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The Darriwilian Acritarch Assemblage from Ordovician Deposits of the Arkhangelsk Oblast, the Northern Russian Plate

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Abstract—Borehole 2506 drilled in the northern area of the Arkhangelsk Oblast penetrated through the Paleozoic sedimentary block isolated in the Vendian thick sequence. A diverse acritarch assemblage has been established within the depth interval of 119.9–217.5 m. The assemblage comprises more than 70 taxa, including species characteristic of the boundary interval between the Volkhov and Kunda horizons of the East European Platform (the graptolite *Didymograptus hirundo* Zone). Stratigraphic position of host deposits was established within the Darriwilian Stage of the Middle Ordovician. The described assemblage of microphytofossils is similar to coeval assemblages from NW Russia, Baltic region, and Scandinavia, being typical of the Baltic phytoplankton province of temperate latitudes. A great number of species in common suggests that the assemblage under consideration is correlative with coeval assemblages of southern China thus offering a possibility of remote correlation.

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Key words: acritarchs, biostratigraphy, Middle Ordovician, Baltic phytoplankton province, Russian Plate.

Ordovician deposits are studied comprehensively in the western, northwestern, and central parts of the Russian Plate, where they are represented by extensive, shallow-water marine, carbonate–terrigenous sedimentary sequences of a gentle attitude without tectonic disturbances. Further northward in the Arkhangelsk oblast, at the Zimnii Coast of the White Sea, Ordovician sediments are preserved only in isolated blocks of Paleozoic rocks, the olistoliths in kimberlite pipes (Bogatikov et al., 2000). Only at the beginning of the 1990s, deposits of the Tremadocian and Arenigian–Caradocian? stages of the Ordovician were established there for the first time based on discovered acritarchs (Verichev et al., 1990; Sivertseva, unpublished data). However, taxonomy of microphytofossils found in rocks was studied at that time to the extent insufficient for a more precise stratigraphic subdivision of isolated sequences buried under recent and Quaternary sediments. During last years, microphytology, taxonomy and general problems of biostratigraphy, biogeography, and biofacies of Ordovician acritarchs have been studied to a greater extent in easily accessible outcrops of northwestern Russia and Scandinavia (Uutela and Tynni, 1991; Ribecai and Tongiorgi, 1995, 1999; Playford et al., 1995; Paškevičiene, 1998; Ribecai et al., 1999, 2002; Bagnoli and Ribecai, 2001; Raevskaya, 1999, 2000; Raevskaya et al., 2003, 2004). Accordingly, a possibility of applying this microfossil group for different geological reconstructions has increased greatly.

The results presented in this work are obtained during microphytological study of Ordovician deposits penetrated in the Arkhangel oblast by boreholes. The objective is to characterize more completely the sampled intervals and, wherever possible, to specify their stratigraphic position.

The borehole 2506 drilled in middle reaches of the Kepina River (Fig. 1) penetrated a block of Paleozoic rocks located in the eastern contact zone of kimberlite pipe no. 496. Schematic geology of the drill site is illustrated in Fig. 2. In terms of lithology, the penetrated rocks are divisible into several intervals. Brecciated rocks in the interval of 185.1–225.2 m are folded in places, represented by clasts of variegated sandstone and siltstone, which are cemented by argillaceous material. The interval of 100.6–185.1 m is made of less brecciated mass of sandstone and siltstone with gray and greenish-gray mudstone interlayers, in places with

† Deceased.

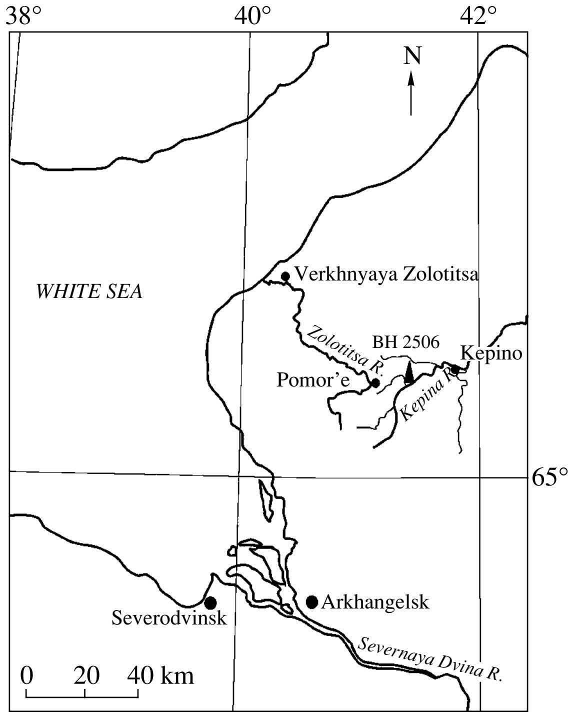


Fig. 1. Geographical position of Borehole 2506.

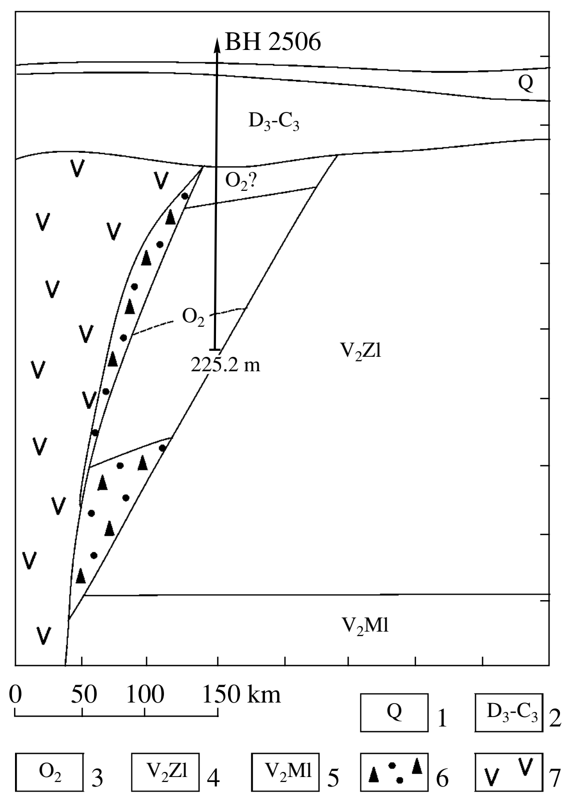


Fig. 2. Geological section through the eastern contact zone of kimberlite pipe no. 496 (modified after A.F. Stankovskii): (1) recent and Quaternary deposits; (2) Upper Devonian–Upper Carboniferous sequence; (3) Middle Ordovician deposits; (4) upper Vendian Zolotitsa Beds; (5) upper Vendian Mel'sk Beds; (6) contact breccia; (7) kimberlite

