

Upper Vendian assemblages of carbonaceous micro- and macrofossils in the White Sea Region: systematic and biostratigraphic aspects

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Abstract: Complexes of microfossils, consisting of spheromorphic acritarchs, and coccoid and filamentous cyanobacterial colonies, characterize distinct levels of the Upper Vendian sequence (Ediacaran) of the White Sea region. Three discrete assemblages of algal macrofossils have been recognized in this succession. The oldest assemblage is characteristic of the Lyamtsa Formation of Early Redkino age, the middle assemblage, the Verkhovka, Zimmegory and lowermost Yorga formations of Late Redkino age, and (provisionally) the youngest assemblage, preserved in the upper part of the Yorga Formation of Early Kotlin age. The Vendian succession studied here can be correlated with a similar succession in the Podolia region of Ukraine.

The study of terminal Neoproterozoic rocks on the Eastern European platform (Aksenov *et al.* 1978) has resulted in the recognition of two stratigraphic subdivisions of the upper part of the Vendian sequence (Ediacaran), which represent so-called 'regional stages'. These regional stages (the Redkino and Kotlin stages) can be recognized across the Eastern European Platform, from Podolia in the southwest to the White Sea Region in the north. This study presents data on the distribution of carbonaceous microfossils to assist in a more detailed correlation across this succession. Similarities of consecutive successions of cyanobacterial and algal fossils between such distant Neoproterozoic sections may be useful for more extensive global correlation using biostratigraphic methods.

Organic microfossils and cyanobacterial assemblages

Different types of organically preserved fossils characterize the Vendian succession on the Eastern European Platform. The more abundant forms are represented by organic biofilms. Numerous filamentous microfossils of cyanobacterial nature, spheromorphic acritarchs and coccoid colonial forms are preserved on the surfaces of these biofilms. The basic components of the cyanobacterial communities are members of the genus *Siphonophycus* Schopf, 1968 and *Oscillatoropsis* Schopf, 1968. The minor components include *Palaeolyngbia* Schopf, 1968 and *Polytrichoides* Hermann, 1974. Filamentous forms in the genus *Siphonophycus* Schopf, 1968 form numerous clusters on the surface of thin organic films (Fig. 1a). They are represented by thin, elastic, smoothly curved or randomly twisted,

non-branched tubular sheaths. These sheaths have a constant width. The absence of transverse cell walls in the trichome is another characteristic feature of these forms. The width of the filaments varies from 2–20 μm , the most common dimension 8–12 μm . Microfossils are similar to recent mat-producing hormogoniacean cyanobacteria in the genera *Microcoleus* and *Phormidium*. These forms have a wide distribution in marine and fresh waters today.

Filamentous microfossils in the genus *Oscillatoropsis* are characterized by a clearly visible cellular structure (Fig. 1b). They are found both as individuals and as fascicular clusters of filaments. The width of the sheaths varies from 4–6 to 30–40 μm . These microfossils resemble the recent cyanobacteria *Oscillatoria*.

The remains of relatively large trichomes (40–60 μm in width) are referred to the genus *Palaeolyngbia* (Schopf 1968) (Fig. 1c). Such sheaths include uniserial cell filaments. The wall of the cells does not closely adjoin the inner surfaces of the sheaths. Cells have a keg-like form and narrow at the point of contact with neighbouring cells.

Microfossils referred to genus *Ostiana* (Fig. 1d) occur in the Zimmie Gory beds of the Ust'-Pinega Formation. These forms are represented by thin organic films, $>1\text{ cm}^2$. There may be several hundred cells in a single colony. Cells have a spherical or ellipsoid form. The diameter of the cells varies from 5–18 μm . Cells occur in individual envelopes that are broader. The cells occurring in a colony have an open distribution, although sometimes (in the cases of dense clusters) the spherical shape of cells can be deformed. Recent analogues for these forms include chroococcalean cyanobacteria of the genera *Microcystis* and *Aphanothece*.

