

Early Arenig acritarchs from the Leetse Formation (St. Petersburg region, northwest Russia) and their palaeogeographic significance

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ABSTRACT – The Leetse Formation of Early Ordovician (*Arenig*: *Hunneberg* and *Billingen*) age consists of quartzose glauconitic sand, greenish-grey clay, and argillaceous glauconitic limestone with clayey intercalations. Palynological studies conducted on samples from four sections along the Baltic-Ladoga Glint within the St. Petersburg region of northwest Russia reveal the presence of three acritarch assemblages containing over 35 diagnostic acritarch taxa. These occur within an interval corresponding to the upper *Paroistodus proteus* through *Oepikodus evae* conodont Zones of Baltoscandia. The acritarch assemblages are correlative with those of Britain, South China, and Australia. Preliminary palaeogeographic assessment of the identified taxa suggests that the Baltic microflora (sensu Vavrdová, 1974) appeared in Baltica after the early *Arenig*, because the *Billingen* acritarch associations reported herein exhibit closest similarities with coeval suites from the Yangtze region, South China.

RIASSUNTO – [Acritarchi dell'*Arenig* inferiore della Formazione di Leetse (regione di St. Petersburg, Russia nordoccidentale) e loro significato paleogeografico] – La Formazione di Leetse, di età ordoviciana inferiore (*Arenig*: *Hunneberg* e *Billingen*) è formata da sabbie quarzose-glauconitiche, argille grigio-verdastre e calcari argillosi glauconitici, con intercalazioni argillose. Studi palinologici su campioni di quattro sezioni lungo il Baltic-Ladoga Glint, nella regione di St. Petersburg (Russia nordoccidentale), mostrano la presenza di tre associazioni di acritarchi, contenenti più di 35 significativi taxa. Questi taxa si trovano in un intervallo che, secondo la biozonazione a conodonti della Baltoscandia, si estende dalla parte superiore della Zona a *Paroistodus proteus* fino alla Zona ad *Oepikodus evae*. Queste associazioni di acritarchi si correlano con quelle dell'Inghilterra, della Cina meridionale e dell'Australia. Una analisi preliminare del significato paleogeografico dei taxa qui riportati, suggerisce che la microflora Baltica (sensu Vavrdová, 1974) sia apparsa in Baltica dopo l'*Arenig* inferiore; infatti, le associazioni di acritarchi del *Billingen*, qui riportate, mostrano le più strette somiglianze con quelle delle coeve successioni della regione dello Yangtze, Cina meridionale.

INTRODUCTION

Rich and mostly well preserved early *Arenig* acritarchs have been widely reported globally, but have been little studied in northwest Russia. Most acritarch researchers who worked in the St. Petersburg region (notably Timofeev, 1959, 1966; Umnova & Fanderflit, 1971; Volkova, 1989, 1990, 1995) focused on the Cambrian and Cambro-Ordovician boundary beds ("Obolus" Sandstone and "Obolus-Dyctyonema" beds), because of protracted debate on the stratigraphic position of the shelly phosphorite layers characterizing that interval. The overlying glauconitic sand (attributed to the lowermost *Arenig*) was considered to be devoid of acritarchs (Piskun *et al.*, 1994). Only a few taxa from the overlying lower *Arenig* argillaceous glauconitic limestone were recorded, albeit not illustrated (Umnova & Fanderflit, 1971; Piskun *et al.*, 1994).

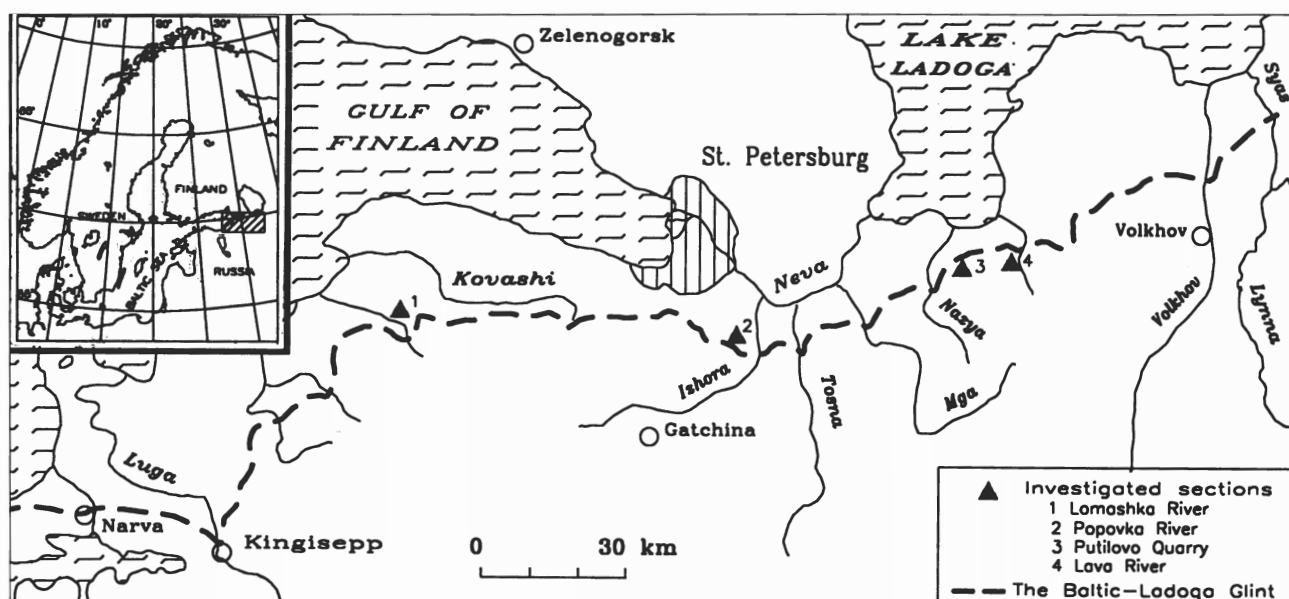
This article presents further information on the distribution of acritarchs in the lower *Arenig* (*Hunneberg* and *Billingen* substages) of the Baltic region and shows their potential for biogeographic reconstructions.

