *sensu* Tongiorgi et al., 1998. Huk Fm., Lysaker Mbr., locality Rortunet N. Sample 2, OSLO2/10-3, CPT110002-01, E.F. T36, ×600. 7–9: *P. velatum* Kjellström, 1971, emend. Playford, Ribecai & Tongiorgi, 1995. 7: Huk Fm., Lysaker Mbr., locality Rortunet N. Sample 2, OSLO2/Stub-2, CPT110002-08, E.F. Q39, ×600. 8: Detail of the processes in the lower part of specimen in 7, ×2000. 9: Huk Fm., Lysaker Mbr., locality Rortunet N. Sample 2, OSLO2/50-3, CPT110002-06, E.F. S28/2, × 600. 10–12: *Peteinosphaeridium* sp. 10: Tøyen Fm., Hagastrand Mbr., locality Rortunet N. Sample 1, OSLO1/TOT-1, CPT110001-01, E.F. J41/1, ×600. 11: Tøyen Fm., Hagastrand Mbr., locality Rortunet N. Sample 1, OSLO1/Stub-2, CPT110001-05, E.F. Q35/4, ×600. 12: Detail of the right side of specimen in 11, showing the features of the process, ×3500.

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