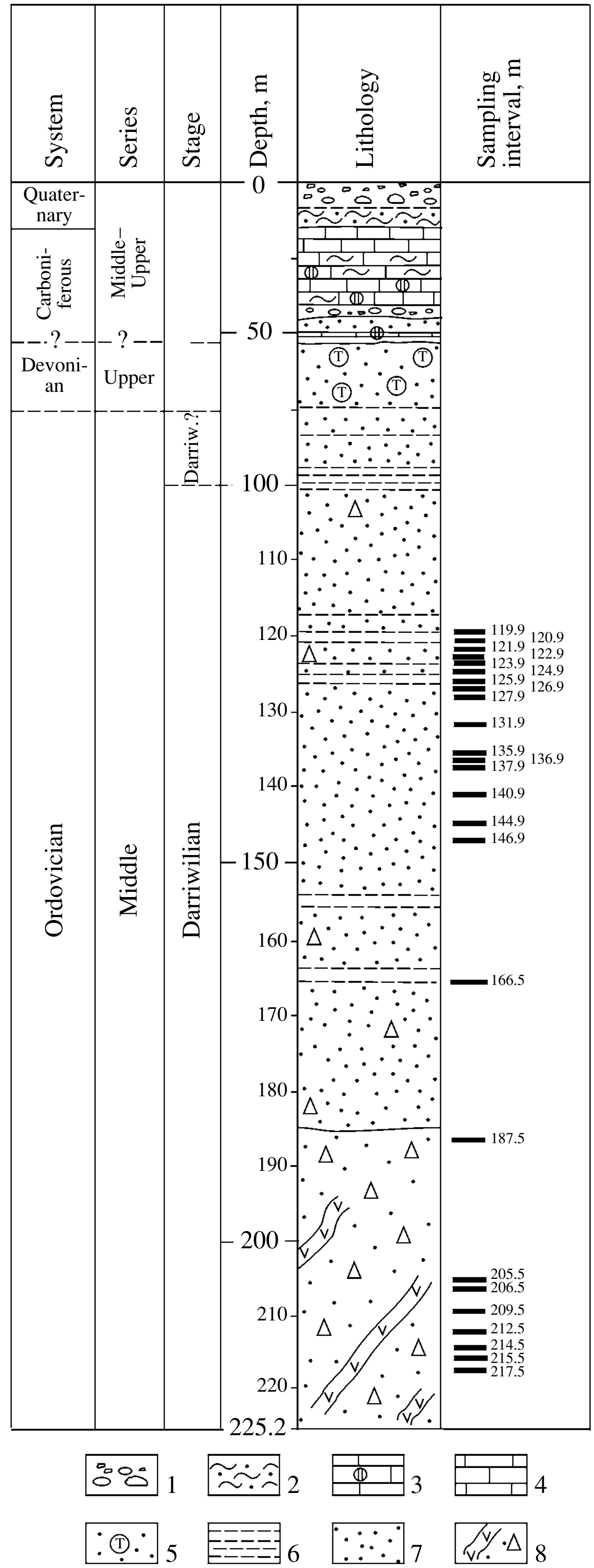


Fig. 3. Lithostratigraphy of deposits penetrated by borehole 2506 and sampling levels for microphytological study: (1) gravelstone; (2) siltstone; (3) limestone with iron concretions; (4) limestone; (5) tuffstone; (6) mudstone; (7) sandstone; (8) brecciated sandstone.

Table 1. Taxonomic composition and distribution of microfossils in borehole 2506

Taxa \ Depth, m	Assemblage 1 (int. 205.5–217.5 m)							Assemblage 2 (int. 119.9–187.5 m)																		
	217.5	215.5	214.5	212.5	209.5	206.5	205.5	187.5	166.5	146.9	144.9	140.9	137.9	136.9	135.9	131.9	127.9	126.9	125.9	124.9	123.9	122.9	121.9	120.9	119.9
Acanthodiacrodium angustizonale	xx			xx	xx	x	xx																		
A. micronatum	x	xx																							
A. spinum		x	x																						
Acanthodiacrodium spp.	x	xx	xx	x	xx	xx	xx																		
Aremoricanium sp.																x									
Baltisphaeridium annelieae	xx	xx				xx																			
B. bystrentos	x	xx													x										
B. calicispinae	x	x	x	xx		xx																			
B. fragile					x																				
B. hirsutoides	x	xx	x	xx			xx				xx	xx		x	x	xx	xx		x						
B. lancettispinae		x	x		x										x										
B. latiradiatum	x	x	x	x				x	xx						x			xx							
B. longispinosum	x	xx	x	xx	xx	xx																			
B. microspinosum	xx				xx		x																		
B. multipilosum	x			x			xx																		
B. nanninum	xx	x																							
B. aff. *B. pauciverrucosum*	x	x	x	x	xx	x																			
Baltisphaeridium spp.	xx	xx	x	xx			xx	xx					xx		x	xx	xx	xx	xx						
Baltisphaerosum variocavatum		x	x																						
Cymatiogalea cristata	xx	x	xx	xx	xx	xx	xx																		
C. aff. *C. cuvillierii*				xx																					
Cymatiogalea sp.	x						x								xx										
Dasydorus cirritus	xx	xx	xx	xx	xx	x	x																		
Filisphaeridium sp.		x		x																					
Florisphaeridium sp.			x		x										x	x									
Goniosphaeridium canningianum	x	xx	xx	x	x		xx		xx						xx										
G. polygonale	xx	x	x	xx	xx			x																	
Goniosphaeridium sp.	xx	xx				x	xx					x			xx	xx		x	x						
Leiosphaeridia sp.		xx									xx		x			xx	xx								
Liliosphaeridium hypertrophicum				x				x	xx						x										
L. intermedium	xx	x	x	xx	x	xx	xx	x	x		x	x			x	x	x	xx	x						
L. kaljoi				x	xx																				
Liliosphaeridium spp.	x						xx						xx		xx	x									
Lophosphaeridium sp.	x	xx	xx		x				x			x	xx		xx	x		xx							
Micrhystridium spp.	xx	x		xx	xx		x		xx						x			xx	xx						
Multiplicisphaeridium irregulare				xx	x	x	x																		

Table 1. (Contd.)

Depth, m / Taxa	Assemblage 1 (int. 205.5–217.5 m)							Assemblage 2 (int. 119.9–187.5 m)																	
	217.5	215.5	214.5	212.5	209.5	206.5	205.5	187.5	166.5	146.9	144.9	140.9	137.9	136.9	135.9	131.9	127.9	126.9	125.9	124.9	123.9	122.9	121.9	120.9	119.9
Multiplicisphaeridium sp.							x	x									x	xx	x						
Nanocyclopia? sp.	**x**	**x**x	**x**x	xx	**x**	xx	xx	xx	xx	xx	**x**	**xx**	**xx**	**xx**	**xx**	<u>xx</u>			<u>xx</u>						
Pachysphaeridium brevispinosum					x	x																			
P. christianii				x	xx	xx																			
P. *mochtiense*					x	xx	x																		
P. robustum						x																			
P. striatum				x		x																			
Pachysphaeridium sp.				x	xx	xx	**x**x																		
Petaloferidium sp.			xx		x			x																	
Peteinosphaeridium angustilaminae	x		xx																						
P. aff. *P. bergstroemii*			x			x																			
P. aff. *P. dissimile*		xx		x			xx																		
P. hymenoferum			xx	xx			xx																		
P. eximium		xx	x	x		xx	xx																		
P. aff. *P. micranthum*				x										x											
P. velatum		x	xx	xx	x			x																	
P. aff. *P. velatum*	x		x	x	x		xx																		
Peteinosphaeridium spp.	x	xx	x	xx		x	**x**	xx	x		xx			x	xx	xx			xx						
Pirea aff. *P. ornata*	xx	x		xx	xx	xx																			
P. levigata		x		x																					
Pirea sp.	x	x						x																	
Poikilofusa sp.			xx				x					xx			**x**x	xx									
Polyancistrodorus? sp.									x							x									
Polygonium spp.		xx		xx			x	xx			xx				xx	xx	x		xx						
Rhopaliophora palmata	x	xx					x																		
R. pilata		x	xx	xx	x		xx	x								x									
Sacculidium inornatum	xx	xx	x	**x**x	xx		xx	x																	
S. peteinoides				xx			x																		
Sacculidium spp.		xx	x	x					xx							x									
Solisphaeridium sp.		x		xx																					
Tongzia sp.	**x**x																								
Tranvikium aff. *T. persculptum*									x								x								
T. polygonale					x			x	xx		x						x	xx							
Veryhachium oklahomense	x	xx			x																				
Veryhachium sp.	**x**	xx		xx	x		x	xx					xx					xx	x						

Note: Acritarch abundance (sp./prep.): x – 1–3, xx – 3–10, **x** – 10–15, **x**x – 15–20, **xx** – 20–50, <u>xx</u> – >50.

