

Silicified microfossils from transitional Meso-Neoproterozoic deposits of the Turukhansk Uplift, Siberia

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ABSTRACT – *Diverse assemblages of silicified microfossils occur in black chert lenses within carbonates of the Mesoproterozoic Sukhaya Tunguska and the Neoproterozoic Burovaya and Shorikha formations, Turukhansk Uplift, northeastern Siberia. These assemblages comprise numerous species of simple filamentous and coccoidal microfossils, multicellular trichomes, thick-walled sphaeromorphic acritarchs, and less abundant, but biostratigraphically important, morphologically complex acanthomorphic acritarchs. The discovery of phytoplanktonic microorganisms in cherts of the Sukhaya Tunguska, Burovaya, and Shorikha formations contributes significantly to understanding of compositional changes in silicified microfossil assemblages across the Meso-Neoproterozoic boundary. These data enhance the biostratigraphic potential of late Precambrian silicified microbiotas and fill the gap in the microfossil succession of the Turukhansk Uplift, which is a possible location for the GSSP (Global Stratotype Section and Point) of the Meso-Neoproterozoic boundary.*

RIASSUNTO – [Microfossili silicizzati in depositi transizionali Meso-Neoproterozoici dell'alto tettonico del Turukhansk, Siberia] – *Diverse associazioni di microfossili silicizzati si trovano nelle lenti di selci nere all'interno dei carbonati della formazione mesoproterozoica Sukhaya Tunguska e delle formazioni neoproterozoiche Burovaya e Shorikha (alto tettonico di Turukhansk, Siberia nordorientale). Queste associazioni comprendono numerose specie di microfossili semplici filamentosi e coccoidali, tricomi multicellulari e acritarchi sferomorfi a parete spessa; meno abbondanti, ma biostratigraficamente significativi, sono gli acritarchi acantomorfi, morfologicamente complessi. La scoperta di organismi fitoplanctonici nelle selci delle formazioni Sukhaya Tunguska, Burovaya, e Shorikha contribuisce significativamente alla comprensione dei cambiamenti nella composizione delle associazioni dei microfossili silicei attraverso il limite Meso-Neoproterozoico. Questi dati aumentano il potenziale biostratigrafico dei microbiota silicei precambriani e riempiono la lacuna nella successione dei microfossili del Turukhansk. Questa zona può essere una possibile localizzazione per il GSSP (Global Stratotype Section and Point) del limite Meso-Neoproterozoico.*

INTRODUCTION

In recent years, significant palaeobiological changes – expressed by the so-called “Neoproterozoic revolution” – have been revealed across the Meso-Neoproterozoic (middle-late Riphean) boundary. The major biological event documented herein is explosive diversification of eukaryotic microorganisms and, as a result, the appearance of morphologically complex microfossils in Neoproterozoic deposits: acanthomorphic acritarchs, branching filaments of green algae, vase-shaped protists, thalluses of bangiophyte red algae, etc. (Jankauskas *et al.*, 1989; Knoll, 1992, 1996; Sergeev, 1992; Knoll & Sergeev, 1995). However, the above mentioned appearances recorded in particular regions was neither instantaneous nor interregionally synchronous. Moreover, a probably important component of the Neoproterozoic revolution was the so-called “hidden” expansion of morphologically simple eukaryotes into peritidal settings and their incorporation into prokaryotic ecosystems. However, such fossilized eukaryotic unicellular microorganisms are, at the present level of knowledge, indistinguishable from prokaryotes. Therefore, this suggestion is based mainly on indirect evidences, e.g., by decline of entophyalidacean and nosto-

calean akinet-producing cyanobacteria in Neoproterozoic silicified microbiotas of peritidal settings (Sergeev *et al.*, 1995; Knoll & Sergeev, 1995; Sergeev, 1997).

Correct identification of these events requires detailed studies of the least-altered Proterozoic stratal sequences containing diverse and representative microbiotas near the Meso-Neoproterozoic boundary. Particularly pertinent in this regard is the Meso-Neoproterozoic sequence of the Turukhansk Uplift, northeastern Siberia, which includes a succession of diverse and well-preserved assemblages of stromatolites and organic-walled and silicified microfossils. Here, the organic-walled microbiotas are among the world's most diverse and best-known (German, 1974, 1990; Jankauskas *et al.*, 1989), but for a long time the associated silicified microbiotas were considered poorly preserved and of low diversity (Mendelson & Schopf, 1982; Sergeev, 1984; Golovenok & Belova, 1993). However, the present author's current and published data (Sergeev *et al.*, 1997; Sergeev, in press) reveals that the Turukhansk silicified microbiotas are represented by coccoidal unicellular microfossils of cyanobacterial or eukaryotic origin, thick-walled sphaeromorphic acritarchs, and morphologically complex acanthomorphic acritarchs. The discovery of