STRATIGRAPHY, LITHOLOGY, AND SAMPLING

The four sections along the Baltic-Ladoga Glint (a prominent natural escarpment of linear extent, across the St. Petersburg region) that are palynologically investigated herein (Text-fig. 1) are located as follows: (1) north side of Lomashka River, ca. 2.3 km downstream from highway bridge in Lomakha village; (2) Pander anticline on Popovka River near Pavlovsk; (3) Putilovo Quarry, ca. 2 km west of Putilovo village; and (4) west side of Lava River, near Gorodishe village.

The lower Ordovician Leetse Formation consists of quartzose glauconitic sand, greenish-grey clay, and argillaceous glauconitic limestone with interbedded clay (Text-fig. 2). It corresponds to the *Hunneberg* and *Billingen* substages, including the upper *Paroistodus proteus*-*Oepikodus evae* conodont zonal interval of Baltoscandia (Löfgren, 1978; WOGOGOB excursion guide, 1997).

The *Hunneberg* strata (represented by the lower Leetse Formation) are mainly preserved in the eastern part of Baltic-Ladoga Glint, east of the Nazya River, but their presence to the west is unclear. These strata were



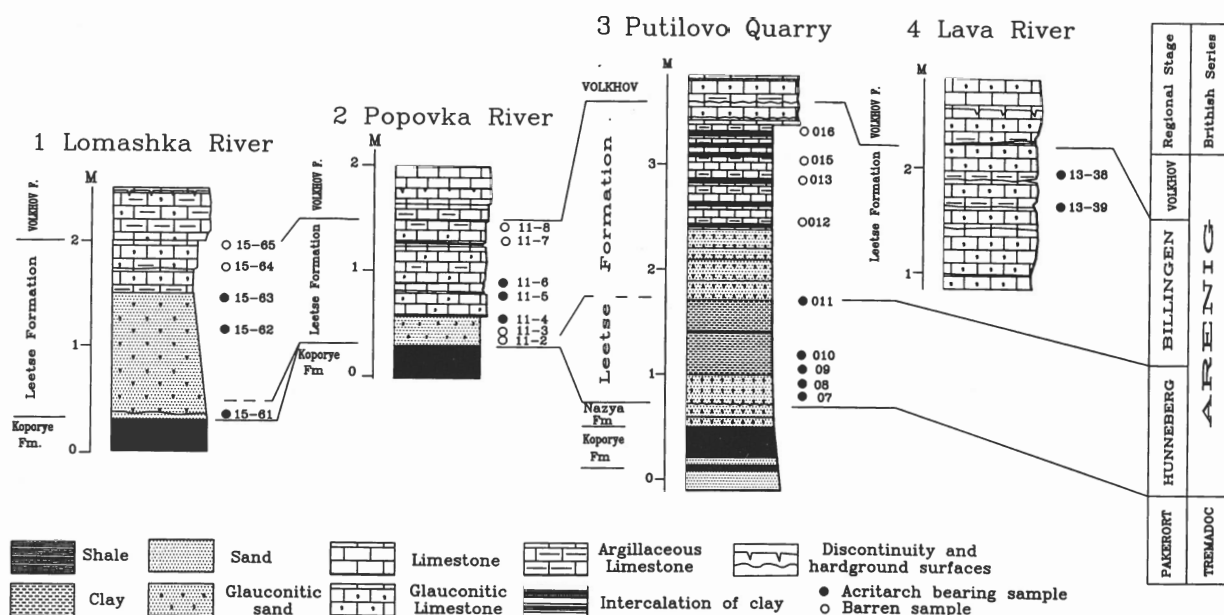
Text-fig. 1 - Geographic location of the investigated sections.

sampled for acritarchs only at the Putilovo Quarry and on the Lomashka River. The basal part of the Leetse Formation consists of fine- to medium-grained quartzose glauconitic sand which unconformably overlies the Nazya Formation. Numerous conodonts occur which are diagnostic of the *Paroistodus proteus* Zone. The overlying greenish-grey clay of the Leetse Formation also contains graptolites of the *Tetraraptus phyllograptoides* Zone and rare conodonts of the *Prioniodus elegans* Zone.

