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MUCCHI - MODENA

Taxonomic composition and palaeobiogeographic significance of the acritarch assemblages from the Tremadoc-Arenig (Hunneberg, Billingen, and lower Volkhov Stages) of the Oslo Region

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ABSTRACT – Fifty two taxa of acritarchs have been identified from 25 samples of the Tremadoc-Arenig Tøyen Shale Formation (Hunneberg-Volkhov) of the Oslo Region, Norway. Preservation is generally poor but most taxa can be identified to the species level. Samples from the Hunneberg Stage contain a mixed cold-water (elements of the messaooudensis-trifidum assemblage) and warm-water (Aryballomorpha-Athabascaella-Lua assemblage) microflora. Samples from the Billingen-lower Volkhov Stages contain species recorded from the Yangtze Platform (South China), which is considered to be part of the cold-water realm (or "Mediterranean Province") located at high southern latitudes around the margin of Gondwana. However, the Oslo samples lack the typical cold- to cool temperate-water indicators from Perigondwana, such as Arbusculidium, Aureotesta, Coryphidium, Striatotheca and Vavrdovella. This is compatible with a mid-latitude position of Baltica during the Arenig and with a pattern of ocean currents causing a warmer climate than in China. On the contrary, the late Volkhov-early Kunda Baltic microflora belongs neither to the cold water Perigondwana realm nor to a less well-defined warm-water realm. Evolution in the composition of phytoplankton from an early Arenig "Mediterranean microflora" to a late Arenig "Baltic microflora" occurs in both South China and Baltica. This implies a reciprocal exchange within a mid-latitude realm controlled more by the pattern of subtropical oceanic gyres rather than latitudinal position alone. A similar evolution of acritarch assemblages is also noted over the East European Platform in Russia and Poland.

RIASSUNTO – [Composizione tassonomica e significato paleobiogeografico delle associazioni ad acritarchi del Tremadoc-Arenig (Hunneberg, Billingen e Volkhov inferiore) della Regione di Oslo] – Cinquantadue taxa di acritarchi sono stati identificati in 25 campioni tremadociano-arenigiani della Tøyen Shale Formation (piani Hunneberg, Billingen e Volkhov inferiore) della Regione di Oslo, Norvegia. Lo stato di conservazione è generalmente non buono ma la maggior parte dei taxa possono essere identificati a livello specifico. I campioni dell'Hunneberg hanno fornito una microflora mista, con rappresentanti sia di acque fredde (elementi della microflora a messaooudensis-trifidum) che di acque calde (microflora ad Aryballomorpha-Athabascaella-Lua). I campioni dei piani Billingen e Volkhov inferiore contengono specie che sono state descritte nella Piattaforma dello Yangtze (Cina Meridionale), che è considerata far parte del reame di acque fredde ("Provincia Mediterranea" auct.) situato ad alte latitudini meridionali, lungo il margine di Gondwana. Tuttavia, i campioni di Oslo sono privi dei più tipici indicatori di acque fredde o temperato-fredde della regione perigondwaniana (Arbusculidium, Aureotesta, Coryphidium, Striatotheca, Vavrdovella). Questo è in accordo con la posizione di Baltica a media latitudine durante l'Arenigiano e con quel sistema di correnti oceaniche che ha indotto un clima di Baltica leggermente più caldo di quello della Cina Meridionale. La composizione della microflora del Volkhov superiore-Kunda di Oslo (microflora "Baltica") non trova invece riscontro né nelle associazioni fredde di Perigondwana, né in quelle di un (peraltro ancora poco definito) reame di acque calde. Una simile evoluzione nella composizione del fitoplancton, dalle associazioni "Mediterranee" dell'Arenig inferiore a quelle "Baltiche" dell'Arenig superiore, si osserva sia nella Cina Meridionale che in Baltica. Questo implica reciproci scambi all'interno di uno stesso reame di medie latitudini, verosimilmente controllato dalla distribuzione dei circuiti oceanici subtropicali, piuttosto che dalla sola latitudine. Un simile quadro evolutivo delle associazioni ad acritarchi è documentato anche nella Piattaforma Est Europea (Russia e Polonia).

INTRODUCTION

The palynology of upper Arenig through lower Llanvirn sequences (upper Volkhov-Kunda) from Baltoscandia and the East European Platform (EEP) has been the object of several, detailed studies for more than seventy years (e.g., Eisenack, 1931 to 1976; Górka, 1969; Kjellström, 1971a, b, 1976; Tynni, 1975, 1982; Uutela, 1989; Uutela & Tynni, 1991; Ribecai & Tongiorgi, 1995, 1999; Playford *et al.*, 1995; Ribecai *et al.*, 2000). The taxonomical composition of the acritarch assemblages during this interval contrasts strongly with those from central and southern Europe, and North Africa (e.g.; Vavrdová, 1965 to 1993; Rauscher, 1974; Vecoli, 1996, 1999). This has led to the notion of a "Baltic Province" (Vavrdová, 1974), mainly characterized by

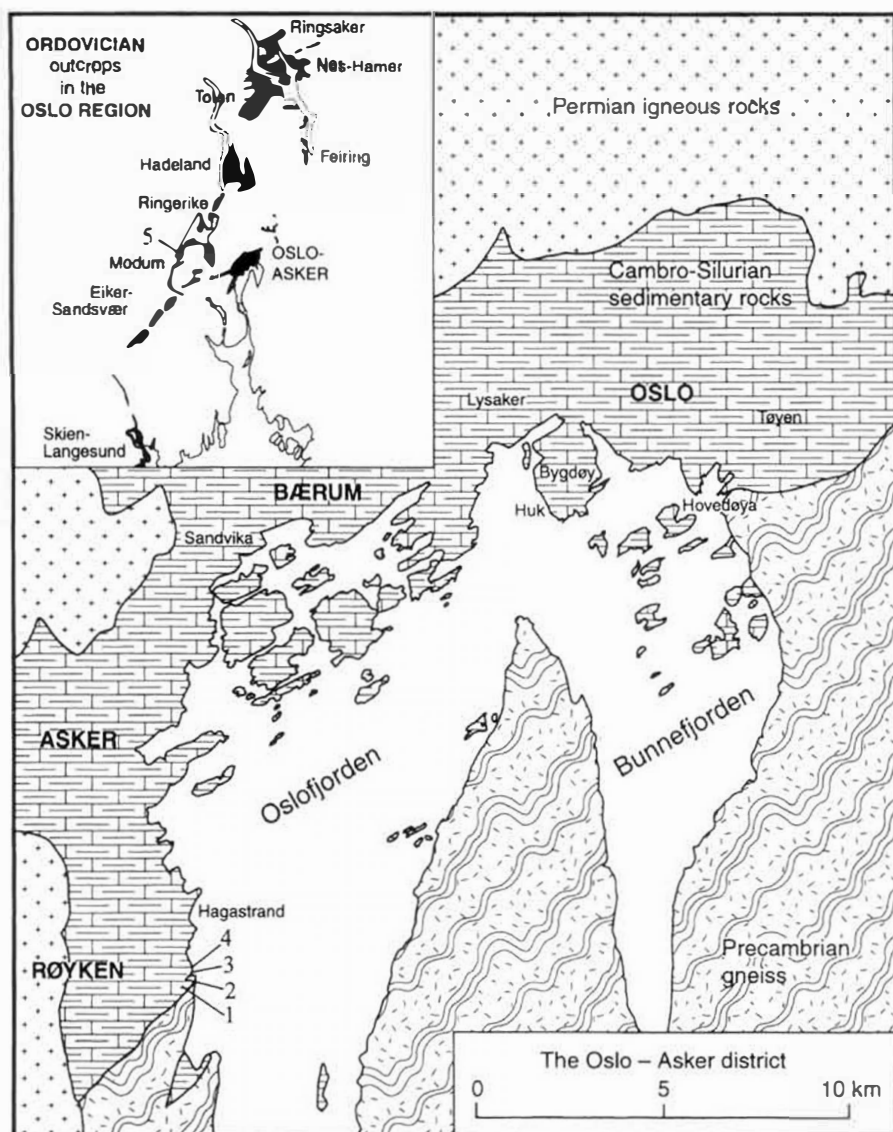
acanthomorphic acritarchs (e.g., *Baltisphaeridium* Eisenack, 1958 ex Eisenack, 1959, *Peteinosphaeridium* Staplin *et al.*, 1965 emend. Playford *et al.*, 1995, and *Polygonium* Vavrdová, 1966 emend. Le Hérisse, 1989), in contrast to a "Mediterranean Province", defined principally on the occurrence of diacromorph acritarchs (e.g., *Acanthodiacrodium* Timofeev, 1958 emend. Deflandre & Deflandre-Rigaud, 1962, and *Arbusculidium* Deunff, 1968 emend. Welsch, 1986). This differentiation may have occurred above the base of the Arenig (Vavrdová, 1974, 1998). The "Mediterranean Province" has been subsequently recognized at several localities (details in Playford *et al.*, 1995) along the northern Gondwana border (Perigondwana). Owing to the absence of marked palaeogeographic barriers between Perigondwana and Baltica during Arenig

and Llanvirn times, Servais & Fatka (1997), following McKerrow & Cocks (1986), preferred the term "realm" instead of "province", to indicate acritarch biogeographic units which are controlled by ecological (mainly climatic) factors. Each realm should be defined by a distinctive acritarch microflora ("Baltic microflora", "Mediterranean microflora" of Tongiorgi & Di Milia, 1999; Tongiorgi *et al.*, in press).

So far, the early Arenig (Hunneberg, Billingen and early Volkhov) microflora from Baltoscandia and the EEP is poorly known, because of unsuitable lithologies (such as the intensively oxidized deposits of most Baltoscandian localities) and discontinuous occurrences. Some pioneer investigations have been carried out in northwestern Russia by Timofeev (1959, 1966) and by Umnova & Fanderflit (1971) and in the Moscow Syncline by Aristova (1980). Modern

studies however, are restricted to the Hunneberg and Billingen of the EEP: Lithuania (Paskieviene, 1998), St. Petersburg region of northwestern Russia (Raevskaya, 1999 and in Tolmacheva *et al.*, 2001; Tongiorgi & Di Milia, 1999; Raevskaya *et al.*, in press), and Poland (Raevskaya *et al.*, in press). Only one Baltoscandian Hunneberg sample has been investigated for acritarchs by Ribecai *et al.* (2000) from the Oslo Region, Norway.