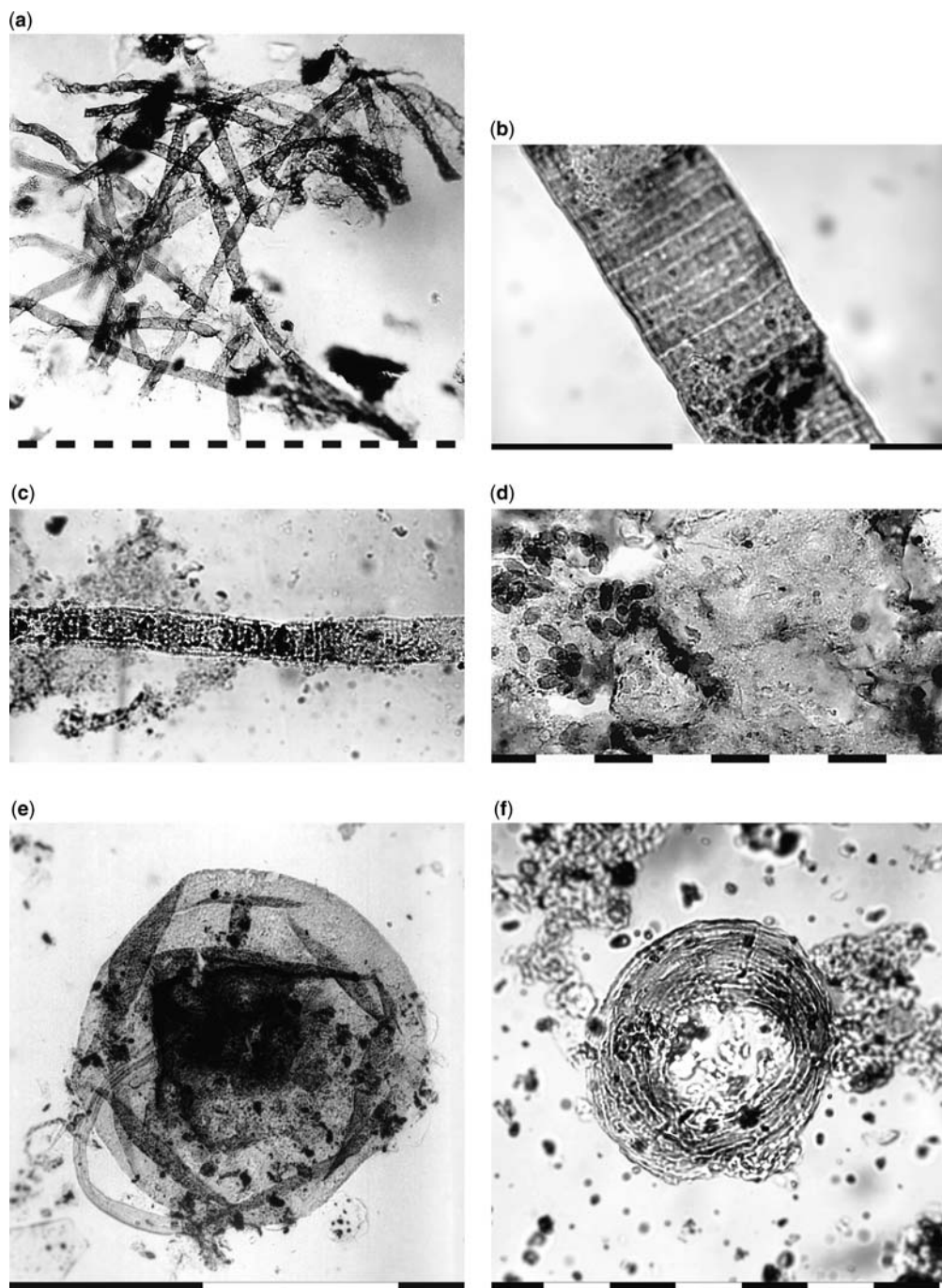


Fig. 1. Microfossils from Upper Vendian succession of the North of Arkhangelsk region. (a) *Syphonophycus* Schopf, 1968. Scale 10 μm . (b) *Oscillatoriopsis* Schopf, 1968. Scale 50 μm . (c) *Palaeolyngbia* aff. *catenata*. Scale 100 μm . (d) Fragments of the colonial microfossils *Ostiana* on the surface of the biofilms. Scale 10 μm . (e) *Leiosphaeridia minutissima*. Scale 100 μm . (f) *Volyniella valdaica*. Scale 10 μm .