The Billingen substage is represented by the upper Leetse Formation which consists of glauconitic sandstone with conodonts of the *P. elegans* Zone;

argillaceous glauconitic limestone with clay intercalations; and glauconitic limestone including numerous discontinuity surfaces and with conodonts of the *Oepikodus evae* Zone.

Of the 23 samples collected from the Leetse Formation, 12 proved to be palyniferous. Three samples from Lomashka River (numbered 15-61, 15-62, and 15-63) yielded sparse, poorly preserved acritarchs. Numerous, diverse, and well-preserved acritarchs were obtained from three Popovka River samples (11-4, 11-5, 11-6), four Putilovo Quarry samples (08, 09, 010, 011) and two Lava River samples (13-38, 13-39).



Text-fig. 2 - Four sections illustrating lithostratigraphic subdivision of the lower Arenig within the St. Petersburg Region.

Hunnberg	Billingen	SUBSTAGES	CONODONT ZONES	ACRITARCH ASSEMBLAGES	ACRITARCHS	SAMPLES	FORMATION
			<i>O. evae</i>	III	<i>Cymatogalea</i> aff. <i>deunffii</i> <i>C. messaoudensis</i> var. <i>messaoudensis</i> <i>Stelliferidium</i> sp. <i>Caldariola glabra</i> <i>Loeblichia heterorhabda</i> <i>Tenuirica</i> var. <i>wadeiae</i> <i>Athabascaella</i> aff. <i>rossi</i> <i>A. playfordii</i> <i>Arthabascaella</i> sp. <i>Rhopaliophora</i> sp. A <i>R. florida</i> <i>Rhopaliophora pilata</i> <i>R. palmata</i> <i>Peteinosphaeridium armatum</i> <i>Peteinosphaeridium</i> sp. 1 <i>C. messaoudensis</i> var. <i>inconnexa</i> <i>Polyancistrodorus radiosus</i> <i>Peteinosphaeridium</i> sp. 2 <i>Rhopaliophora mamilliformis</i> <i>Peteinosphaeridium tenuifiliosum</i> <i>P. robustiramosum</i> <i>? Stelomorpha</i> sp. <i>Baltisphaeridium</i> sp. <i>Pireia</i> sp. <i>Pireia levigata</i>	13-38 13-39 (15-63) 11-6 (15-62) 11-5 11-4 011 010 (15-61) 09 08	LEETSE
			<i>P. elegans</i>	b			
			<i>P. proteus</i>	a			
				I			

Text-fig. 3 - Distribution of selected acritarch taxa in the samples studied.

RESULTS

The following is an inventory of all taxa identified in the study samples. Asterisks indicates illustration of taxa herein [Pls. 1, 2].

Ammonidium sp.

Athabascaella playfordii Martin, 1984, emend. Martin & Yin, 1988

Athabascaella sp. aff. *A. rossi* Martin, 1984, emend. Martin & Yin, 1988

* *Athabascaella* sp. A [Pl. 1, fig. 10]

Baltisphaeridium kunmingense Fang, 1986

* *Baltisphaeridium* spp. [Pl. 2, fig. 9]

Buedingiisphaeridium disgregum Playford & Martin, 1984

Caldariola glabra (Martin, 1972) Molyneux in Molyneux & Rushton, 1988

Cymatogalea sp. aff. *C. deunffii* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974

* *C. messaoudensis* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974 var. *inconnexa* Servais & Molyneux, 1997 [Pl. 1, figs. 3, 4]

* *C. messaoudensis* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974, var. *messaoudensis* Servais & Molyneux, 1997 [Pl. 1, figs. 1, 2]

Gorgonisphaeridium sp.

* *Loeblichia heterorhabda* Playford & Wicander, 1988 [Pl. 1, fig. 5]

Multiplicisphaeridium sp.

Navifusa sp.

* *Ordovicidium* sp. [Pl. 1, fig. 15]

* *Peteinosphaeridium armatum* Tongiorgi, Yin & Di Milia, 1995 [Pl. 2, fig. 8]

P. cf. P. coronula Yin, Di Milia & Tongiorgi, 1998

* *P. robustiramosum* Tongiorgi, Yin & Di Milia, 1995 [Pl. 2, fig. 14]

* *P. tenuifiliosum* Tongiorgi, Yin & Di Milia, 1995 [Pl. 2, fig. 10]

* *Peteinosphaeridium* spp. [Pl. 2, figs. 7, 11-13]

* *Pireia levigata* Tongiorgi, Yin & Di Milia, 1995 [Pl. 2, fig. 5]

* *P. sp.* [Pl. 2, fig. 6]

* *Polyancistrodorus radiosus* Playford & Wicander, 1988 [Pl. 2, fig. 1]

Polygonium spp.