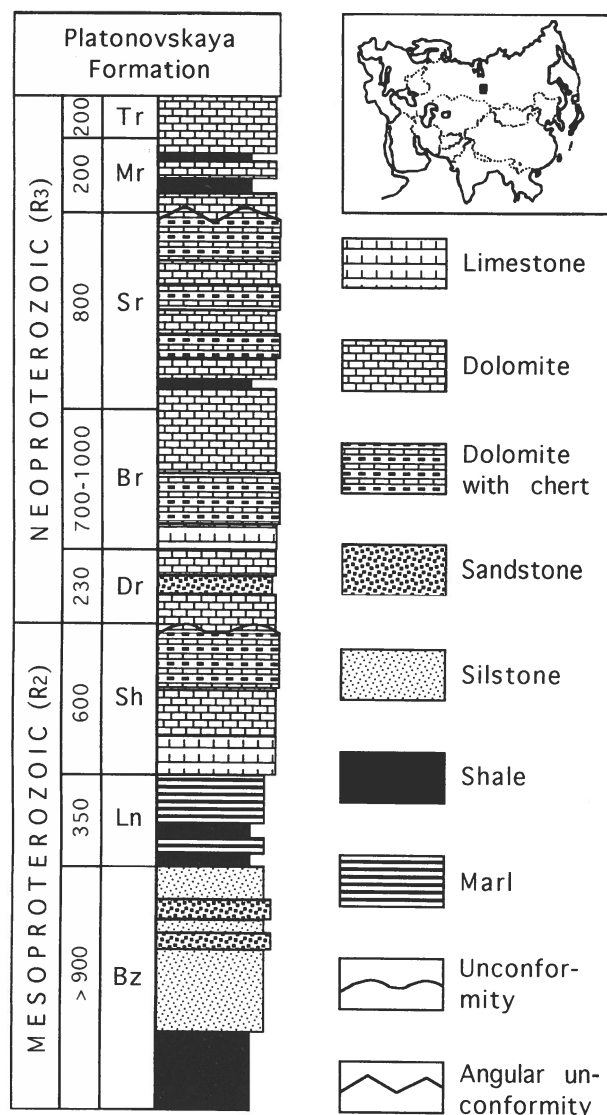
phytoplanktonic microorganisms in the cherts of the Sukhaya Tunguska, Shorikha, and Burovaya Formations provides new important information about the composition of the microfossil assemblages of the Turukhansk Riphean succession and increases the biostratigraphic potentiality of the upper Precambrian silicified microbios.

REGIONAL GEOLOGY AND AGE

The Turukhansk Uplift is located near the north-western margin of the Siberian Platform (Text-fig. 1). The upper Precambrian (Riphean and Vendian) deposits in this region constitute a westward-deeping monocline or asymmetrical syncline (130-150 km long; up to 30 km wide) delimited by three major and a series of minor meridionally trending thrust faults. The exposed portion of the Mesoproterozoic to Neoproterozoic (late middle to early late Riphean) sedimentary package (up to 4 km thick) begins with the siliciclastic Bezmyannyi Formation which grades up-section into the carbonate-dominated Linok and Sukhaya Tunguska formations. The succeeding, predominantly or exclusively carbonate part of the succession is preceded by an erosional unconformity and embraces the Derevnya, Burovaya, Shorikha, Miroyedikha, and Turukhansk formations (Text-fig.1). The entire Riphean Turukhansk succession is overlain unconformably by terminal Proterozoic (Vendian) to Lower Cambrian rocks of the Platonovskaya and Kostino formations (Dragunov, 1963; Semikhatov & Serebryakov, 1983).

Dating of the Turukhansk succession is based on radiometric, palaeontological, and chemostratigraphic data. A 16-points Pb-Pb isochron for the middle Sukhaya Tunguska carbonates yielded an age of 1035 ± 60 Ma (Ovchinnikova *et al.*, 1995); and the K-Ar age determinations on glauconite from various formations suggest that the entire succession was affected about 850 Ma ago by a low-temperature event related to uplift and partial unroofing (Semikhatov & Serebryakov, 1983; Gorokhov *et al.*, 1995). This is supported by recent C-isotopic chemostratigraphic data which demonstrate the absence of late Neoproterozoic deposits younger than 850-800 Ma from the Turukhansk Riphean succession (Knoll *et al.*, 1995).