These studies failed to confirm Vavrdová's (1974, 1997) hypothesis of a strong provincialism which characterised acritarch assemblages since the base of the Arenig. On the contrary, Raevskaya (1999) and Raevskaya in Tolmacheva *et al.* (2001) showed that acritarch assemblages of the EEP are characterised by elements of the latest Tremadoc-earliest Arenig *mesaoudensis-trifidum* microflora; i.e., of a microflora



Text-fig. 1 - Geological map of the Oslo-Asker district with sample localities indicated:
 1) Rortunet N;
 2) Bjørkåsholmen old quarry;
 3) Bjørkåsholmen shore line;
 4) Djupprekkodden.
 The inset map shows the Ordovician outcrops in the districts of the Oslo Region (Strømmer, 1953) and the Hovland locality 5 of the Modum district. Modified from Ribecai *et al.*, 2000. Geographic coordinates of sample localities are given in the text.

which is typical of high latitude localities of Perigondwana (Servais & Mette, 2000). Thereafter, (upper Hunneberg-lower Billingen), representatives of the *messauensis-trifidum* microflora rapidly decrease in abundance and disappear at the base of the upper Billingen. At the same time, immigrant species (Raevskaya *et al.*, in press) known from coeval assemblages from the Yangtze Platform of South China, appear (cf. Li, 1987; Tongiorgi *et al.*, 1995, and in press; Yin, 1995; Yin *et al.*, 1998). Species shared with South Chinese assemblages were also found in the lower Volkhov of the St. Petersburg region (Tongiorgi & Di Milia, 1999).

Preliminary data from the Oslo Region, Norway (Ribecai *et al.*, 2000) showed a similar situation to that of the EEP, and acritarchs of the lower Hunneberg (below the *T. approximatus* graptolite Zone) include elements of the *messauensis-trifidum* microflora.

Using new collections made by MT and DLB, in the year 2000, the aim of the present paper is to discuss the taxonomic composition and the palaeobio-

geographical significance of the acritarch assemblages present in Tremadoc-Arenig (Hunneberg, Billingen, and lower Volkhov Stages) rocks of the Oslo Region (Text-fig. 1). It represents the first detailed investigation of acritarchs from this stratigraphic interval in Baltoscandia.

GEOLOGICAL SETTING

A sequence of pale grey and black silty shales with a thickness in excess of 20 m, make up the Tøyen Formation (Text-fig. 2) of latest Tremadoc-middle Arenig age in the central Oslo Region, Norway (Owen *et al.*, 1990). These shales were deposited on the continental slope forming the western edge of the Baltic platform and overlie limestones of the Tremadoc Bjørkåsholmen Formation (Owen *et al.*, 1990, fig. 3; Ebbestad, 1999). Both units can be traced westwards into the allochthonous units of the Scandinavian Caledonides (Bruton *et al.*, 1989; Rasmussen & Bruton, 1994; Rasmussen, 2001) and

Baltic Stages		Conodont biozonations		Graptolite	biozonation			
Baltic Area		South China		Baltic Area	South China			
(1)		(1, 2, 3)		(1)	(1)			
KUNDA	Aluoja	<i>E. pseudoplanus</i>		<i>E. suecicus</i>	<i>N. fasciculatus</i>	<i>N. fasciculatus</i>		
				<i>D. tablepointensis</i>				
		<i>Y. crassus</i>		" <i>E.</i> " <i>crassus</i>				
	Valaste	<i>L. variabilis</i>		<i>H. lentus</i>	<i>A. ellesae</i>			
	Hunderum			<i>L. variabilis</i>				
VOLKHOV	Langevoja	<i>B. norlandicus</i>	<i>L. antivaribilis</i>	<i>L. antivaribilis</i>	<i>D. hirundo</i>	<i>U. austrodentatus</i>		
			<i>T. quadrangul.</i>				<i>B. norlandicus</i>	<i>E. clavus</i>
							<i>M. parva</i>	
	Vääna	<i>P. originalis</i>	<i>P. originalis</i>	<i>E. clavus</i>				
		<i>B. navis</i>	<i>B. navis</i>			<i>I. caduceus imitatus</i>		
	Saka	<i>B. triangulans</i>	<i>B.?</i> <i>triangulans</i>	<i>B.?</i> <i>triangulans</i>			<i>A. suecicus</i>	
LATORP	Billingen	<i>O. evae</i>		<i>P. angustifolius elongatus</i>	<i>A. suecicus</i>			
				<i>P. densus</i>		<i>D. deflexus</i>		
		<i>P. elegans</i>	<i>O. communis (S. diversus)</i>	<i>D. balticus</i>			<i>P. fruticosus</i>	
	Hunneberg	<i>P. proteus (partly)</i>		<i>T. phyllograptoides</i>	<i>T. approximatus</i>			

Text-fig. 2 - Chronostratigraphy of the interval studied with reference to Baltoscandian stages, conodont and graptolite biostratigraphy and equivalents in South China, after (1) Webby *et al.* (in press); (2, 3) Lötgren (1995, 2000); (4, 5, 6) Wang *et al.* (1996), Zhang (1998), Wang & Bergström (1999).

eastwards where they form part of the autochthon of the Baltoscandian platform. Both here and shorewards, limestone units with trilobites occur within the shales of the Tøyen Formation (for summary see Hoel, 1999a, b). Both in the Oslo Region and Scania, graptolites (Lindholm, 1991), dominate in the shales of the Tøyen Formation which belongs to the Oslo-Scania-Lysøgor confacies of Erdtman & Paalits (1994).

In Norway, the Tøyen Formation is divided into two members, the pale grey poorly fossiliferous Hagastrand Member at the base, overlain by the black graptolitic Galgeberg Member (Owen *et al.*, 1990, figs. 4-6). Discussions on the Tremadoc-Arenig boundary and the status of the Hunneberg Stage in the Oslo Region are given by Lindholm (1991) and Hoel (1999a, b).

Shales of the Tøyen Formation are succeeded by another widespread limestone unit, the Huk Formation (Owen *et al.*, 1990; Nielsen, 1995; Rasmussen, 2001). This unit covers the Volkhov and Kunda Stages and thus contains the Arenig-Llanvirn boundary (Text-fig. 2). Acritarchs have been described from this unit (Ribecai *et al.*, 2000). In the present paper we discuss specimens from one new sample of the Lysaker Member at the base of the formation.

As noted by Ribecai *et al.*, (2000), deformation of the rocks in the Asker-Røyken district of the Oslo Region, from which the bulk of our collecting has been made, is generally low, but a weak cleavage is present together with some tectonically-deformed fossils. Local Permian intrusive bodies suggest that sediments have been subjected to temperatures of 300 degrees C or more, as indicated by the conodont Colour Alteration Index (CAI) of 4.5-5 (Bergström, 1980). This also seems to be the case for new samples collected in the Modum area to the northwest.

MATERIAL AND METHODS

ORDOVICIAN SUBDIVISIONS AND REGIONAL STRATIGRAPHY

Stratigraphic terminology followed herein is tabulated in Text-figure 2. The conodont-based biostratigraphic subdivisions of the Hunneberg-Kunda interval (upper Tremadoc-lower Llanvirn) of Baltica are those established by Löfgren (1995, 2000). Correlation with graptolite biostratigraphy and equivalents in South China is after Webby *et al.* (in press), Löfgren (1995, 2000), Wang *et al.* (1996), Zhang (1998), Wang & Bergström (1999). Locality map references are from Topografisk Kart 1:50 000-M711 series.

FIELD SAMPLING

Bjorkåsholmen, Oslo-Asker district (NM 844 294)

This section along the shore of the Oslofjord (Text-fig. 1, locality 3), contains the basal stratotype

for the Bjorkåsholmen Formation. Sixteen samples (labelled BSL) were collected from the overlying Hagastrand Member (Text-fig. 3) of the Tøyen Formation (see Owen *et al.*, 1990, fig. 3). For correlation purposes, these samples belong to the lower Hunneberg Stage and correspond to the *Hunnegraptus copiosus* graptolite Zone of Lindholm (1991) and the lower *Paroistodus proteus* conodont Zone.

Hovland, near Vikersund, Modum district (NM 556 444)

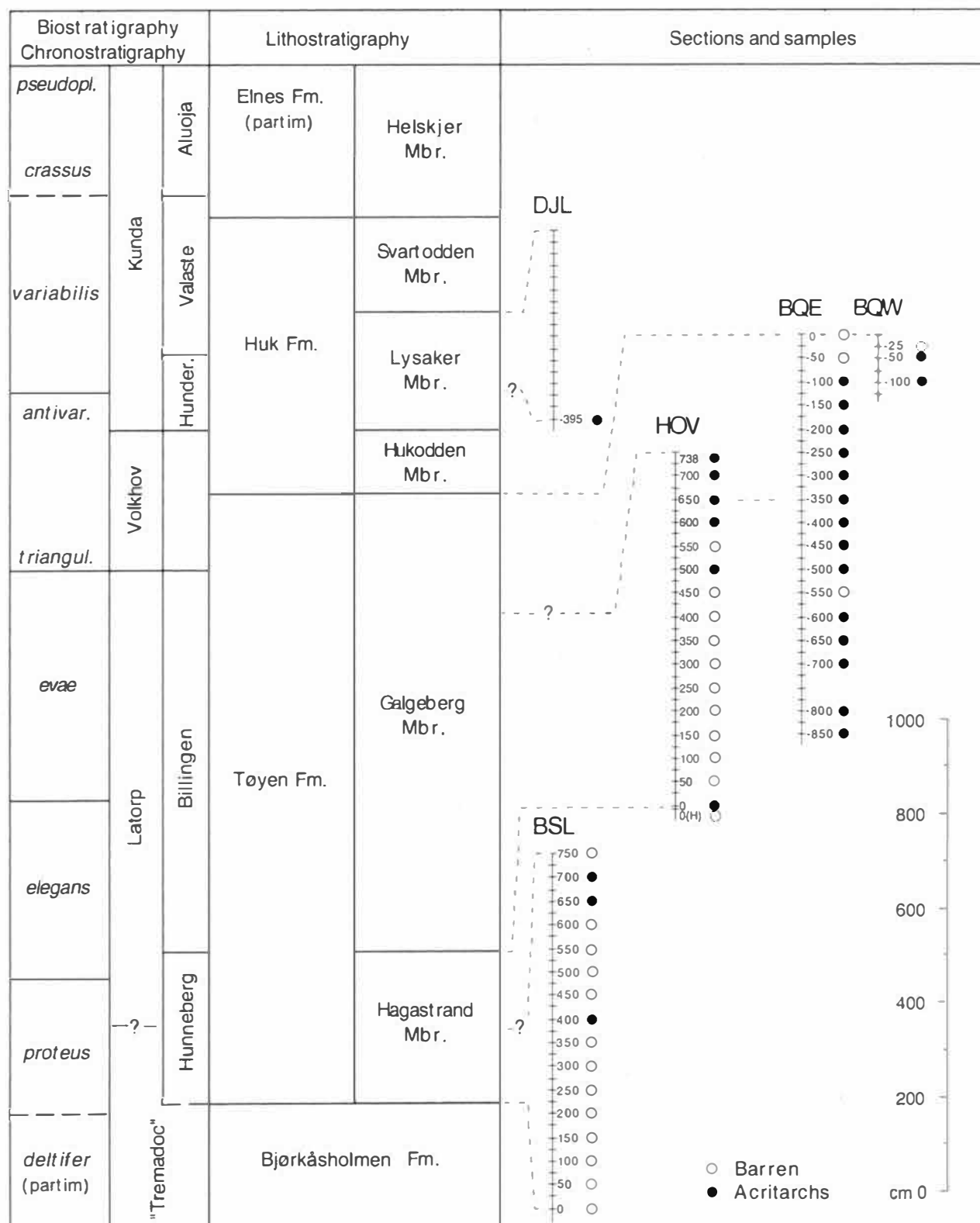
This locality (Text-fig. 1, locality 5) corresponds to the lane section leading to Øvre Øren farm of previous authors (Owen *et al.*, 1990; Ebbestad, 1999, fig. 9; Hoel, 1999a, b) and there seems to be a wide discrepancy in the map reference for the same locality cited by Ebbestad. The latter described the trilobites from the Bjorkåsholmen Formation, whilst trilobites from limestones of the overlying Hagastrand Member, Hunneberg Stage (including the basal? *Megistaspis* (*Ekeraspis*) *armata* trilobite Zone) were described by Hoel (1999a, b). The succeeding black shales of the Galgeberg Member form a hypostratotype section for this unit and are 7.5 m thick (Owen *et al.*, 1990, p. 11). Seventeen samples (labelled HOV) were collected from this unit (Text-fig. 3). For correlation purposes, these samples include the uppermost Hunneberg and the Billingen Stages from the middle *Prioniodus elegans* to the *Oepikodus evae* conodont Zones.

