Chapter 12
Biogenic–Abiogenic Interactions in Stromatolites: Study Possibilities and Outlooks

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Abstract Stromatolites are produced by a complicated interplay of biogenic and abiogenic processes, whose contributions are hard to estimate without applying specialized techniques enabling the researcher to reproduce these processes. Stromatolites are fairly widespread in nature and are found as building organisms of various shape and size. Most researchers classify them into layered and columnar types or subtypes, which comprise complicatedly but systematically branching columns, oncolites, and microstromatolites. In spite of the morphological diversity of stromatolites, stromatolite reefs were formed over significant areas during a certain span of geological time, with only some types of structures found in them. It was determined that the morphological types of stromatolites obviously show a certain spatiotemporal distribution. This fact cannot be explained by the sedimentation conditions alone, and it indicates that biogenic processes and matter played a key role in the origin of stromatolites. However, no stromatolite-forming organisms had long been found. The later transformations of these rocks further complicated the problem in view of the fact that the great majority of stromatolites are of Precambrian age. A recently suggested and tested technique makes it possible to identify the building organisms of stromatolites and estimate their role in forming the structural–textural features of these rocks. This technique involves SEM studies. This publication discusses the potentialities of the techniques and the reliability of results obtained using it, as well as the outlooks in its application to solving specific problems (identification of cyanobacteria) and more general issues concerning the geology of the Precambrian.

Keywords Stromatolite structures · Electron microscope · Biogenic ultramicrostructures · New method · Cyanobacteria · Morphology

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12.1 Introduction

The mid-20th century was marked by growing needs to study ancient rocks hosting vast reserves of iron, base metals, gold, platinum-group elements (PGE), and rare-earth elements (REE) and other valuable minerals. This work was largely complicated by the fact that neither paleontological nor isotopic dating methods cannot be applied to constrain the age of Precambrian rocks. It was then suggested to try to use morphological features of stromatolites and their age in solving these problems. Starting in the mid-20th century, stromatolites were actively studied, and data thus obtained were more and more widely applied in geology and stratigraphy to constrain the age of fossil-free Precambrian rocks.

The very first found stromatolites were then thought to be produced with the involvement of living organisms, but all efforts to find these organisms failed. Stromatolites were documented unsystematically until a uniform approach was suggested thanks to the invention of two methods. One of them was the technique of graphical preparing (Krylov 1963) and allowed the researcher to reproduce the 3D shape of the stromatolite structures and the branching specifics of the columns, determine the nature of their boundaries, and identify the occurrence of cornices, visors, connecting bridges, etc. The other method (Wolcott 1914) was based on studying the microstructures, i.e., the shapes and sizes of the clods of carbonate matter (Komar 1989) in stromatolites. This method provided descriptions of the relative position of smaller features than those studied by the previous technique, but in its core meaning, this technique was an extension of the aforesaid (morphological) approach. Both methods were widely applied by various researchers (Komar et al. 1962; Serebryakov 1975; Shapovalova 1974 and others) and have yielded interesting results. A uniform formalism and terminology and the similar means of application largely simplified and systematized the work of the researchers. The methods have long been used to develop and refine the systematics of stromatolites, into which more and more new finds were systematically integrated (Awramik et al. 1983; Krylov 1975; Semikhatov and Raaben 1994, 1996, 2000; Shapovalova 1974; Serebryakov 1975). This systematics was of formalized nature because it was based not on organisms themselves but on the shapes of stromatolite structures and the fabrics of the rocks. Nevertheless stromatolites made it possible to suggest the very first justified stratigraphic subdivision of the Precambrian.

By the early 21st century, all preexisting possibilities of studying these rocks had been exhausted, and this led to the almost complete termination of these studies. At the same time, new dating methods of ancient rocks were developed, including isotopic dating, and dating using silicified cyanobacteria, acritarchs etc. This made it senseless to search for and document new stromatolite types and, hence, studies of stromatolites were almost completely terminated.

However, these rocks, which were the first to be formed when life emerged on the planet, continued to provoke keen interest. Most researchers believed that the morphology of stromatolite structures was controlled first of all by the composition of the

stromatolite-building organisms and their living activities, although sedimentation circumstances should also have played an important part.

Regretfully, all attempts to find these organisms either under an optical microscope or by studying rock sections under an electron microscope failed.