The organic-walled microfossils constitute three diverse and abundant assemblages confined to the Bezmyannyi, Derevnya, and Miroyedikha formations and yield important chronostratigraphic information on the Turukhansk Uplift sequence. The Bezmyannyi assemblage, characterized mainly by long-ranging and morphologically simple forms, contains large (up to 1000-1500 μ m) acritarchs (*Leiosphaeridia jacutica* (Timofeev) Mikhailova & Jankauskas, 1989 and *Chuarina circularis* Walcott, 1899); colonial coccoidal *Ostiana microcystis* German, 1976; filamentous ribbon-like *Asperato-*



Text-fig. 1 - Generalized stratigraphic column of the Meso-Neoproterozoic (middle-upper Riphean) deposits of the Turukhansk Uplift. The latter area is shown as a black square on the inset map of Eurasia. Formation names abbreviated as follows: Bz = Bezmyannyi; Ln = Linok; Sh = Sukhaya Tunguska; Dr = Derevnya; Br = Burovaya; Sr = Shorikha; Mr = Miroyedikha; Tr = Turukhansk. Formation thicknesses in metres.

filum exuperatus (German) German, 1989 and *Taenitrichoides jaryschevicus* Assejeva, 1983; broad, longitudinally striated thalluses and several other complex morphotypes (Veis & Petrov, 1994, and references cited therein). Veis (1988), among others, dated this assemblage as late Riphean (early Neoproterozoic); however, this conflicts with its characteristic lower-middle Riphean (Mesoproterozoic)

appearance (Sergeev *et al.*, 1995, 1997). The assemblage also contains small problematical spiny forms of *Trachyhystrichosphaera parva* Mikhailova, 1989, but large representative acanthomorphic acritarchs attributed to the Neoproterozoic index genus *Trachyhystrichosphaera* Timofeev & German, 1976 appear only higher in the succession, in the Derevnaya Formation. Microbiota recorded in the Derevnaya Formation are represented by abundant acanthomorphic acritarchs (*Trachyhystrichosphaera aimika* German, 1976 and *Prolatiforma aculeata* Mikhailova, 1989) together with large thalluses of *Ulophyton ripheicum* Timofeev & German, 1979, *Majaphyton antiquum* Timofeev & German, 1976, and *Archeoclada prima* German, 1989 and several other morphotypes known to be widely distributed in upper Riphean (early Neoproterozoic) deposits of Siberia and elsewhere (German, 1990; Petrov & Veis, 1995, and references cited therein). The Miroyedikha assemblage of organic-walled microfossils includes all the above-mentioned taxa. It demonstrates further size and diversity increase among coccoidal forms and trichoms; appearances of new representatives (e.g., *Cymatio-sphaeroides* sp., *Cerebrosphaera* sp., *Cephalonyx sibiricus* Weiss, 1984, *Pellicularia* sp., *Pseudotawuia* sp.); and introduction of a distinctive set of complex, as yet undescribed forms (German, 1974, 1990; Veis *et al.*, 1998). Thus, the organic-walled microfossil assemblages indicate a Neoproterozoic age for the Derevnaya and younger formations and connote a Mesoproterozoic age for the pre-Derevnaya sequence. Moreover, as discussed below, the silicified microfossil suites confirm this conclusion.

Stromatolites in the lower part of the Turukhansk succession are represented by endemic middle-upper Riphean (Meso-Neoproterozoic) form genera, whereas the Derevnaya Formation contains distinctive and cosmopolitan taxa known to appear in the lower upper Riphean. The post-Derevnaya sequence includes both endemic and cosmopolitan upper Riphean (Neoproterozoic) form genera (Semikhatov, 1991; Shenfil', 1991). The unconformably overlying Platonovskaya Formation is attributed to the late Vendian based on C-isotopic, chemostratigraphic, and palaeontological data (Bartley *et al.*, 1998). Accordingly, the entire pre-Platonovskaya part of the Turukhansk succession is dated as late middle-early late Riphean (Meso-Neoproterozoic, pre- "Neoproterozoic-III"); and it seems likely that the Meso-Neoproterozoic (middle-upper Riphean) boundary separates the Sukhaya Tunguska and Derevnaya formations.

COMPOSITION OF THE TURUKHANSK SILICIFIED MICROBIOTAS

Silicified microbiotas occur in the Sukhaya Tunguska, Shorikha, and Burovaya formations of the Turukhansk Uplift and exhibit important variations in taxonomic composition.