Stratigraphic subdivisions (Grazhdankin 2003)			Macrophytes (Ragozina 2001; Gnilovskaya 2003; Leonov 2003)							
System										
Regional Stage										
Formation										
			Disperse organic films of type h							
			Disperse organic films of type I							
			<i>Archyfasma</i> sp. Gnil., 2003							
			<i>Eoholynia fruticulosa</i> A. Istchenko in Gnilovskaya et al., 1988							
			<i>Beltanelloides sorichevae</i> Sokolov, 1965							
			<i>Serebrina crustacea</i> A. Istchenko, 1988							
			Organic films of type f							
			<i>Eoholynia moscuensis</i> Gnil., 1975							
			<i>Pliitela composita</i> Aseeva, 1976							
Vendian	Cam-brian	Rov-no								
	Kotlin	Padun								
		Yorga							III	
	Redkino	Zimnie Gory								
		Verkhov-ka								
		Lyamtsa	I							

Fig. 2. Distribution of algal microfossils in the Upper Vendian succession of the White Sea. Taxa written in bold are significant for regional biostratigraphic correlation. Roman numbers in circles mark assemblages mentioned in text.

Two types of cyanobacterial colonies (monotaxonomic assemblages of *Ostiana* and poly-taxonomic assemblages of filamentous microfossils) are known to occur in the Upper Vendian succession that crops out in the Suzma and Zimnie Gory beds of the Ust'-Pinega Formation. These two types of colonies possibly occupied different habitats in a shallow epicontinental marine basin of Late Ediacaran age.

Spheromorphic acritarchs also occur in the Zimnie Gory beds of the Ust'-Pinega Formation (Zimnie Gory locality, boreholes 1000 and 1000-1). They are represented by thin-walled forms with smooth or slightly sculptured shagrinated surfaces and few collapse folds. These forms are referred to the genus *Leiosphaeridia* (*Leiosphaeridia* minor, *L. pellicula*, *L. aperta*, *L. effusa*, *L. bituminosa*, *L. magna*, *L. minutissima* (Fig. 1e). Microfossils of the genera *Stictosphaeridium* and *Orygmato-sphaeridium* occur infrequently. *Volyniella valdaica* is another distinctive form of microfossil (Fig. 1f). These species characterize the Upper Vendian deposits (Redkino Regional Stage) of the Eastern European Platform.

Metaphyta

Macroscopic algal remains are relatively rare and concentrated in the more fine-grained members of the sequences noted above. Three assemblages of organically preserved macrofossils can be recognized at present (Fig. 2).

The first complex is typical of the lowermost Lyamtsa Formation. It includes small bush-shaped thalli of *Eoholynia fruticulosa* (Istchenko 1983) (Fig. 3e), round phytollems of *Beltanelloides sorichevae* with thin concentric wrinkles along their periphery (Fig. 3f) and relatively large, strap-like phytollems of *Archyfasma* sp. (Fig. 3a). The latter genus has a simple, ribbon-like morphology, a non-branched thallus, but tissue grade organization with thallus differentiation and a multilayered structure. Phytollems of archyfasmalean algae consist of a cortex layer with papillae and an inner layer of longitudinally oriented filaments (Gnilovskaya 2003). The level of complexity of these thalli is comparable with more highly complex living algae. Dispersed organic biofilms of types 'h' (Fig. 3c) and 'I' (Fig. 3b) (classification by Aseeva 1988a) were also found. This complex of macrofossils may be correlated with ones from the Mogilev Formation of Podolia (Ukraine) (Aseeva 1988a; Gnilovskaya et al. 1988). The stratigraphic level of this first association corresponds with the lower and middle part of the Upper Vendian Redkino Regional Stage.