Table 2. Stratigraphic scheme of Lower–Middle Ordovician deposits of the East European Platform (IGCP Project no. 410, Eds. B. Webby et al., 2001, unpublished)

International Stratigraphic Scale			British standard	East European Platform			
System	Series	Stage		Horizons		Graptolite zones	Conodont zones
Ordovician	Middle	Darriwilian	Llanvirnian	Kunda		*D. fasciculatus*	*E. suecicus*
						D. lentus	*L. variabilis*
			Arenigian	Volkhov		*D. hirundo*	*B. norrlandicus*
		“Stage 3”					*P. originalis*
							B. navis
							B. triangularis
	Lower	“Stage 2”		Latorp	Billingen	*P. elongatus*	*O. evae*
						P. densus	
						D. balticus	*P. elegans*
					Hunneberg	*T. phyllograptoides*	
		Tremadocian	Tremadocian			*H. copiosus*	*P. proteus*
						A. murrayi	

traces of intense carbonatization. According to initial core documentation, both intervals were considered to be of the Late Devonian–Middle Carboniferous age, but later on they were attributed to the undifferentiated Lower–Middle Ordovician based on identified microfossils (Sivertseva, unpublished data). Red beds of dense calcareous siltstone and sandstone with ferruginous cement, which are penetrated in the upper part of the section (interval of 76.9–100.6 m), are also probably of the Ordovician age (Sivertseva, unpublished data). These sediments are overlain by tuffaceous rocks (interval of 60.7–76.9 m) and sandstone beds (interval of 44.1–15.6 m) of the Upper Devonian–Middle Carboniferous or by undifferentiated carbonate sequence of the Middle–Late Carboniferous (interval of 44.1–15.6 m).

One hundred and thirty samples were collected from the interval of 76.9–225.2 m for microphytological analysis, but acritarchs were found only in 45 samples; in a half of samples, they occurred as single or extremely rare specimens. Nevertheless, 25 samples from thin argillaceous interlayers yielded rather diverse and abundant microphytofossils of satisfactory or very good preservation. Exactly these samples have been

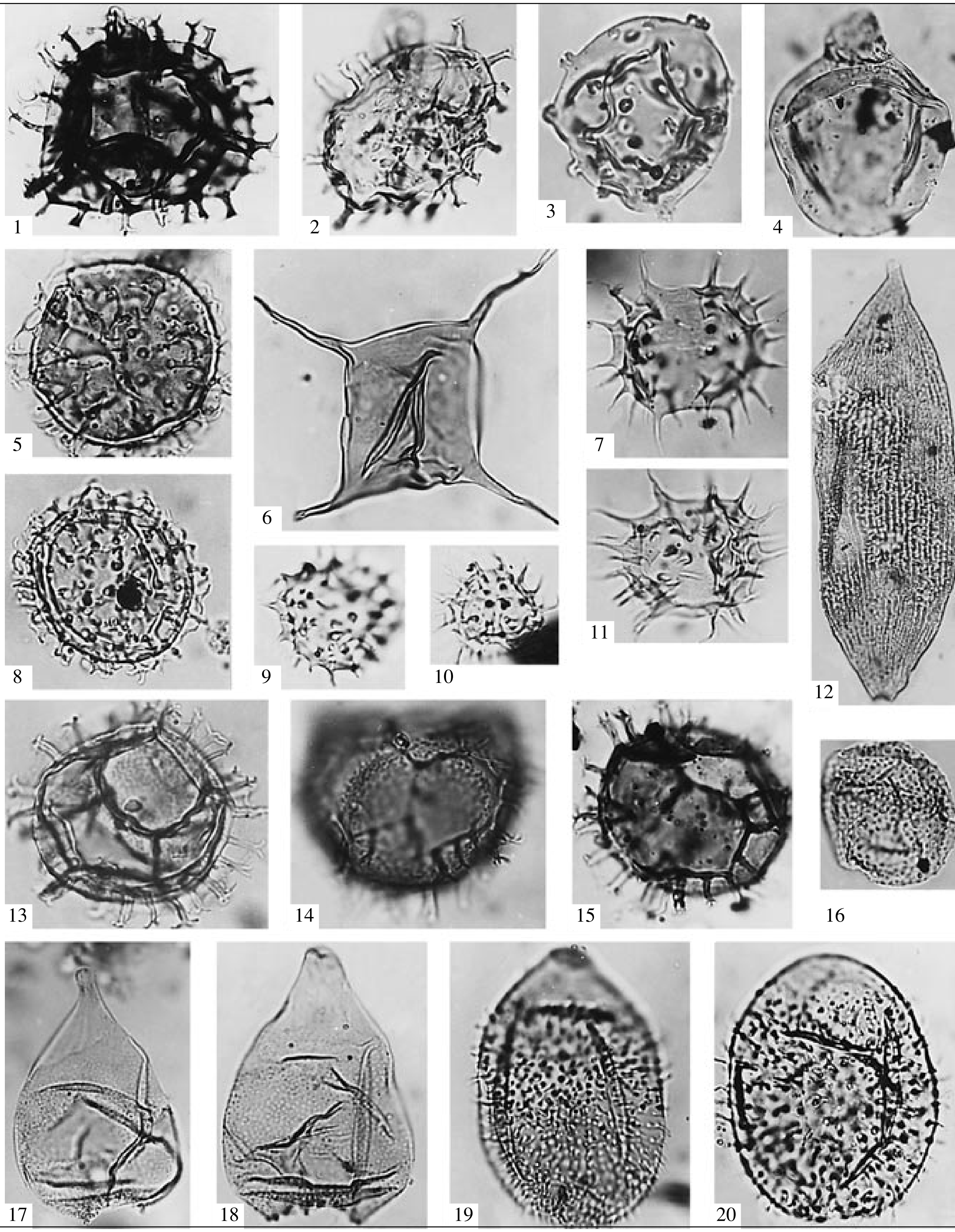
→

Plates I–IV. Acritarchs of the Darriwilian Stage, Middle Ordovician, from the Arkhangelsk oblast. All figured specimens are stored at the Institute of Precambrian Geology and Geochronology, RAS, St. Petersburg.

Plate I (magnification ×600 for Figs. 4, 12 and ×1000 for the other).