Bjorkåsholmen old quarry, Oslo-Asker district (NM 839 289)

This disused factory site (Text-fig. 1, locality 2) is that identified as the "Abandoned factory section, Slemmestad", by Malerz (1997) who described Llanvirn graptolites from the Elnes Formation, the youngest part of the section exposed. Twenty samples (labelled BQE and BQW) were collected from the upper parts of the Galgeberg Member of the Tøyen Formation along the eastern and western walls of the factory site (Text-fig. 3). For correlation purposes, these samples cover the *Oepikodus evae* conodont Zone of the middle-upper Billingen Stage and the lower part of the Volkhov Stage, corresponding to the *Baltoniodus? triangularis* - *B. navis* conodont Zones and possibly to (a part of?) the *Paroistodus originalis* Zone (compare Text-figures 3 and 2).

PALYNOLOGICAL PREPARATIONS AND REPOSITORY

Samples were treated using the method described by Tongiorgi (*in* Bagnoli *et al.*, 1988). All slides are housed in the type collections of the "Museo di Storia Naturale e del Territorio", Certosa di Calci; Pisa. Catalogue numbers are prefixed CPT, followed by



Text-fig. 3 - Tremadoc - Llanvirn stratigraphy of the Oslo Region (Owen *et al.*, 1990) with reference to Baltoscandian stages and conodont zones, and location of samples collected from sections at Bjorkåsholmen shore line (BSL), Hovland (HOV), Bjorkåsholmen old quarry (BQE, BQW) and Djuptrakkodden (DJI).

numbers indicating the geographic location (110), the sample (020, 021, etc.) and, preceded by a hyphen, the number (01, 02, etc.) of the slide.

RESULTS

THE PALYNOLOGICAL CONTENT

Twenty-three samples of 53 (about 43%) were barren or almost so, the remaining samples (about 57%) being more or less rich in palynomorphs. However, the acritarchs are black in colour, deeply corroded, often incomplete and with truncated processes. Identification below the generic level is therefore possible only for a few more complete specimens but a certain degree of uncertainty remains in some cases.

LIST OF ACRITARCH TAXA AND THEIR DISTRIBUTION IN EACH SECTION

The palynomorph-rich samples from the sections studied herein, yielded the following taxa:

1. *Athabascaella playfordii* Martin, 1984 emend. Martin & Yin, 1988
2. *Athabascaella* sp.
3. *Baltisphaeridium denticulatum* Lu, 1987
4. *Baltisphaeridium* sp. cf. *B. fragile* Tongiorgi *et al.*, 1995
5. *Baltisphaeridium klabavense* (Vavrdová, 1965) Kjellström, 1971
6. *Baltisphaeridium* sp. cf. *B. kunmingense* Fang, 1986
7. *Baltisphaeridium* spp.
8. *Caldariola glabra* (Martin, 1973 emend. Tongiorgi in Bagnoli *et al.*, 1988) Molyneux in Molyneux & Rushton, 1988
9. *Cycloposphaeridium* sp.
10. *Cymatiogalea* sp. cf. *C. deunffii* Jardiné *et al.*, 1974
11. *Cymatiogalea granulata* Vavrdová, 1966
12. *Cymatiogalea messaoudensis* Jardiné *et al.*, 1974 var. *inconnexa* Servais & Molyneux, 1997
13. *Cymatiogalea messaoudensis* Jardiné *et al.*, 1974 var. *messaoudensis*
14. *Cymatiogalea* sp.
15. *Gorgonisphaeridium?* *pusillum* Playford & Wicander, 1988
16. *Loeblichia heterorhabda* Playford & Wicander, 1988
17. *Leiosphaeridia* (s.l.) spp.
18. *Michrhystridium* sp. aff. *M. acuminosum* Cramer & Díez, 1977
19. *Multiplicisphaeridium* sp. cf. *M. irregulare* Staplin *et al.*, 1965
20. *Multiplicisphaeridium* spp.
21. ?*Ordovicidium yangtzeense* Tongiorgi *et al.*, 1995
22. *Pachysphaeridium rhabdocladium* (Lu, 1987 emend. Tongiorgi *et al.*, 1995) Ribecai & Tongiorgi, 1999
23. *Pachysphaeridium striatum* (Lu, 1987 emend. Tongiorgi *et al.*, 1995) Ribecai & Tongiorgi, 1999
24. *Peteinosphaeridium armatum* Tongiorgi *et al.*, 1995
25. *Peteinosphaeridium dissimile* Górka, 1969
26. *Peteinosphaeridium exornatum* Tongiorgi *et al.*, 1995
27. *Peteinosphaeridium robustiramosum* Tongiorgi *et al.*, 1995
28. *Peteinosphaeridium tenuiflosum* Tongiorgi *et al.*, 1995
29. *Peteinosphaeridium* sp. A (= *Peteinosphaeridium* sp. in Raevskaya, 1999, pl. 2, fig. 7)
30. *Peteinosphaeridium* spp.
31. *Picostella turgida* Yin *et al.*, 1998
32. *Pireia* sp. cf. *P. colliformis* (Burmman, 1970) Eisenack *et al.*, 1976
33. *Polyancistrodorus?* sp. aff. *P.?* *radiosus* Playford & Wicander, 1988
34. *Polyancistrodorus?* *taleatus* Playford & Wicander, 1988
35. *Polygonium gracile* Vavrdová, 1966
36. *Polygonium* spp.
37. *Rhopaliophora mamilliformis* Lu, 1987 emend. Tongiorgi *et al.*, 1995
38. *Rhopaliophora palmata* (Combaz & Peniguel, 1972) emend. Playford & Martin, 1984
39. *Rhopaliophora pilata* (Combaz & Peniguel, 1972) emend. Playford & Martin, 1984
40. *Rhopaliophora?* sp. A (sp. aff. *Rhopaliophora* sp. A in Raevskaya, 1999, pl. 1, fig. 14)
41. ?*Solisphaeridium* sp. cf. *S. solare* Cramer & Díez, 1977
42. *Solisphaeridium* sp. aff. *S. solidispinosum* Cramer & Díez, 1977
43. *Solisphaeridium* spp.
44. *Stelliferidium stelligerum* (Górka, 1967) emend. Deunff *et al.*, 1974
45. *Stelliferidium striatulum* (Vavrdová, 1966) emend. Deunff *et al.*, 1974
46. *Stelliferidium* spp.
47. *Stelomorpha composta* Yin *et al.*, 1998
48. *Stelomorpha erchunensis* (Fang 1986) Yin 1994 emend. Tongiorgi *et al.*, 1995
49. *Tenuirica?* spp.
50. *Tongzia meitana* Li, 1987
51. *Tongzia vavrdovae* Yin *et al.*, 1998
52. *Tongzia* sp.

Tables 1-4 illustrate the distribution (ordered by first appearance) of all taxa (excluding leiospheres) from the sections studied:

TAXA	SAMPLES	400	650	700
<i>Athabascaella playfordii</i>		X	X	X
<i>Caldariola glabra</i>		X	X	X
<i>Cymatiogalea cf. deunffii</i>		X		
<i>Cymatiogalea mess. inconnexa</i>		X		
<i>Cymatiogalea mess. messaoudensis</i>		X	X	X
<i>Michrystridium</i> spp.		X		
<i>Pireia cf. colliformis</i>		X		
<i>Peteinosphaeridium</i> sp. A		X	X	
<i>Peteinosphaeridium</i> spp.		X	X	X
<i>Rhopaliophora pilata</i>		X		
<i>Stelliferidium</i> spp.		X	X	
<i>Athabascaella</i> sp.		X	X	

Tab. 1 - Bjørkåsholmen shoreline section. Samples labelled BSL; levels (in centimetres) measured above the base of Galgeberg Member.

STRATIGRAPHIC DISTRIBUTION OF ACRITARCH TAXA

Hunneberg and basal Billingen assemblages

Early Hunneberg (*Paroistodus proteus* conodont Zone) acritarch assemblages occur in the Hagastrand Member of the Tøyen Formation at Bjørkåsholmen (samples BSL400, BSL650, and BSL700; Tab. 1). All these assemblages are dominated by *Cymatiogalea messaoudensis messaoudensis*, locally (sample BSL400) accompanied by *C. messaoudensis inconnexa*. *C. messaoudensis* was previously identified, though tentatively, at the locality Rørtunet Nord (sample Oslo1; Ribecai *et al.*, 2000), from the *Tetraraptus phyllo-*

graptoides graptolite Zone (upper *P. proteus* conodont Zone). Here it occurs together with, ?*Cymatiogalea deunffii* Jardiné *et al.*, 1974. *C. messaoudensis messaoudensis* is also very common at the very base of the Galgeberg Mbr. of the Tøyen Fm. (lowermost Billingen, lower *Prioniodus elegans* conodont Zone) at Hovland (sample HOV0).

Billingen and lower Volkhov assemblages

Middle Billingen (*Oepikodus evae* conodont Zone), acritarch assemblages occur in the Galgeberg Member of the Tøyen Formation at Hovland (samples HOV500, HOV650, HOV700, and HOV738; Tab. 2), and in samples from the Bjørkåsholmen old quarry (BQE-650, BQE-700, BQE-650, BQE-600, BQE-500, BQE-450, BQE-400, BQE-350, BQE-300, BQE-250, BQE-200, BQE-250, and BQE-100; BQW-100 and BQW-50; Tabs. 3-4). The latter, however, cover a larger interval extending from the lower *Oepikodus evae* and possibly the upper *Prioniodus elegans* conodont Zone, to the lower Volkhov, *Baltioniodus? triangularis* - *B. navis* (and *Paroistodus originalis?*) conodont Zones (Text-fig. 2).