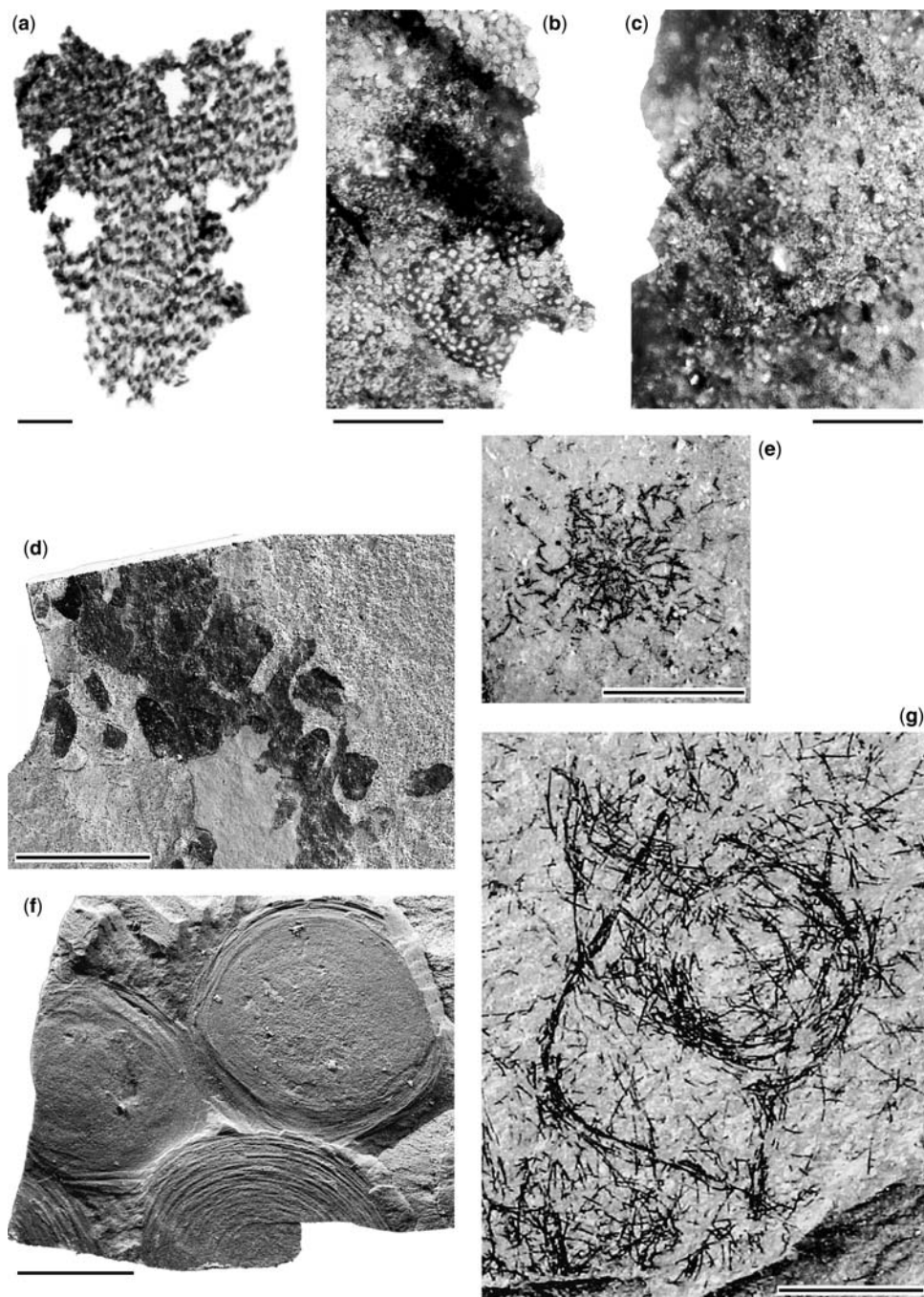


Fig. 3. Macroscopic algae from the Upper Vendian succession of the North of Arkhangelsk region. (a) *Archyfasma* sp. Fragment of macerated cortex layer of phytolima with papillar structure, lower part of Redkino Regional Stage, Lyamtsa Formation. Scale 1 mm. (b, c) Disperse organic films—fragments of algal tissues. Lower part of Redkino Regional Stage, Lyamtsa Formation. Scale 100 µm. (b) film of type 'l'. (c) film of type 'h' (classification by Aseeva 1988a). (d) *Serebrina crustacea*, crust-like thalli on the rock surface, middle part of Redkino Regional Stage, Verkhovka Formation. Scale 10 mm. (e) *Eoholynia* cf. *fruticulosa*, lower part of Redkino Regional Stage, Lyamtsa Formation. Scale 1 mm. (f) *Beltanelloides sorichevae*, imprints of phytolima on the rock surface, lower part of Redkino Regional Stage, Lyamtsa Formation. Scale 5 mm. (g) *Pilitella composita*, Kotlin Regional Stage, Yorga Formation. Scale 10 mm.