(1, 2) *Sacculidium inornatum* Ribecai, Raevskaya et Tongiorgi: (1) Sample 148/2, depth 215.5 m, (2) Sample 156/4, depth 212.5 m; (3) *Florisphaeridium* sp.; Sample 146/1, depth 209.5 m; (4) *Aremoricanium* sp.; Sample 147/1, depth 131.9 m; (5, 8) *Tongzia* sp.; Sample 144/2, depth 217.5 m; (6) *Veryhachium oklahomense* Loeblich; Sample 144/2, depth 217.5 m; (7, 11) *Acanthodiacrodium angustizonale* Burmann: (7) Sample 171/4, depth 206.5 m, (11) Sample 131/4, depth 205.5 m; (9, 10) *Micrhystridium* sp.; Sample 144/2, depth 217.5 m; (12) *Poikilofusa* sp.; Sample 169/4, depth 135.9 m; (13–15) *Cymatiogalea cristata* (Downie) Rauscher: (13, 14) Sample 131/4, depth 205.5 m, (15) Sample 135/4, depth 214.5 m; (16) *Lophosphaeridium* sp.; Sample 139/3, depth 126.9 m; (17, 18) *Pirea* aff. *P. ornata* (Burmann) Eisenack et al.; Sample 146/1, depth 209.5 m; (19, 20) *Dasydorus cirritus* Playford et Martin: (19) Sample 171/4, depth 206.5 m, (20) Sample 148/2, depth 215.5 m.

Plate I



studied in this work; the sampling levels are shown in Fig. 3.

No substantial difference in taxonomic composition of acritarchs has been revealed within the sampled interval. However, their species in the upper part of the section are not as diverse as below that is likely related to a high carbonatization of rocks. Accordingly, we distinguish two acritarch assemblages, although this subdivision is of no biostratigraphic importance. In total, more than 70 species of microphytofossils have been identified. Data on their distribution and abundance in the section are presented in Table I. Assemblage 1 comprises 68 of 71 identified taxa, being dominated by *Cymatiogalea cristata* (Downie) Rauscher, *Acanthodiacrodium angustizonale* Burmann, some species of genera *Baltisphaeridium, Goniosphaeridium, Micrhystridium*, and by problematic remains *Nanocyclopia?* sp. This assemblage is characteristic of the interval 205.5–217.5 m in the basal brecciated rocks. Assemblage 2 is two times less diverse, consisting of 33 identified species, including *Nanocyclopia?* sp. undoubtedly prevailing in the assemblage. Its other remarkable components are single specimens of *Aremoricanium* sp. and *Tranvikium* aff. *T. perculptum* Ribecai et al., which do not occur below.

All the identified species are characteristic of the Lower–Middle Ordovician in the East European platform. Many of them are of wide stratigraphic and geographic ranges. Most species of genera *Baltisphaeridium, Goniosphaeridium, Micrhystridium, Multiplicisphaeridium*, and *Solisphaeridium* are of this kind. The other taxa of special interest are *Liliosphaeridium hypertrophicum* (Eisenack) Playford et al., *L. intermedium* (Eisenack) Playford et al., *L. kalioj* Uutela et Tynni, *Pachysphaeridium brevispinosum* (Eisenack) Ribecai et Tongiorgi, *P. christanii* (Kjellström) Ribecai et Tongiorgi, *P. mochtiense* (Górka) Ribecai et Tongiorgi, *P. robustum* (Eisenack) Fensome et al., *P. striatum* (Lu) Ribecai et Tongiorgi, *Peteinosphaeridium angustilaminae* Playford et al., *P. hymenoferum* (Eisenack Fensome et al., *P. eximium* Playford et al., *P.* aff. *P. micranthum* (Eisenack) Eisenack et al., *P. velatum* Kjellström, emend. Playford et al., *Rhopaliophora palmata* (Combaz et Peniguel) Playford et Martin, *R. pilata* Combaz et Peniguel, *Sacculidium inornatum* Ribecai et al., *S. peteinoides* Ribecai et al., *Tranvikium polygonale* (Tynni) Uutela et Serjeant, *T.* aff. *T. persculptum*, and *Veryhachium oklahomense* Loeblich. These species are abundant in deposits of the Leningrad oblast, Baltic region, and Scandinavia, where they are mainly confined to the Volkhov and Kunda horizons of the Middle Ordovician, and only the genus *Rhopaliophora* appears in the middle Arenigian deposits. Moreover, many of the listed taxa are typical of coeval intervals beyond the Baltic paleobasin.

Species *Rhopaliophora palmata* and *R. pilata* were found for the first time in upper Tremadocian deposits of southern China (Martin and Yin, 1988). Later on, they were also found in younger Ordovician sequences: the upper Tremadocian–Arenigian in Spain (Mette, 1989), the lower Arenigian in Czechoslovakia (Fatka, 1992; 1993) and Argentina (Rubinstein and Toro, 2001), the Arenigian–Llanvirnian in western Australia (Playford and Martin, 1984) and the Baltic region (Uutela and Tynii, 1991). In northwestern areas of Russia, these forms were found at the base of the Arenigian, in deposits of the Hunneberg Horizon, which correspond to the graptolite *T. phyllograptoides* Zone and upper part of the conodont *P. proteus* Zone (Raevskaya, 1999; Tolmacheva et al., 2001).

Species *Pachysphaeridium striatum*, described initially under the generic name *Gorgonisphaeridium* and later repeatedly described as a form of genera *Papilliferum* or *Costatilobus*, is of widespread occurrence in lower Arenigian deposits of southern China, where it was found in the interval of the *O. evae–B. triangularis* conodont zones (Tongiorgi et al., 1995; Ribecai and Tongiorgi, 1999). In the Leningrad oblast, this species appears for the first time at the base of *B. triangularis* Zone in the Volkhov Horizon that is correlated with the lower boundary of the graptolite *D. hirundo* Zone (Raevskaya, 1999). In Sweden, *P. striatum* was also found in younger sediments corresponding to the lowermost part of the Kunda Horizon. This level corresponding to the base of the *Lenodus* sp. *A. (= L. variabilis)* Zone of conodont zonation represents the upper limit of the species range (Ribecai and Tongiorgi, 1999). Disappear-

Plate II (magnification ×600 for all the figures).

(1, 2) *Liliosphaeridium intermedium* (Eisenack) emend. Playford, Ribecai et Tongiorgi: (1) Sample 171/4, depth 206.5 m, (2) Sample 144/2, depth 217.5 m; (3) *Liliosphaeridium kaljoi* Uutela et Tynii emend. Playford, Ribecai et Tongiorgi; Sample 146/1, depth 209.5 m; (4) *Liliosphaeridium* sp.; Sample 169/4, depth 137.9 m; (5, 6, 8) *Peteinosphaeridium eximium* Playford, Ribecai et Tongiorgi: (5) fragment, Sample 148/2, depth 215.5 m, (6) Sample 171.4, depth 206.5 m, (8) Sample 131/4, depth 205.5 m; (7, 13) *Peteinosphaeridium velatum* Kjellström emend. Playford, Ribecai et Tongiorgi: (7) Sample 146/1, depth 209.5 m, (13) Sample 156/4, depth 212.5 m; (9) *Peteinosphaeridium* sp.; Sample 148/2, depth 215.5 m; (10) *Peteinosphaeridium* aff. *P. velatum* Kjellström emend. Playford, Ribecai et Tongiorgi; (7) Sample 146/1, depth 209.5 m, (10) Sample 135/4, depth 214.5 m; (11) *Peteinosphaeridium angustilaminae* Playford, Ribecai et Tongiorgi; Sample 135/4, depth 214.5 m; (12) *Peteinosphaeridium* aff. *P. dissimile* Gorka; Sample 131/4, depth 205.5 m; (14) *Peteinosphaeridium hymenoferum* (Eisenack) Fensome et al.; Sample 131/4, depth 205.5 m.