Issues concerning interaction between biogenic and abiogenic matter in stromatolites and the origin not only of rocks of unusual structure but also stromatolite reefs as an integrated biological system were solved purely theoretically in the absence of factual material. This called for inventing principally new techniques able to acquire data at a principally other, much more detailed level.

Many attempts have been made to apply electron microscope in studying stromatolites. However, similar to the situation with using optical microscope for these purposes, the researchers managed only to see an uniform carbonate material and nothing else. At the same time, the equipment was successfully used to model stromatolites in the laboratory (Krylov and Orleansky 1988; Orleansky et al. 2000 and others), including examining changes in the shapes of the bacteria in the course of their fossilization and the step by step development of modern biogenic structures during their silicitization (Krylov and Tikhomirova 1988; Ushatinskaya 2002).

A newly developed techniques (Litvinova 2009) has offered principally new potentialities. The application of an electron microscope equipped with an energy dispersive spectrometer (EDS) enables the researcher to reveal microorganisms involved in building stromatolite reefs and estimate the geochemical aspects of interaction between these organisms and sedimentation. It also makes it possible to evaluate the evolutionary modification and subsequent degradation of stromatolite structures (Naugolnych and Litvinova 2014) and changes under the effect of secondary processes (Litvinova 2014a). The data thus acquired should, however, be carefully tested with regard for the possible occurrence of newly formed biogenic structures. Moreover, the researcher should be confident that the identified organisms were coeval with sedimentation and were not brought to the rock much later, for example, in the Phanerozoic. To do this, we have tested of the acquired data.

The technique has been tested and allowed us to obtain principally new interesting results (Litvinova 2014a, b, 2016, 2018; Naugolnych and Litvinova 2014 and others) on the biogenic ultramicrostructures of stromatolites that had various age and were sampled at a number of localities. The technique itself and experience in its application have never been described before, and hence, most researchers are still not familiar with it. This publication bridges this gap and cautions the reader against possible errors and drawbacks by describing the technique of the work in much detail.

12.2 Materials and Method

The specifics of the method suggested herein is the preparation of the samples. These are not thin sections, which have been unsuccessfully utilized previously in electron microscopic studies of stromatolites, but freshly obtained stromatolite chips that

include their organogenic layer. This enables the researcher to observe the biogenic structures as 3D (but not 2D) images, because otherwise they are indiscernible from the host rock.

The working routine was as follows. Stromatolites were first examined in field (in outcrops) and then in thin sections under a stereoscope or binocular magnifier. It has been established that the ultramicrotexture of the rock plays a key role on an electron-microscopic level too and hence, it was principally important to select fragments of the sample that included sites most promising for identification of the best preserved bios. This fragment must show structures typical of the taxon in question and be minimally modified by any overprinted processes. The electron microscopic study was carried out using a few samples smaller than 5–6 mm across, with fresh variably oriented chippings. This made it possible to obtain the most comprehensive information on both the stromatolite-building organisms and the secondary processes that overprinted the rock. The analyzed elemental composition of the rocks (including its trace-element composition) is not only an important parameter of the rock but also provides clues to better understanding the genesis of the likely biogenic structures. In view of this, the samples were not preparatorily treated by acids, because otherwise it was senseless to analyze the composition of such samples. Furthermore, the necessity for submerging samples into water after their acid treatment may stimulate the growth of modern fungi and thus mislead the researcher. The samples were sputter-coated with gold to enable identification of elevated carbon concentrations in the supposedly biogenic structures. Upon their coating, the samples were mounted on the electron-microscope stage 11 mm in diameter and placed into the vacuum column. Neither long-term storage nor washing of the samples were admissible.

The studies were conducted on a TesScanMV-2300 scanning electron microscope equipped with Cambridge Instruments INCA-200 energy-dispersive spectrometer. The diameter of the analyzed spot was thereby no larger than 1 μm. The genesis of each of the supposedly biogenic ultramicrostructures was tested using a microprobe accurate to 0.001%. Long-term studies of stromatolites by this method have shown that the stromatolites contain a vast amount of various biogenic ultramicrostructures (Litvinova 2009, 2014a, 2018 and others), which were responsible for the origin of certain structural features of the rock. A provisional classification of stromatolites was developed (Litvinova 2016), and the first attempts were undertaken to compare the identified species with siliceous microfossils (Litvinova and Sergeev 2018). Comparison of our materials with experimental data and with descriptions of currently living stromatolites helped in understanding and interpreting this material, but many issues remained uncertain and can be settled only based on systematic studies of biogenic ultramicrotextures of the rocks.