White Sea region		Regional Stages	Podolia	
Microfossils (Ragozina & Sivertseva, 1985, Ragozina & Leonov, 2004)	Macrophytes (Ragozina 2001, Gnilovskaya 2003, Leonov 2003)		Macrophytes (Gnilovskaya et al. 1988, Aseeva 1988)	Microfossils (Aseeva 1988)
		Formations	Groups	
		Mela	Kanlovka	<i>Stictosphaeridium implexum</i> Tim.; <i>Bicuspidata funiformis</i> As.; <i>Leiosphaeridia volynica</i> Tim.; <i>Cochleatina canilovica</i> ; <i>Cochleatina rara</i> (Pask.); <i>Leiosphaeridia undulata</i> Tim.; <i>Podoliella irregularis</i> Tim.; <i>Studenicia bacolica</i> As.; <i>Orygmatosphaeridium</i> sp.
<i>Oscillatorioropsis rhomboidalis</i> Shverzeva, 1985	<i>Pilitea composita</i> Aseeva, 1976	Yorga	Nagorny	<i>Pilitea composita</i> As. 1976; <i>Kalusina</i> sp.; <i>Fusosquamula viasovi</i> Aseeva, 1976; <i>Vendotaenia antiqua</i> Grill., 1974
<i>Oscillatorites wernadskii</i> Schep.; <i>Stratimorphis plana</i> As.; <i>Leiotrichoides</i> sp.; <i>Polytrichoides lineatus</i> Herm.; <i>Tortunema sibirica</i> Herm.; <i>Oscillatorioropsis magna</i> Tynni et Bonner; <i>Oscillatorioropsis funiformis</i> sp. nov.; <i>Palaeolyngbia</i> sp.; <i>L. culta</i> (Andr.); <i>L. magnum</i> (Schep.); <i>V. sp.</i> ; <i>Oscillatorioropsis constricta</i> T. et B.	<i>Serbrina crustacea</i> A. Istchenko in Gnilovskaya et al., 1988, <i>Eoholynia mosquensis</i> Gnil., 1975	Zimnie Gory	Yaryshev	<i>Serbrina crustacea</i> A. Istchenko in Gnilovskaya et al., 1988, <i>Eoholynia</i> sp.; <i>Eoholynia fruticulosa</i> A. Istchenko in Gnilovskaya et al., 1988; <i>Morania zinkovi</i> A. Istchenko in Gnilovskaya et al., 1988; <i>Ljadovites</i> A. Istchenko, 1983; <i>Beltanelloides podolicus</i> A. Istchenko in Gnilovskaya et al., 1988.
<i>Oscillatorioropsis</i> sp.; <i>Palaeolyngbia catenata</i> Herman, <i>Polytrichoides</i> sp.; <i>Striatella coriacea</i> As.; <i>Synplassosphaeridium</i> sp.; <i>Leiosphaeridia gigantea</i> (Schep.); <i>Baviniella faviculata</i> Schep.; <i>Leicminiscula minuta</i> Naum.; <i>Leiotrichoides typicus</i> Herm.; <i>Leiosphaeridia effusa</i> (Schep.)		Verkhn'-ka		<i>Oscillatorioropsis</i> sp.; <i>Oscillatorites wernadskii</i> Schep.; <i>Palaeolyngbia catenata</i> Herm.; <i>Striatella coriacea</i> As.; <i>Polytrichoides</i> sp.; <i>Ljadovia perforata</i> As.; <i>Leiosphaeridia pruniformis</i> As.; <i>Arctocellularia</i> sp.; <i>Halytrix</i> sp.; <i>Taenitrichoides jaryshevici</i> As.; <i>Tubulosa corrugata</i> As.; <i>Trematosphaeridium hottedahlii</i> Tim.; <i>Nucellosphaeridium</i> sp.; <i>Leiosphaeridia jacutica</i> (Tim.);
<i>Rudnjana</i> Golub; <i>Volyniella valdaica</i> (Schep.) As.; <i>Trachysphaeridium partiale</i> (Schep.); <i>Synsphaeridium bullatum</i> Andr.; <i>Pterospemomorphosphaeridia insolita</i> Tim.; <i>Leiosphaeridia bitumosa</i> Tim.; <i>Stictosphaeridium pectinatum</i> Tim.; <i>Gloeosapromorpha</i> sp.; <i>Leiosphaeridia pelucida</i> (Schep.); <i>Trachysphaeridium</i> Istchenko, 1988; <i>Beltanelloides bavlense</i> (Schep.); <i>Stictosphaeridium sinapiculiferum</i> Tim.; <i>Orygmatosphaeridium sorichevae</i> Sokolov, 1965; <i>rubiginosum</i> Andr.; <i>Synsphaeridium sorediforme</i> Tim.; <i>Synsphaeridium conglutinatum</i> Tim.	disperse organic films of types "h", "t", "f", <i>Eoholynia cf. fruticulosa</i> A. Istchenko, 1988; <i>Beltanelloides</i> Sokolov, 1965, <i>Archyasma</i> sp.	Lyantisa	Mogilev	<i>Rudnjana</i> Gol.; <i>Volyniella valdaica</i> (Schep.) As.; <i>Trachysphaeridium partiale</i> (Schep.); <i>Leiosphaeridia minor</i> (Schep.); <i>Leiosphaeridia pedicula</i> (Schep.); <i>Leiosphaeridia gigantea</i> (Schep.); <i>Leiosphaeridia asapha</i> (Tim.) As.; <i>Stictosphaeridium</i> sp.; <i>Leiotrichoides typicus</i> Herm.; <i>Stratimorphis rubiginosum</i> (Andr.) As.; <i>Oscillatorites wernadskii</i> Schep.; <i>Stratimorphis plana</i> As.; <i>Trachytrichoides ovalis</i> Herm.; <i>Polycavita bullata</i> (Andr.) As.; <i>Tubulosa jampolica</i> (Ass.) As.; <i>Leiosphaeridia laocata</i> (Tim.) As.; <i>Circumiella mogilevica</i> (Ass.) As.; <i>Orygmatosphaeridium flexuosum</i> (Tim.) As.; <i>Orygmatosphaeridium undulatum</i> As.; <i>Leiotrichoides gracilis</i> Pjat.; <i>Polycavita concentrica</i> As.
			Volyn	<i>Kladinella sinica</i> Tim.; <i>Leiosphaeridia parva</i> As.