Plate II

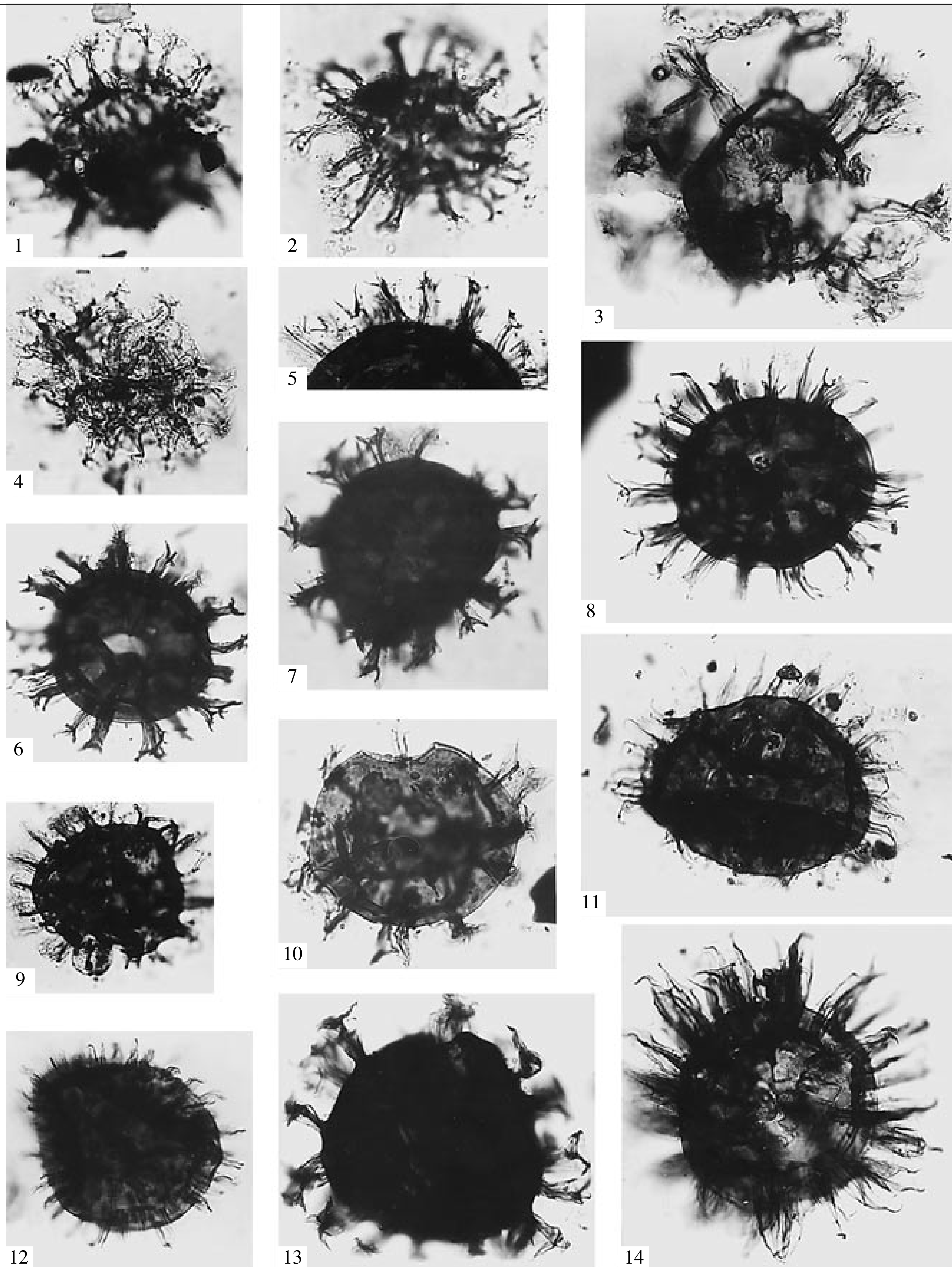
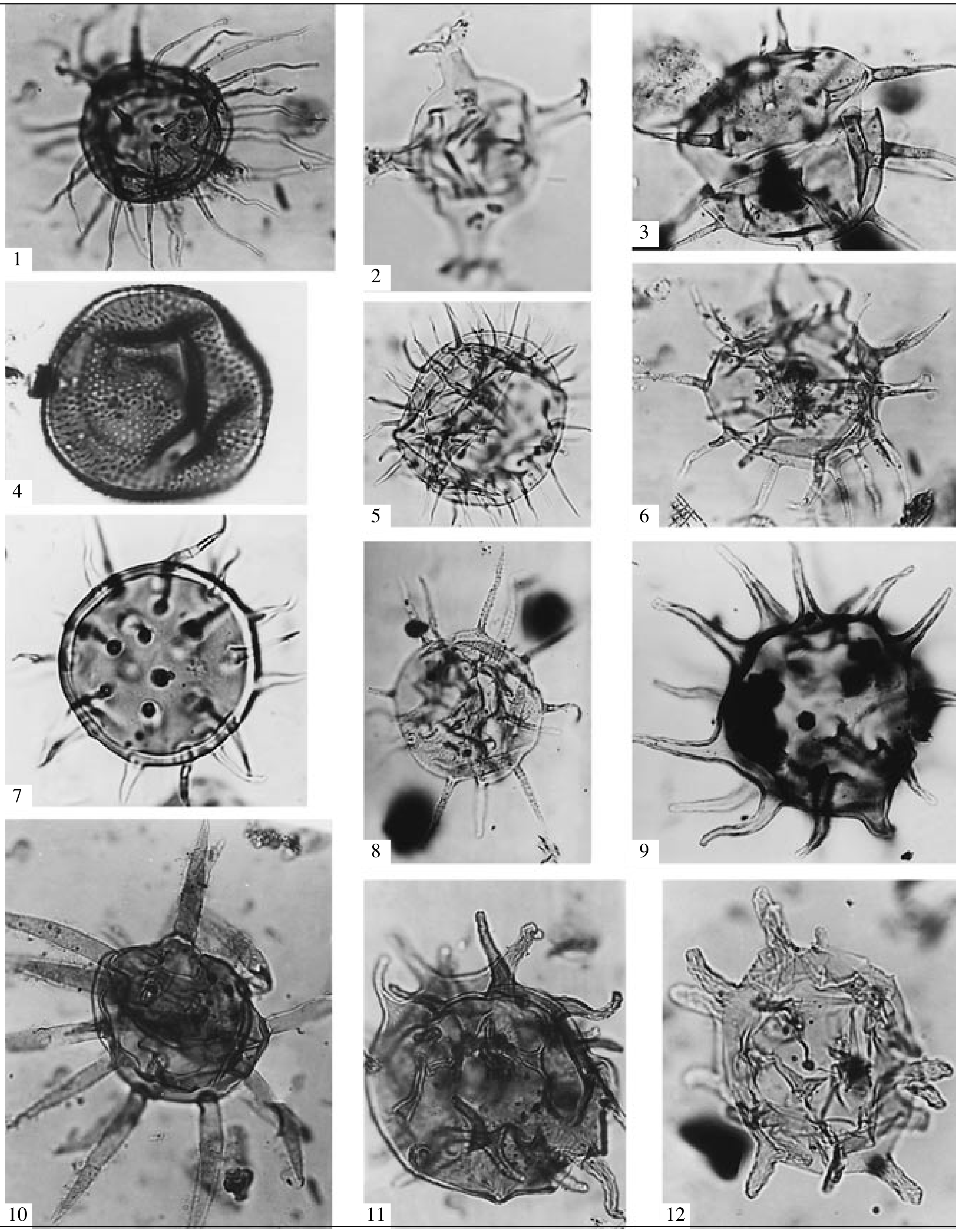


Plate III



ance of this species in the boundary interval between Volkhov and Kunda horizons of the Baltic region and Scandinavia is accompanied by appearance of some other species of the genus *Pachysphaeridium*, which keep on existing in the Middle and Late Ordovician. Representatives of the last genus from borehole 2506 are *P. christianii, P. mochtiense*, and *P. robustum.* These species also appear successively in sections of the Leningrad oblast starting from the uppermost part of the Volkhov Horizon. The range for *P. brevispinosum* species is confined to the Middle Ordovician (Ribecai and Tongiorgi, 1999).