* *Rhopaliophora florida* Yin, Di Milia & Tongiorgi, 1998 [Pl. 1, figs. 8, 11]

* *R. mamilliformis* (Lu, 1987) emend. Tongiorgi, Yin & Di Milia, 1995 [Pl. 2, figs. 2, 4]

R. palmata (Combaz & Peniguel, 1972) emend. Playford & Martin, 1984

* *R. pilata* (Combaz & Peniguel, 1972) emend. Playford & Martin, 1984 [Pl. 1, fig. 9]

* *Rhopaliophora* sp. A [Pl. 1, fig. 14]

* *Rhopaliophora* sp. B [Pl. 1, figs. 12, 13]

Solisphaeridium spp.

Stelliferidium simplex (Deunff, 1961) emend. Deunff, Gorka & Rauscher, 1974

Stelliferidium sp.

* ? *Stelomorpha* sp. [Pl. 2, fig. 3]

* *Tenuirica* sp. aff. *T. wadeiae* Playford & Wicander, 1988 [Pl. 1, figs. 6, 7].

Three acritarch assemblages are recognizable in the Leetse Formation, covering the conodont zonal interval of upper *P. proteus* through *O. evae* (Text-fig. 3). They can be tied with conodont and graptolite zones of Baltoscandia and correlated with the biostratigraphic subdivisions in Britain, South China, and Australia (Text-fig. 4).

Assemblage I occurs in a single sample (08, Putilovo Quarry) derived from the glauconitic sand

of the lower Leetse Formation (equivalent to the Hunneberg substage, upper *P. proteus* conodont Zone, *T. phyllograptoides* graptolite Zone). This assemblage is relatively poor in number of species and contains mainly galeate taxa together with *Loeblichia*, *Multiplicisphaeridium*, *Polygonium*, and *Tenuirica*. The most characteristic taxa are: *Buedingii-sphaeridium* sp. aff. *B. disgregum*, *Caldariola glabra*, *Cymatiogalea* sp. aff. *C. deunffii*, *C. messaoudensis* var. *messaoudensis*, *Loeblichia heterorhabda*, *Multiplicisphaeridium* sp., *Polygonium* sp., *Stelliferidium simplex*, *Stelliferidium* sp., and *Tenuirica* sp. aff. *T. wadeiae*.

Assemblage II occurs in samples 09, 010, 011 (Putilovo Quarry) from the clay bed of the lower Leetse Formation (Hunneberg substage, uppermost *P. proteus*-*P. elegans* conodont Zones, uppermost *T. phyllograptoides* graptolite Zone) and is poorly represented in sample 15-61 (Lomashka River). This assemblage is characterized by a richer and more diversified acritarch content. At least 19 species make their first appearances, including *Athabascaella playfordii*, *A. sp.* aff. *A. rossii*, *Athabascaella* sp. A, *Gorgonisphaeridium* sp., *Navifusa* sp., *Rhopaliophora florida*, *R. palmata*, *R. sp.* A, *Rhopaliophora* sp. B, *Ordoviciidium* sp., *Peteinosphaeridium armatum*, *Peteinosphaeridium* spp., and *Polyancistrodorus radiosus*.

Two sub-assemblages may be distinguished, based on successive appearance and progressive disappearance of species. Sub-assemblage II-a (samples 09, 010) is characterized by the appearance of diverse *Athabascaella* and *Rhopaliophora* and by decreasing

representation of *Cymatiogalea messaoudensis*. Some specimens of *Athabascaella* sp., *C. messaoudensis* var. *messaoudensis* and *Rhopaliophora* sp. A also occur in sample 15-61.

Sub-assemblage II-b (sample 011) mostly contains *C. messaoudensis* var. *inconnexa* and *Caldariola glabra*, together with various forms of *Peteinosphaeridium*, while *Athabascaella* and *Stelliferidium* practically disappear. *Loeblichia*, *Ordoviciidium*, *Solisphaeridium* and *Tenuirica* are present in both sub-assemblages.

Because conodonts of the *P. elegans* Zone first appear in the upper part of the clay bed, sub-assemblage II-a is attributed to the *P. proteus* conodont Zone whereas sub-assemblage II-b is stratigraphically located within the *P. elegans* Zone.