THE SUKHAYA TUNGUSKA MICROBIOTA

The Sukhaya Tunguska microbiota (Text-fig. 2) is dominated by morphologically simple cyanobacterial cells, trichomes, and sheaths; but some simple spheroids may be eukaryotic (Sergeev *et al.*, 1997). Several orders of cyanobacteria are recognized in the Sukhaya Tunguska cherts. Five taxa (*Calypthothrix* sp., *Eomicrocoleus* sp., *Uluksanella* sp., *Oscillatoriaopsis media* Mendelson & Schopf, 1982, *Palaeolyngbya* sp.) are assigned to the Oscillatoriales; *Archaeoellipsoides dolichos* (Zhang), Sergeev *et al.*, 1985 is interpreted as the preserved akinete of a nostocalean cyanobacterium; and four taxa [*Siphonophycus robustum* (Schopf) Knoll *et al.*, 1991, *S. typicum* (German) Butterfield, 1994, *S. solidum* (Golub) Butterfield, 1994, *Circumvaginalis* sp.] belong to either the Oscillatoriales or the Nostocales. The Chroococcales are represented by *Eoaphanocapsa oparinii* Nyberg & Schopf, 1984, *Gloeodiniopsis lamellosa* Schopf, 1968, *Gyalosphaera golovenokii* Sergeev & Knoll, 1997, *Eosynechococcus moorei* Hofmann, 1976, *E. medius* Hofmann, 1976, *Sphaerophycus medium* Horodyski & Donaldson, 1980 and *S. parvum* Schopf, 1968. *Eoentophysalis arcata* Mendelson & Schopf, 1982 and *E. sp. cf. E. belcherensis* belong to the Entophysaliales and the Pleurocapsales are represented by *Polybessurus bipartitus* Fairchild, 1975 ex Green *et al.*, 1987. *Myxococcoides minor* Schopf, 1968, *M. inornata* Schopf, 1968, *M. grandis* Horodyski & Donaldson, 1980, *Myxococcoides* sp. 1., and *Leiosphaeridia* sp. are simple spheroidal fossils that could be variously interpreted: as preserved protistan cells, cyanobacterial cell walls, or extracellular envelopes of coccoidal cyanobacteria. The predominance of cyanobacteria in the Sukhaya Tunguska Formation reflects the restricted, peritidal environment of its early diagenetic silica nodules (Petrov *et al.*, 1995). By contrast, the open-marine shelf deposits of the lower member of that formation (Petrov *et al.*, 1995) yields the true phytoplanktonic microorganisms, e.g., double-walled vesicles up to 320 µm in diameter (Pl. 1, figs. 1, 2). These fossils are similar morphologically and in size to the Neoproterozoic acanthomorphic acritarchs of the genus *Trachyhystrichosphaera* Timofeev & German in Timofeev *et al.*, 1976, which are double-walled vesicles with inner and outer envelopes connected by processes that arise from the inner envelope and are commonly truncated at the outer one. But the Sukhaya Tunguska microfossils do not show the processes supporting the outer envelope and, therefore, these microorganisms were described as unnamed planktonic forms (Sergeev *et al.*, 1997). Accepting such morphological variability and its stratigraphic position, the specimens from the Sukhaya Tunguska Formation are among the world's oldest phytoplanktonic *Trachyhystrichosphaera*-like microorganisms. It could be assumed that the ancestors of the Neoproterozoic acanthomorphic acritarchs

Phylum CYANOBACTERIA					Relative abundance		
Class HORMOGONEAE					AB = Abundant		
Order OSCILLATORIALES					CO = Common RA = Rare		
Order NOSTOCALES							
Class COCCOGONEAE					Sh-Sukhaya Tunguska Fm		
Order CHROOCOCCALES					Br-Burovaya Formation		
Order PLEUROCAPSALES					Sr-Shorikha Formation		
INCERTAE SEDIS					Sh	Br	Sr
 <i>Siphonophycus robustum</i>			N	O	AB	AB	AB
 <i>Siphonophycus typicum</i>			N	O	AB	AB	AB
 <i>Siphonophycus solidum</i>			N	O	CO	CO	RA
 <i>Palaeolyngbya</i> sp.				O	RA		
 <i>Calyptothrix</i> sp.				O	RA		
 <i>Uluksanella</i> sp.			N	O	CO		
 <i>Eomicrocoleus</i> sp.				O	CO		
 <i>Eomicrocoleus crassus</i>				O		CO	
 <i>Oscillatoriopsis obtusa</i>				O		RA	
 <i>Oscillatoriopsis media</i>				O	RA		CO
 <i>Oscillatoriopsis</i> sp.				O			RA
 <i>Partitiofilum</i> sp.				O			RA
 <i>Circumvaginalis</i> sp.			N	O	RA		
 <i>Archaeoellipsoides dolichos</i>			N		CO		
 <i>Archaeoellipsoides</i> sp ₁ .			N			CO	
 <i>Archaeoellipsoides</i> sp ₂ .			N				RA
 <i>Coniunctiophycus conglobatum</i>			C		CO		
 <i>Sphaerophycus parvum</i>			C		CO		
 <i>Sphaerophycus medium</i>			C		CO		
 <i>Eoaphanocapsa oparinii</i>			C		CO		
 <i>Gloeodiniopsis lamellosa</i>			C		CO	AB	
 <i>Gyalosphaera golovenokii</i>			C		CO		
 <i>Eosynechococcus moorei</i>			C		CO		
 <i>Eosynechococcus medius</i>			C		CO		
 <i>Eosynechococcus grandis</i>			C				CO
 <i>Eoentophysalis arcata</i>			C		CO		
 <i>Eoentophysalis</i> cf. <i>E. belcherensis</i>			C		RA		
 <i>Polybessurus bipartitus</i>			P		RA		
 <i>Polysphaeroides contextus</i>		I				RA	
 <i>Myxococcoides minor</i>		I			CO		CO
 <i>Myxococcoides inornata</i>		I			CO		CO
 <i>Myxococcoides grandis</i>		I			CO		
 <i>Myxococcoides stragulescens</i>		I					AB
 <i>Myxococcoides</i> sp ₁ .		I				RA	
 <i>Myxococcoides</i> sp ₂ .		I					CO
 <i>Scissilisphaera gradata</i>		I	P				AB
 <i>Pterospermopsimorpha</i> ? sp.		I					RA
 <i>Trachyhystrichosphaera parva</i>		I					CO
 <i>Leiosphaeridia jacutica</i>		I					CO
 <i>Leiosphaeridia</i> sp.		I			CO		
 Unnamed planktonic form		I			RA		
 Problematic vase-shaped form		I				RA	
 Problematic spiny form		I					CO