Tranvikium polygonale (= *Ampullula suetica* Righi) was described from the Arenigian–Llanvirnian interval corresponding to the graptolite *D. hirundo–D. bifidus* zones, which are studied in detail on the *Oland* Island in Sweden (Tynni, 1982; Righi, 1991; Ribecai et al., 2002), where the *bifidus* Zone base is roughly comparable with the Llanvirnian base in Britain (Righi, 1991). The species under consideration is also encountered in the interval of the *A. suecicus–U. sinodentatus* local graptolite zones of southern China equivalent to the lower part of the *D. hirundo* Zone in Baltic countries (Tongiorgi et al., 1995; Brocke, 1997), being known as well from North Africa (Vecoli, 1999). *T. persculptum* species has been found so far in Sweden only, in limestones of the Kunda Horizon corresponding to the graptolite *D. bifidus* Zone (Ribecai et al., 2002).

Peteinoid acritarchs, represented in the described assemblage by genera *Liliosphaeridium* and *Peteinosphaeridium*, are most characteristic taxa of the Middle Ordovician in the Baltic region. In sections of the Öland Island, Sweden, *L. intermedium* appears in the middle of the conodont *B. norrlandicus* Zone, the upper part of the Volkhov Horizon. Above this zone, near the base of the conodont *L. variabilis* Zone of the Kunda Horizon, it is joined first by *L. hypertroficum* and then by *L. kaljoi* (Playford et al., 1995; Bagnoli and Ribecai, 2001). Species *P. eximium, P. hymenoferum, P. micranthum*, and *P. velatum* are known from the interval of the conodont *M. parva (= B. norrlandicus)* Zone (Ribecai and Tongiorgi, 1995). All the listed species are also known in Estonia (Uutela and Tynii, 1990), Lithuania (Paškevičiene, 1998), and the Leningrad oblast (Raevskaya, 1999), where they are confined to boundary deposits between Volkhov and Kunda horizons. *L. kaljoi* and *L. intermedium* have been recently established in the Kunda deposits of Norway, in the upper part of the graptolite *D. hirundo* Zone correlative to the conodont *Lenodus* sp. A. *(=L. variabilis)* Zone (Ribecai et al., 1999). Beyond the Baltic region, these taxa are widespread in coeval deposits of southern China (Tongiorgi and Di Milia, 1999).

S. inornatum (some well-known specimens of *Peteinosphaeridium macrophylum* Eisenack are included in its synonymy) and *S. peteinoides* appear in the upper part of the Volkhov Horizon (*B. norrlandicus* Zone of conodont zonation) in Sweden, Estonia, and northwestern Russia (Ribecai et al., 2002). In Sweden, the upper limit of *S. peteinoides* stratigraphic range is not higher than the upper boundary of the conodont *L. variabilis* Zone. Both species have been also established in southern China (*P. macrophylum* s. 1, Tongiorgi and Di Milia, 1999).

V. oklahomense is also a common form in Baltic sections. It is a characteristic taxon in the acritarch assemblage from the Kunda Horizon of Sweden (Ribecai and Tongiorgi, 1995) and the Leningrad oblast (Raevskaya, 1999).

Hence, based on stratigraphic ranges of aforementioned species, the examined rocks can be dated confidently. The section lower part containing microphytological assemblage 1 can be correlated with an upper part of the graptolite *D. hirundo* Zone that corresponds to the boundary interval of the Volkhov and Kunda horizons in the East European platform. Until recently, this interval has been compared to the Arenigian Stage of Britain, a subdivision of the Lower Ordovician. However, stratigraphic subdivision of the Ordovician is revised with respect to stage boundaries and ranges, being considerably changed in the course of successful work of the International Geological Correlation Program (IGCP Project no. 410). According to recent agreement (Servais and Paris, 2000), the uppermost part of *D. hirundo* Zone is accepted for the base of the upper stage in the Middle Ordovician, which is referred to as Darriwilian (Table 2).

The higher interval of section, where microphytological assemblage 2 is detected, most likely belongs to the Darriwilian Stage of the Middle Ordovician as well. It is difficult to suggest unambiguous age inter-

Plate III (magnification ×600 for all figures).

(1) *Baltisphaeridium fragile* Tongiorgi, Yin et Di Milia; Sample 146/1, depth 209.5 m; (2) *Petaloferidium* sp.; Sample 146/1, depth 209.5 m; (3, 6) *Baltisphaeridium* aff. *B. pauciverrucosum* Kjellström: (3) Sample 144/2, depth 217.5 m, (6) Sample 146/1, depth 209.5 m; (4) *Baltisphaeridium nanninum* Eisenack; Sample 144/2, depth 217.5 m; (5) *Baltisphaeridium multipilosum* (Eisenack) Eisenack; Sample 131/4, depth 205.5 m; (7) *Baltisphaeridium hirsutoides* Eisenack; Sample 169/4, depth 135.9 m; (8) *Baltisphaeridium calicispinae* Gorka; Sample 171/4, depth 206.5 m; (9) *Pachysphaeridium christianii* (Kjellström) Ribecai et Tongiorgi; Sample 171/4, depth 206.5 m; (10) *Baltisphaeridium lancettispinae* Gorka; Sample 146/1, depth 209.5 m; (11) *Pachysphaeridium mochtiense* (Gorka) Ribecai et Tongiorgi; Sample 146/1, depth 209.5 m; (12) *Pachysphaeridium striatum* (Lu) Ribecai et Tongiorgi; Sample 171/4, depth 206.5 m.