The method was tested on numerous samples of diverse stromatolites of various types, which were sampled at different localities and described in our earlier publications.

12.3 Results and Discussion

Biogenic ultramicrotextures were identified in stromatolites based on their morphology: with these ultramicrotextures are clearly discernible from the pelitomorphic and/or more rare fine-crystalline material (Fig. 12.1a). Their genesis is or is not confirmed by data on the chemical composition of the objects. The high sensitivity of microprobe analysis allowed us to identify biophile elements even in replicas of prokaryotes. Any fossilized organism (Fig. 12.1a) is made up of the same carbonate material as the host rocks (Fig. 12.1a_1) but differs from the latter in containing much more carbon (Fig. 12.1a_2). Organic carbon in cyanobacteria are commonly associated with inclusions of microportions of other biophile elements, which are absent from the host rock.

Carbon concentrations are at a maximum in the laminae, which are widespread flat bacterial films in stromatolites. Their accumulations are seen even in small fragments of the samples, in which they are often arranged parallel to the layering (Fig. 12.1b), although they are sometimes randomly distributed in the material. These structures are usually folded, twisted (Fig. 12.1c), and have a wrinkled surface (Fig. 12.1d), which was formed because of dehydration when the sediment was lithified. The laminae are often found in association with coccoid structures or bundles of cyanobacterim threads, sometime include both (Fig. 12.1d) and envelop the organism.

The bacterial films are former glycocalyx enriched in polysaccharoids. They concentrated organic carbon and some other elements and were able to long maintain water balance in the organisms around which the films developed. Glycocalyx (slime) protected cyanobacteria from aggressive environmental factors, including drying. For a while, it could perform the functions of the nourishing medium (which is exhausted at the time) and provide life necessities for the organisms. Thanks to its universal functions and composition, glycocalyx practically played the role of a capsule surrounding prokaryotes.

The glycocalyx is formed and then widely spreads on the surface of the sediment, and hence, its dehydrated fragments are practically always preserved and can be thus used as identification guides, which make it possible to find the bios or even estimate its role in the origin of a given rock. Bacterial films are found not only in stromatolites but also occur in other biogenic rocks, for example, phosphorites from the Lesser Karatau (Fig. 12.1e, e_2), in which they accompany phosphate pellets (Fig. 12.1e, e_1), in shungite from Karelia (Fig. 12.1f), and in other bioliths (Leonova et al. 2014). The nature of phosphate pellets is currently explained by some researchers as related to their biogenic origin, as reportedly may follow from their diverse but still repeatedly found morphologies (Kholodov and Paul 1996b; Litvinova 2007), some features of their inner structure (Litvinova 2007), and incremental variations in the size, as is typical solely of biological objects (Kholodov and Paul 1996a). Under an electron microscope, the pellets can be observed as 3D images (Fig. 12.1e_1) and in cross-section (Fig. 12.1e, 12.1q), which enables the researcher to examine their inner structures. The presence of bacterial films confirms that bios was involved in producing the phosphate pellets.