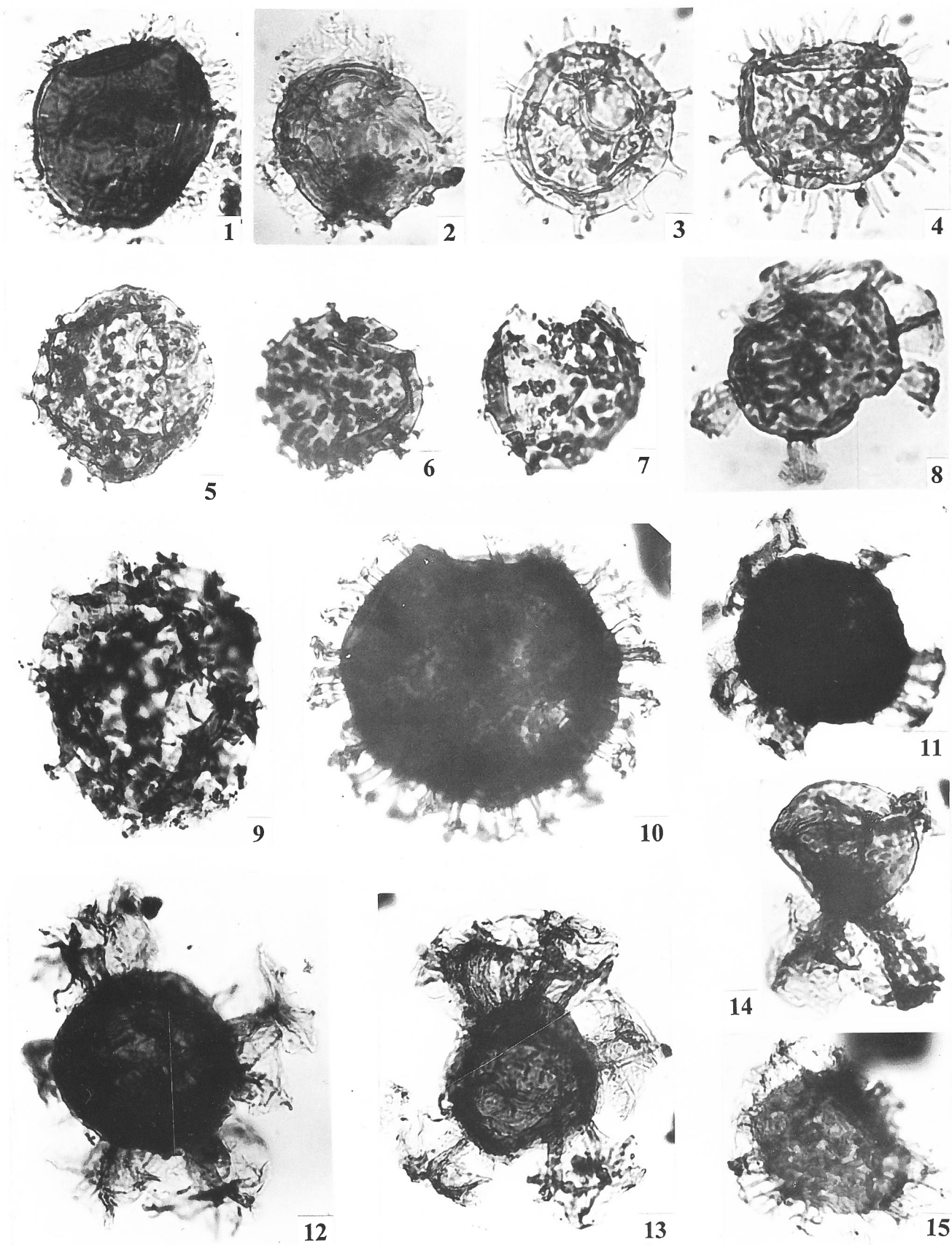
Assemblage III occurs in samples 11-4, 11-5, 11-6 (Popovka River) and 13-39, 13-38 (Lava River); i.e., in the upper part of the Leetse Formation (Billingen substage, *O. evae* conodont Zone, *P. densus* and *P. elongatus* graptolite Zones). Assemblage III is characterized by predominant *Baltisphaeridium* and by first occurrence of *Peteinosphaeridium robustiramosum*, *P. tenuifilum*, *Rhopaliophora mamilliformis*, *Pireia levigata*, *Pireia* sp., and ?*Stelomorpha* sp. Most taxa which characterize assemblages I and II (such as *Caldariola*, *Cymatiogalea*, *Loeblichia*, and *Tenuirica*) do not extend into assemblage III, whereas *Rhopaliophora florida*, *R. palmata*, and *R. pilata* are still present.

Samples 15-62 and 15-63 (Lomashka River) contain only rare *Baltisphaeridium* spp. and some broken vesicles of *Peteinosphaeridium* sp.

EXPLANATION OF PLATE 1

- Figs. 1, 2 - *Cymatiogalea messaoudensis* Jardiné, Combaz, Magloire, Peniguel & Vachey, 1974 var. *messaoudensis* Servais & Molyneux, 1997:
1) sample 08, slide 4839/1, EF: S41/1,2.
2) sample 08, slide 4839/1, EF: H22/2.
- Figs. 3, 4 - *Cymatiogalea messaoudensis* Jardine, Combaz, Magloire, Peniguel & Vachey, 1974 var. *inconnexa* Servais & Molyneux, 1997:
3) sample 011, slide 4842/2, EF: M8.
4) sample 011, slide 4842/2, EF: M8/2.
- Fig. 5 - *Loeblichia heterorhabda* Playford & Wicander, 1988; sample 011, slide 4842/1, EF: Q 33/3,4.
- Figs. 6, 7 - *Tenuirica* sp. aff. *T. wadeiae* Playford & Wicander, 1988:
6) sample 010, slide 4841/1, EF: E17/2
7) sample 010, slide 4842/ 2, EF: K14.
- Figs. 8,11 - *Rhopaliophora florida* Yin, Di Milia & Tongiorgi, 1998:
8) sample 010, slide 4841/1, EF: C26, D26/3,1.
11) sample 11-4, slide 4953/2, EF: K13.
- Fig. 9 - *Rhopaliophora pilata* (Combaz & Peniguel, 1972) emend. Playford & Martin, 1984; sample 09, slide 4840/1, EF: H20/3.
- Fig. 10 - *Athabascaella* sp. A; sample 010, slide 4841/1, EF: J33/1,3.
- Figs. 12,13 - *Rhopaliophora* sp. B:
12) sample 09, slide 4840/1, EF: T28.
13) sample 010, slide 4841/1, EF: M30,31/2,1.
- Fig. 14 - *Rhopaliophora* sp. A; sample 09, slide 4840/2, EF: K10.
- Fig. 15 - *Ordoviciidium* sp.; sample 09, slide 4840/1, EF: O13.