Plate IV

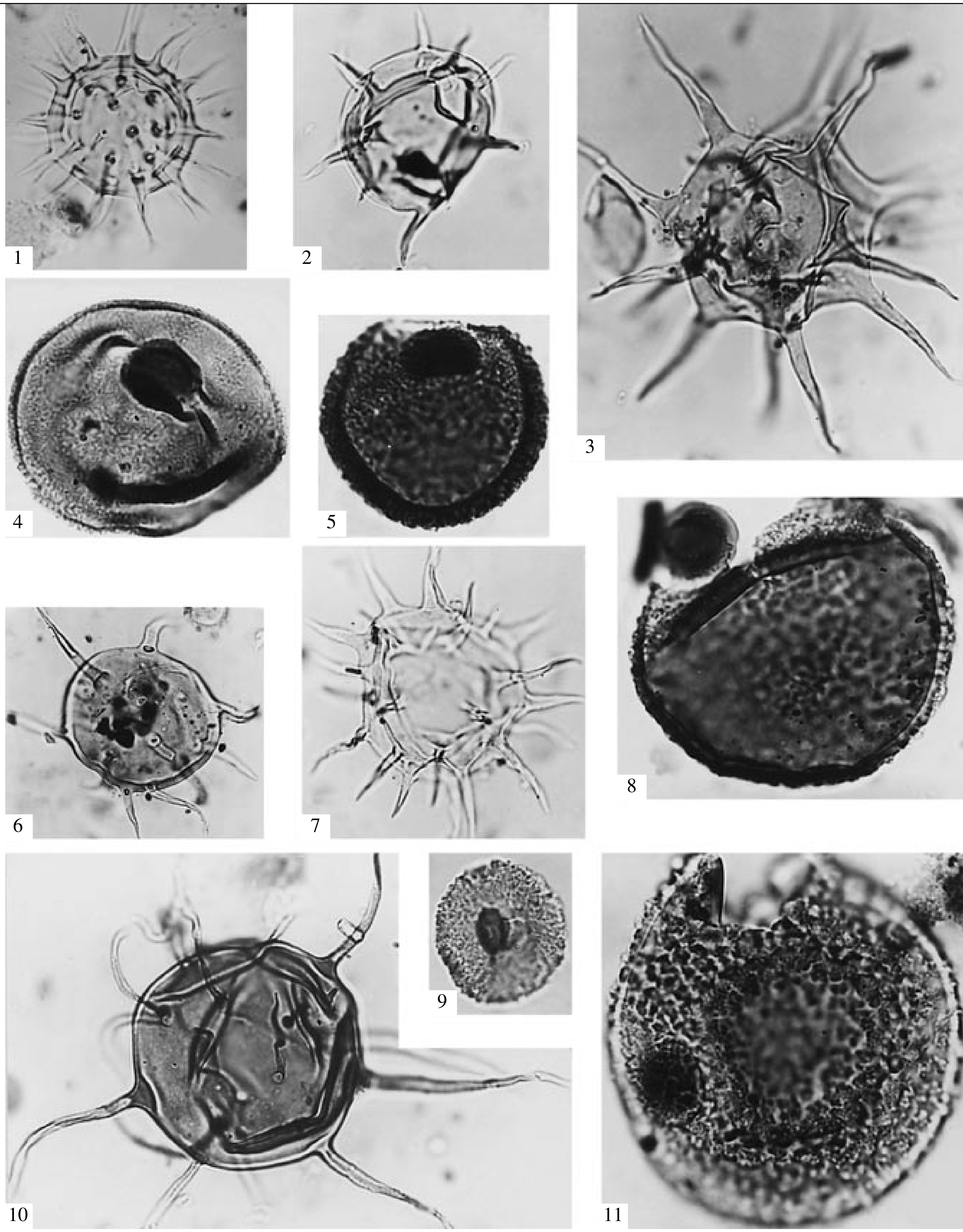


Plate IV (magnification ×1000 for figs. 8, 11 and ×600 for the other).

(1) *Goniosphaeridium canningianum* (Combaz et Peniguel) Playford et Martin; Sample 144/2, depth 217.5 m; (2) *Goniosphaeridium* sp.; Sample 144/2, depth 217.5 m; (3) *Goniosphaeridium polygonale* (Eisenack) Eisenack; Sample 146/1, depth 209.5 m; (4, 5, 8–9, 11) *Nanocyclopia?* sp.: (4, 5) Sample 169/4, depth 135.9 m, (8, 11) Sample 131/4, depth 205.5 m, (9) Sample 144/2, depth 217.5 m; (6) *Baltisphaeridium hirsutoides* Eisenack; Sample 135/4, depth 214.5 m; (7) *Polygonium* sp., Sample 169/4, depth 135.9 m; (10) *Baltisphaeridium longispinosum* (Eisenack) Eisenack; Sample 148/2, depth 215.5 m.

pretation for rocks of this interval because of a gradual disappearance of stratigraphically significant species and decreasing taxonomic diversity of fossils. At the same time, single forms of *Aremoricanium* sp. and *Tranvikium* aff. *T. persculptum*, which appear here as is noted above, do not contradict their affiliation with the Darriwilian Stage. Species of the genus *Aremoricanium* are characteristic of the Middle and Late Ordovician in Baltoscandia (Kjellström, 1971, 1976), whereas *T. persculptum* is of a narrower stratigraphic range. In sections on the Öland Island, Sweden, the last species appears first at the lower level of the conodont *B. norrlandicus* Zone, which is correlative with the upper part of the graptolite *D. hirundo* Zone, and its last occurrence is recorded in deposits of the *D. bifidus (= D. artus)* Zone (Ribecai et al., 2002).

The described assemblages of microphytofossils are analogous to coeval assemblages of Scandinavia, Baltic region, and northwestern part of Russia. It is apparent that an epicontinental basin covering a vast area of the paleocontinent Baltica was populated in the Middle Ordovician by microphytoplankton of persistent taxonomic composition. Local assemblages with depleted species composition or with changeable proportions of some taxa are the exceptions, being under direct control of local environmental conditions. Characteristic of the acritarch community in general is a distinct set of species, which can be surely identified in the western deeper part of the basin, i.e., in Scandinavia, and further northeastward in the Zimnii Coast sections of the White Sea region. Besides abundant and widespread genera *Baltisphaeridium, Goniosphaeridium, Micrhystridium*, and *Multiplicisphaeridium*, in the latter region there are diverse representatives of genera *Peteinosphaeridium, Liliosphaeridium, Pachysphaeridium*, and *Sacculidium*, which are typical of the Baltic (or Boreal) phytoplankton province situated in temperate latitudes during the Ordovician (Vavrdová, 1974; Servais et al., 2003, and references therein).

As is mentioned above, many taxa encountered in the Arkhangelsk oblast are known from coeval deposits in South China. A great taxonomic similarity of Ordovician acritarchs from the Baltic region and South China was considered repeatedly in publications (Playford et al., 1995; Tongiorgi et al., 1995, 1998; Tongiorgi and Di Milia, 1999; Raevskaya et al., 2004). Among possible causes of this similarity, there were regarded the past proximity of paleocontinents within similar climatic zones and configuration of global oceanic currents responsible for a free water exchange that has been corrected by seasonal changes and transgression–regression processes.

A more careful consideration of these problems is beyond bounds of this work. Nevertheless, it should be emphasized that the acritarch assemblage discovered in the Arkhangelsk oblast was undoubtedly a member of the Baltic phytoplankton community that consisted during the considered time span of taxa having narrow stratigraphic but wide geographic ranges, which are therefore of a high biostratigraphic potential.

Reviewers T.N. Koren and A.S. Alekseev

REFERENCES

1. G. Bagnoli and C. Ribecai, "On the Biostratigraphic Significance of the Ordovician Acritarch Genus *Liliosphaeridium* on Öland, Sweden," Rev. Palaeobotan. Palynolog. **17**, 195–215 (2001).
2. O. A. Bogatikov, V. K. Garanin, V. A. Kononova, et al., *Arkhangelsk Diamond-bearing Province (Geology, Geochemistry, and Mineralogy)* (Mosk. Gos. Univ., Moscow, 2000) [in Russian].
3. R. Brocke, "Evaluation of the Ordovician Acritarch Genus *Ampullula* Righi," Ann. Geol. Belgique **120** (1), 73–97 (1997).
4. O. Fatka, in *Contribution to Acritarch and Chitinozoan Research*, Ed. by S. G. Molyneux and K. G. Dorning (Věstn. České. Geol. ústavu. **67** (4), 277–292 (1992).
5. O. Fatka, "Chitinozoans and Acritarchs in Latest Tremadoc–Early Arenig Sediments of the Prague Basin, Czech Republic", Spec. Pap. in Palaeontology **48**, 29–36 (1993).
6. G. Kjellström, "Middle Ordovician Microplankton from the Grötlingbo Borehole 1 in Gotland, Sweden," Sver. geol. unders., Ser. C NR 669 **65** (15), 6–35 (1971).
7. G. Kjellström, "Lower Viruan (Middle Ordovician) Microplankton from the Ekön Borehole 1 in Östergötland, Sweden," Sver. geol. unders., Ser. C NR 724 **70** (6), 6–45 (1976).
8. J. Li, "Ordovician Acritarchs from the Meitan Formation of Guizhou Province, South-West China," Palaeontol. **30** (3), 613–634 (1987).
9. F. Martin and L. Yin, "Early Ordovician Acritarchs from Southern Jilin Province, North-East China," Palaeontol. **31** (1), 109–127 (1988).
10. W. Mette, "Acritarchs from Lower Paleozoic Rocks of the Western Sierra Morena, SW-Spain and Biostrati-

graphical Results," Geol. et Palaeontologica **23**, 1–19 (1989).

