Real Eukaryotes and Precipitates First Found in the Middle Riphean Stratotype, Southern Urals

V. N. Sergeev* and Lee Seong-Joo**

*Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia
**Geological Faculty, Kyungpook National University, Taegu, 702-701 Republik of Korea
Received December 27, 2004; in final form, February 10, 2005

Abstract—New investigations considerably extended taxonomic list of microbiotas from cherts of the Kataskin and Revet subformations of the Avzyan Formation in the Yurmata Group, the Middle Riphean stratotype in southern Urals. It is recognized in distinction from previous works that found remains of eukaryotic unicellular organisms represent a considerable percentage of fossil microbial population buried in the Kataskin Subformation. In addition to cyanobacteria known before, cherts of the subformation yielded fossil microorganisms representing eukaryotic phytoplankton. These remains described formerly as organic-walled microfossils from siliciclastic sediments of the Zigazino-Komarovo and Avzyan formations had not been known from cherty–carbonate strata of the Middle Riphean. The discovery is consistent with recent data on microfossils of complex morphology present in silicified microbiotas, which has been regarded as prokaryotic exclusively. Layered inorganic precipitates found for the first time in the Kataskin Subformation are widespread in pre-Upper Riphean successions and disappear near the Middle–Upper Riphean boundary. Besides, silicified cyanobacterial remains described formerly from the Avzyan Formation are revised, and their formal composition is corrected in accord with the present-day classification of fossil blue-green algae. The correction results and new microfossils found elucidate microphytological characterization of the Middle Riphean that is important for biostratigraphic correlation of Proterozoic deposits and helps to solve some problems of taxonomy of Precambrian microfossils. The assemblage of microfossils from the Avzyan Formation offers a unique opportunity to understand a transitional moment in history of Proterozoic microorganisms, when entophysalidacean and stalked cyanobacteria developed jointly parallel to expansion of eukaryotic unicellular algae into prokaryotic ecosystems. The work includes description of 10 microfossil species attributed to 7 genera.

DOI: 10.1134/S0869593806010011

Key words: microfossils, cyanobacteria, prokaryotes, eukaryotic phytoplankton, Middle Riphean, Riphean type succession, southern Urals.

INTRODUCTION

The Riphean type succession exposed in the western limb of Bashkirian meganticlinorium, the southern Urals, is of priority significance for biostratigraphy of the Precambrian, because microfossil and stromatolite assemblages identified here represent the comparison standards for successive biotas of that time, which are established in other regions. At present, microphytological characterization of the Riphean stratotype is based on diverse organic-walled (Yankauskas, 1979a, 1979b, 1982; Keller and Yankauskas, 1980; Veis *et al.*, 1990; 2000; 2003) and silicified microfossils (Schopf *et al.*, 1977, 1979; Nyberg and Schopf, 1984; Sergeev and Krylov, 1986; Krylov and Sergeev, 1986; Sergeev, 1988, 1992a, 1992b, 1994, 2003; Sergeev and Lee Seong-Joo, 2004). Organic remains of both types belong to several successive assemblages of different taxonomic composition, which are indicative of certain stages in evolution of microorganisms during the Late Precambrian. According to modern demands however, biostratigraphy of the Riphean type and reference sections must be clarified further based on research of new collections and reexamination of formerly described materials. Moreover, the taxonomy of microfossils has been recurrently revised during the last 10–15 years, and Uralian microbiotas described before need in a formal correction of their taxonomic composition. Consequently, it is necessary to pay attention once more to the Riphean stratotype of southern Urals in order to get a deeper insight into its microphytological characterization based on materials collected recently and parallel reexamination of microbiotas described before at the modern level of understanding. Chert samples perspective for discovery of microfossils have been collected from the Riphean type section of the Urals during the field seasons of 1998–2000 and 2003. New data on silicified microfossils from the Lower Riphean Satka Formation are already published (Sergeev and Lee Seong-Joo, 2004). In this work, we present new information on taxonomic composition and stratigraphic interpretation of silicified microbiota from the Avzyan Formation of the Middle Riphean stratotype.
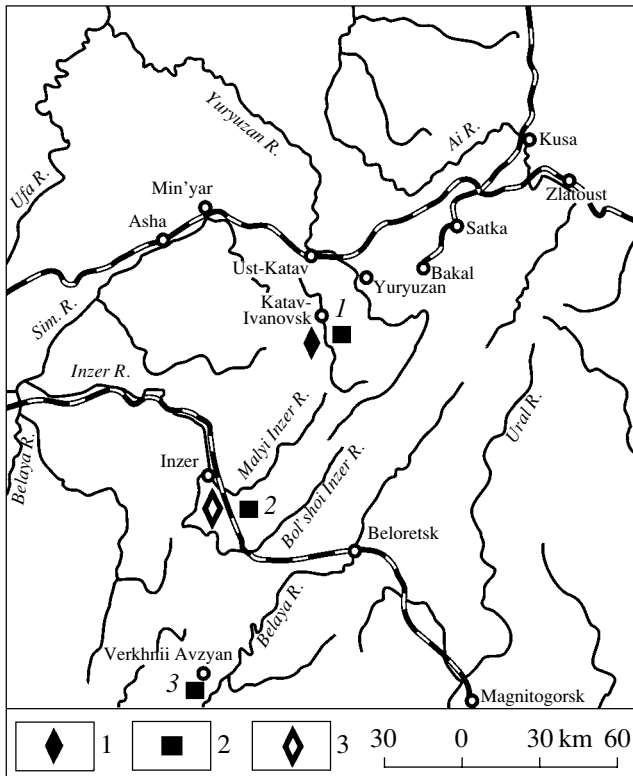
Fig. 1. Studied localities of microfossils from the Avzyan Formation, southern Urals: (1) exposure of the Kataskin Subformation sediments with microfossils; (2) exposures of the Revet Subformation sediments with microfossils; (3) exposure of the Kataskin Subformation sediments, where microfossils have not been discovered.

STRUCTURE AND AGE LIMITS OF THE MIDDLE RIPHEAN TYPE SUCCESSION

Stratigraphy of Middle Riphean deposits. The Riphean type succession up to 15 km thick in total is composed of weakly altered sedimentary and subordinate volcanogenic rocks, which are divided into the Burzyan, Yurmata, and Karatau groups separated by unconformities. The groups representing large sedimentary cycles are authorized as stratotypes of the Lower, Middle, and Upper Riphean respectively (Figs. 1 and 2). The Yurmata Group corresponding to the Middle Riphean type section consists of four conformable subdivisions: the Mashak (siliciclastic and volcanogenic rocks 1500–2000 m thick), Zigal'ga (predominantly quartz sediments 200 to 600 m thick), Zigazino-Komarovo (sandstones and shales 650–1500 m thick), and Avzyan formations (shale–carbonate succession 900–1800 m thick).

The Avzyan Formation of dolostones, calcareous dolostones and limestones, which are intercalated with shale, siltstone and sandstone members and interlayers, is divided in turn into the Kataskin, Malyi Inzer, Ushakovo, Kutkur, Revet, and Tyul'men subformations.

The Kataskin Subformation is composed predominantly of dark gray dolostones, calcareous dolostones, and limestones. Subordinate rocks are shales and less frequent siltstones and sandstones. Carbonate rocks enclose lenses and interlayers of black cherts containing microfossils. In dolostones, there are magnesite and limonite sheet deposits, which originated after siderite oxidation. The subformation is 350–750 m thick.

The Malyi Inzer Subformation of gray to brown-gray quartz and arkosic sandstones and siltstones with intercalations of quartz-sericite-clay and sericite-chlorite-clay slates is 250 to 400 m thick.

The Ushakovo Subformation is represented by gray to dark gray dolostones and dolomitic limestones containing interlayers of sericite-quartz-clay slates. Carbonate rocks also enclose lenses of black and gray cherts, which are found to be barren of microfossils. The subformation is 80–250 m thick.

The Kutkur Subformation of green to bluish green and dark red quartz-sericite-clay shales encloses subordinate interlayers of gray to greenish gray siltstones and sandstones. In its upper part, there are dolostone interbeds and local sheet deposits of brown iron ore. The subformation is 100–250 m thick.

The Revet Subformation is composed mostly of gray to pinkish gray dolostones, less frequent dolomitic limestones, and subordinate thin shale interbeds. Characteristic of the subformation are stromatolitic bioherms of *Baicalia, Jacutophyton*, and other stromatolite forms. Dolostones lacking stromatolites contain lenses of white, gray, and black cherts. Black cherts confined predominantly to the upper subformation interval contain microfossils. The subformation is 200–500 m thick.

The Tyul'men Subformation, terminal one in the Avzyan Formation section, is composed of gray and variegate dolomitic siltstones and sandstones. The apparent thickness of sediments is not greater than dozens of meters. It is determined imprecisely, because the subformation is exposed fragmentarily, being known in general from drilling results. Variegate siliciclastic rocks appearing in the unit, which resemble visually the basal sediments of the overlying Zilmerdak Formation, grounded the idea of conformable relations between the Yurmata and Karatau groups (Keller *et al.*, 1983; Kozlov *et al.*, 1997). However, the traditional viewpoint (Shatsky, 1945; Garan', 1963) suggesting the discordant boundary between the groups is confirmed in later works (Maslov *et al.*, 1998, 2001).

Age of Middle Riphean deposits in southern Urals. The lower age limit of the Yurmata Group is determined by isotopic dates obtained for the Berdyaush rapakivi granites, which crosscut the underlying Burzyan Group and are discordantly overlain by volcanogenic-sedimentary succession of the Mashak Formation. The Rb–Sr and U–Pb isochron ages of granites correspond respectively to 1348 ± 13 and 1354 ± 20 Ma (Krasnobaev, 1986). These dates are consistent with age values obtained for volcanic rocks of the Mashak Formation: the Rb–Sr age of whole-rock dacites and liparite-dacites from the formation is 1346 ± 41 Ma,
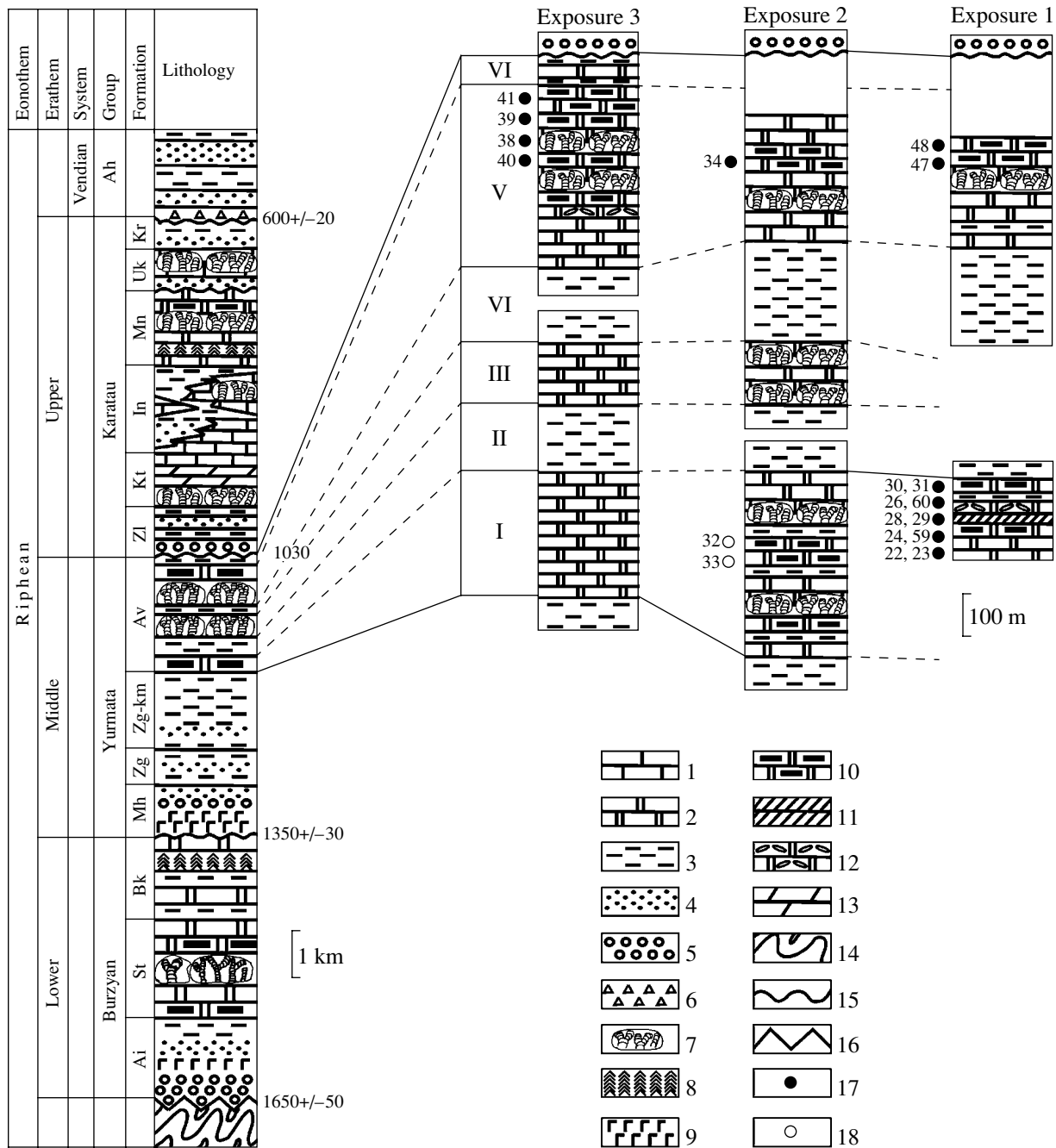
Fig. 2. Schematic structure of Riphean deposits in southern Urals and stratigraphic relations between subdivisions of the Avzyan Formation containing silicified microfossils: (1) limestone; (2) dolostone; (3) siltstone, shale; (4) sandstone; (5) conglomerate; (6) tillite, tilloid; (7) bioherms with columnar stromatolites; (8) columnar stromatolites of the *Conophyton* group; (9) tuff, tuffaceous sandstone; (10) dolostone with chert lenses and interlayers; (11) magnesite; (12) flakestone; (13) marl; (14) gneisses of basement; (15) hiatus, unconformity; (16) azimuthal discordance; (17) samples with microfossils; (18) samples barren of microfossils. Subformations of the Avzyan Formation: (I) Kataskin; (II) Malyi Inzer; (III) Ushakovo; (IV) Kutkur; (V) Revet; (VI) Tyul'men. Indices of formations: (Ai) Ai; (St) Satka; (Bk) Bakal; (Mh) Mashak; (Zg) Zigal'ga; (Zg-km) Zigazinskii-Komarovo; (Av) Avzyan; (Zl) Zilmerdak; (Kt) Katav; (In) Inzer; (Mn) Min'yar; (Uk) Uk; (Kr) Krivaya Luka; (Ah) Asha Group. Numbers of stratigraphic columns correspond to section numbers in Fig. 1; sample numbers are plotted to the right of columns; isotopic ages (Ma) of stratigraphic boundaries are shown to the right of the generalized column of Riphean succession.