The older assemblages (BQE850 to BQE400; HOV500 and HOV600) are not particularly distinctive. They are dominated by various species of *Baltisphaeridium*, *Michrystridium* Deflandre, 1937 emend. Lister, 1970, and *Peteinosphaeridium*, in addition to rare specimens of *Polygonium*, while characteristic Hunneberg species have completely disappeared at these levels. However, elements of a differ-

TAXA	SAMPLES	0	500	600	650	700	738
<i>Baltisphaeridium</i> spp.		X	X	X	X	X	X
<i>Cycloposphaeridium</i> sp.		X					
<i>Cymatiogalea mess. messaoudensis</i>		X					
<i>Peteinosphaeridium</i> spp.		X	X	X	X		X
<i>Polygonium</i> spp.		X			X		X
<i>Stelliferidium</i> spp.		X			X	X	
<i>Cymatiogalea granulata</i>			X				
<i>Multiplicisphaeridium</i> spp.			X				
<i>Michrystridium</i> spp.				X	X		X
<i>Peteinosphaeridium armatum</i>				X	X	X	
<i>Baltisphaeridium denticulatum</i>					X	X	
<i>Loeblichia heterorhabda</i>					X		
<i>Peteinosphaeridium exornatum</i>					X		
<i>Peteinosphaeridium robustiramosum</i>					X		
<i>Peteinosphaeridium tenuifilum</i>					X		
<i>Polyancistrodorus? taleatus</i>					X		
<i>Rhopaliophora? sp. A</i>					X		
<i>Solisphaeridium aff. solidispinosum</i>					X		
<i>Stelomorpha erchunensis</i>					X		
<i>Tongzia vavrdovae</i>					X		
<i>Stelomorpha compasta</i>						X	
<i>Baltisphaeridium klabavense</i>							X
<i>Multiplicisphaeridium cf. irregulare</i>							X
<i>Picostella turgida</i>							X
<i>Polygonium gracile</i>							X

Tab. 2 - Hovland section. Samples labelled HOV; levels (in centimetres) measured from the base of Galgeberg Member.

TAXA	SAMPLES	-850	-800	-700	-650	-600	-500	-450	-400	-350	-300	-250	-200	-150	-100
<i>Baltisphaeridium</i> spp.		X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Michrystidium</i> spp.		X			X	X	X	X	X	X	X	X	X	X	X
<i>Baltisphaeridium</i> cf. <i>fragile</i>			X								X			X	
<i>Polygonium</i> spp.			X		X	X			X	X	X				
<i>Tongzia meitana</i>				X						X				X	X
<i>Peteinosphaeridium armatum</i>				X						X				X	X
<i>Peteinosphaeridium tenuifilum</i>				X					X	X	X		X	X	X
<i>Peteinosphaeridium</i> spp.				X	X		X	X	X	X	X			X	X
<i>Multiplicisphaeridium</i> spp.							X	X	X		X	X	X		
<i>Cycloposphaeridium</i> sp.							X								
<i>Gorgonisphaeridium</i> ? <i>pusillum</i>								X		X					
<i>Polyancistrodorus</i> ? <i>taleatus</i>								X				X			
<i>Baltisphaeridium denticulatum</i>									X				X	X	
<i>Michrystidium</i> aff. <i>acuminosum</i>									X	X		X		X	X
<i>Rhopaliophora pilata</i>									X						
? <i>Solisphaeridium</i> cf. <i>solare</i>									X						
<i>Stelliferidium stelligerum</i>									X	X					X
<i>Stelliferidium striatulum</i>									X						X
<i>Baltisphaeridium</i> cf. <i>kunmingense</i>										X					X
? <i>Ordoviciidium yangtzeense</i>										X					
<i>Pachysphaeridium rhabdocladium</i>										X		X		X	
<i>Pachysphaeridium striatum</i>										X		X			
<i>Polyancistrodorus</i> ? aff. <i>radiosus</i>										X				X	
<i>Rhopaliophora mamilliformis</i>										X					
<i>Rhopaliophora palmata</i>										X		X			
<i>Solisphaeridium</i> aff. <i>solidispinosum</i>										X					
<i>Stelomorpha composta</i>										X		X		X	
<i>Stelomorpha erchunensis</i>										X	X		X		X
<i>Peteinosphaeridium robustiramosum</i>											X	X		X	
<i>Baltisphaeridium klabavense</i>														X	X
<i>Polygonium gracile</i>														X	X
<i>Tongzia vavrdovae</i>														X	
<i>Tongzia</i> sp.														X	
<i>Cymatogalea granulata</i>															X
<i>Cymatogalea</i> sp.															X

Tab. 3 - Björkåsholmen quarry, east wall section. Samples labelled BQE; levels (in centimetres) measured downwards from the base of the Huk Formation.

ent microflora gradually appear including *Tongzia meitana* (starting from BQE-800), *Peteinosphaeridium armatum* and *P. tenuifilum* (from sample BQE-700, upwards), *Cymatogalea granulata* (from sample HOV500), *Baltisphaeridium denticulatum*

and *Michrystidium* sp. aff. *M. acuminosum* (from sample BQE-400, upwards). In the Björkåsholmen old quarry, east wall section, the microfossil turnover is completed at -350 cm below the base of the overlying Huk Fm. (sample BQE-350), where *Pachysphaeridium rhabdocladium*, *P. striatum*, *Stelomorpha composta*, and *S. erchunensis* first appear. At Hovland, the same level is recognized at 650 cm from the base of the Galgeberg Member (sample HOV650; Text-fig. 2).

Volkhov to lower Kunda assemblages

A description of acritarch assemblages from the upper Volkhov and lower Kunda Stages is beyond the scope of this paper. Nevertheless, it should be noted that in Baltoscandia a completely different microflora appears after the lower Volkhov interval. Ribecai *et al.* (2000) recovered the following taxa from the dark grey, nodular limestones of the Huk Fm. (Lysaker Member, *Asaphus expansus* trilobite Zone, Volkhov/Kunda boundary interval) at Djuptrekkoden (sample Oslo4): *Baltisphaeridium* spp., *Cycloposphaeridium auriculatum* Uutela & Tynni, 1991, emend. Playford

TAXA	SAMPLES	-100	-50
<i>Multiplicisphaeridium</i> spp.		X	
<i>Pachysphaeridium striatum</i>		X	
<i>Peteinosphaeridium armatum</i>		X	
<i>Peteinosphaeridium dissimile</i>		X	
<i>Peteinosphaeridium robustiramosum</i>		X	
<i>Tongzia vavrdovae</i>		X	
<i>Baltisphaeridium</i> spp.		X	X
<i>Peteinosphaeridium tenuifilum</i>		X	X
<i>Peteinosphaeridium</i> spp.		X	X
<i>Stelomorpha composta</i>		X	X
<i>Polygonium</i> sp.			X
<i>Stelliferidium striatulum</i>			X

Tab. 4 - Björkåsholmen quarry, west wall section. Samples labelled BQW; levels (in centimetres) measured downwards from the base of the Huk Formation.

et al., 1995, *Liliosphaeridium hypertrophicum* (Eisenack 1976) emend. Playford *et al.*, 1995, *Micrhystridium* spp., *Multiplicisphaeridium* spp., *Pachysphaeridium* spp., *Peteinosphaeridium dissimile*, *P. eximium* Playford *et al.*, 1995, *P. sp. cf. P. velatum* Kjellström, 1971 emend. Playford *et al.*, 1995, "*P. macropylum* Form Group" (= *Sacculidium* Ribecai *et al.*, 2002), *Polygonium* sp., and *Verybachiium* sp.

In a subsequent sample (labelled DJL) collected by us from the same locality and about the same stratigraphic level (lower Huk Formation, Lysaker Member, 395 cm below the overlying Svartodden Member of the same formation) we recognized *Baltisphaeridium* sp. cf. *B. longispinosum*, (Eisenack, 1931 ex O. Wetzell, 1933) Eisenack, 1959, *Baltisphaeridium* spp., *Ordovicidium* sp., *Multiplicisphaeridium* sp., *Pachysphaeridium christianii* (Kjellström, 1976) Ribecai & Tongiorgi, 1999, *Peteinosphaeridium dissimile*, *Polygonium* spp., *Sacculidium inornatum* Ribecai *et al.*, 2002, and *Sacculidium tenuibarbatum* (Eisenack, 1976) Ribecai *et al.*, 2002.

Ribecai *et al.* 2000 identified from a slightly younger level of the Lysaker Member (sample Oslo2; "Lenodus sp. A" Zone = ?*Lenodus variabilis* conodont Zone, herein; lower Kunda, Hunderum): *Baltisphaeridium* spp., *Dasydorus cirritus* Playford & Martin, 1984, *Liliosphaeridium intermedium* (Eisenack, 1976) emend. Playford *et al.*, 1995, *L. kaljoi* (Uutela & Tynni, 1991) emend. Playford *et al.*, 1995 (= *Liliosphaeridium tintinnabulum* Bagnoli & Ribecai, 2001), *Micrhystridium* spp., *Multiplicisphaeridium* spp., *Peteinosphaeridium dissimile*, *P. ? hystrichoreticulatum* (Eisenack, 1938) Eisenack *et al.*, 1973, *P. sp. cf. P. eximium* Playford *et al.*, 1995, *P. velatum*, "*P. macropylum* Form Group" [= *Sacculidium* Ribecai *et al.*, 2002, including, *S. inornatum*, *S. macropylum* (Eisenack, 1959) Ribecai *et al.*, 2002, and *S. peteinoideis* Ribecai *et al.*, 2002], *Polygonium* spp.

DISCUSSION

INTERPRETATION OF BARREN SAMPLES

Absence or extreme rarity of palynomorphs in the palynological residues may be due to various factors, such as high sedimentation rate of the original sediments, bioerosion at the depositional surface or immediately below, syn- or post-sedimentary (diagenetic) oxidization, or past and/or present-day surface weathering. Thus, no definite interpretation can be attached to the distribution of barren samples (Tongiorgi *et al.*, in press).

In the Oslo sections, barren samples in the Tøyen Formation are more frequent down section, where the organic content is higher. Dark sediment, rich in organic matter, frequently yields depauperate palynomorph assemblages or even lacks organic-walled microfossils. This is probably because organic matter-

rich sea floors may be characterised by intense bacterial activity, which can corrode or even completely destroy the palynomorphs. Moreover, whenever the palynological residues include a large amount of amorphous organic matter, concentration of structured elements (such as palynomorphs) from this is very difficult or even impossible. Actually, the residues from the Oslo "barren" samples yielded large clumps of fine-grained, unstructured organic matrix which are difficult to separate and sieve. Thus, in our opinion, all samples collected for this study could be considered potentially rich in palynomorphs.

CORRELATION AND BIOGEOGRAPHIC AFFINITY OF THE PALYNOMORPH ASSEMBLAGES

Hunneberg and basal Billingen

C. messaoudensis, which is a common component of the Hunneberg and basal Billingen assemblages from Oslo, has been also identified in other localities of Baltica (the Baltic palaeoplate) by Paalits (in Servais & Molyneux, 1997) in the Hunneberg of Estonia and by Raevskaya (1999) in the Hunneberg (Assemblage I, upper *P. proteus* conodont Zone) and near the base of the Billingen (Assemblage II, uppermost *P. proteus* and *P. elegans* conodont Zones) of the St. Petersburg region (northwestern Russia).