All figures × 600.



DISCUSSION

It is commonly believed that lower Ordovician palaeophytoplankton were palaeogeographically differentiated; many causes have been suggested by different authors in literature. For instance, microphytoplankton distribution may be controlled by palaeoisotherms, in turn paralleling palaeolatitudes; or by palaeoenvironmental gradients across continental margins; or by oceanic currents (see discussions in Playford *et al.*, 1995; Tongiorgi *et al.*, 1995, and Tongiorgi & Di Milia, this volume).

Vavrdová (1974) introduced the concept of two different European acritarch palaeoprovinces (Baltic and Mediterranean) during the Ordovician, based on the presence or absence of distinctive acritarch taxa. According to Vavrdová, the Baltic Province should have been characterized by the prevalence of acanthomorphids (considered to be warm-water taxa), while the Mediterranean (or Perigondwanan) Province should have been characterized by the exclusive occurrence of diacromorphids (regarded as typifying a cold-water environment). The northern part of the former Soviet Union was included in the mid-latitude Baltic Province. However, the present study indicates that early Arenig acritarch assemblages from northwest Russia include taxa thought to be typical of different palaeophytoprovinces, with a clear predominance of cold-water forms.

Assemblages I and II are dominated by representatives of cold-water Perigondwanan palyonoflora. The cold-water taxa are scarcely diversified in the St. Petersburg material (only four species were identified), but they predominate quantitatively. *Caldariola glabra*, *Cymatiogalea* sp. aff. *C. deunffii*, *Cymatiogalea messaoudensis*, and *Stelliferidium* sp. are known as among the most characteristic taxa of the so called *messaoudensis-trifidum* assemblage (Servais & Molyneux, 1997), originally described by Fortey (in Fortey *et al.*, 1991,

Cooper *et al.*, 1995), under the name of "*trifidum* flora", from the Ordovician Skiddaw Group of the English Lake District. The same species were also found in the lower Ordovician of southwest Spain (Mette, 1989), in the Prague Basin, Czechoslovakia (Fatka, 1992, 1993), and from the island of Rügen, northeast Germany (Servais & Katzung, 1993; Servais, 1994; Servais & Molyneux, 1997). In the Baltic region, *Caldariola glabra*, *Cymatiogalea deunffii* and some species of *Stelliferidium* were previously reported from the upper Tremadoc to lower Arenig of Estonia (Volkova, 1989, 1995) and Lithuania (Paskeviciene, pers. comm.). *Caldariola glabra* and *Stelliferidium* have been also reported from the middle to upper Tremadoc of Öland, Sweden (Tongiorgi in Bagnoli *et al.*, 1988).