Fig. 4. Provisional chart: biostratigraphic correlation of the White Sea and Podolia Upper Vendian successions.

The second association is present at several levels on the Verkhovka Formation (Yarnema, Agma, Solza and Suzma localities) and the lower member of Zimnigory Formation (Zimnie Gory locality). The most abundant forms are rounded or ellipsoidal crust-like thalli of *Serebrina crustacea* (Istchenko 1983) (Fig. 3d). Diameters of these fossils vary from 0.9–12 mm. Bush-shaped thalli described as *Eoholynia moscuensis* Gnilovskaya, 1975 are also found. Dispersed fragments of these thalli have a close similarity to the genus *Polysphaeroides* Timofeev (Aseeva 1988b) and are also found in samples from the lower Zimnigory Formation level. Such fossils are found in several assemblages, both *in situ* and in allochthonous oryctocoenoses. The large masses of cyanobacterial biofilms with filamentous microfossils were found with allochthonous clusters of this fossil. Also phytoleims of *Beltanelloides sorichevae* were observed at different levels. This association is similar to assemblages observed in the Yaryshev Formation of Podolia and the Redkino Formation of the Moscow Syncline (Gnilovskaya 1975; Istchenko 1983; Gnilovskaya *et al.* 1988), characterizing the upper part of the Redkino Regional Stage.

The third association occurs in the lower and middle mesocycles of the Yorga Formation (Zimnie Gory and Bolshaya Torozhma localities). Thin dichotomous, strap-like organic films are present. Their morphology is similar to that of some fossils in the family Vendotaeniaceae (Gnilovskaya *et al.* 1988) but this observation requires further study of microstructure for confirmation. Relatively large, bush-shaped algae, assigned to *Pilitela composita* Aseeva, 1988a (Fig. 3g) were also found at this level, forms that also characterize the Kalus beds of the Upper Vendian Nagoryany Formation of Podolia.

Summary

Almost all of the Yorga Formation (perhaps omitting the lowermost member) appears to be of early Kotlin age. This is significant because of the rich association of soft-bodied metazoans that survive into Kotlin time. It is possible now to biostratigraphically correlate between the Upper Vendian successions of Podolia (Ukraine) and the White Sea region on the basis of these macro- and microfossils (Fig. 4). It is significant that the order of appearance of macrofossil taxa is similar in regions of sufficiently different sedimentological history, often lacking corresponding facies. In future, studies of several known assemblages may allow a much more detailed biostratigraphic

subdivision of the Upper Vendian sequence, and this may have a regional or even a global application.

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