Text-fig. 2 - Check-list of silicified microfossils in the Sukhaya Tunguska, Burovaya, and Shorikha formations of the Meso-Neoproterozoic succession in the Turukhansk Uplift.

were doubled-walled vesicles without spines, and that the processes evolved subsequently and originally had a purely mechanical function to support the outer membrane against hydrostatic pressure (Sergeev, 1996). However, this is just a suggestion, not a comprehensive theory.

THE BUROVAYA FORMATION MICROBIOTA

The Burovaya Formation microbiota is dominated by abundant empty sheaths of hormogonian cyanobacteria; viz., *Siphonophycus robustum*, *S. typicum*, and *S. solidum*. It also contains threads of oscillatorian cyanobacteria (*Oscillatoria obtusa* Schopf, 1968 and *Eomicrocoleus crassus* Horodyski & Donaldson, 1980), together with sheath-less filaments from the spherical cells of *Polysphaeroides contextus* German, 1976 interpreted either as branching filaments of stigonematalean cyanobacteria or thalluses of chromophytic algae, e.g., green algae.

The coccoidal microfossils are represented by the common Proterozoic cyanobacterium *Gloeodiniopsis lamellosa*. The simple spheroids of *Myxococcoides* (70–100 µm in diameter) are probably microplankton remains. The ellipsoidal microfossils (*Archaeo-ellipsoides* sp. 1: Pl. 1, fig. 3) are comparable to akinetes of *Anabaena*-like cyanobacteria (Sergeev *et al.*, 1995) or, due to large size, they could be interpreted as eukaryote cysts. The Burovaya microbiota also contains problematical, poorly-preserved, large, ellipsoidal microfossils (Pl. 1, fig. 4) which could be either akinetes of cyanobacteria or vase-shaped protists comparable to the Neoproterozoic form *Melanocyrrillum* Bloeser, 1985. The latter genus has been interpreted as representative of either unicellular heterotrophic protists or eukaryotic algae (Bloeser, 1985). Further investigations of these fossils, extracted from the rock matrix per hydrofluoric acid treatment and examined under SEM, are necessary to help solve this question.

The scarcity of eukaryotic remains in the Burovaya cherts is more a manifestation of the somewhat peritidal environments of the early diagenetic chert nodules (Petrov & Semikhatov, 1998) than of the overall taxonomic composition of the Neoproterozoic ecosystems.

THE SHORIKHA FORMATION MICROBIOTA

The Shorikha Formation microbiota constitutes the most diverse assemblage of silicified eukaryotic microphytoplankton in the entire Turukhansk succession. Simple spheroids of *Myxococcoides stragulescens* Green *et al.*, 1989 are predominant; their interpretation is unclear, but many of their features suggest a relationship to modern *Dunaliella*-like green algae (Green *et al.*, 1989). Another abundant Shorikha form is the coccoidal microfossil *Scissilisphaera gradata* Green *et al.*, 1989; this is com-

parable to pleurocapsalean cyanobacteria (Green *et al.*, 1989), but alternatively it could be interpreted as a green alga. Also common in the Shorikha microbiota are such forms as *Myxococcoides minor* and *M. inornata*, the biological affinities of which are difficult to interpret owing to their morphological simplicity. The empty sheaths of hormogonian cyanobacteria are widespread in the Shorikha cherts and are represented by *Siphonophycus robustum*, *S. typicum*, and *S. solidum*. Moreover, the cherts contain the trichomes of the hormogonian cyanobacteria *Oscillatoria media*, *O. sp.*, and *Partitiofilum* sp.