?*Cymatiogalea deunffii* has the same stratigraphical and spatial distribution. In the St. Petersburg region a similar form (*C. sp. aff. C. deunffii*) occurs from the upper *P. proteus* conodont Zone, *T. phyllograptoides* graptolite Zone (Assemblage I of Raevskaya, 1999).

Cymatiogalea messaoudensis is a distinctive element of the *messaoudensis-trifidum* microflora (Martin, 1996; Molyneux & Rushton, 1988; Servais & Katzung, 1993; Servais & Molyneux, 1997; Servais & Mette, 2000) which, during latest Tremadoc-earliest Arenig times, characterises the cold-water realm located at high southern latitudes (>60°S), along the northern margin of Gondwana (Servais & Fatka, 1997; Servais & Mette, 2000).

The occurrence in our samples of *Caldariola glabra* and the abundance of *Stelliferidium* spp., together with the relatively rare occurrence of *Peteinosphaeridium* spp., are compatible with the presence of elements of the *messaoudensis-trifidum* microflora (Servais & Molyneux, 1997). However, several typical representatives of this latter microflora [e.g., *Acanthodiacrodium? dilatatum* Molyneux in Molyneux & Rushton, 1988, *Stellechinatum sicaforme* Molyneux in Molyneux & Rushton, 1988, *Vavrdovella areniga* (Vavrdová, 1973) Loeblich & Tappan, 1976, and *Stelliferidium trifidum* (Rasul, 1974) Fensome *et al.*, 1990] are absent in Norwegian samples.

By contrast, other species we have identified (*Athabascaella playfordii*: samples HOV400, HOV650, and HOV700; *Athabascaella* sp.: samples HOV650 and HOV700; ?*Athabascaella playfordii*

and ?*A. rossii* Martin, 1984 emend. Martin & Yin, 1988: sample Oslo1 in Ribecai *et al.*, 2000) are considered diagnostic of a middle Tremadoc to earliest Arenig, warm-water, low latitude realm (Martin & Yin, 1988; Volkova, 1997; Barker & Miller, 1990; Servais & Fatka, 1997), characterised by the occurrence of *Aryballomorpha* Martin & Yin, 1988, *Athabascaella* Martin, 1984 emend. Martin & Yin, 1988, and *Lua* Martin & Yin, 1988. These genera were documented from the Tremadoc of Texas, U.S.A. (Barker & Miller, 1990), the middle-upper Tremadoc of Öland, Sweden (Tongiorgi in Bagnoli *et al.*, 1988), the uppermost Tremadoc of Estonia (Volkova, 1995), the uppermost Tremadoc to lowermost Arenig of northeastern China (Martin & Yin, 1988), and the lowermost Arenig (upper *P. proteus* conodont Zone) of the St. Petersburg region, northwestern Russia (Raevskaya, 1999: Assemblages I and IIa). However, *Athabascaella playfordii* has been recently also recorded by Breuer & Vanguetstaine (Vanguetstaine, personal communication) from the upper Tremadoc of Belgium.

As discussed in the previous paragraphs, the mixed microflora of the Hunneberg and basal Billingen of the Oslo region corresponds to Raevskaya's (1999) Assemblage I and Assemblage IIa from the East European Platform. Also the middle Tremadoc assemblages described by Tongiorgi (in Bagnoli *et al.*, 1998) from the island of Öland, Sweden, include *Aryballomorpha* and *Athabascaella*, associated with genera which are common in the cold seas of Perigondwana (*Acanthodiacrodium* Timofeev, 1958 emend. Deflandre & Deflandre-Rigaud, 1962, *Cymatiogalea* Deunff, 1961 emend. Deunff *et al.*, 1974, *Dasydiacrodium* Timofeev ex Deflandre &

Deflandre-Rigaud, 1962 emend. Deflandre & Deflandre-Rigaud, 1962, and *Stelliferidium*).

It is also of interest to note the occurrence of *Peteinosphaeridium* sp. A in the Hunneberg of the Oslo Region (samples BSL400 and BSL650; *P. proteus* conodont Zone), which seems to be the same as Raevskaya's (1999, pl. 2, fig. 7) *Peteinosphaeridium* sp. from the Assemblage IIa, upper *P. proteus* conodont Zone of the St. Petersburg region. This species can be a possible ancestor of a Baltic upper Volkhov form such as *P. bergstroemii* Staplin *et al.*, 1965. Both have a weakly flaring trunk composed of four laminae, a serrated profile of the lamina edges and long, distally tapering branches delimiting a central, slightly concave structure (Playford *et al.*, 1995).

In recent palaeogeographic reconstructions (Scotese & McKerrow, 1991; Torsvik *et al.*, 1996; Christiansen & Stouge, 1999) Baltica is placed in an intermediate latitudinal position, between 30° S and 60° S. However, its climate is claimed to have been milder than expected at this latitude, due to the fact that Baltoscandia and the East European Platform "constituted the southeasternmost limitation of the subtropical anticyclone gyre in the Iapetus Ocean" (Christiansen & Stouge, 1999; cf. also Wilde, 1991, and Raevskaya *et al.*, in press). These palaeogeographic and palaeoceanic constraints may explain the mixed character of the Hunneberg microflora of the Oslo Region (samples BSL400, BSL650, and BSL700), which includes representatives of both cold-water (elements of the *messauoudensis-trifidum* microflora) and warm-water microfloristic assemblages (elements of the *Aryballomorpha-Athabascaella-Lua* microflora).

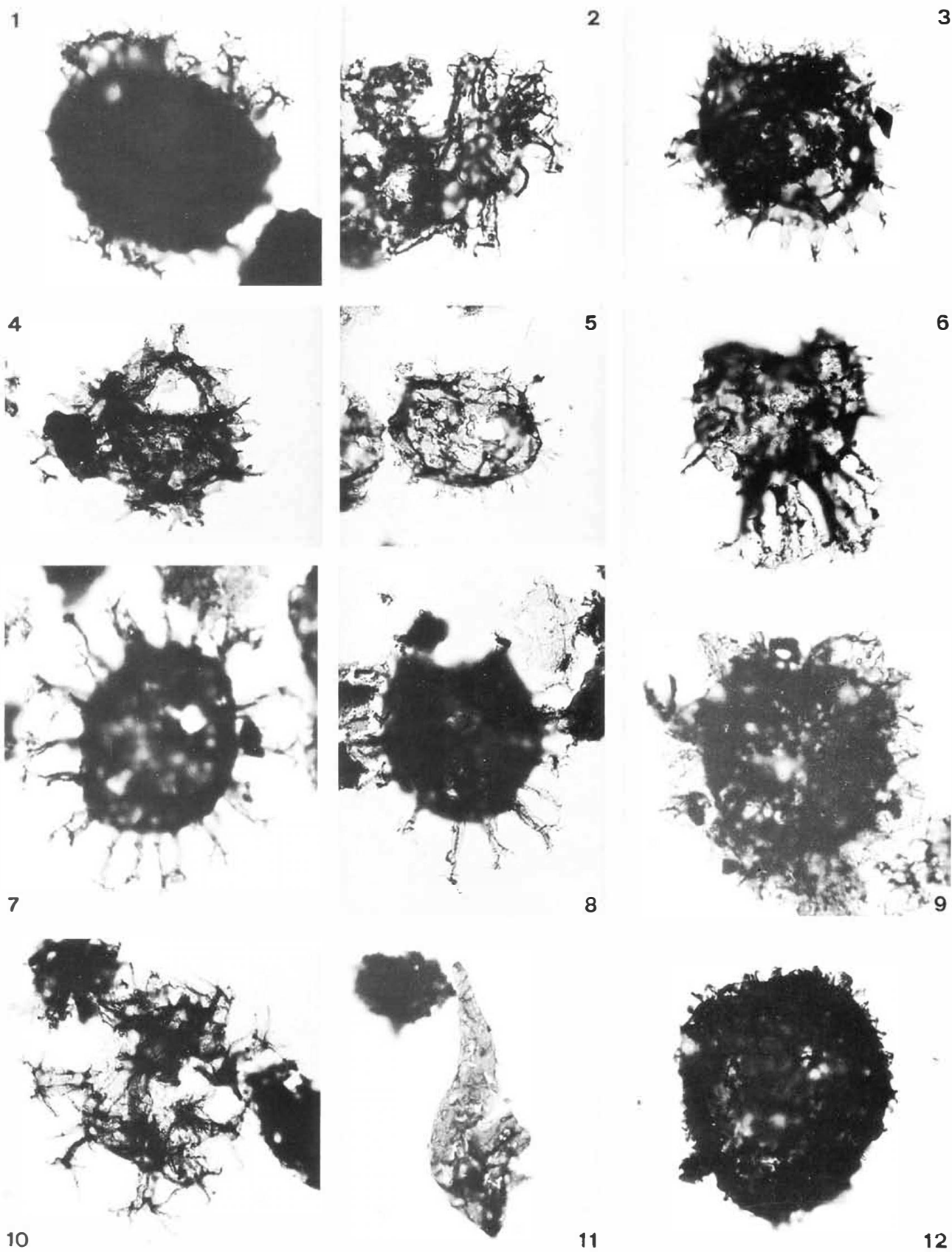
Our sample from Hovland (HOV0), with *Cymatiogalea messauoudensis messauoudensis* but without

EXPLANATION OF PLATE 1

Selected Hunneberg and basal Billingen species.

- Figs. 1-2 - *Athabascaella playfordii* Martin, 1984 emend. Martin & Yin, 1988. 1) CPT110078-01; slide BSL-400/tot.01; EF K32/1; Björkåsholmen. 2) Some processes of a fragmentary specimen: CPT110078-01; slide BSL-400/tot.01; EF R49; Björkåsholmen.
- Figs. 3-5 - *Cymatiogalea messauoudensis* Jardiné *et al.*, 1974 var. *inconnexa* Servais & Molyneux, 1997. 3) Specimen in lateral view: CPT110078-01; slide BSL-400/tot.01; EF P48/3-Q48/1; Björkåsholmen. 4) Specimen in approximately polar view (pylome pole): CPT110078-01; slide BSL-400/tot.01; EF C44-C44/4; Björkåsholmen. 5) Specimen in lateral view: CPT110078-01; slide BSL-400/tot.01; EF U38; Björkåsholmen.
- Figs. 6-8 - *Cymatiogalea messauoudensis* Jardiné *et al.*, 1974 var. *messauoudensis*. 6) Specimen in lateral view, showing membranes stretched between processes reduced by corrosion to rag-like fragments: CPT110078-01; slide BSL-650/tot.01; EF S44/1; Björkåsholmen. 7) Specimen in polar view, membranes almost completely missing: CPT110078-01; slide BSL-400/tot.01; EF F48/4-F49/3; Björkåsholmen. 8) Specimen in lateral view, devoid of membranes (eroded): CPT110078-01; slide BSL-400/tot.01; EF O50/1; Björkåsholmen.
- Fig. 9 - *Cycloposphaeridium* sp. CPT110051-01; slide HOV0/tot.01; EF O43/1; Hovland.
- Fig. 10 - *Peteinosphaeridium* sp. A (= *Peteinosphaeridium* sp. in Raevskaya, 1999, pl. 2, fig. 7). CPT110078-01; slide BSL-400/tot.01; EF R24/4; Björkåsholmen.
- Fig. 11 - *Pireia* sp. cf. *P. colliformis* (Burmann, 1970) Eisenack *et al.*, 1976. CPT110078-01; slide BSL-400/tot.01; EF R32; Björkåsholmen.
- Fig. 12 - *Rhopaliophora pilata* (Combaz & Peniguel, 1972) emend. Playford & Martin, 1984. CPT110078-01; slide BSL-400/tot.01; EF G55/1; Björkåsholmen.