and U–Pb age of zircons from these rocks corresponds to 1350 ± 30 Ma (Krasnobaev, 1986; Kozlov *et al.*, 1989). As is decided at the 3rd All-Russia Conference on General Problems of Subdividing the Precambrian

(*Resolutions...*, 2001), the Yurmata Group lower boundary is 1350 ± 30 Ma old according to the above U–Pb zircon age. The upper age limit of the group is determined less precisely. The K–Ar dates obtained a

while ago for mineralogically unstudied glauconites from the Avzyan Formation and basic dikes crosscutting this formation correspond to 1200 and 1170–1010 Ma (Keller, 1973; Keller *et al.*, 1983), but these dates are reasonably regarded now as outdated. The Pb–Pb isochron age of 836 ± 25 Ma obtained for limestones of the Katav Formation of the overlying Karatau Group is reliable in methodological aspect, but it determines the time of early diagenesis (Ovchinnikova *et al.*, 1998), and contribution of microphytological data to the problem solution is certainly decisive. Important changes in assemblages of organic-walled microfossils, which are established at the base of the upper Zilmerdak Subformation (Veis *et al.*, 2000, 2003), are similar to those observed in Siberian succession at the level of about 1030 Ma (Semikhatov *et al.*, 2000). This date suggests that upper horizons of the Yurmata Group are 1050 Ma old, not younger.

Successive assemblages of organic-walled microfossils from the Riphean stratotype demonstrate a clear trend of secular changes (Yankauskas, 1979a, 1979b, 1982; Mikhailova and Podkovyrov, 1992; Veis *et al.*, 1990, 2000, 2003). In the Yurmata Group, microfossils are known from the Zigazino-Komarovo and Avzyan formations. The mass abundance of large acritarchs of the genus *Kildinella* (including *Kildinella nordia* forms with tumuli), tabular *Satka elongata*, colonial *Synsphaeridium* sp. and spheroids *Leiosphaeridia bicrura* thorn to halves is recorded first in the Zigazino-Komarovo Formation. On the other hand, *Symplassosphaeridium undosum*, *Satka favosa*, *Protosphaeridium flexuosura*, and *Leiosphaeridia ternata* widespread in the Lower Riphean almost disappear at this level. Similar though less diverse microfossil assemblages are characteristic of the Avzyan Formation as well. The most remarkable subdivision of the latter is the Tyul'men Subformation containing abundant and diverse microbiota. In addition to frequent *Leiosphaeridia* forms (*L. incrassata, L. minutissima, L. jacutica, L. bicrura*) and other transit taxa, this microbiota includes morphotypes-newcomers typical of the Karatau Group: *Navifusa majensis, Ostiana microcystis, Sphaerocongregus variabilis, Polytrichoides lineatus, Asperatofilum*, and some others (Yankauskas *et al.*, 1989; Yankauskas, 1982; Veis *et al.*, 1990, 2000; Kozlova, 1993).

Silicified microfossils of the Riphean stratotype are known from the lower and upper Kusa subformations of the Lower Riphean Satka Formation, from the Kataskin and Revet subformations of the Middle Riphean Avzyan Formation, and from the Upper Riphean Min'yar Formation (Nyberg and Schopf, 1984; Sergeev and Krylov, 1986; Krylov and Sergeev, 1986; Sergeev, 1988, 1992a, 1992b, 1994; Sergeev and Lee Seong-Joo, 2004). The most diverse assemblage of microfossils occurs in cherts of the Kataskin Subformation. It includes abundant remains of eukaryotes, stalked cyanobacteria, and some other morphotypes, whereas the assemblage of the Revet Subformation is considerably less diverse, represented by cyanobacterial remains occurring more persistently over the distribution area.

KATASKIN MICROBIOTA

Geographic locality. Cherts containing microfossils have been discovered at one site, in the Kataskin Subformation section exposed on the right bank of the Katav River directly upstream of the abandoned narrow-gauge railway bridge 2 km away from the town Katav-Ivanovsk (Figs. 1 and 2; Exposure 1; sample nos. 4688/22–24, 26, 28, 29–31, 59, 60). Cherts are confined to dolostone and magnesite layers displaying wavy microlamination (alternation of dark- and light-colored laminae).

Composition of microbiota. Microbiota includes the following taxa: *Siphonophycus robustum* (Schopf), *Siphonophycus typicum* (Hermann), *Siphonophycus kestron* Schopf, *Siphonophycus solidum* (Golub), *Eomicrocoleus* sp., *Eoentophysalis dismallakesensis* Horodyski et Donaldson, *Eoentophysalis belcherensis* Hofmann, *Eosphaeronostoc kataskinicum* Sergeev, *Polybessurus bipartitus* Fairchild ex Green et al., *Gloeodiniopsis lamellosa* Schopf, *Sphaerophycus medium* Horodyski et Donaldson, *Coniunctiophycus conglobatum* Zhang, *Eosynechococcus amadeus* Knoll et Golubic, *Leiosphaeridia crassa* (Naumova), *L. atava* (Naumova), *L. jacutica* (Timofeev), and *Paratetraphycus* aff. *P. giganteus Zhang* (Fig. 3).

Dominant and mat-forming forms. Dominant in the microbiota are entophysalidacean algae *Eoentophysalis dismallakesensis* originally described as *Eogloeocapsa avzyanica* Sergeev, because distinct palmelloid colonies of the fossils have not been observed (Sergeev, 1992a, 1992b, 1994). Nevertheless, besides these colonies the microfossils in question posses the other diagnostic features of entophysalidacean algae. The species are of a rather variable morphology, but prevalent in the material studied are isolated *Gloeocapsa*-like colonies frequently containing two or three generations of nannocysts, which are successively enclosed into common envelopes. Spheroids are from 6.0 to 22.0 µm across, and envelopes surrounding them range from 15.0 to 45.0 µm in diameter. Colonies of this kind begin to prevail in the life cycle of entophysalidacean algae in response to a high sedimentation rate (Golubic and Hofmann, 1976), and this factor exactly seems responsible for prevalence of *Gloeocapsa*-like colonies *E. dismallakesensis* in the microbiota (Sergeev, 1992a, 1992b, 1994). Dark coloration of cells periphery and colonization of hard grounds, the characteristic features of many Precambrian entophysalidacean forms, are also typical of their representatives from the Kataskin Subformation (Plate I, figs. 1, 6). In some cases, elongated spheroids *E. dismallakesensis* show unidirectional polarized growth (Plate 1, fig. 2), one of the cardinal characters of entophysalidacean cyanobacteria (Golubic, 1976; Mendelson and Schopf, 1982). *Eoentophysalis belcherensis*, the second species of the genus, is represented in microbiota by single specimens. Spheroids of this species have one-, maximum two-layered envelopes 2.0 to 10.0 µm in diameter and form colonies of hundreds specimens dark-colored along periphery.
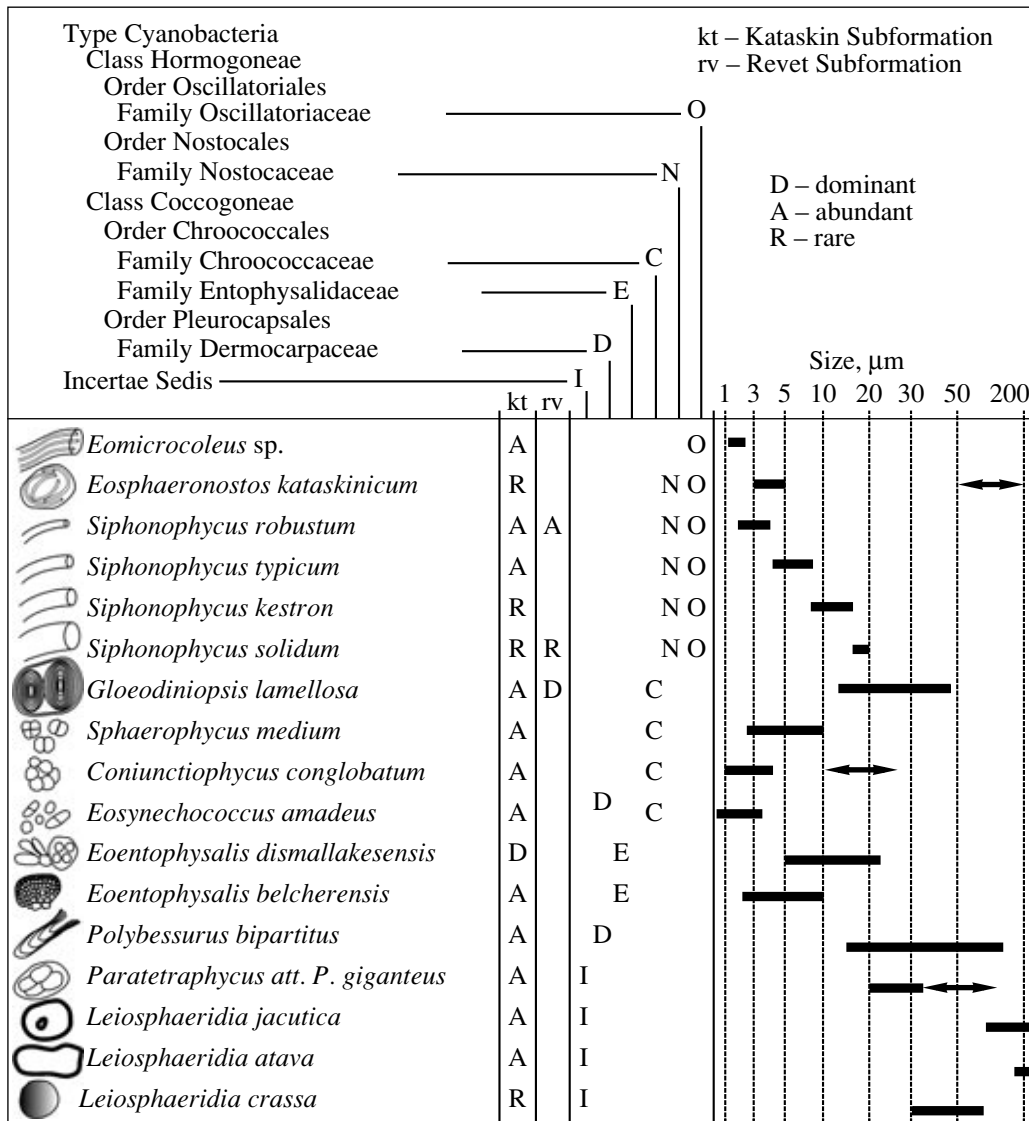
Fig. 3. Synopsis of silicified microfossils from the Avzyan Formation cherts (size in logarithmic scale). Solid bars denote size ranges of individual spheroids and filaments, and arrows characterize size variations of fossil colonies or their envelopes.