Stratigraphically, the most important taxon of the Shorikha assemblage is the acanthomorphic acritarch *Trachyhystrichosphaera parva* (Pl. 1, figs. 5, 6) with vesicle diameter of 50–90 µm. This species has been reported from numerous late Mesoproterozoic and Neoproterozoic formations in Siberia, the southern Urals, and the East European Platform (Jankauskas *et al.*, 1989). The Shorikha biota contains mostly smaller doubled-walled microfossils (vesicle diameter: 5–65 µm) having problematical spines (Pl. 1, figs. 9, 10). These spines may be of a secondary origin, resulting from post-mortem degradation or diagenetic alteration; e.g., during the deformation of primarily smooth surfaces of *Gloeodiniopsis*-like or *Myxococcoides*-like cells by diagenetically growing crystals of dolomite or magnesite (Sergeev, 1992, 1994; Sergeev *et al.*, 1995; Knoll, 1996).

Other stratigraphically important Shorikha microfossils are doubled-walled and relatively large envelopes (up to 280 µm in diameter) without spines between inner and outer layers (Pl. 1, fig. 7). These have been identified as *Pterospermopsimorpha?* sp., showing resemblance to species of that genus and to other microfossils described from several Neoproterozoic formations, e.g. the Ryssö Formation of Spitsbergen (Knoll & Calder, 1983). The dark spherical envelopes of *Leiosphaeridia jacutica* (70–210 µm in diameter) are encountered less frequently in the Shorikha assemblage; these can also be regarded as remnants of eukaryotic microphytoplankton possessing a robust thick wall typical of eukaryotes (Pl. 1, fig. 8).

BIOSTRATIGRAPHIC SIGNIFICANCE

The microbiotas from the Turukhansk succession demonstrate significant changes in the taxonomic composition across the Meso-Neoproterozoic boundary, as known coevally elsewhere. The oldest problematical acanthomorphic acritarchs came from the lower member of the Sukhaya Tunguska Formation. These are similar in size and morphology to Neoproterozoic acanthomorphic acritarchs attributable to *Trachyhystrichosphaera* and also to *Shuiyousphaeridium* Yan, 1992. The latter was described from the probably late Mesoproterozoic Ruyang and Gaoshanhe groups of China (Yan &

Zhu, 1992; Xiao *et al.*, 1997). However, Mesoproterozoic deposits have been lesser studied than those of Neoproterozoic age; hence the occurrence of these acanthomorphic problematica in the basal part of the Turukhansk succession cannot be considered precisely age-definitive. Nevertheless their presence does provide useful information on the first appearance and early evolution of acanthomorphic acritarchs. The genuine acanthomorphic acritarch species *Trachyhystrichosphaera aimika* appears only in the overlying Derevnya Formation of indubitable Neoproterozoic (late Riphean) age. Another stratigraphically efficacious microfossil in the Sukhaya Tunguska assemblage is the stalked cyanobacterium *Polybessurus bipartitus*. This species first appears in the late Mesoproterozoic and occurs widely in Neoproterozoic assemblages elsewhere (Green *et al.*, 1989; Sergeev, 1992, 1994; Butterfield *et al.*, 1994).

The Burovaya assemblage is dominated by filamentous and coccoidal microfossils, mainly remnants of cyanobacteria. In addition to these evolutionary conservative and stratigraphically long-ranging forms, the Burovaya assemblage contains the problematical vase-shaped microfossils, possibly protists of uncertain affinity, and branching filaments of *Polysphaeroides contextus*. The vase-shaped elements, referred to *Melanocyrrillium* appear in Neoproterozoic (800-850 Ma) deposits of North America and Europe (Knoll, 1996); this is in general agreement with the inferred age of the Burovaya Formation. The branching filaments of *Polysphaeroides contextus* - possible remnants of eukaryotic algae - are well-known from the Neoproterozoic (German, 1990).