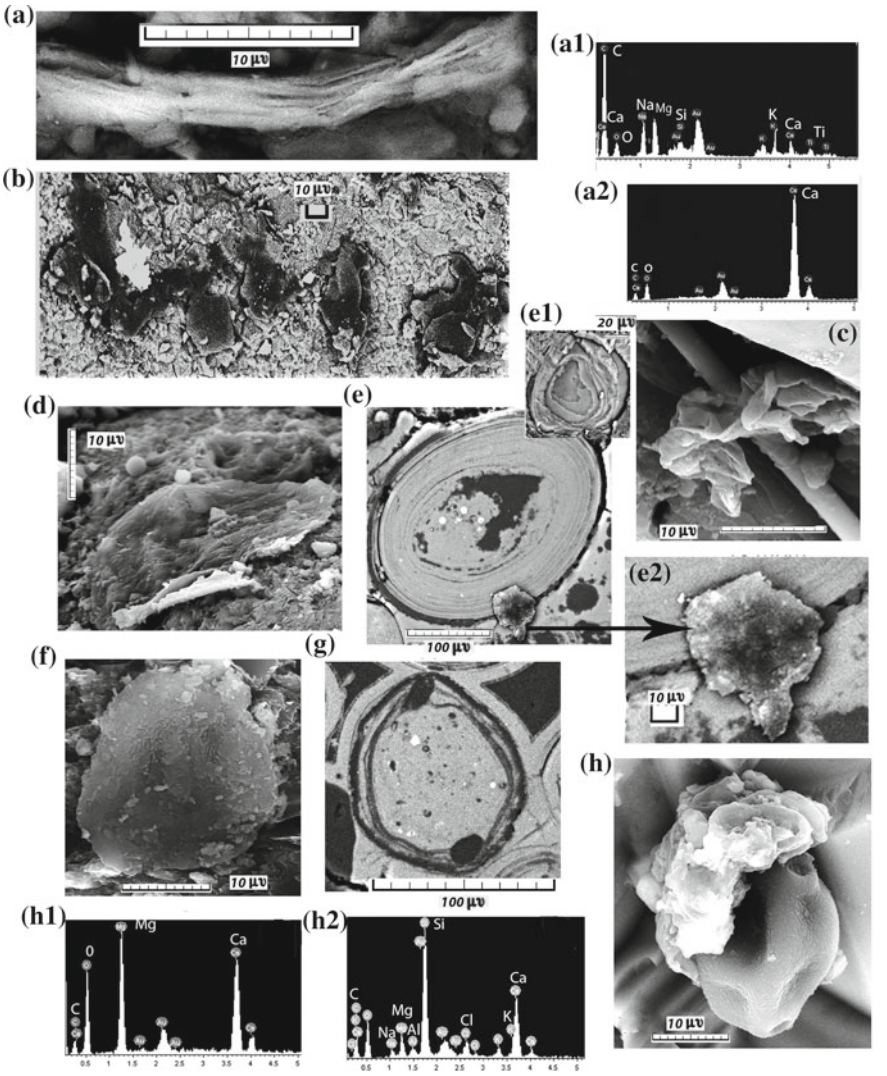

Fig. 12.1 **Biogenic ultramicrostructures**: **a**, $\mathbf{a_1}$ thread cyanobacterium and its composition, $\mathbf{a_2}$ composition of the host rocks; **b**, **c**, **d**, $\mathbf{e_2}$, **f** bacterial films in stromatolites; **e**, $\mathbf{e_1}$, **g** phosphate pellets (Kazakhstan, Lesser Kara-Tau, Early Cambrian); **h** coccoid cyanobacterium *Myxococcoides sp* with a bacterial film; $\mathbf{h_1}$, $\mathbf{h_2}$ composition of, respectively, the host rocks and *Myxococcoides sp*. Paleoproterozoic, Sundozero, Karelia

Elevated carbon concentrations are usually found in Precambrian biogenic ultramicrostructures only if they contain at least minor silica concentrations, which serve as a preservative. An increase in the silica concentration is associated with an increase in the content of organic carbon. This may suggest that the element is be better preserved in fossilized cyanobacteria rather than that the living conditions of the organisms and sedimentation circumstances were different, particularly with regard for the fact that siliceous stromatolites are usually of secondary nature. Intense transformations involving silica may have resulted in partial or complete recrystallization and obliteration of the biogenic ultramicrostructures, blurring their contours, and the complete destruction of any traces and molds of the organisms. In these situations, carbon is not always preserved. However, this process is rare and is commonly fragmentary, so that carbon can usually be readily identified in microfossils, and the shapes of the organisms are better preserved thanks to silica.