Microbiota also includes abundant empty sheaths of three species representing hormogonian cyanobacteria of the genus *Siphonophycus*. These are *S. robustum*, *S. typicum*, and *S. kestron*, which have diameter ranges 2.0–4.0, 4.0–8.0, and 8.0–16.0, respectively. The colonies of sheaths usually consisting of many hundreds interlacing specimens are widespread in the Kataskin microbiota. We encountered as well the larger sheaths (16.0–22.0 μm) identified as *S. solidum* in the formal classification nomenclature suggested by Butterfield (Butterfield *et al.*, 1994). It is possible that mat-forming microorganisms of the Kataskin microbiota are also represented by polytrichotomous filaments *Eomicrocoleus* sp. Fascicular aggregates of filaments, which did not preserve septae in many cases, are set in common sheaths ranging in diameter from 4.0 to 40.0 μm. This taxon resembles some cyanobacterial species of the genus *Microcoleus*, which form mats widespread in intertidal zone of present-day sea basins. Mats of the genus have been likely widespread in the same zone of Proterozoic basins (Horodyski and Donaldson, 1980; Hofmann and Jackson, 1991; Kah *et al.*, 1999), but having a poor taphonomic potential, sheaths disintegrated leaving dispersed inner trichomes (Horodyski *et al.*, 1977; Venetskaya and Gerasimenko, 1988). In the fossil state, these remains are suitable to be identified either as representatives of the genus *Siphonophycus* (if transverse septae are not preserved), or as taxa of multicellular trichomes (septae are retained).

Coccoidal symbionts. Mats *Siphonophycus robustum* consisting of interlacing sheaths enclose species *Gloeodiniopsis lamellosa* (spheroids 10.0 to 45.0 μm across) that represents remains of chroococcalean cyanobacteria similar to *Gloeocapsa* or *Chroococcus*.
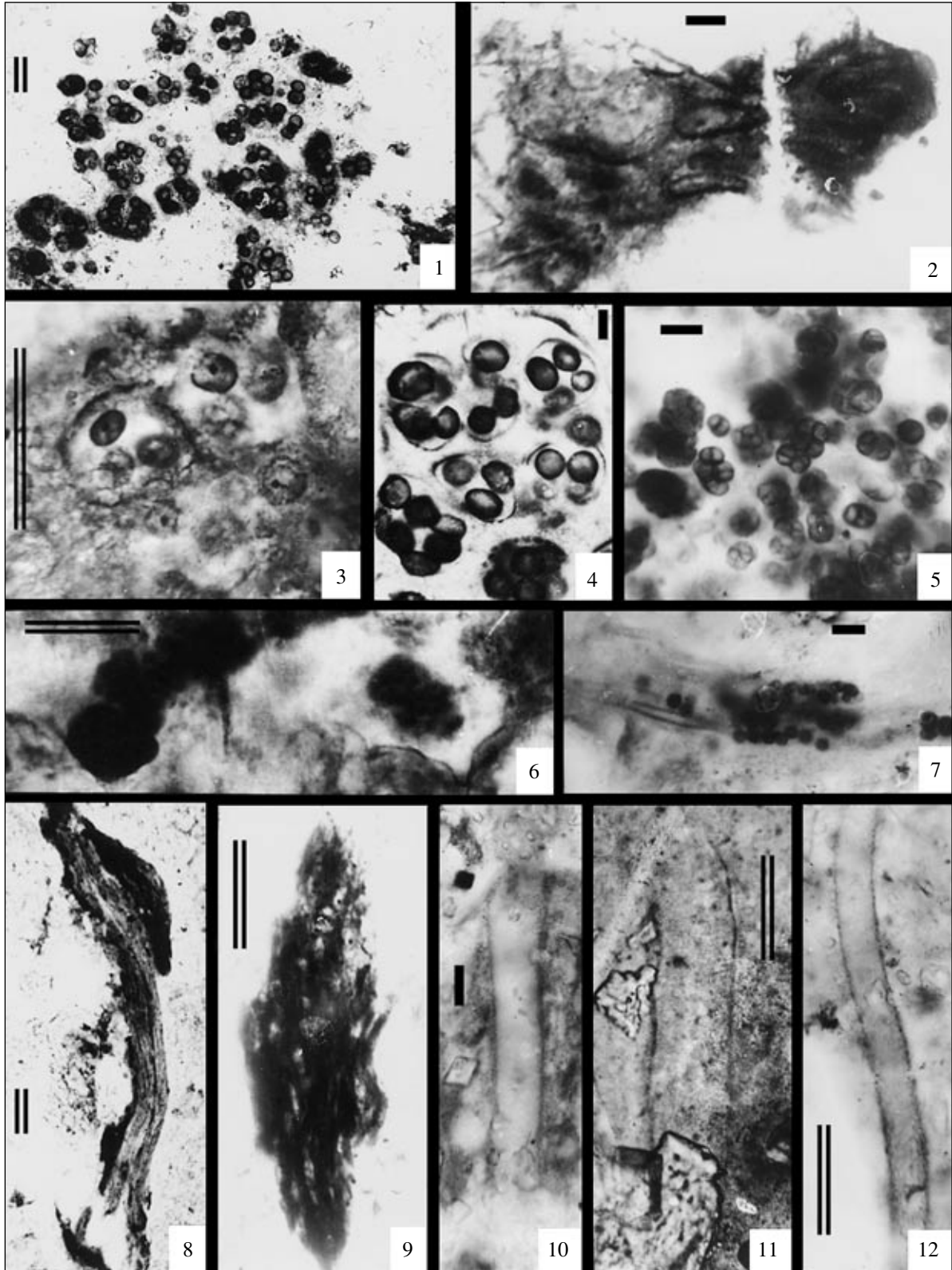
Plate I

Plate I. Coccoidal and filamentous microfossils from the Avzyan Formation

(1–4, 6) *Eoentophysalis dismallakesensis* Horodyski et Donaldson: (1) specimen GIN no. 750, sample 4688-60, thin section 894-04, point 20; (2) specimen GIN no. 751, sample 4688-60, thin section 894-04, point 12; (3) specimen GIN no. 60, sample 4688-22, thin section 415-85, point 5; (4) specimen GIN no. 40, sample 4688-22, thin section 422-85, point 19; (6) specimen GIN no. 752, sample 4688-60, thin section 894-04, point 14. (5) *Sphaerophycus medium* Horodyski et Donaldson, specimen GIN no. 70, sample 4688-30, thin section 432-85, point 20. (7) *Eosynechococcus amadeus* Knoll et Golubic among filaments *Eomicrocoleus* sp., specimen GIN no. 56, sample 4688-22, thin section 421-85, point 32. (8, 9) *Eomicrocoleus* sp.: (8) specimen GIN no. 753, sample 4688-22, thin section 899-04, point 13; (9) specimen GIN no. 754, sample 4688-22, thin section 851-01, point 21; (10) *Siphonophycus kestron* Schopf, specimen GIN no. 54, sample 4688-25, thin section 431-85, point 8. (11, 12) *Siphonophycus solidum* (Golub): (11) specimen GIN no. 755, sample 4688-60, thin section 894-04, point 12; (12) specimen GIN no. 88, sample 4688-34, thin section 442-85, point 3. Specimen 755 is from the Revet Subformation of the Avzyan Formation, Exposure 2; all other specimens are from the Kataskin Subformation of the Avzyan Formation, Exposure 1 (ordinary and double scale bars correspond to 10 and 50 μm respectively).

Originally smooth walls of spheroids *G. lamellosa* experienced bacterial (?) destruction to become corroded and having pseudospines, which are surrounded sometime by a membranous film. In such a case, microfossils resemble acanthomorphic acritarchs (Sergeev, 1992a, 1992b, 1994). Also belonging to coccoidal symbionts of microbiota under consideration are colonies of small (0.5 to 3.5 μm in greatest dimension) ellipsoidal spheroids *Eosynechococcus amadeus*, which occur between filaments *Siphonophycus* and *Eomicrocoleus* sp. (Plate I, fig. 7) or in the colonies *Eoentophysalis*. Colonies *E. amadeus* likely represent remains of cyanobacteria similar to *Synechococcus* or bacteria that developed in dead algal mats.

Associated coccoidal forms. Species *Polybessurus bipartitus* is one of peculiar taxa of the Kataskin microbiota and represents coccoidal microfossils having multilayer stalks. The preserved fragments of stalks usually are 15–50 μm in diameter, but being up to 300 μm long they are up to 100.0 μm across at the termination. The mat-forming function of *Polybessurus bipartitus* recognizable in some Precambrian microbiotas (Green *et al.*, 1987) has not been established in the Kataskin microbiota containing only isolated specimens of this stalked cyanobacterium.

Rare components of microbiota, which deserve special attention nevertheless, are microfossils *Eosphaeronostoc kataskinicum.*[1] This species exemplifies the intricate clews of small sheaths (up to 5.0 μm in diameter), which are surrounded by spherical envelopes up to 200 μm across. Colonies of this type are characteristic of contemporaneous nostocalean blue-green algae of the genus *Sphaeronostoc,* and relevant specimens from the Kataskin microbiota may represent their fossil analogues. It cannot be excluded also that some smooth spheroids more than 200 μm in diameter, which occur in the biota and have been described as *Leiosphaeridia atava*, represent empty envelopes of colonies *Eosphaeronostoc kataskinicum.*

Among other morphotypes present in the Kataskin Subformation, there are remarkable colonies *Sphaerophycus medium* and *Coniunctiophycus conglobatum* with diameter ranges of spheroids corresponding respectively to 2.5–10.5 and 1.0–4.0 μm. These taxa most likely represent remains of planktonic cyanobacteria of the *Microcystis* type (Sergeev *et al.*, 1995, 1997), although some of them may be fragments of colonies belonging to *Eoentophysalis belcherensis* or to other small benthic chroococcalean cyanophytes (Zhang, 1981).

Problematic eukaryotes and eukaryotic phytoplanktonic forms. Some forms identified in the Kataskin microbiota can be interpreted as eukaryotic microorganisms tentatively divisible into benthic and planktonic groups. The first group includes large spherical envelopes containing several spheroids inside (Plate II, figs. 7–9). In morphology, they resemble chroococcalean cyanobacteria of genera *Chroococcus* or *Gloeocapsa*, being however different from prokaryotic microorganisms in dimensions (individual spheroids are 20 to 50 across and their colonies are 30 to 100 μm in diameter) and presence of real pyramidal tetrads. These remains are identified as representatives of the genus *Paratetraphycus* used to be classed with red algae, although this conclusion needs verification.