The Shorikha microbiota includes many morphologically complex eukaryotic microphytoplankton, as well as chroococcoidal and hormogonial cyanobacteria. The emergence of acanthomorphic and other morphologically complex acritarchs is one of the principal manifestations of major diversification of eukaryotes about 1000 Ma. Indeed, some researchers have suggested that the introduction of acanthomor-

phic acritarchs (of the genus *Trachyhystrichosphaera*) may be used as a criterion to mark the lower boundary of the Neoproterozoic or of the upper Riphean (Knoll, 1992; Sergeev, 1992; Butterfield *et al.*, 1994; Semikhatov, 1995). However, because of the discovery of acanthomorphic acritarchs in Chinese deposits of probable Mesoproterozoic age (Yan & Zhu, 1992; Xiao *et al.*, 1997), the presence of a spiny microfossil alone cannot be regarded as signifying a Neoproterozoic or younger age. The Shorikha microphytoplankton microfossils are, in general, diagnostic of Neoproterozoic age. The doubled-walled *Pterospermopsimorpha*-like envelopes, the acanthomorphic acritarchs *Trachyhystrichosphaera parva*, and the large robust envelopes of *Leiosphaeridia jacutica* are known from many sequences of Neoproterozoic age (Jankauskas *et al.*, 1989; Sergeev, 1992; Knoll & Calder, 1983; Butterfield *et al.*, 1994); nonetheless, the last-mentioned taxon occurs also in older deposits.

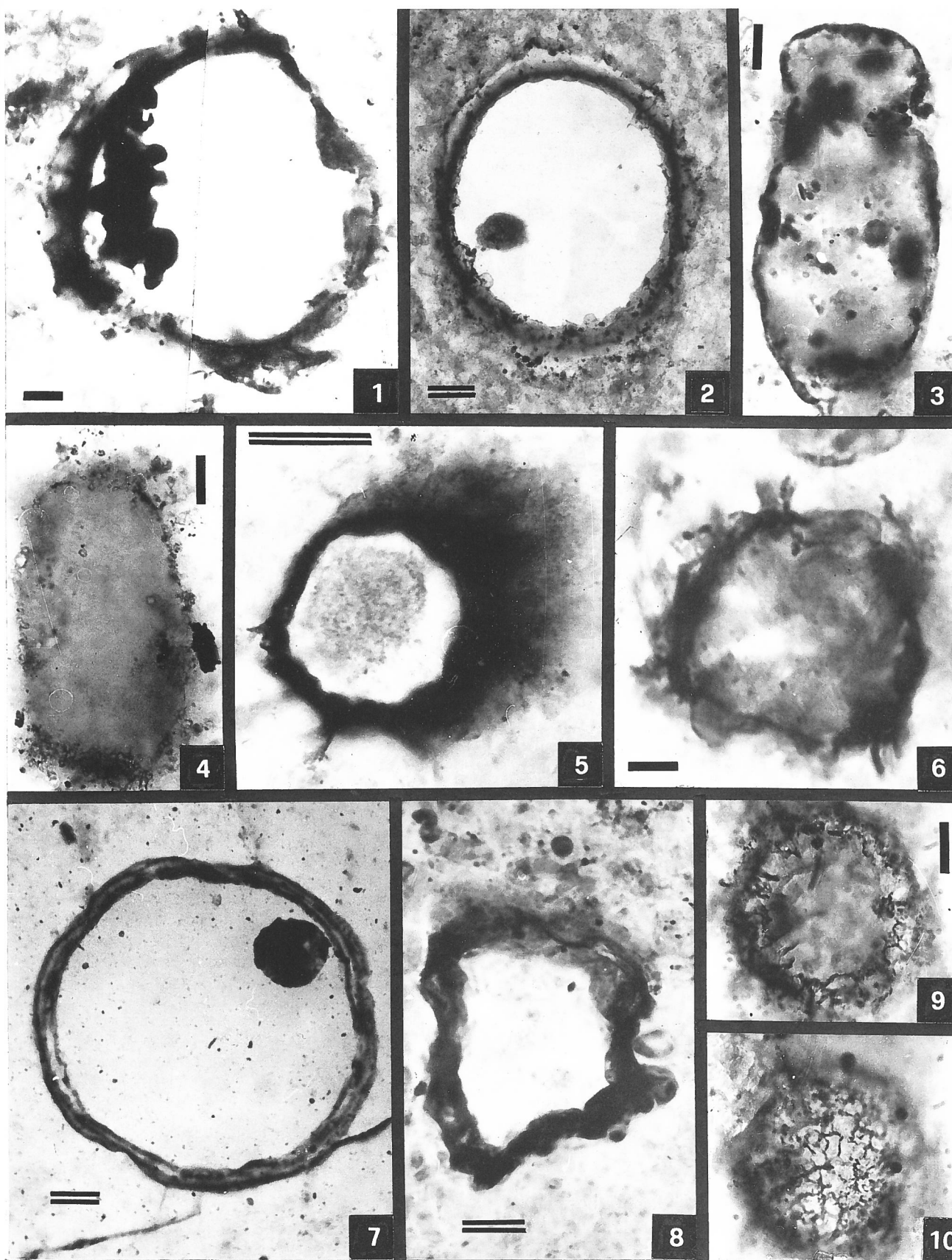
The spherical forms *Myxococcoides stragulescens* and *Scissilisphaera gradata* from the Shorikha Formation may be of both stratigraphic and evolutionary importance. Despite the simplicity of these fossils, Green *et al.* (1989) have suggested that they could prove to be remnants of green algae. Entophysalidacean cyanobacteria, which are widespread and abundant in Paleo- and Mesoproterozoic assemblages, are absent in most Neoproterozoic silicified microbiotas of peritidal settings (Hofmann, 1976; Knoll & Sergeev, 1995; Sergeev *et al.*, 1995, 1997), including those from the Burovaya and Shorikha formations. Absence of entophysalidacean cyanobacteria in the Shorikha microbiota as well as dominance therein of *M. stragulescens* and *S. gradata* (possible remnants of eukaryotic unicellular organisms) seem to be of evolutionary and environmental significance and a probable reflection of the "hidden" expansion (see above) of morphologically simple eukaryotic microorganisms in prokaryotic ecosystems (Knoll & Sergeev, 1995; Kah & Knoll, 1996; Sergeev, 1997).