11. L. Paškevičiene, "Lower Ordovician Acritarchs of Northwestern Lithuania," Geologija **26**, 90–98 (1998).
12. G. Playford and F. Martin, "Ordovician Acritarchs from the Caning Basin, Western Australia," Alcheringa **8**, 187–223 (1984).
13. G. Playford, C. Ribecai, and M. Tongiorgi, "Ordovician Acritarch Genera *Peteinosphaeridium, Liliosphaeridium*, and *Cycloposphaeridium*: Morphology, Taxonomy, Biostratigraphy and Palaeogeographic Significance," Bull. Soc. Paleontol. Ital. **34** (1), 3–54 (1995).
14. E. G. Raevskaya, "Subdivision and Correlation of Upper Cambrian–Middle Ordovician Deposits of the Glint Belt, Russia (North-West of the East European Platform); Implications of Acritarchs," in *Proceedings of the Jubilee Conference: Oil-and-Gas Geology at the Verge of Centuries. Prediction, Prospecting, Exploration, and Development of Mineral Deposits. Vol. 2. Stratigraphy, General Geology, Regional Forecast* (VNIGRI, St. Petersburg, 1999), pp. 179–192 [in Russian].
15. E. G. Raevskaya, Extended Abstract of Candidate's Dissertation in Geology and Mineralogy (St. Petersburg, 2000) [in Russian].
16. E. Raevskaya, M. Tongiorgi, and M. Vecoli, "*Rhopaliophora? asymmetrica*, a New Acritarch Species from the Lowermost 'Arenig' of Baltica and Its Biostratigraphic Potential," Rev. Palaeobotan. and Palynolog. **126**, 39–48 (2003).
17. E. Raevskaya, M. Vecoli, W. Bednarczyk, and M. Tongiorgi, "Billingen (Lower Arenig/Lower Ordovician) Acritarchs from the East-European Platform (St. Petersburg Region, Northwestern Russia, and Leba Area, Northwestern Poland) and Their Palaeobiogeographic Significance," Lethaia **37**, 97–111 (2004).
18. C. Ribecai and M. Tongiorgi, "Arenigian Acritarchs from Horns Udde (Öland, Sweden): a Preliminary Report," Rev. Palaeobotan. and Palynolog. **86**, 1–11 (1995).
19. C. Ribecai and M. Tongiorgi, "The Ordovician Acritarch Genus *Pachysphaeridium* Butmann 1970: New, Revised, and Reassigned Species," Palaeontographia Ital. **86**, 117–153 (1999).
20. C. Ribecai, D. Bruton, and M. Tongiorgi, "Acritarchs from the Ordovician of the Oslo Region, Norway," Norsk Geol. Tidsskrift **80**, 251–258 (1999).
21. C. Ribecai, E. Raevskaya, and M. Tongiorgi, "*Sacculidium* gen. nov. (Acritarcha), a New Representative of the Ordovician Stelomorpha–*Tranvikium plexus*," Rev. Palaeobotan. and Palynolog. **121**, 163–203 (2002).
22. E. Righi, "*Ampullula*, a New Acritarch Genus from the Ordovician (Arenig–Llanvirn) of Öland, Sweden," Rev. Palaeobotan. and Palynolog. **68**, 119–126 (1991).
23. C. V. Rubinstein and B. A. Toro, "Review of Acritarch Biostratigraphy in the Arenig of the Eastern Cordillera, Northwestern Argentina: New Data and Calibration with the Graptolite Zonation," Ed. R. H. Weiss *Contribution to Geology and Palaeontology of Gondwana in Honour of Helmut Wopfiner* (Cologne, 2001), pp. 421–439.
24. Th. Servais and F. Paris, "Ordovician Palynology: Balance and Future Prospects at the Beginning of the Third Millennium," Rev. Palaeobotan. and Palynolog. **113** (1–3), 1–14 (2000).
25. Th. Servais, J. Li, S. Molyneux, and E. Raevskaya, "Ordovician Organic-Walled Microphytoplankton (Acritarch) Distribution: the Global Scenario," Palaeogeogr., Palaeoclimatol., Palaeoecol. **195**, 149–172 (2003).
26. T. J. Tolmacheva, T. N. Koren, L. E. Holmer, et al., "The Hunneberg Stage (Ordovician) in the Area East of St. Petersburg, Northwestern Russia," Paleontol. Zh. **74** (4), 543–561 (2001).
27. M. Tongiorgi and A. Di Milia, "Differentiation and Spread of the Baltic Acritarch Province (Arenig–Llanvirn)," Bull. della Soc. Paleontol. Ital. **38** (2-3), 297–312 (1999).
28. M. Tongiorgi, L. Yin, and A. Di Milia, "Arenigian Acritarchs from the Daping Section (Yangtze Gorges Area, Hubei Province, Southern China) and Their Palaeogeographic Significance," Rev. Palaeobotan. Palynolog. **86**, 13–48 (1995).
29. M. Tongiorgi, L. Yin, A. Di Milia, and C. Ribecai, "Changing Palaeogeographical Affinities of the Acritarch Assemblages Throughout the Dawan Formation (Arenig, Yichang Area, South China)," Palynology **22**, 181–196 (1998).
30. R. Tynni, "On Paleozoic Microfossils in Clastic Dykes on the Åland Islands and in the Core Samples of Lumparn. Paleozoic Sediments in the Rapakivi Area of the Åland Islands," Eds. L. Bergman R. Tynni, and B. Winterhalter, *Bull. Geol. Surv. Finland* (London, 1982), Vol. 317, pp. 35–94.
31. A. Uutela and R. Tynni, "Ordovician Acritarchs from Rapla Borehole, Estonia" *Bull. Geol. Surv. Finland* (London, 1991), Vol. 353, pp. 1–135.
32. M. Vavrdová, "Geographycal Differentiation of the Ordovician Acritarch Assemblages in Europe," Rev. Palaeobotan. and Palynolog. **18**, 171–175 (1974).
33. M. Vecoli, "Cambro-Ordovician Palynostratigraphy (Acritarchs and Prasinophytes) of the Hassi-R'Mel Area and Northern Rhadames Basin, North Africa," Palaeontographia Ital. **86**, 1–112 (1999).
34. E. M. Verichev, N. A. Volkova, L. V. Piskun, et al., "Ordovician Acritarchs of the Northern Russian Plate," Izv. Akad. Nauk SSSR, Ser. Geol., No. 7, 152–155 (1990).
35. N. A. Volkova and I. A. Sivertseva, "New Acritarchs from the Tremadocian of the Northern Russian Plate," Paleontol. Zh., No. 3, 119–123 (1991).