In the second group, at least some smooth-walled spheroids can be certainly regarded as remains of phytoplanktonic eukaryotic microorganisms (Plate II, figs. 1, 2, 5, 6). They are attributed to different species of sphaeromorphic acritarchs of the genus *Leiosphaeridia* (*L. crassa, L. atava, L. jacutica*) whose diameter ranges are 30 to 50 × 700, 180 × 250, and 80 × 225 μm, respectively. However, taxonomy of eukaryotic phytoplankton is rather problematic, because the majority of *Leiosphaeridia* species likely

---

[1] Nagovitsyn (2000, 2001a, 2001b) considered genus *Eosphaeronostoc* Sergeev, 1992, as synonym of the genus *Glomophycus* Yakshin, 1991 (Yakshin, 1991), because they both represent fossil analogues of sphaeronostocalean cyanobacteria belonging to the genus *Sphaeronostoc* Elenk. However, the analysis of Kotuikan and Yusmastakh microbiotas from the Anabar Uplift clearly showed that type species *G. tortilis* of the genus *Glomophycus* represent an artefact, i.e., the result of fossilization of spheroids *Myxococcoides grandis* and *Myxococcoides* sp., thus having no relations with nostocalean cyanobacteria (Sergeev *et al.*, 1995). The problem is even more complicated, because Nagovitsyn (2000, 2001a, 2001b) revised the genus *Glomophycus* and distinguished two new species in its composition: *G. bistratosus* Primatchok et Nagovitsin and *G. amplus* Primatchok et Nagovitsin, which actually represent spherical colonies of filamentous microfossils but are of specific structure owing to surficial localization of filaments. The problem of relations between genera *Eosphaeronostoc* and *Glomophycus* remains open therefore and their synonymy suggested by Nagovitsyn is not accepted in this work.
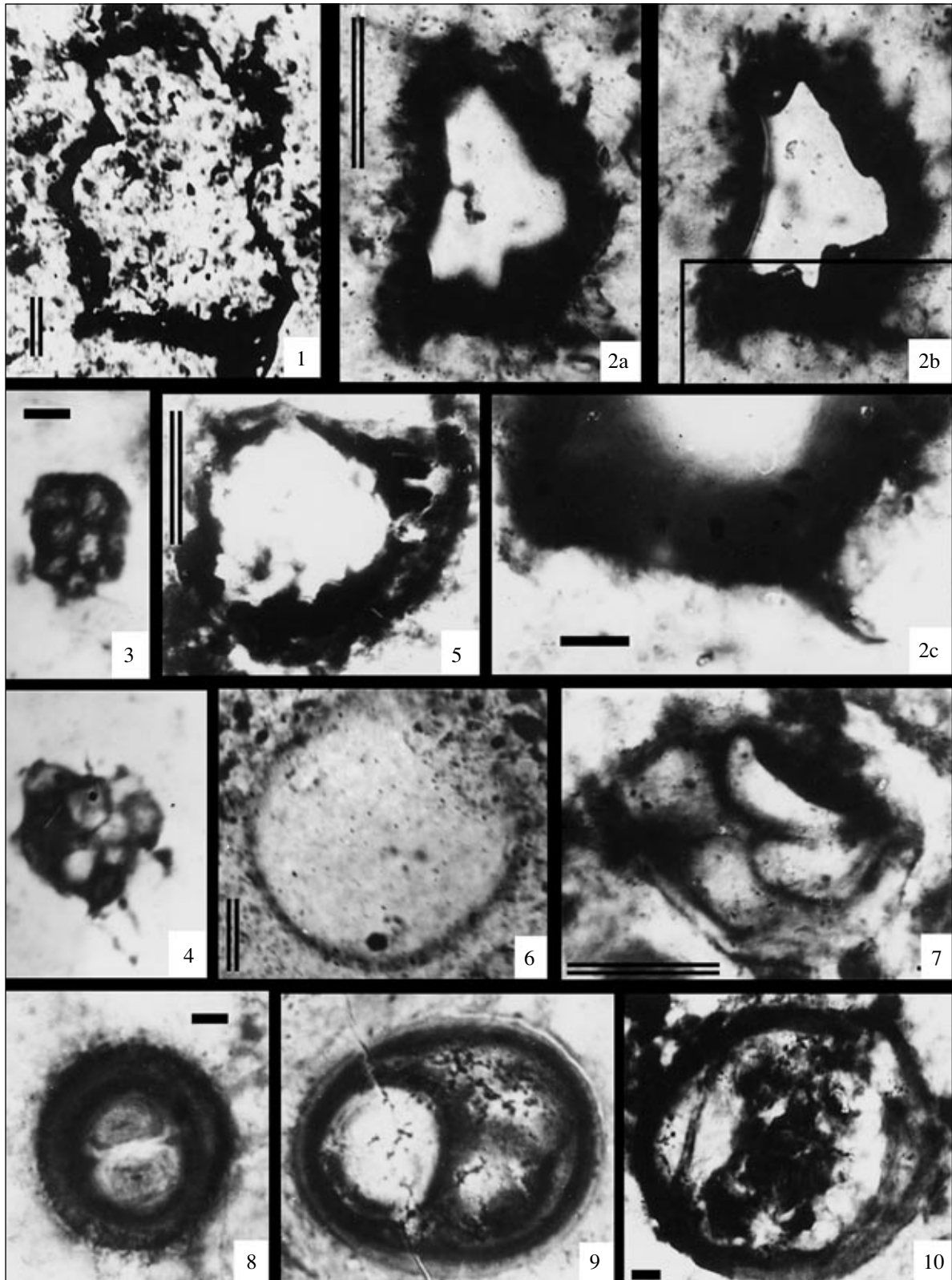
Plate II

Plate II. Coccoidal microfossils from the Avzyan Formation

(1) *Leiosphaeridia atava* (Naumova), specimen GIN no. 756, sample 4688-59b, thin section 902-04, point 1. (2, 5) *Leiosphaeridia crassa* (Naumova): (2 and 2b) specimen GIN no. 757, sample 4688-59, thin section 891-04, point 10 under different focus depth (rectangular in 2b); (5) specimen GIN no. 758, sample 4688-596, thin section 902-04, point 6. (3, 4) *Sphaerophycus medium* Horodyski et Donaldson: (3) specimen GIN no. 759, sample 4688-22, thin section 903-04, point 11; (4) specimen GIN no. 760, sample 4688-22, thin section 903-04, point 3. (6) *Leiosphaeridia jacutica* (Timofeev), specimen GIN no. 761, sample 4688-22, thin section 913-04, point 7. (7–9) *Paratetraphycus giganteus* Zhang: (7) specimen GIN no. 762, sample 4688-22, thin section 908-04, point 5; (8) specimen GIN no. 763, sample 4688-22, thin section 901-04, point 4; (9) specimen GIN no. 764, sample 4688-22, thin section 903-04, point 11. (10) *Eosphaeronostoc kataskinicum* Sergeev, specimen GIN no. 765, sample 4688-22, thin section 913-04, point 6. All specimens are from the Kataskin Subformation of the Avzyan Formation, Exposure 1 (ordinary and double scale bars correspond to 10 and 50 μm respectively; scale bar in fig. 2a is valid for fig. 2b, in fig. 3 for fig. 4, and in fig. 8 for fig. 9).

represent heterogeneous remains of different microorganisms, and the genus includes the form species only (Yankauskas *et al.*, 1989). Nevertheless, microfossils identified as *Leiosphaeridia crassa* have thick robust walls that is a diagnostic character of unicellular eukaryotic microorganisms. In addition, some specimens of this species have problematic spines at the surface (Plate II, figs. 2a, 2b, 2c). On the other hand, the originally smooth spheroids of chroococcalean cyanobacteria *G. lamellosa* may have surficial pseudospines, and we cannot state for sure that external processes of *L. crassa* are their inherent feature thus leaving the problem solution for the future. With due account for different preservation state of *Leiosphaeridia* forms in the Kataskin microbiota, we assume in general that microfossils under consideration represent remains of different microorganisms, including the real unicellular eukaryotes and presumable empty envelopes of colonies of prokaryotic phytoplanktonic microorganisms.

Non-organogenic precipitates. These precipitates discovered for the first time in the Kataskin Subformation represent peculiar microfacies originally carbonate and progressively silicified later, which can be determined as microstratified laminae (Bartley *et al.*, 2000; Sharma and Sergeev, 2004). Individual microlaminae range in thickness from 2.0–3.0 to 4.0–5.0 μm, being up to 400–500 μm long. Jointly they form a lamina up to 200–300 μm thick and 500–900 μm long. Precipitates occur sporadically in the Kataskin Subformation as single microscopic patches. They are lacking remains of diverse cyanobacteria (Plate III, figs. 8, 9) in distinction from similar microstructures occurring in the Lower Riphean Kotuikan Formation of the Anabar Uplift, Jaradog Fawn Limestone of India, Middle Riphean Sukhaya Tunguska Formation of the Turukhansk Uplift, and in some other successions (Sergeev *et al.*, 1995; Bartley *et al.*, 2000; Sharma and Sergeev, 2004).

Paleoecological interpretation. Species *Eoentophysalis belcherensis* present in the Kataskin microbiota suggest that relevant association of microorganisms likely dwelt in a closed lagoon with elevated water salinity. The suggestion appears to be valid, because modern analogues of jointly occurring *Polybessurus bipartitus* are known from lagoons and intertidal zone of Bahamas (Golubic, 1976; Green *et al.*, 1987). Empty sheaths *S. robustum* abundant in the Kataskin micro-

biota are oriented in many cases at the right angle relative to bedding planes. This orientation of fossil cyanobacterial remains has been interpreted as reaction to the high sedimentation rate in intertidal settings (Sergeev, 1994; Sergeev *et al.*, 1995). Contemporaneous hormogonian blue-green algae show the same orientation, when their mats experience desiccation and subsequent flooding (Horodyski *et al.*, 1977). On the other hand, the microbiota under consideration includes remains of prokaryotic and eukaryotic phytoplanktonic microorganisms, and this suggests that the Kataskin Subformation is composed of alternating sediments, which have been deposited in intertidal and upper subtidal zones. As is assumed, these environments of carbonate sedimentation within a shallow shelf were characteristic in the Kataskin epoch over the entire area of the Bashkirian meganticlinorium (Maslov *et al.*, 2001, p. 65, Fig. 47).

REVET MICROBIOTA

Geographic localities. Cherts containing microfossils have been discovered in three exposures of the Revet Formation sediments (Figs. 1, 2): on the left bank of the Katav River 4.5 km upstream of the abandoned narrow-gauge railway bridge in the Katav-Ivanovsk district (Exposure 1, sample nos. 4688/47 and 4688/48), near the Kataskin farm (Exposure 2, Sample 4688/34), and at the Verkhnii Avzyan site (Exposure 3, sample nos. 4688/40 and 4688/41). Dolostones containing cherty lenses with microfossils are microlaminated, and lamination of this kind is traceable in cherty nodules as well.