EXPLANATION OF PLATE 1

- Figs. 1, 2 - Unnamed planktonic form, Sukhaya Tunguska Formation. 1) Sample 661, slide 69, p.1, GINPC 500. 2) Sample 690, slide 69, p.1, GINPC 501.
 Fig. 3 - *Archaeoellipsoides* sp. 1, Burovaya Formation. Sample 47, slide 747, p. 8, GINPC 621.
 Fig. 4 - Problematic vase-shaped form, Burovaya Formation. Sample 47, slide 747, p. 9, GINPC 626.
 Figs. 5, 6 - *Trachyhystrichosphaera parva* Mikhailova, 1989, Shorikha Formation. 5) Sample 110, slide 758, p. 2, GINPC 613. 6) Sample 110, slide 754, p. 8, GINPC 612.
 Fig. 7 - *Pterospermopsimorpha?* sp., Shorikha Formation. Sample 110, slide 754, p. 7, GINPC 611.
 Fig. 8 - *Leiosphaeridia jacutica* (Timofeev) Mikhailova & Jankauskas, 1989, Shorikha Formation. Sample 509, slide 849, p. 22, GINPC 615.
 Figs. 9, 10 - Problematic spiny form, Shorikha Formation. Sample 110, slide 759, p. 15, GINPC 637.

(Coordinates refer to the numbers of the points at the strips of paper attached at the end of the thin sections).

Illustrated specimens are deposited in the Paleontological Collection of the Geological Institute of Russian Academy of Sciences (GINPC) #4694. Scale of figures: single bar = 10 µm; double bar = 50 µm.



CONCLUSIONS

The silicified microbiotas of the Sukhaya Tunguska, Burovaya, and Shorikha Formations are dominated by morphologically simple filaments and coccoids interpreted mainly as remnants of hormogonian and chroococcacean cyanobacteria. Subordinate, but biostratigraphically important taxa in these assemblages are remains of eukaryotic microorganisms; these include morphologically complex phytoplankton and the first acanthomorphic acritarchs. Appearance of these new taxa, particularly the acanthomorphic acritarch *Trachyhystrichosphaera*, marks an important change in the late Precambrian microbiota at the Mesoproterozoic-Neoproterozoic (middle-upper Riphean) transition (Knoll & Sergeev, 1995; Semikhatov, 1995). The occurrence of these taxa increases the biostratigraphic potential of silicified Precambrian microbiotas, which were traditionally considered to be composed only of morphologically simple and conservative microfossils of negligible stratigraphic importance. The data obtained complete one of the world's best-known transitional Meso-Neoproterozoic microfossil successions, effectively filling the gap between Derevnya and Miroyedikha organic-walled microbiotas with the relatively diverse silicified assemblages from the Burovaya and Shorikha formations. Overall, organic-walled and silicified microbiotas are now recorded from the following units of the Turukhansk Upper Precambrian sequence: the Bezmyannyi, Sukhaya Tunguska, Derevnya, Burovaya, Shorikha, and Miroyedikha formations. The observed changes in the taxonomic composition of these microbiotas are characteristic for the transitional Meso-Neoproterozoic microbiotas elsewhere and reflect a major radiation and diversification of unicellular eukaryotic microorganisms across the Meso-Neoproterozoic (Middle-Upper Riphean) boundary.

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