Specimen magnification x800; England Finder coordinates (EF) measured on slides with the repository label oriented to the right.



Athabascaella (Tab. 2), marks the transition to the Billingen microfloral assemblages and could correspond to Raevskaya's (1999) Assemblage IIb, which is of the same age (*P. elegans* conodont Zone).

The presence of *Cycloposphaeridium* sp. in this sample is very interesting. The monospecific genus *Cycloposphaeridium* Uutela & Tynni, 1991 emend. Playford *et al.*, 1995 was originally established (type-species *C. auriculatum* Uutela & Tynni, 1991) on Estonian material from the Volkhov?-Aseri Stages (Uutela & Tynni, 1991). It was subsequently recorded from the Kunda Stage (Hunderum Substage) of Sweden (Ribecai & Tongiorgi, 1995; Playford *et al.*, 1995) and from the lower Arenig (*A. suecicus*-lower *U. sinodentatus* graptolite Zones) of Sichuan and Hubei Provinces, South China (Brocke *et al.*, 2000; as "cf. *Cycloposphaeridium auriculatum*"). Tongiorgi *et al.* (in press) recovered two still unnamed species of *Cycloposphaeridium* from the lower *O. evae* conodont Zone (corresponding to the Baltic lower upper Billingen) of the Hubei Province, South China. This latter occurrence led Tongiorgi *et al.* (in press) to accept a Chinese origin for this genus. However, the present record herein from Hovland (sample HOV0, *P. elegans* conodont Zone) further predates the FAD of *Cycloposphaeridium*, and thus a Baltic origin of the genus now could appear more probable. But, as observed by Vanguetaine (personal communication), presently available information is probably insufficient to establish a predictable model of species distribution both in space and time.

Billingen and lower Volkhov

Genera considered typical of the Arenig cold- to temperate-waters of Perigondwana (such as *Arbusculidium* Deunff, 1968, *Aureotesta* Vavrdová, 1972 emend. Brocke *et al.*, 1998, *Coryphidium* Vavrdová, 1972, *Striatotheca* Burmann, 1970, *Vavrdovella* Loeblich & Tappan, 1976. See Li, 1987, 1990;

Brocke *et al.*, 1995; Servais & Fatka, 1997) are absent in the acritarch assemblages of the Billingen and lower Volkhov of the Oslo Region. However, all species identified from these assemblages are known from coeval assemblages of the Yangtze Platform of South China (cf. Li, 1987; Tongiorgi *et al.*, 1995; Yin, 1995; Yin *et al.*, 1998; Brocke, 1997, 1998; Tongiorgi *et al.*, in press), though the latter include *Arbusculidium*, *Aureotesta*, *Coryphidium*, and *Striatotheca* and are therefore closer to the cold-water assemblages of Perigondwana (the "Mediterranean Province" of Vavrdová, 1974 and Li, 1987, 1990).

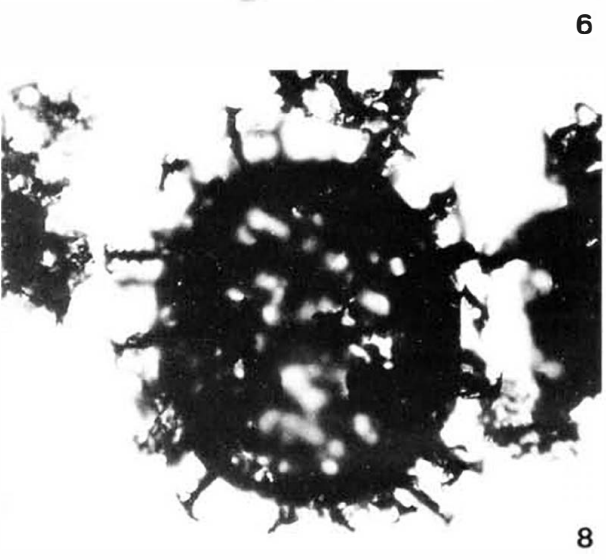
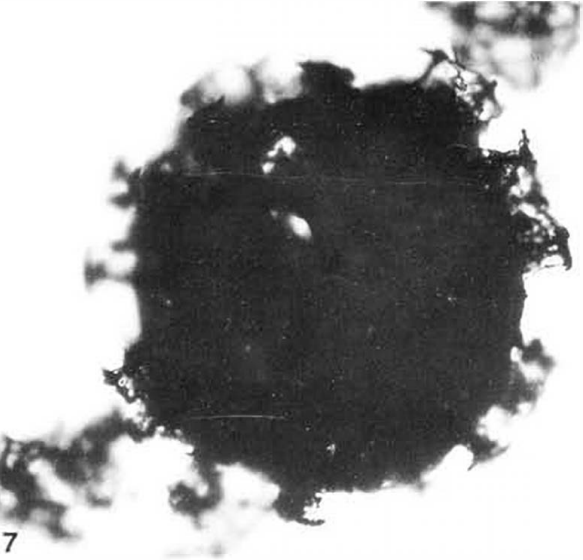
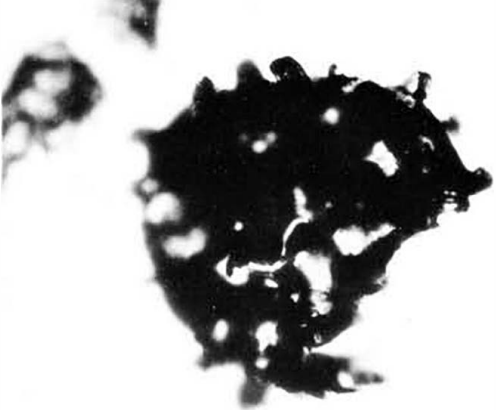
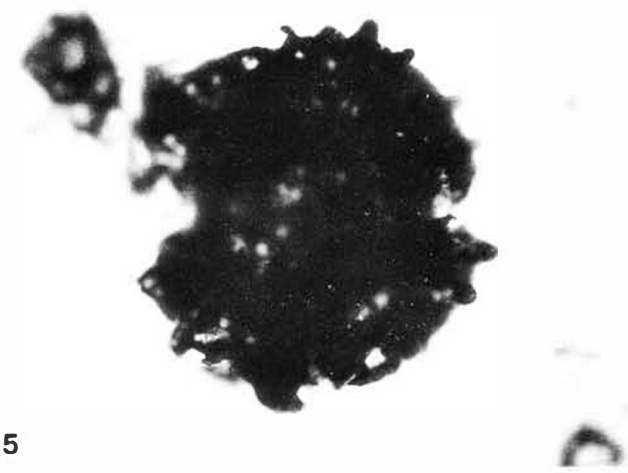
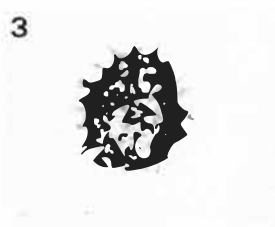
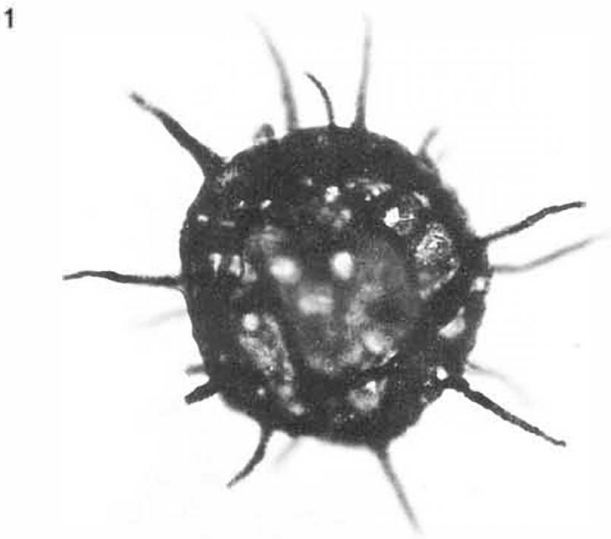
The acritarch microflora from the Billingen to lower Volkhov deposits of the Oslo region, is similar to the Billingen microflora of northwestern Russia and northern Poland (Raevskaya, 1999, Tongiorgi & Di Milia, 1999; Raevskaya *et al.*, in press), which, despite the absence of stenotopic cold-water species, also show a substantial similarity with South Chinese phytoplankton. In particular, the following "South Chinese" species from Oslo also occur in Assemblage IIb and/or Assemblage III (lower Billingen, *P. elegans* conodont Zone, and upper Billingen, *O. evae* conodont Zone, respectively) of the St. Petersburg district (Raevskaya, 1999): *Baltisphaeridium denticulatum*, *B. kummingense*, *Peteinosphaeridium armatum*, *P. robustiramosum*, *P. tenuifilum*, *Rhopaliophora mamilliformis*. Raevskaya *et al.* (in press) from the same levels recognized also *Rhopaliophora* sp. aff. *R. mamilliformis*, *Pachysphaeridium rhabdocladium*, and *Stelomorpha erchunensis*, among many other "South Chinese" species. Polish samples (Billingen, *Phyllograptus angustifolius elongatus* graptolite Zone) have yielded more abundant and better preserved acritarchs, including *Pachysphaeridium rhabdocladium*, *Rhopaliophora* sp. cf. *R. mamilliformis*, *Stelomorpha composita*, *S. erchunensis*, and *Tongzia* sp., among others (Raevskaya *et al.*, in press). *Pachysphaeridium rhabdocladium* and *P. striatum* were also identified by Tongiorgi & Di Milia (1999) in a

EXPLANATION OF PLATE 2

Selected Billingen specie.

- Fig. 1 - *Baltisphaeridium denticulatum* Lu, 1987. CPT110064-01; slide HOV650/tot.01; EF Z27; Hovland.
- Fig. 2 - *Baltisphaeridium klabavense* (Vavrdová, 1965) Kjellström, 1971. Fragmentary specimen showing the filamentous ornamentation of the process wall; CPT110023-02; slide BQE-150/tot.02; EF Q49/1; Björkåsholmen quarry, east wall.
- Fig. 3 - *Michrystidium* sp. aff. *M. acuminosum* Cramer & Diez, 1977. CPT110025-02; slide BQE-250/tot.02; EF M41/2; Björkåsholmen quarry, east wall.
- Fig. 4 - *Multiplicisphaeridium* sp. cf. *M. irregulare* Staplin *et al.*, 1965. CPT110066-01; slide HOV738/tot.01; EF D51; Hovland.
- Fig. 5 - *Pachysphaeridium rhabdocladium* (Lu, 1987 emend. Tongiorgi *et al.*, 1995) Ribecai & Tongiorgi, 1999. CPT110027-01; slide BQE-350/tot.01; EF D49-D49/4; Björkåsholmen quarry, east wall.
- Fig. 6 - *Pachysphaeridium striatum* (Lu, 1987 emend. Tongiorgi *et al.*, 1995) Ribecai & Tongiorgi, 1999. CPT110027-01; slide BQE-350/tot.01; EF Z50; Björkåsholmen quarry, east wall.
- Fig. 7 - *Peteinosphaeridium exornatum* Tongiorgi *et al.*, 1995. CPT110064-01; HOV650/tot.01; EF U31/3; Hovland.
- Fig. 8 - *Peteinosphaeridium armatum* Tongiorgi *et al.*, 1995. CPT110027-01; slide BQE-350/tot.01; EF P32/1; Björkåsholmen quarry, east wall.