Composition of microbiota. The Revet microbiota consists of three species only, namely of *Siphonophycus robustum* (Schopf), *S. solidum* (Golub.), and *Gloeodiniopsis lamellosa* Schopf (Fig. 3). Coccoidal microfossils *Gloeodiniopsis lamellosa* dominant in this microbiota are represented by spheroids ranging in diameter from 11.0 to 45.0 μm like in the Kataskin microbiota. Abundant colonies of this taxon consist of hundreds spheroids loosely set in amber-yellow cherty mass, being in a perfect preservation state sometimes. Colonies of sheaths *Siphonophycus robustum* (2.0–4.0 μm in diameter) are rare and poorly preserved. Sheaths *Siphonophycus solidum*
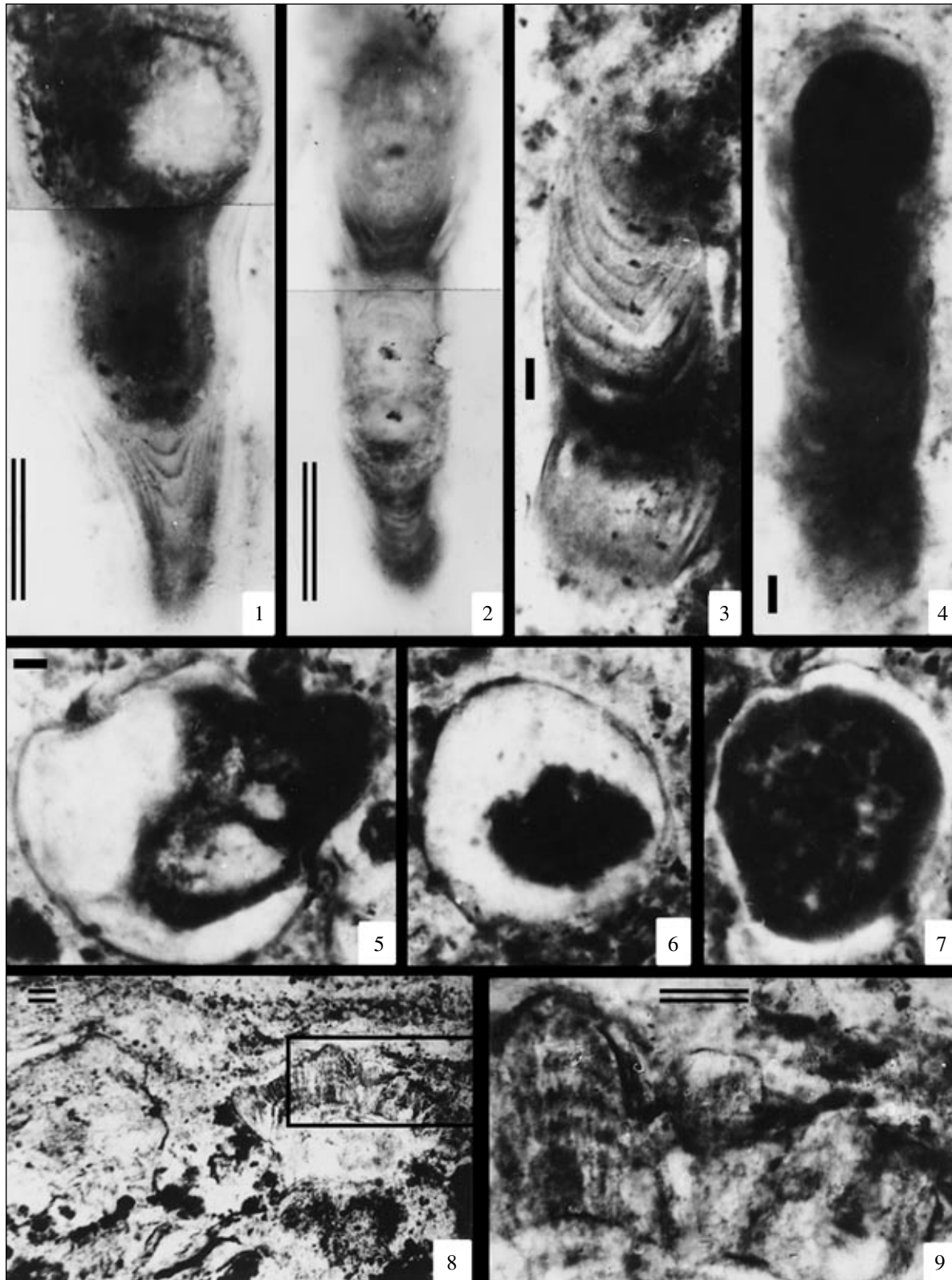
Plate III

Plate III. Pedicellate and coccoidal microfossils and precipitates from the Avzyan Formation.

(1–4) *Polybessurus bipartitus* Fairchild ex Green et al.: (1) specimen GIN no. 766, sample 4688-22, thin section 421-85, point 24; (2) specimen GIN no. 767, sample 4688-22, thin section 421-85, point 11; (3) specimen GIN no. 768, sample 4688-22, thin section 899-04, point 4; (4) specimen GIN no. 769, sample 4688-22, thin section 908-04, point 1. (5–7) large spheroidal morphotypes: (5) specimen GIN no. 770, sample 4688-22, thin section 899-04, point 4; (6) specimen GIN no. 771, sample 4688-22, thin section 899-04, point 4'; (7) specimen GIN no. 772, sample 4688-22, thin section 899-04, point 12. (8) non-organogenic precipitates, sample 4688-22, thin section 908-04, point 2; (9) enlarged rectangular area in fig. 8. All specimens are from the Kataskin Subformation of the Avzyan Formation, Exposure 1 (ordinary and double scale bars correspond to 10 and 50 μm respectively).

ranging in diameter from 16.0 to 20.0 μm occur as single specimens.

Gloeodiniopsis lamellosa does not form mats in the Revet Subformation despite abundant colonies of this microfossil. Studying similar colonies *G. lamellosa* in the Bitter Springs Formation of Australia, Knoll and Golubic (1979) arrived at the conclusion that they represent remains of chroococcalean cyanophytes, which dwelt in little pools of intertidal zone in ancient sea basins. In the Revet Subformation, colonies *G. lamellosa* are however almost lacking nannocytogenesis, and their abundance seems to be indicative of a slow sedimentation in an epicontinental basin. *Siphonophycus robustum*, the most widespread mat-forming microorganism of the Proterozoic, is considerably less abundant than *Gloeodiniopsis lamellosa*, and this fact is likely a consequence of taphonomic factor. The point is that chroococcalean cyanobacteria *Chroococcus* have outer walls highly resistant to destruction and turn into fossilized state more frequently than other microorganisms (Knoll and Golubic, 1979). It is likely therefore that mats of *Siphonophycus robustum* had been more widespread in the Revet basin and were destroyed by fossilization.

Lateral distribution and paleoecological interpretation. The Revet Subformation composed predominantly of dolostones is of persistent composition all over the western limb of the Bashkirian meganticlinorium. Its sections remote from each other yield assemblages of microfossils, which are of low diversity and specific in composition. These data suggest that the Revet microbiota developed in upper subtidal and intertidal zones of a shallow epicontinental basin that is consistent with sedimentological criteria specifying the accumulation environments of the subformation (Maslov and Anfimov, 2000).

CONCLUSIONS

Shallow-water coastal habitat environments of the Kataskin and Revet microbiotas determined their conservative character. In majority, microfossils of both microbiotas are represented by taxa of extremely wide stratigraphic range, which existed since the Early Proterozoic until present. Phytoplanktonic forms of complex morphology, having spines and processes, which are known from the Middle–Upper Riphean boundary deposits (Yan and Zhu, 1992; Sergeev *et al.*, 1997; Xiao

et al., 1997; Yin, 1997) and presumably even from the Lower Riphean (Javaux *et al.*, 2001) do not occur in the studied microbiotas. Nevertheless, it can be stated now that the Kataskin microbiota originally attributed to the prokaryotic type (Sergeev, 1992a, 1992b, 1994) includes remains of morphologically simple eukaryotes. Abundant remains of presumably eukaryotic phytoplankton known before from shales of the Zigazino-Komarovo and Avzyan formations (Yankauskas, 1979b, 1982; Veis *et al.*, 1990, 2000) have never been discovered in cherty-carbonate successions of the Middle Riphean. The tendency of discovering a growing number of eukaryotic microfossils in microbiotas regarded formerly as prokaryotic in origin is characteristic of the current microphytology of the Precambrian. Remains of eukaryotic phytoplankton are getting now new significance for the Precambrian biostratigraphy, especially for biostratigraphy of the Upper Riphean. They occur in both the organic-walled and silicified microbiotas confined to sedimentary facies of open-sea settings. At present, however, it is difficult to judge about stratigraphic significance of eukaryotes from the Avzyan Formation, because the whole set of Precambrian microorganisms, especially of those confined to the pre-Upper Riphean successions, is known inadequately. The exact stratigraphic evaluation of new microfossil morphotypes discovered in the Avzyan Formation is a problem of future that can be solved when similar remains will be found in other sections.

An important new peculiarity of the Kataskin Subformation consists in carbonate precipitates occurring in this subdivision. Similar non-organogenic sedimentary structures precipitated from seawater without direct participation of cyanobacterial mats and widespread in the Archean, Lower Proterozoic, and Lower Riphean are less abundant in the Middle Riphean and disappear almost completely in the Upper Riphean and Vendian. Many researchers relate this tendency of precipitates reduction in the Earth geological record with evolution of sedimentation settings and physicochemical conditions on the planet surface, first of all with the content of atmospheric carbon dioxide and composition of seawater (Grotzinger, 1986, 1989, 1994; Kah and Knoll, 1996; Bartley *et al.*, 2000; Sharma and Sergeev, 2004). It is remarkable that precipitates in question are extremely rare near the Middle–Upper Riphean boundary, being actually known from the Sukhaya Tunguska

Formation of the Turukhansk Uplift at the level of the upper Middle Riphean only, where they occur in tight association with remains of cyanobacteria *Eoentophysalis dismallakesensis* (Sergeev *et al.*, 1997; Sharma and Sergeev, 2004). In opinion of many researches, primarily the evolution of grounds was responsible for this paradoxical biostratigraphic differentiation of conservative cyanophytes in the vertical succession. Entophysalidacean cyanobacteria colonized most readily the hard grounds, which were widespread in the Early Proterozoic and Early–Middle Riphean, being formed in response to the early lithification of deposited precipitates. In addition, specific facies environments of precipitates formation were favorable for the total germination of filaments of nostocalean cyanophytes (Knoll and Sergeev, 1995; Sergeev *et al.*, 1995; Kah and Knoll, 1996; Bartley *et al.*, 2000). When soft ground became prevailing in the Late Riphean, composition of microbiotas changed significantly: abundance of entophysalidacean and nostocalean cyanophytes reduced sharply, and they gave way to stalked cyanobacteria *Polybessurus*, which developed in abundance and colonized the soft grounds exactly (Kah and Knoll, 1996).

In general, assemblages of microfossils from the Avzyan Formation offer a unique chance to view that transitional moment, when entophysalidacean and pedicellate cyanobacteria coexisted in Proterozoic communities of microorganisms. That was the epoch of expansion of unicellular eukaryotic algae into prokaryotic ecosystems.

DESCRIPTION OF MICROFOSSILS

New microfossils found in the Avzyan Formation are described below along with characterization of several taxa formerly identified in microbiota under different names. All the materials described are stored at the Geological Institute, Russian Academy of Sciences, collection no. 4688.

KINGDOM EUBACTERIA WOESE AND FOX, 1977

DIVISION CYANOBACTERIA STANIER ET AL., 1978

CLASS COCCOGONEAE THURET, 1875

ORDER CHROOCOCCALES WETTSTEIN, 1924

FAMILY ENTOPHYSALIDACEAE GEITLER, 1932

Genus *Eoentophysalis* Hofmann emend. Mendelson et Schopf, 1982

Type species *Eoentophysalis belcherensis* Hofmann, 1976

Eoentophysalis dismallakesensis Horodyski et Donaldson, 1980

Plate I, figs. 1–4, 6

Eoentophysalis dismallakesensis Horodyski and Donaldson, 1980, pp. 146–149, figs. 10 A–10 D, 11 A–F, G, 12 A, B; Ogurtsova and Sergeev, 1987, Plates X, 11, 12; Sergeev, 1992, p. 83, Plate XXII, figs. 7–9; Sergeev *et al.*, 1994, p. 33, Plate II, figs. 1–10.

Eoentophysalis arcata Mendelson and Schopf, 1982, pp. 76, 77, Plate 2, figs. 1a–1b, text-figs. 5, 6; Yankauskas *et al.*, 1989, p. 90, Plate XIX, figs. 11–12; Schopf, 1992, Plate 10, fig. E; Knoll, Sergeev, 1995, fig. 5; Petrov *et al.*, 1995, Plate I, figs. 11, 14, 16, 17; Sergeev *et al.*, 1997, pp. 222–224, fig. 10A–10D, 11A–11F.

Eoentophysalis yudomatica Lo, 1980, pp. 146–150, Plate II, figs. 4–8; Sergeev, 2002, p. 31, Plate I, figs. 5–11.

Eogloeocapsa avzyanica Sergeev, 1992b, p. 109, Plate IX, figs. 6, 8, 12, Plate X, figs. 5–10; Sergeev, 1992, p. 79, Plate VI, figs. 4–10, Plate VII, figs. 9, 12, Plate VIII, figs. 1–10; Sergeev, 1994, pp. 245, 246, figs. 5A–5H, 6G–6I, 7E–7G.

Microfossils, type 4, Sergeev, 1988, p. 709, figs. 1f–1k.