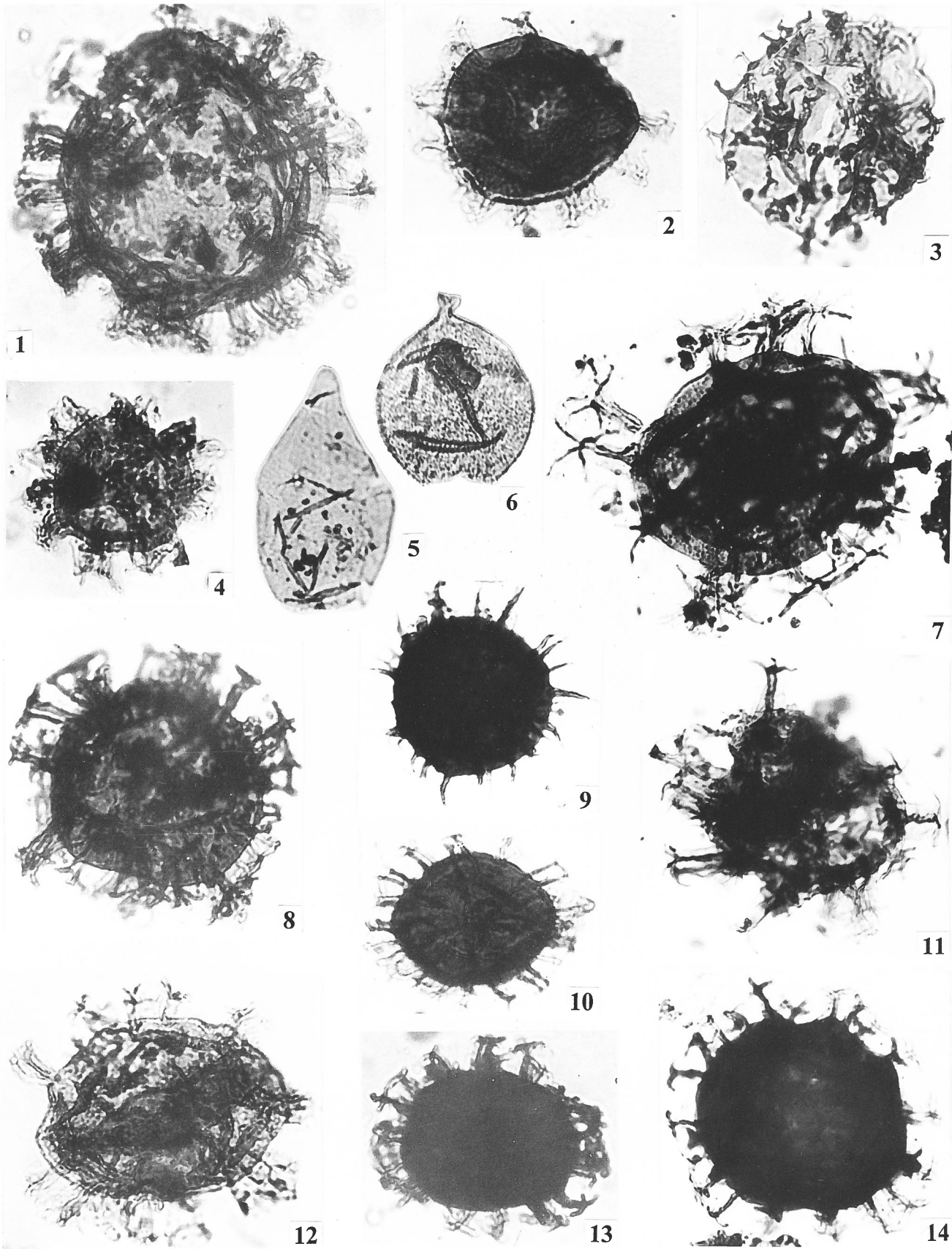
Less plentiful components of assemblages I and II, such as *Loeblichia heterorhabda* and *Tenuirica* sp. aff. *T. wadeiae*, were described originally from the lower Arenig Coolibah Formation of eastern Australia (Playford & Wicander, 1988) and supposed to be typical representatives of the subtropical Australian palyonoflora. *L. heterorhabda* was subsequently recorded from the Dawan Formation (Arenig), Yangtze region, South China (Tongiorgi *et al.*, 1995; Brocke, 1997).

Athabascaella playfordii and *A.* sp. aff. *A. rossii*, which occur in sub-assemblage II-a, were previously documented from the upper Tremadoc of Alberta, Canada (Martin, 1984), from the latest Tremadoc to earliest Arenig of northeast China (Martin & Yin, 1988), from southwest China (Brocke, 1996) and from the middle to upper Tremadoc of Sweden (Tongiorgi in Bagnoli *et al.*, 1988). Both species were figured by Volkova (1995) from the uppermost Tremadoc of Estonia and were considered as characteristic taxa of a warm-water phytoplankton association (Volkova, 1997). Both species are very rare in the material studied herein, and are accompanied by much more abundant *Athabascaella* sp. A (not yet described). *Rhopaliophora palmata* and *R. pilata* are

EXPLANATION OF PLATE 2

- Fig. 1 - *Polyancistrodorus radiorus* Playford & Wicander, 1988; sample 011, slide 4842/1, EF: 33/1,2.
 Figs. 2, 4 - *Rhopaliophora mamilliformis* (Lu, 1987) emend. Tongiorgi, Yin & Di Milia, 1995:
 2) sample 11-4, slide 4955/2, EF: L22/2.
 4) sample 11-4, slide 4955/2, EF: M13.
 Fig. 3 - ? *Stelomorpha* sp.; sample 11-6, slide 4955/2, EF: N23/4
 Fig. 5 - *Pirea levigata* Tongiorgi, Yin & Di Milia, 1995; sample 11-6, slide 4955/1, EF: R32/1.
 Fig. 6 - *Pirea* sp.; sample 13-38, slide 5102/2, EF: W 19
 Fig. 7 - *Peteinosphaeridium* sp.; sample 09, slide 4840/2, EF: L28, 29/2,1
 Fig. 8 - *Peteinosphaeridium armatum* Tongiorgi, Yin & Di Milia, 1995; sample 010, slide 4841/1, EF: R31/1.
 Fig. 9 - *Baltisphaeridium* sp.; sample 09, slide 4840/1, EF: R15/2.
 Fig. 10 - *Peteinosphaeridium tenuifilum* Tongiorgi, Yin & Di Milia, 1995; sample 13-38, slide 5102/1, EF: V17/3.
 Fig. 11 - *Peteinosphaeridium* sp.; sample 13-38, slide 5102/1, EF: K22/2.
 Fig. 12 - *Peteinosphaeridium* sp.; sample 15-62, slide 15-62/1, EF: O47.
 Fig. 13 - *Peteinosphaeridium* sp.; sample 11-4, slide 4953/2, EF: V37/1.
 Fig. 14 - *Peteinosphaeridium rabustiramosum* Tongiorgi, Yin & Di Milia, 1995; sample 11-4, slide 4953/2, EF: T20.