Specimen magnification x800; England Finder coordinates (EF) measured on slides with the repository label oriented to the right.



lower Volkhov sample (*B.?* *triangularis* - *B. navis* conodont Zone), collected by E. Raevskaya in the St. Petersburg area.

All the "South Chinese" species shared by the Norwegian, Russian and Polish assemblages (Billingen to lower Volkhov), occur in China from the *O. evae* conodont Zone and the following disappear before the end of this zone (Tongiorgi *et al.*, in press): *Baltisphaeridium denticulatum*, *B. fragile*, *Ordovicidium yangtzeense* (which has been discovered also in the lower Arenig of northwestern Argentina: Rubinstein *et al.*, 1999; Rubinstein & Toro, 2001; both as *Ordovicidium* sp. cf. *O. yangtzeense*), *Peteinosphaeridium exornatum*, *P. robustiramosum*.

In China, *Picostella turgida* is present only in samples from the upper *O. evae* conodont Zone (Yin *et al.*, 1998; Tongiorgi *et al.*, in press), but it also occur in the lower Arenig (*D. bifidus* graptolite Zone) of northwestern Argentina (Rubinstein & Toro, 2001) and in the lower and lower upper Arenig of Chitral, Pakistan (Quintavalle *et al.*, 2000). *Rhopaliophora mamilliformis* possibly disappears in China just below the base of the *B.?* *triangularis* - *B. navis* conodont Zone, (i.e., just below the base of the Baltoscandian Volkhov); but its presence in these zones can not be excluded. The same is true for *Stelomorpha composta*, which might extend to the lower and middle *B.?* *triangularis* - *B. navis* conodont Zone, like another (and more frequent) species of the same genus, i.e. *S. erchunensis*, which positively ranges into the lower Volkhov (Tongiorgi *et al.*, in press).

Baltisphaeridium sp. cf. *B. kunmingense* disappears in China at the base of the *B.?* *triangularis* - *B. navis* conodont Zone, while *Peteinosphaeridium armatum* and *P. tenuifilum* extend to the middle part of the zone and *Multiplicisphaeridium* sp. cf. *M. irregulare*

reaches the upper part (Tongiorgi *et al.*, in press). *Pachysphaeridium rhabdocladum* and *P. striatum* disappear in China about at the same level, in the middle part of the *B.?* *triangularis* - *B. navis* conodont Zone, but in Baltoscandia (Öland, Sweden) they extend to the lower Kunda Stage (lower Hunderum; lower *L. variabilis* conodont Zone), (Ribecai & Tongiorgi, 1999). *Tongzia meitana* and *T. vavrdovae* are common in the lower Arenig of South China (Li, 1989; Yin *et al.*, 1998), but are also known from younger horizons at other Perigondwana localities (e.g., lower Arenig to lower upper Arenig; Chitral, Pakistan: Tongiorgi *et al.*, 1994, Quintavalle *et al.*, 2000; upper Arenig; central Bohemia, Vavrdová, 1990).

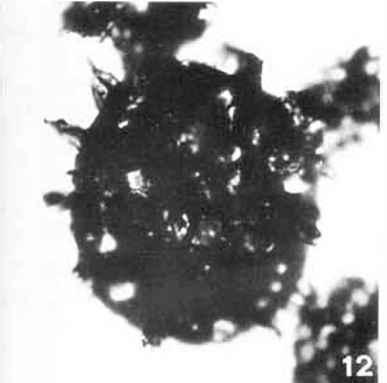
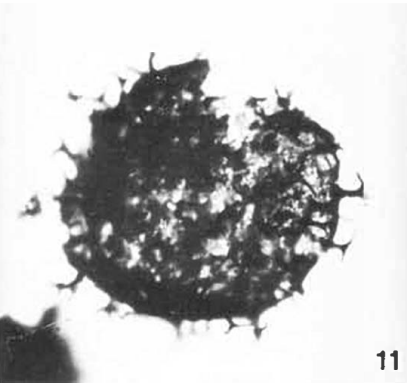
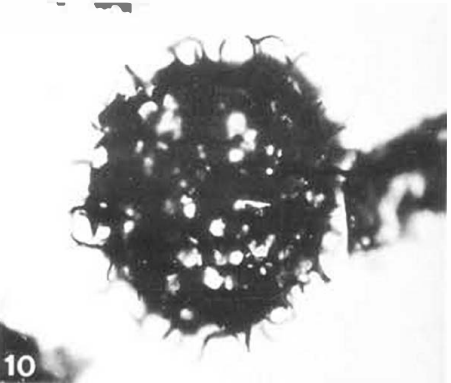
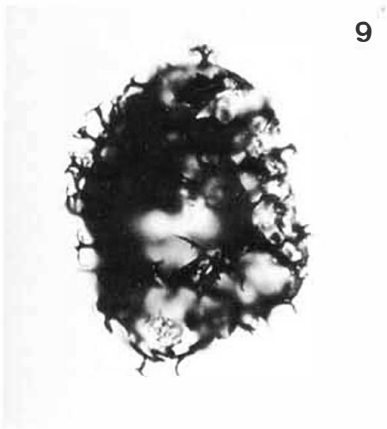
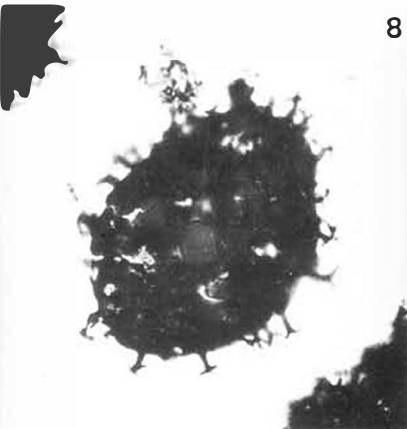
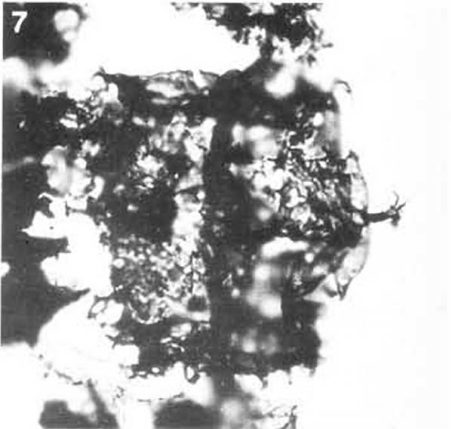
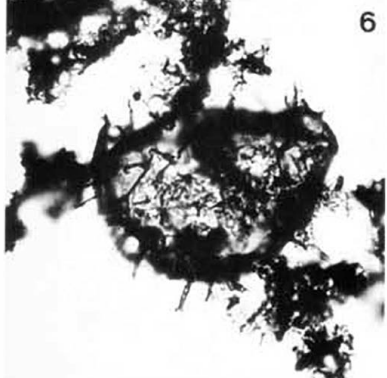
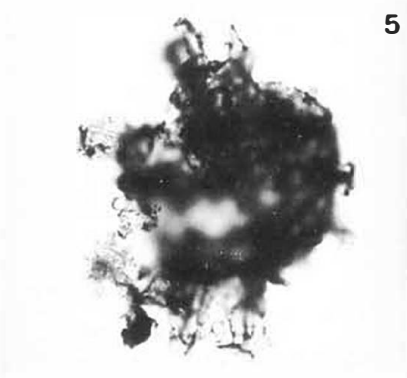
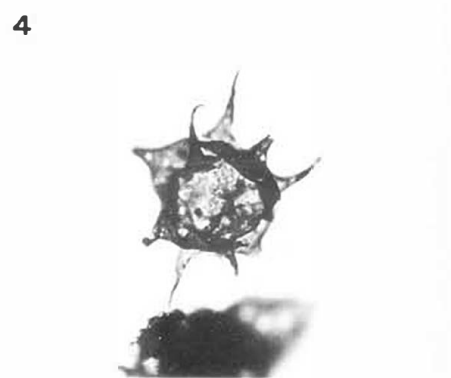
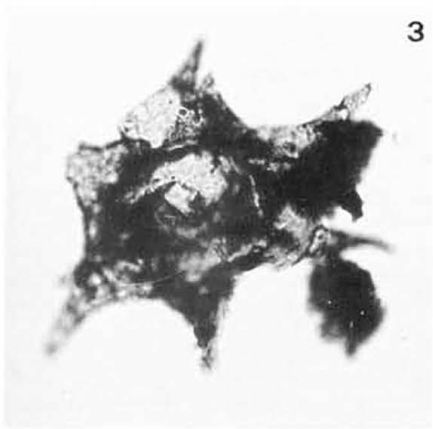
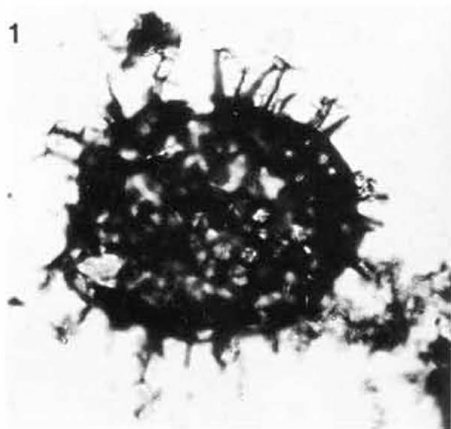
Of particular significance for intercontinental correlation, may be *Peteinosphaeridium dissimile* Górka, 1969. This species occurs in the Björkåsholmen quarry (BQW-100) near the top of the Tøyen Shale Formation (lower Volkhov, *B.?* *triangularis* - *B. navis* and *P. originalis?* conodont Zones). In South China *P. dissimile* first appears in the middle part of the *B.?* *triangularis* - *B. navis* conodont Zone (Tongiorgi *et al.*, in press) and extends to at least the *Undulograptus austrodentatus* graptolite Zone (uppermost *Lenodus variabilis* conodont Zone). Its appearance in China marks the beginning of the transition from the cool Mediterranean microflora of the *O. evae* conodont Zone (Li, 1987, 1990), to a, possibly warmer, microflora which exhibits Baltic affinities (Tongiorgi *et al.*, 1998; Tongiorgi & Di Milia, 1999). In Baltoscandia, *P. dissimile* extends up to the lower Kunda Stage (Hunderum Substage), uppermost *Baltoniodus norrlandicus* or lower *L. variabilis* conodont Zone on Öland, Sweden (Ribecai, personal communication) and at Rortunet N, Oslo-Røyen, Norway (Ribecai *et al.*, 2000).