Eogloeocapsa arcata Golovenok, Belova, 1992, pp. 115–116, figs. 1a, 1b, 2, 1993, Plate I, figs. a–d, Fig. 4.

Unnamed microfossils, Golovenok and Belova, 1993, Plate II, fig. 3.

Holotype, Geological Survey of Canada, thin section 57987; Lower Riphean, Dismal Lake Group, North America.

Description. Multilayer spheroids occurring in dyads, triads, and tetrads form colonies consisting of few to thousands specimens. The colonies are of diverse morphology, varying from "loose" clusters of *Gloeocapsa*-like spheroids to irregular or cubiform aggregates and palmelloid colonies, which form continuous or discrete spherical and hemispherical mats covering perceptible areas. Individual spheroids are spherical to ellipsoidal, frequently elongated-ellipsoidal in shape probably because of unidirectional accelerated growth of algae, which tried to escape burial under conditions of high sedimentation rate. Many colonies are dark-colored in their periphery, although this is not a characteristic feature of the genus. Frequently enough, spheroids are preserved in peripheral zones of colonies, which are empty in central areas. External layers of spheroid walls are semitransparent, fine-grained, about 0.5 μm thick. Inner layers are almost opaque, medium- to coarse-grained, approximately 1.0 μm thick. The opaque spherical inclusion 0.5 to 3.0 μm in diameter is attached to the inner side of the wall internal layer. The outer diameter of spheroids ("diameter of the wall outer layer") is from 6.0 to 22.0 μm, whereas the inner diameter ("diameter of the wall central layer") ranges from 4.0 to 13.0 μm. The *Gloeocapsa*-like colonies are from 15.0 to 45.0 μm across.

Comparison. *E. dismallakesensis* is greater in size than *E. belcherensis*.

Remarks. (1) In distinction from type population of the species, largest representatives of microfossils

attributed to *E. dismallakesensis* in this work are somewhat greater in dimensions (spheroids *E. dismallakesensis* from the Dismal Lake Group are 4.0–13.0 μm long and 3.0–10.0 μm wide). In the type population however, outer layers of spheroids *E. dismallakesensis* are transformed into amorphous mass (Horodyski and Donaldson, 1980, Fig. 11), and above dimensions of spheroids from the group correspond in fact to inner size parameters of spheroids under consideration.

(2) *E. dismallakesensis* from the Kataskin Subformation of the Avzyan Formation has been originally described as *Eogloeocapsa avzyanica* (Sergeev, 1992b) based on respective morphology of discovered spheroid clusters lacking features of typical sessile palmelloid colonies. Reexamination of microfossils from the Avzyan Formation showed that they have signs of unidirectional polarized growth, which are typical of entophysalidacean algae, and form in fact the sessile palmelloid colonies, although these are rare because of a high sedimentation rate in particular settings (Sergeev, 1992a, 1992b, 1994). Based on these diagnostic features of entophysalidaceans, we include the studied microorganisms into the genus *Entophysalis*.

(3) After a thorough reexamination of fossil populations *E. dismallakesensis* from the Debengda Formation, *E. arcata* from the Sukhaya Tunguska Formation, and *E. yudomatica* from the Yudoma Group, it became clear that they represent one species that must be identified as *E. dismallakesensis* according to the priority principle. Spheroids of the species are greater in size than those of *E. belcherensis*. However its distinctions from other large representatives of the genus *Entophysalis*, e.g., from *E. croxfordii* (Muir, 1976) and *E. magna* (McMenamin *et al.*, 1983) with spheroids up to 20.0 μm across, are not so clear. Subsequent research may show that these two species are synonyms of *E. dismallakesensis* or, in contrast, have no relation to the genus *Entophysalis*, like for instance, the postmortem cell clusters of chroococcalean cyanobacteria *Gloeodiniopsis lamellosa* from the Min'yar Formation, which have been erroneously identified earlier as colonies of *E. yudomatica* (Sergeev and Krylov, 1986).

Distribution. Middle Riphean: Dismal Lake Group, Canada, Debengda Formation, Olenek Uplift, Siberia, Avzyan Formation, southern Urals; Middle–Upper Riphean: Sukhaya Tunguska Formation, Turukhansk Uplift, Siberia; Upper Riphean (?) or Vendian(?): Chuchkan Formation, southern Kazakhstan; Vendian: Yudoma group, Uchur–Maya region, Siberia.

Material: hundreds colonies from the Kataskin Subformation of the Avzyan Formation.

CLASS HORMOGONEAE THURET, 1875

ORDER OSCILLATORIALES ELENKIN, 1949

FAMILY OSCILLATORIACEAE (S.F. GRAY) DUMORTIER EX KIRCHNER, 1898

Genus *Eomicrocoleus* Horodyski et Donaldson, 1980

Type species *Eomicrocoleus crassus* Horodyski et Donaldson, 1980

***Eomicrocoleus* sp.**

Plate 1, figs. 7–9

Description. Trichomes disposed in a parallel manner, surrounded or not surrounded by common sheath, are poorly preserved because of compression after death of microorganisms. Transverse septae of trichomes are almost invisible, and their lateral walls are coarse-grained. Diameter of trichomes is 1.0–2.0 μm, and their sheaths, if present, are 4.0 to 40.0 μm wide. Coarse-grained walls are about 1.0 μm thick.

Remarks. *Eomicrocoleus* sp. from the Kataskin Subformation of the Avzyan Formation are almost identical in morphometric parameters to *E. crassus.* We identified these microfossils in open nomenclature because of a worse preservation state.

Material: approximately ten poorly preserved filaments from the Kataskin Subformation of the Avzyan Formation.

ORDER NOSTOCALES OR OSCILLATORIALES

Genus *Siphonophycus* Schopf emend. Knoll et Golubic, emend. Knoll, Swett et Mark, 1991

Type species *Siphonophycus kestron* Schopf, 1968

***Siphonophycus solidum* (Golub) comb. Butterfield, 1994**

Plate I, figs. 11, 12

Siphonophycus solidum Butterfield *et al.*, 1994, p. 67, figs. 25H–25I, 27D; Sergeev *et al.*, 1997, p. 231, figs. 14I, 14K; Sergeev, Lee, 2001, p. 11, Plate I, figs. 1–3; Sergeev, 2001, pp. 442–443, fig. 7.7; Sergeev, 2002, Plate II, fig. 15.

Omalophyma solida Golub: Golub, 1979, p. 151, Plate 31, figs. 1–4, 7.

Large-diameter "Oscillatoriacean" sheaths, Mendelson and Schopf, 1982, pp. 62–63, Plate 3, figs. 4, 5.

Siphonophycus sp., Sergeev, 1992b, Plate IX, fig. 5; Sergeev, 1994, p. 251, fig. 10A.

Siphonophycus sp. $_2$, Sergeev, 1992a, Plate X, fig. 2.

Microfossils of the third category, Sergeev, 1988, p. 709, fig. 1b. (complete synonymy is presented in monograph by Butterfield *et al.*, 1994)

Holotype, collection at the All-Russia Institute of Geology, St, Petersburg, Russia, preparation no. R-163/3; Upper Vendian, Smolensk Formation (Borehole Rudnyanskaya, depth interval 747.8–763.3 m); East European platform, northern part of the Orsha basin, Russia.

Description. Non-branching tubular morphotypes aseptate and fistulate, which occur as separate specimens in general. These tubular structures are from 16.0 to 20.0 μm in diameter. Lateral fine-grained walls about 1.0 μm thick are smooth at the surface. The maximum length of encountered filaments is 150 μm (a specimen preserved incompletely).

Comparison. Filaments have greater diameters than other species of the genus *Siphonophycus*.

Remarks. In the Revet microbiota, dispersed specimens of *Siphonophycus solidum* usually occur in association with filaments *S. robustum* and spheroids *G. lamellosa.* It is possible to assume that tubular fistulate morphotypes *S. solidum* are empty sheaths relatively large in size of monotrichomatous *Lyngbia*-like or polytrichomatous *Microcoleus*-like cyanobacteria.

Distribution. The species is widespread in assemblages of Proterozoic microfossils.

Material: several tens of specimens from the Revet Subformation of the Avzyan Formation.

INSERTAE SEDIS

**Genus *Paratetraphycus* Zhang Z.,
emend. Zhang Y. et al., 1998**

Type species *Paratetraphycus giganteus* Zhang Z.,
1985

***Paratetraphycus* aff. *P. giganteus* Zhang Z.,
emend. Zhang Y. et al., 1998**

Plate II, figs. 7–9

Paratetraphycus giganteus Zhang Z., 1985, p. 166, Plate I, figs. 1, 4, 6, 7; Plate II, fig. 6; Yuan, Hofmann, 1998, p. 208, figs. 12 A–12D; Zhang Y. *et al.*, 1998, p. 46, figs. 20.4–20.8.

Gloeodiniopsis lamellosa (partim), Sergeev, 1992a, Plate IX, figs. 5, 6, 8, 9, Sergeev, 1994, figs. 8G (for complete synonymy, see Yuan and Hofmann, 1998).

Holotype, paleobotanical collection no 62354 at the University of Beijing, thin section M-21-1A, coordinates England Finder S-24-2; Vendian, Doushantou Formation, China.

Description. Spheroids with one-layer walls, which occur isolated or in dyads, triads, tetrads (flat and pyramidal), and colonies of dozens closely spaced specimens. Spheroid walls are usually semitransparent, spherical to elongate-ellipsoidal in shape. The outer surface and lateral walls 1.0 to 1,5 µm thick are medium-grained. Spheroid diameters range from 20.0 to 50.0 µm. Spherical or irregular envelopes of spheroid clusters are transparent, one- or two-layer in structure, ranging in size from 30.0 to 100.0 µm across. External surface of envelopes is medium-grained like their walls, which are 1.0–2.0 µm thick. Daughter spheroids present inside envelopes are semitransparent, 4.0 to 8.0 µm in diameter. Their medium-grained walls are 1.0–1.5 µm thick.

Comparison. The genus consists of one species.

Remarks. The described spheroids have been originally identified in the Kataskin Subformation as *Gloeodiniopsis lamellosa* (Sergeev, 1992a, 1992b). Additional specimens found recently show however that they are of a larger size and belong presumably to remains of eukaryotic algae. Despite the greater size, these microfossils are very close in morphology to

Paratetraphycus giganteus identified in the Doushantou Formation of the Lower Vendian in China ((Zhang, 1985; Zhang *et al.*, 1998; Yuan and Hofmann, 1998). Based on morphometric parameters, *Paratetraphycus* forms are comparable with red bangiomorphic algae (Zhang *et al.*, 1998), and their occurrence in the Avzyan Formation may characterize one of the stages in evolution of eukaryotic microorganisms, because approximately concurrent deposits of the Hunting Formation in North America yielded oldest representatives of doubtless filamentous bangiomorphs (Butterfield, 2000, 2001). Being less definite in terms of morphometric parameters, forms from the Avzyan Formation are attributed in this work to Insertae Sedis. In general, these microfossils may represent remains of other eukaryotic taxa, for instance, of green algae.

Distribution: Middle Riphean, Avzyan Formation, southern Urals; Vendian, Doushantou Formation, China.

Material: several hundreds specimens from the Kataskin Subformation of the Avzyan Formation.

Genus *Leiosphaeridia Eisenack,* 1958

Type species *Leiosphaeridia baltica* Eisenack, 1958

***Leiosphaeridia jacutica* (Timofeev).
comb. Mikhailova et Jankauskas, 1989**

Plate II, fig. 6

Leiosphaeridia jacutica (Timofeev), Yankauskas *et al.*, 1989, pp. 77–78, Plate XII, figs. 3a, 3b, 7, 9; Butterfield *et al.*, 1984, p. 42, fig. 16H; Sergeev, 1999, Plate 1, fig. 8; Sergeev, 2001, p. 444, figs. 8.7–8.10 (for complete synonymy, see monograph by Yankauskas *et al.*, 1989).

Holotype, paleontological collection at the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, preparation no. 452/1; Upper Riphean, Lakhanda group, Neryuen Formation, Uchur–Maya region, Siberia (lost holotype).

Paratype, paleontological collection at the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, preparation no. 1821/1; Upper Riphean, Derevnya Formation, Turukhansk Uplift, Siberia.