All figures $\times 600$.



Chronostr.	BRITAIN		BALTO-SCANDIA				SOUTH CHINA		AUSTRAL.
	Graptolite Zones		Subst	Graptolite Zones	Conodont Zones	Acrit. Assem.	Graptolite Zones	Conodont Zones	Substages
ARENIG	<i>D. extensus</i>	<i>D. nitidus</i>	BILLINGEN	<i>P. elongatus</i>	<i>O. evae</i>	III	<i>D. deflexus</i>	<i>B. triangularis</i>	Ch 1-2
		<i>D. deflexus</i>		<i>P. densus</i>				<i>O. evae</i>	
	not established			<i>D. balticus</i>	<i>P. elegans</i>	II	<i>A. filiformis</i>	<i>S. diversus</i> <i>B. communis</i>	Be 1-4
	<i>T. phyllo graptoides</i>		HUNNEBERG	<i>T. phyllo graptoides</i>					

Text-fig. 4 - Correlation chart of lower Arenig biostratigraphic units of Britain (modified from Fortey *et al.*, 1995), Baltoscandia (after WOGOGOBI excursion guide, 1997; conodont biostratigraphy according to Löfgren, 1978), South China (after Wang *et al.*, 1997) and Australia (after Vandenberg & Cooper, 1992).

cosmopolitan, while *R. florida* has been recorded previously only from the lower Arenig of South China (Yin *et al.*, 1998). Two other forms of the same genus, viz., *Rhopaliophora* sp. A and *Rhopaliophora* sp. B, were also identified (albeit await formal description). Several species of *Peteinosphaeridium* and *Baltisphaeridium* are also essential, though not numerically dominant, components of assemblage II. *P. armatum* is known from the lower Arenig of South China (Tongiorgi *et al.*, 1995) as is *P. coronula* (Yin *et al.*, 1998). Brocke (1996) reported diversified populations of *Peteinosphaeridium* and *Baltisphaeridium* from the lower Meitan Formation (lowermost Arenig) of South China.

Assemblage III is not very diverse. Elements typical of Perigondwana (*Caldariola*, *Cymatiogalea*, *Stelliferidium*) and Australia (*Loeblichia*, *Tenuirica*) are absent, and the assemblage is dominated by *Baltisphaeridium* and *Peteinosphaeridium*. Most of the species identified (e.g., *Baltisphaeridium kunmingense*, *Peteinosphaeridium robustiramosum*, *P. tenuifilum*, *Pireia levigata*, and *Rhopaliophora mamilliformis*) were originally described from the lower Arenig Dawan Formation of South China (Tongiorgi *et al.*, 1995). In addition, some specimens were questionably assigned to *Stelomorpha*, another South Chinese taxon (Yin, 1994). Thus, assemblage III reveals strong similarities with coeval (*O. evae* conodont Zone) acritarch associations of South China. The latter also include *Arbusculidium*, *Coryphidium*, and *Striatotheca* which are considered to have clear Mediterranean affinities (Tongiorgi *et al.*, 1995).

CONCLUSIONS

The Leetse Formation of the St. Petersburg region contains rich and well preserved lower Arenig acritarch

assemblages. Assemblages I and II correspond to the Hunneberg substage (*P. proteus*-*P. elegans* conodont Zones of Baltoscandia) and assemblage III equates to the Billingen substage (*O. evae* conodont Zone).

Palaeogeographic affinities of the Hunneberg taxa from the Leetse Formation show a mixture of elements representing difference acritarch palaeoprovinces. *Caldariola*, *Cymatiogalea*, and *Stelliferidium* (i.e., some of the characteristic taxa of the Perigondwanan "messauoudensis-trifidum assemblage") are very prominent numerically; other components include *Loeblichia* and *Tenuirica* (Australian elements) together with several species previously reported from South China. Endemic taxa are less numerous.

In the Billingen palynoflora, elements characteristic of the "messauoudensis-trifidum assemblage" disappear and the Australian taxa abruptly decline in abundance. Conversely, some species become here dominant which in South China are associated with the Mediterranean *Arbusculidium*, *Coryphidium*, and *Striatotheca*.

Finally, during Billingen time the acritarchs of the St. Petersburg region are still of a cold-water, Mediterranean affinity. The Baltic microflora *sensu* Vavrdová (1974) appeared subsequently in this region during the Volkhov (latest early Arenig to late Arenig).

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