EXPLANATION OF PLATE 3

Selected Billingen and lower Volkhov species.

- Fig. 1 - *Peteinosphaeridium tenuifilum* Tongiorgi *et al.*, 1995. CPT110034-01; slide BQE-700/tot.01; EF C37/1; Björkåsholmen quarry, east wall.
- Fig. 2 - *Peteinosphaeridium robustiramosum* Tongiorgi *et al.*, 1995. Some processes of a fragmentary specimen: note the deeply serrate lamina edges: CPT110026-01; slide BQE-300/tot.01; EF U26; Björkåsholmen quarry, east wall.
- Fig. 3 - *Picostella turgida* Yin *et al.*, 1998. CPT110066-01; slide HOV738/tot.01; EF E34; Hovland.
- Fig. 4 - *Polygonium gracile* Vavrdová, 1966. CPT110023-02; BQE-150/tot.02; EF S40/3; Björkåsholmen quarry, east wall.
- Fig. 5 - *Rhopaliophora*? sp. A (sp. aff. *Rhopaliophora* sp. A in Raevskaya, 1999, pl. 1, fig. 14). CPT110064-01; HOV650/tot.01; EF Q37/3; Hovland.
- Fig. 6 - *Stelliferidium striatulum* (Vavrdová, 1966) emend. Deunff *et al.*, 1974. CPT110028-01; BQE-400/tot.01; EF T33-733/3; Björkåsholmen quarry, east wall.
- Fig. 7 - *Stelomorpha composta* Yin *et al.*, 1998. Specimen showing the "tubular extension" (salpinx) in the upper part of the microphotograph: CPT110012-01; BQW-100/tot.01; EF G51/3; Björkåsholmen quarry, west wall.
- Figs. 8-9 - *Stelomorpha erchunensis* (Fang, 1986) Yin, 1994 emend. Tongiorgi *et al.*, 1995. 8) Specimen showing the "tubular extension" (salpinx) in the right-upper part of the microphotograph: CPT110027-02; BQE-350/tot.02; EF Z39/4; Björkåsholmen quarry, east wall. 9) CPT110026-01; slide BQE-300/tot.01; EF F42/2; Björkåsholmen quarry, east wall.
- Figs. 10-11 - *Tongzia vavrdovae* Yin *et al.*, 1998. 10) CPT110012-01; BQW-100/tot.01; EF N24; Björkåsholmen quarry, west wall. 11) CPT110023-02; BQE-150/tot.02; EF I44/74; Björkåsholmen quarry, east wall.
- Fig. 12 - *Peteinosphaeridium dissimile* Górka, 1969 CPT110012-01. BQW-100/tot.01; EF I44; Björkåsholmen quarry, west wall.

Specimen magnification x800; England Finder coordinates (EF) measured on slides with the repository label oriented to the right.



In the Chinese literature (e.g., Finney & Chen, 1990; Nie, 1991; Chen & Rong, 1992; Wang & Chen, 1995) the Yangtze Platform is placed at a moderate-low southern latitude, during Arenig times (see also Lindström *et al.*, 1991, p. 205). However, whilst the Yangtze Platform was located at about the same latitude as northern Baltica (Scotese & McKerrow, 1990, 1991; Christiansen & Stouge, 1999; for the orientation of Baltica, see Torsvik & Trench, 1991), the climate of these regions during the Arenig should have been different because, at least during the southern hemisphere winter, northern Baltica (i.e., the palynomorph-bearing sections of Baltoscandia and the EEP) was influenced by a warm subequatorial oceanic current (Wilde, 1991; Christiansen & Stouge, 1999), while a cool current of subpolar origin (like the modern Humboldt Current) was flowing along the South China coast (Wilde, 1991; Tongiorgi *et al.*, 1995; Raevskaya *et al.*, in press). Nevertheless, a subtropical oceanic gyre enabled phytoplankton exchanges in both directions, from China to Baltica and *vice versa* (Wilde, 1991; Tongiorgi & Di Milia, 1999). However, only some species (probably the more "opportunistic" taxa, capable of adapting to different ecological conditions) occur in both regions.

Finally, the Billingen to lower Volkhov acritarchs of the Oslo Region exhibit some characters of the Mediterranean cold to temperate microflora known from Perigondwana (Perigondwana oceanic realm of Playford *et al.*, 1995; cold-water realm of Servais & Fatka, 1997), but show a closer affinity to the South China assemblages of the *O. evae* to the *B. triangularis* - *B. navis* conodont Zones. However, the typical cold-water indicators (*Arbusculidium*, *Aureotesta*, *Coryphidium*, and *Striatotheca*), common in South China, are absent in the Oslo Region, thus suggesting that in Baltoscandia the climate was slightly warmer than it was in South China.

Upper Volkhov to lower Kunda

The Oslo assemblages from the upper Volkhov to lower Kunda stratigraphic interval, include most of the taxa that Tongiorgi & Di Milia (1999) considered distinctive of the Baltic microflora, such as *Peteinosphaeridium dissimile*, *P. velatum*, *P. hystriochoreticulatum*, *Liliosphaeridium* spp., *Pachysphaeridium* spp., and *Sacculidium* spp. (cited by Tongiorgi & Di Milia, 1999, as "*Peteinosphaeridium*" *macropyllum* s.l.). Contrary to the lesser known Hunneberg, Billingen and lower Volkhov acritarch assemblages, those from the upper Volkhov and lower Kunda of Baltoscandia have been studied extensively (see Introduction for references). They are quite different from the coeval, late Arenig to lower Llanvirn assemblages of Perigondwana (cf. the North African assemblages described by Deunff, 1977; Jardiné *et al.*, 1974; Vecoli, 1999; Vecoli *et al.*, 1999), characterised by the common occurrence of genera such as

Dicrodiacrodium Burmann, 1968, *Arkonina* Burmann, 1970, and *Frankea* Burmann, 1970 emend. Servais, 1993, in addition to *Arbusculidium*, *Aureotesta*, *Coryphidium*, and *Striatotheca* (Brocke *et al.*, 1995). Tongiorgi & Di Milia (1999) maintain that separation between the Baltic and the Mediterranean microfloras is documented in Europe since the late Volkhov, *B. norrlandicus* conodont Zone.

According to Tongiorgi *et al.* (1998, and in press), a Baltic microflora (including *Liliosphaeridium brevicalyx* Bagnoli & Ribecai, 2001, *L. intermedium*, *L. kaljoi*, *L. tintinnabulum*, *Pachysphaeridium pachyconcha* Ribecai & Tongiorgi, 1999, *P. sidereum* Ribecai & Tongiorgi, 1999, *Peteinosphaeridium angustilaminae* Playford *et al.*, 1995, *P. dissimile*, *P. eximium*, *P. velatum*, *P. hystriochoreticulatum*, *Sacculidium macropyllum*, *S. peteinoides*, *Tranvikium polygonale* Tynni, 1982, etc.) is present also in the upper Arenig of South China (upper *P. originalis* to upper *L. antivariabilis* conodont Zones). Meanwhile, some elements of the Perigondwanan cold-water assemblages rarely occur in late Volkhov to early Kunda assemblages of both Baltica and South China (in Baltica, sparse representatives of the following genera occur: *Acanthodiacrodium* Timofeev, 1958 emend. Deflandre & Deflandre-Rigaud, 1962, ?*Barakella* Cramer & Diez, 1977, *Pirea* Vavrdová, 1972, and *Stelliferidium* Deunff *et al.*, 1974; Uutela & Tynni, 1991; Ribecai & Tongiorgi, 1995; Tongiorgi, unpublished). Conversely, isolated representatives of the Baltic microflora invaded Perigondwana (Tongiorgi & Di Milia, 1999) during the Arenig (Bohemia) and early Llanvirn times (Belgium, Spain, Tunisia). This suggests that Baltica and South China belong to a common, mid-latitude, temperate realm, with a transition to the cold-water Perigondwana realm.

CONCLUSIONS

The acritarch assemblages from the upper Tremadoc-lowermost Arenig (Hunneberg and basal Billingen) of the Oslo Region, are mixed and include representatives of both the cold-water *messaooudensis-trifidum* microflora from Perigondwana and the warm-water *Aryballomorpha-Athabascaella-Lua* microflora from low latitudes seas (northern America, northeastern China). This is in accordance with the intermediate latitudinal position of Baltica at this time. A good correspondence also exists between assemblages from Oslo and those from northwestern Russia.

Younger Arenig assemblages (Billingen to lower Volkhov) of the Oslo Region contain species known from the coeval cool temperate-water microflora of the Yangtze Platform, South China. A good correspondence also exists with the Billingen microflora of northwestern Russia and northern Poland. In Baltica, assumed stenothermal, cold-water taxa, such as *Arbusculidium*, *Coryphidium* and *Striatotheca* (typical of the colder waters of Perigondwana but also present

in South China) are absent, suggesting that the climate of northern Baltica (Baltoscandia including the East European Platform), was slightly warmer than it was in South China.

Notwithstanding these differences, it should be recognised that there was a relative uniformity among the phytoplankton assemblages over a wide range of latitudes during the early Arenig.

The invasion of middle latitude platforms, such as Baltica and the Yangtze Platform of South China, by acritarchs typical of colder water masses of deep water oceans and/or a high latitude (circumpolar) habitats (Perigondwana oceanic realm of Playford *et al.*, 1995), can be related to an extensive global transgressive event which occurred during the lower Arenig (the *O. evae* transgression of Nielsen, 1992). As noted by Raevskaya *et al.* (in press), during transgressions, cool oceanic water penetrates platforms extensively bringing with it offshore phytoplankton onto the shelf. Thus, "times of transgression may appear as times of provincial breakdown" (Fortey, 1984).

The late Arenig-early Llanvirn (upper Volkhov to lower Kunda) acritarch assemblages of the Oslo Region are similar to those known from Sweden, Russia and Poland. This Baltic microflora differs markedly from the cold-water Mediterranean microflora of Perigondwana, with the exception of South China where a Baltic-like phytoplankton appears at the same stratigraphical level (Tongiorgi & Di Milia, 1999; Tongiorgi *et al.*, in press).

On the other hand, a secular negative sea level change, including repeated regressive peaks, developed after the lower Volkhov (second order negative cycle of Ross & Ross, 1992; Nielsen, 1992). This trend would have produced an enhanced provincialism leading to the differentiation of a distinctive Baltic microflora on the middle latitude Baltica and Yangtze platforms (Tongiorgi & Di Milia, 1999; Tongiorgi *et al.*, in press).

In conclusion, we document parallel changes in the composition of the acritarch assemblages of both Baltica and South China during the entire early Arenig-early Llanvirn interval. The transition from a Mediterranean- (or Mediterranean-like) to a Baltic microflora, implies reciprocal phytoplankton exchange between both areas which also share a similar geological and physiographical evolution (Lindström *et al.*, 1991).

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