Description. Solitary spheroids with one-layer opaque walls; their walls 2.0 to 3,0 µm thick and outer surface are coarse-grained or granulated. Spheroid diameters range from 80.0 to 225.0 µm.

Comparison. *L. jacutica* differs from other *Leiosphaeridia* species in dimension of spheroid diameters and wall thickness (see Yankauskas *et al.*, 1989, pp. 24–25, Plate III).

Remarks. In this work, we follow the formal classification of morphologically simple coccoidal phytoplanktonic microfossils and *Leiosphaeridia* species, which is suggested in monograph by Yankauskas *et al.* (1989). According to this classification, genus

Leiosphaeridia includes all smooth-walled spherical microfossils, which are less than 1000 μm in diameter. In such an understanding, genus *Leiosphaeridia* includes many taxa, which have been considered as representatives of other genera (*Trachysphaeridium, Kildinella, Protoleiosphaeridium*), and small morphotypes of the genus *Chuaria.* Species of the genus *Leiosphaeridia* are identified based on formal criteria, mainly on diameters of spheroids and thickness of their walls. Species *L. jacutica* correspond to morphologically simple spheroids with diameters 70–800 μm and thick (2.0 μm and thicker) opaque or semitransparent one-layer walls.

Distribution: a component of many Proterozoic assemblages of microfossils.

Material: 10 specimens from the Kataskin Subformation of the Avzyan Formation.

Leiosphaeridia atava (Naumova) emend. Jankauskas, 1989

Plate II, fig. 1

Leiosphaeridia atava Naumova 1960, Plate III, fig. 15; Yankauskas *et al.*, 1989, pp. 74–75, Plate X, figs. 4–7 (complete synonymy is presented in monograph by Yankauskas *et al.*, 1989).

Holotype, paleontological collection at the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, preparation no. 452/1; Upper Riphean, Lakhanda group, Neryuen Formation, Uchur–Maya region, Siberia (lost holotype).

Description. Solitary spheroids with one-layer semitransparent walls whose surface and walls about 1.5 μm thick are fine-grained. Spheroids are up to 180.0–250.0 μm in diameter.

Comparison. *L. atava* differs from other *Leiosphaeridia* species in dimension of spheroid diameters and wall thickness (see Yankauskas *et al.*, 1989, pp. 24–25, Plate III).

Distribution: a component of many Proterozoic assemblages of microfossils.

Material: two specimens from the Kataskin Subformation of the Avzyan Formation.

Leiosphaeridia crassa (Naumova) emend. Jankauskas, 1989

Plate II, figs. 2a–2c, 5

Leiosphaeridia crassa Naumova, 1949, Plate I, fig. 3; Yankauskas *et al.*, 1989, pp. 75–76, Plate IX, figs. 5–10; Butterfield *et al.*, 1994, pp. 40–42, figs. 16F, 23K (complete synonymy is presented in monograph by Yankauskas *et al.*, 1989).

Holotype, Naumova, 1949, Plate I, fig. 3; paleontological collection at the Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia, preparation no. 452/1; Lower Cambrian, Lontova Formation, Estonia.

Description. Solitary spheroids with one-layer opaque walls; their walls thicker than 2.0 μm and outer surface are coarse-grained or granulated. Spheroid diameters range from 30.0 to 70.0 μm.

Comparison. *L. crassa* differs from other *Leiosphaeridia* forms in dimension of spheroid diameters and wall thickness (see Yankauskas *et al.*, 1989, pp. 24–25, Plate III).

Remarks. Some specimens of *L. crassa* have acanthi at the surface (Plate II, figs. 2a–2c), but at present it is unclear whether they are of primary or secondary origin.

Distribution: a component of many Proterozoic assemblages of microfossils.

Material: 47 specimens from the Kataskin Subformation of the Avzyan Formation.

REFERENCES

1. J. K. Bartley, A. H. Knoll, J. P. Grotzinger, and V. N. Sergeev, "Lithification and Fabric Genesis in Precipitated Stromatolites and Associated Peritidal Carbonates, Mesoproterozoic Billiakh Group, Siberia," SEPM Special Publication **67**, 59–73 (2000).

2. N. J. Butterfield, "Paleobiology of the Late Proterozoic (ca. 1200 Ma) Hunting Formation, Somersed Island, Arctic Canada," Precambrian Res. **111**, 235–256 (2001).

3. N. J. Butterfield, "*Bangiomorpha pubescens* n. gen., n. sp.: Implications for the Evolution of Sex, Multicellularity and the Mesoproterozoic–Neoproterozoic Radiation of Eukaryotes," Paleobiology **26**, 386–404 (2000).

4. N. J. Butterfield, A. H. Knoll, and K. Swett, "Paleobiology of the Neoproterozoic Svanbergfiellet Formation, Spitsbergen," Fossils and Strata, No. 34, 84 (1994).

5. M. I. Garan', "Correlation of the Upper Precambrian Successions in the Urals," in *Stratigraphy of the USSR* (GONTI, Moscow, 1963), Vol. 2 [in Russian].

6. V. K. Golovenok and M. Yu. Belova, "Microfossils in Cherts from the Riphean Deposits of the Turukhansk Uplift," Stratigr. Geol. Korrelyatsiya **1** (3), 51–62 (1993) [Stratigr. Geol. Correlation **1** (3), 279–288 (1993)].

7. V. K. Golovenok and M. Yu. Belova, "Microfossils in Cherts of the Riphean Sukhaya Tunguska Formation, Turukhansk Uplift," Dokl. Akad. Nauk SSSR **323** (1), 114–118 (1992).

8. I. N. Golub, "A New Group of Problematic Microstructures in Vendian Deposits of the Orsha Basin (Russian Platform)," in *Paleontology of the Precambrian and Early Cambrian* (Nauka, Leningrad, 1979), pp. 147–155 [in Russian].

9. S. Golubic, "Organisms That Build Stromatolites," *Stromatolites*, Ed. by M.R. Walter (Elsevier, Amsterdam, 1976), pp. 113–126.

10. S. Golubic and H. J. Hofmann, "Comparison of Holocene and Mid-Precambrian Entophysalidaceae (Cyanophyta) in Stromatolitic Algal Mats: Cell Division and Degradation," J. Paleontol. **50**, 1074–1082 (1976).

11. J. W. Green, A. H. Knoll, S. Golubic, and K. Swett, "Paleobiology of Distinctive Benthic Microfossils from the Upper Proterozoic Limestone–Dolomite 'Series', Central-East Greenland," Am. J. Bot. **74** (6), 928–940 (1987).

12. P. D. Grevello, J. L. Wilson, J. F. Sarg, and J. F. Read, SEPM Special Publication **44**, 79–106 (1989).

13. J. P. Grotzinger, "Evolution of Early Proterozoic Passive-Margin Carbonate Platform, Rocknest Formation, Wopmay Orogen, Northwest Territories, Canada," J. Sediment. Petrology **56**, 831–847 (1986).

14. J. P. Grotzinger, "Facies and Evolution of Precambrian Carbonate Depositional Systems: Emergence of the Modern Platform Archetype," SEPM Spec. Publ. **44**, 79–106 (1989).

15. J. P. Grotzinger, "Trends in Precambrian Carbonate Sediments and Their Implication for Under standing Evolution," *Early Life on Earth*, Ed. by S. N. Y. Bengston (Columbia Univ. Press, Columbia, 1994), pp. 245–258.

16. H. J. Hofmann and C. D. Jackson, "Shelf-Facies Microfossils from the Uluksan Group (Proterozoic Bylot Supergroup), Baffin Island, Canada," J. Paleontol. **65**, 361–382 (1991).

17. R. J. Horodyski and J. A. Donaldson, "Microfossils from the Middle Proterozoic Dismal Lakes Group, Arctic Canada," Precambrian Res. **11**, 125–159 (1980).

18. R. J. Horodyski, B. Bloeser, and S. V. Haar, "Laminated Algal Mats from a Coastal Lagoon, Laguna Mormona, Baja California," J. Sediment. Petrology **47**, 680–696 (1977).

19. E. J. Javaux, A. H. Knoll, and M. R. Walter, "Morphology and Ecological Complexity in Early Eukaryotic Ecosystems," Nature **412** (6872), 66–69 (2001).

20. L. C. Kah and A. H. Knoll, "Microbenthic Distribution of Proterozoic Tidal Flats: Environmental and Taphonomic Considerations," Geology **24**, 79–82 (1996).

21. L. C. Kah, A. G. Sherman, G. M. Narbonne, *et al.*, "δC^{13} Stratigraphy of the Proterozoic Bylot Supergroup, Baffin Island, Canada: Implications for Regional Lithostratigraphic Correlations," Can. J. Earth Sci. **36**, 313–332 (1999).

22. B. M. Keller, *Tectonic and Formation History of the Upper Precambrian, Itogi Nauki Tekh., Ser.: Obsh. Geol.* (VINITI, Moscow, 1973) [in Russian].

23. B. M. Keller and T. V. Yankauskas, "Microfossils from the Riphean Stratotype in the Southern Urals," Izv. Akad. Nauk SSSR, Ser. Geol., No. 12, 58–68 (1980).

24. B. M. Keller, V. I. Kozlov, and A. F. Rotar', "The Middle Riphean (Yurmatinian)," in *Stratotype of the Riphean: Stratigraphy, Geochronology* (Nauka, Moscow, 1983), pp. 30–49 [in Russian].

25. A. H. Knoll and S. Golubic, "Anatomy and Taphonomy of a Precambrian Algal Stromatolite," Precambrian Res. **10**, 115–151 (1979).

26. A. H. Knoll and V. N. Sergeev, "Taphonomic and Evolutionary Changes across the Mesoproterozoic–Neoproterozoic Transition," Neues Jahrb. Palaeontol., Abh. **195** (1995).

27. V. I. Kozlov, A. A. Krasnobaev, N. N. Larionov, *et al.*, *The Lower Riphean of Southern Urals* (Nauka, Moscow, 1989) [in Russian].

28. V. I. Kozlov, N. D. Sergeeva, N. N. Larionov, *et al.*, "The Upper Precambrian of Southern Urals and Adjacent Eastern Areas of the Russian Plate," in *The Riphean of North Eurasia: Geology, General Problems of Stratigraphy* (Ural. Otd. Ross. Akad. Nauk, Yekaterinburg, 1997), pp. 85–93 [in Russian].

29. E. V. Kozlova, "Organic-Walled Microfossils from Deposits of the Avzyan Formation, Southern Urals," in *The Upper Precambrian of Southern Urals and Eastern Areas of the Russian Plate* (UNTs RAN, Ufa, 1993), pp. 60–68 [in Russian].

30. A. A. Krasnobaev, *Zircon as an Indicator of Geologic Processes* (Nauka, Moscow, 1986) [in Russian].

31. I. N. Krylov and V. N. Sergeev, "Riphean Microfossils of the Southern Urals in the Kusa Area," in *Stratigraphy, Lithology and Geochemistry of the Upper Precambrian, the Southern Urals and Adjacent Region* (Bashkir. Filial AN SSSR, Ufa, 1986), pp. 95–109 [in Russian].

32. S. C. Lo, "Microbial Fossils from the Lower Yudoma Suite, Earliest Phanerozoic, Eastern Siberia," Precambrian Res. **13**, 109–166 (1980).

33. A. V. Maslov and L. V. Anfimov, *The Avzyan Productive Formation of the Middle Riphean in the Southern Urals (Lithostratigraphy, Genesis, Mineralization)* (Inst. Geol. Geokhim., Yekaterinburg, 2000) [in Russian].

34. A. V. Maslov, E. Z. Gareev, and M. T. Krupenin, *Sedimentary Succession of the Riphean in the Type Area* (GP Print, Ufa, 1998) [in Russian].

35. A. V. Maslov, M. T. Krupenin, E. Z. Gareev, and L. V. Anfimov, *The Riphean of the Southern Urals Western Flank (Classical Sections, Sedimentation, Lithogenesis, Mineralization, Natural Geological Monuments)* (Inst. Geol. Geokhim., Yekaterinburg, 2001) [in Russian].

36. D. S. McMenamin, S. Kumar, and S. M. Awramik, "Microbial Fossils from the Kheinjuo Formation, Middle Proterozoic Semri Group (Lower Vindhyan), Son Valley Area, Central India," Precambrian Res. **21** (1/2), 247–271 (1983).

37. C. V. Mendelson and J. W. Schopf, "Proterozoic Microfossils from the Sukhaya Tunguska, Shorikha, and Yudoma Formations of the Siberian Platform, USSR," J. Paleontol. **56**, 42–83 (1982).

38. N. S. Mikhailova and V. N. Podkovyrov, "New data on Organic-Walled Microfossils from the Upper Precambrian of the Urals," Izv. Akad. Nauk SSSR, Ser. Geol., No. 10, 111–123 (1992).

39. M. D. Muir, "Proterozoic Microfossils from the Amelia Dolomite, McArthur Basin, Northern Territory," Alcheringa **1** (1), 143–158 (1976).

40. M. Sharma and V. N. Sergeev, "Genesis of Carbonate Precipitate Patterns and Associated Microfossils in Mesoproterozoic Formations of India and Russia—a Comparative Study," Precambrian Res. **134**, 317–347 (2004).

41. K. E. Nagovitsin, "Silicified Microbiota of the Upper Riphean from the Yenisei Ridge," Appendix to Geol. Geofiz. **41** (2–3), 7–31 (2000).

42. K. E. Nagovitsin, "New Late Riphean Composite Microfossils from the Yenisei Ridge," Paleontol. Zh., No. 3, 5–13 (2001a) [Paleontol. J. **35** (3), 225–232 (2001a)].

43. K. E. Nagovitsin, Extended Abstract of Candidate's Dissertation in Geology and Mineralogy (Novosibirsk, 2001b).

44. S. N. Naumova, "Spores of the Lower Cambrian," Izv. Akad. Nauk SSSR, Ser. Geol., No. 4, 49–56 (1949).

45. S. N. Naumova, "Spore–Pollen Spectra of Riphean and Loer Cambrian Deposits in the USSR," in *Proceedings of the Intern. Geol. Congress, Session XXI* (Nauka, Moscow, 1960), pp. 109–116 [in Russian].

46. A. Y. Nyberg and J. W. Schopf, "Microfossils in Stromatolitic Cherts from the Upper Proterozoic Min'yar Formation, Southern Ural Mountains, USSR," J. Paleontol. **58** (3), 738–772 (1984).

47. R. N. Ogurtsova and V. N. Sergeev, "Microbiota of the Chichkan Formation, Upper Precambrian of the Lesser Karatau (Southern Kazakhstan)," Paleontol. Zh., No. 2, 107–116 (1987).

48. G. V. Ovchinnikova, I. M. Vasil'eva, M. A. Semikhatov, *et al.*, "U–Pb Systematics on Proterozoic Carbonate Rocks: The Inzer Formation of the Upper Riphean Stratotype (Southern Urals)," Stratigr. Geol. Korrelyatsiya **6** (4), 20–31 (1998) [Stratigr. Geol. Correlation **6** (4), 336–347 (1998)].

49. P. Yu. Petrov, M. A. Semikhatov, and V. N. Sergeev, "Development of the Riphean Carbonate Platform and Distribution of Silicified Microfossils: the Sukhaya Tunguska Formation, Turukhansk Uplift, Siberia," Stratigr. Geol. Korrelyatsiya **3** (6), 79–99 (1995) [Stratigr. Geol. Correlation **3** (6), 602–620 (1995)].

50. Resolution of the Third All-Russian Meeting "General Problems of Precambrian Stratigraphy," Stratigr. Geol. Korrelyatsiya **9** (3), 101–106 (2001) [Stratigr. Geol. Correlation **9** (3), 304–308 (2001)].

51. J. W. Schopf, "Atlas of Representative Proterozoic Microfossils," in *The Proterozoic Biosphere*, Ed. by J. W. Schopf and C. Klein (Cambridge University Press, Cambridge, 1992), pp. 1055–1118.

52. J. W. Schopf, T. A. Dolnik, I. N. Krylov, *et al.*, "Six New Stromatolitic Microbiotas from the Proterozoic of the Soviet Union," Precambrian Res. **4** (3), 269–284 (1977).

53. M. A. Semikhatov, G. V. Ovchinnikova, I. M. Gorokhov, *et al.*, "Isotope Age of the Middle-Upper Riphean Boundary: Pb-Pb Geochronology of the Lakhanda Group Carbonates, Eastern Siberia," Dokl. Akad. Nauk **372** (2), 216–221 (2000) [Dokl. Earth Science **372** (2), 625–629 (2000)].

54. V. N. Sergeev, "Silicified Microfossils from the Middle Riphean Stratotype, the Southern Urals," Dokl. Akad. Nauk SSSR **303** (3), 708–710 (1988).

55. V. N. Sergeev, "Silicified Microfossils from Transitional Meso-Neoproterozoic Deposits of the Turukhansk Uplift, Siberia," Boll. Soc. Paleontol. Ital. **38** (2-3), 287–295 (1999).

56. V. N. Sergeev, "Silicified Microfossils from the Avzyan Formation of the Southern Urals," Paleontol. Zh., No. 2, 103–112 (1992b).

57. V. N. Sergeev, *Silicified Microfossils of the Precambrian and Cambrian in the Urals and central Asia* (Nauka, Moscow, 1992a) [in Russian].

58. V. N. Sergeev, "Microfossils in Cherts from the Middle Riphean (Mesoproterozoic) Avzyan Formation, Southern Ural Mountains, Russian Federation," Precambrian Res. **65**, 231–254 (1994).

59. V. N. Sergeev, "Paleobiology of the Neoproterozoic (Upper Riphean) Shorikha and Burovaya Silicified Microbiotas, Turukhansk Uplift, Siberia," J. Paleontol. **75** (2), 427–448 (2001).

60. V. N. Sergeev, "Silicified Microfossils from the Vendian Yudoma Group, the Uchur-Maya Region of Siberia: Facies Dependence and Biostratigraphic Potential," Stratigr. Geol. Korrelyatsiya **10** (6), 20–39 (2002) [Stratigr. Geol. Correlation **10** (6), 547–564 (2002)].

61. V. N. Sergeev, Extended Abstract of Doctoral Dissertation in Geology and Mineralogy (Moscow, 2003).

62. V. N. Sergeev and Lee Seong-Joo, "Microfossils from Cherts of the Middle Riphean Svetlyi Formation, the Uchur-Maya Region of Siberia, and Their Stratigraphic Significance," Stratigr. Geol. Korrelyatsiya **9** (1), 3–12 (2001) [Stratigr. Geol. Correlation **9** (1), 1–10 (2001)].

63. V. N. Sergeev and Lee Seong-Joo, "New Data on Silicified Microfossils from the Satka Formation of the Lower Riphean Stratotype, the Urals," Stratigr. Geol. Korrelyatsiya **12** (1), 1–21 (2004) [Stratigr. Geol. Correlation **12** (1), 1–21 (2004)].

64. V. N. Sergeev, A. H. Knoll, and J. P. Grotzinger, "Paleobiology of the Mesoproterozoic Billiakh Group, Anabar Uplift, Northeastern Siberia," J. Paleontol. **69** (1995).

65. V. N. Sergeev, A. H. Knoll, and P. Yu. Petrov, "Paleobiology of the Mesoproterozoic—Neoproterozoic Transition: The Sukhaya Tunguska Formation, Turukhansk Uplift, Siberia," Precambrian Res. **85**, 201–239 (1997).

66. V. N. Sergeev, A.H. Knoll, S. P. Kolosova, and P. N. Kolosov, "Microfossils in Cherts from the Mesoproterozoic (Middle Riphean) Debengda Formation, the Olenek Uplift, Northeastern Siberia," Stratigr. Geol. Korrelyatsiya **2** (1), 23–38 (1994) [Stratigr. Geol. Correlation **2** (1), 19–33 (1994)].

67. V. N. Sergeev and I. N. Krylov, "Microfossils of the Min'yar Formation, the Inzer River Basin," Paleontol. Zh., No. 1, 84–95 (1986).

68. N. S. Shatskii, *Tectonics of the Volga–Ural Petroliferous Province and Adjacent Flank Zone of the Southern Urals* (Akad. Nauk SSSR, Moscow, 1945) [in Russian].

69. D. V. Shopf, T. A. Dol'nik, I. N. Krylov, *et al.*, "Microfossils in Precambrian Stromatolitic Rocks of the USSR," in *Paleontology of the Precambrian and Early Cambrian* (Nauka, Leningrad, 1979), pp. 104–109 [in Russian].

70. A. F. Veis, E. V. Kozlova, and N. G. Vorob'eva, "Organic-Walled Microfossils of the Riphean Type Section (Southern Urals)," Izv. Akad. Nauk SSSR, Ser. Geol., No. 9, 20–36 (1990).

71. A. F. Veis, V. I. Kozlov, N. D. Sergeeva, and N. G. Vorob'eva, "Microfossils from the Upper Riphean Type Section (the Karatau Group of Southern Urals)," Stratigr. Geol. Korrelyatsiya **11** (6), 19–44 (2003) [Stratigr. Geol. Correlation **11** (6), 550–572 (2003)].

72. A. F. Veis, N. N. Larionov, and N. G. Vorob'eva, Lee Seong-Joo,"Significance of Microfossils for Riphean Stratigraphy of the Southern Urals (Bashkirian Meganticlinorium) and Adjacent Region (Kama–Belaya Aulacogen)," Stratigr. Geol. Korrelyatsiya **8** (6), 3–28 (2003) [Stratigr. Geol. Correlation **8** (6), 550–572 (2003)].

73. S. L. Venetskaya and L. M. Gerasimenko, "Electron-Microscopic Study of Microorganisms in Halophilic Cyanobacterial Community," Mikrobiologiya **57** (3), 450–457 (1988).

74. S. Xiao, A. H. Knoll, A. J. Kaufman, *et al.*, "Neoproterozoic Fossils in Mesoproterozoic Rocks? Chemostratigraphic Resolution of a Biostratigraphic Conuntdrum from the North China Platform," Precambrian Res. **84**, 197–220 (1997).

75. Xunlai Yuan and H. J. Hofmann, "New Microfossils from the Neoproterozoic (Sinian) Doushantuo Formation, Guizhou Province, Southwestern China," Alcheringa **22**, 189–222 (1998).

76. M. S. Yakshin, *Vodoroslevaya mikrobiota nizhnego rifeya Anabarskogo podnyatiya* (Nauka, Novosibirsk, 1991) [in Russian].

77. Y. Yan and S. Zhu, "Discovery of Acanthomorphic Acritarchs from the Baicaoping Formation in Yongji, Shanxi and Its Geological Significance," Acta Micropaleontol. Sinica **9** (3), 267–282 (1992).

78. T. V. Yankauskas, "Microbiotas of the Lower Riphean in the Southern Urals," Dokl. Akad. Nauk SSSR **247** (6), 1465–1467 (1979a).

79. T. V. Yankauskas, "Microbiotas of the Middle Riphean in the Southern Urals," Dokl. Akad. Nauk SSSR **248** (1), 190–193 (1979b).

80. T. V. Yankauskas, "Riphean Microfossils from the Southern Urals," in *Stratotype of the Riphean: Paleontology, Paleomagnetism* (Nauka, Moscow, 1982), pp. 84–120 [in Russian].

81. T. V. Yankauskas, N. S. Mikhailova, T. N. German, *et al.*, *Precambrian Microfossils of the USSR* (Nauka, Leningrad, 1989) [in Russian].

82. L. Yin, "Acanthomorphic Acritarchs from Meso-Neoproterozoic Shales of the Ruyang Group, Shanxi, China," Rev. Palaeobot. Palynol. **98**, 15–25 (1997).

83. Z. Zhang, "Coccoid Microfossils from the Doushantou Formation (Late Sinian) of Southern China," Precambrian Res. **28**, 163–173 (1985).

84. Y. Zhang, "Proterozoic Stromatolite Microfloras of the Gaoyuzhuang Formation (Early Sinian: Riphean), Hebei, China," J. Paleontol. **55**, 485–506 (1981).

85. Y. Zhang, L. Yin, S. Xiao, and A. H. Knoll, "Permineralised Fossils from the Terminal Proterozoic Doushantou Formation, South China," J. Paleontol. **72** (1998).