The situation with phosphate rocks is somewhat different. If small phosphorus amounts appear, with this element initially replacing biogenic structures, organic carbon is preserved, but the penetrative phosphatization of the rock leads to the complete disappearance of carbon. This may be suggestive of a secondary nature of the process and may be confirmed by the presence of coeval carbonate or siliceous stromatolites with analogous morphological features in the area in question. Silica usually replaces the whole rock, in contrast to phosphorus, which is first adsorbent on biological material. This selective replacement makes it possible to study the inner structure of biological objects (Litvinova 2007), which consist of carbonate and silica. As the phosphorus concentration increases, all constituents of the rocks are completely replaced, as is well illustrated by phosphate stromatolites in the Zmeinyi Mountains in the Southern Urals, Russia. In this instance, the contours and morphology of the fossilized cyanobacteria are seen not as clearly (Litvinova 2014b) and no carbon is preserved in them. When working with biogenic ultramicrostructures, one should be aware of the fact that carbon preservation in them strongly depends on the reworking of the primary material and the intensity of rock replacement.

Cyanobacteria and their glycocalyx can accumulate some other biophile elements necessary for their vital functions. The second, after carbon, most widespread and well preserved element is magnesium (Fig. 12.1a$_1$), which can thereby be absent from the host rock (Fig. 12.1a$_2$). However, if the rock does contain any appreciable magnesium concentrations (Fig. 12.1h$_1$), the fossilized cyanobacteria (Fig. 12.1h) contain much lower concentrations of this element (Fig. 12.1h$_2$), in the absence of reasons for storing this element that is abound in the ambient. An excess of any element is almost as harmful for an organism as its deficit, and glycocalyx thereby again plays a protective role.

Biogenic ultramicrostructures in stromatolites also contain other elements typical of the bios: these are potassium, chlorine, and sodium. Their concentrations are low not only because of their originally small amounts but also because it is hard to retain volatile components in Precambrian rocks. However, the presence of these elements is definitely typical only of the biogenic ultramicrostructures, and they are always found together with carbon. Moreover, fossilized organisms may also contain iron,

manganese, sometimes phosphorus, rare-earth elements, and some other chemical elements absent from the host rocks.

Data on modern stromatolites at Shark Bay show that the fossilized biogenic organisms are similar in shape (Litvinova 2016) and morphology to ancient ones and show evidence of a number of transformation stages of the glycocalyx into dehydrated wrinkled flakes, whose contours are clearly discernible and whose specific concentrations of carbon, magnesium, and some other elements are higher.

Microprobe analysis makes it possible not only to distinguish between fossilized organisms and mineral aggregates but also to obtain valuable additional information on the host rocks and their secondary transformations. The identification of various cyanobacteria in stromatolites, analysis of their role in the development of the ultramicrostrtucture and morphology of the stromatolite structures, analysis of the composition of the accessory minerals, and elucidation of the role of overprinted processes compose a far from complete list of potentialities offered by the application of a scanning electron microscopy in studying stromatolites and other biogenic rocks.

The texture of a rock developed as follows. A very thin (no thicker than 2 mm) bacterial film, which comprised a community of organisms, coater the mineral layer and gradually expanded over a progressively greater area. Newly brought portions of sedimentary material covered the film, and the units of fine alternating organogenic and chemogenic layers were then lithified. Stromatolites typically inherit components from the host rock, as is evident at different levels of their study, from visual to ultramicroscopic ones. As a result, characteristics of stromatolites obtained by studying them under a binocular magnifier and/or an electron microscope are practically identical, but the capabilities of these methods are different. In the former situation (when stromatolites are studied under a binocular), an increase in the number of components of the rock does not provide additional information, while in the latter, the application of electron microscopy allows the researcher to determine organisms involved in building the reef. The organogenic layer is responsible for the shape of stromatolite structures and their microstructure, and this made it possible to suggest a formalized classification of stromatolites and successfully apply it in stratigraphy. To be sure that the fossilized organisms of stromatolites identified under an electron microscope lived synchronously with sedimentation (but were not later introduced into the rock), the researcher should analyze the roles of these organisms in the microstructure.

The organogenic layer can include various organisms (Litvinova 2016), but they are commonly dominated by cyanobacteria and certain individual organisms accompanying them. Under an electron microscope, one can practically always identify the structure-forming organisms in each individual stromatolite taxon. A number of illustrative examples discussed below are stromatolites sampled in the northern Anabar area (in the area of the Fomich River, Russia, Lower Riphean) and Karelia (Lower Proterozoic).

The species *Colonnella laminata Komar* (Komar 1964,) was distinguished based on its linear microstructure (Fig. 12.2a) discernible at high magnifications (Fig. 12.2a$_1$). Detailed studies of the structures show that the layer was formed

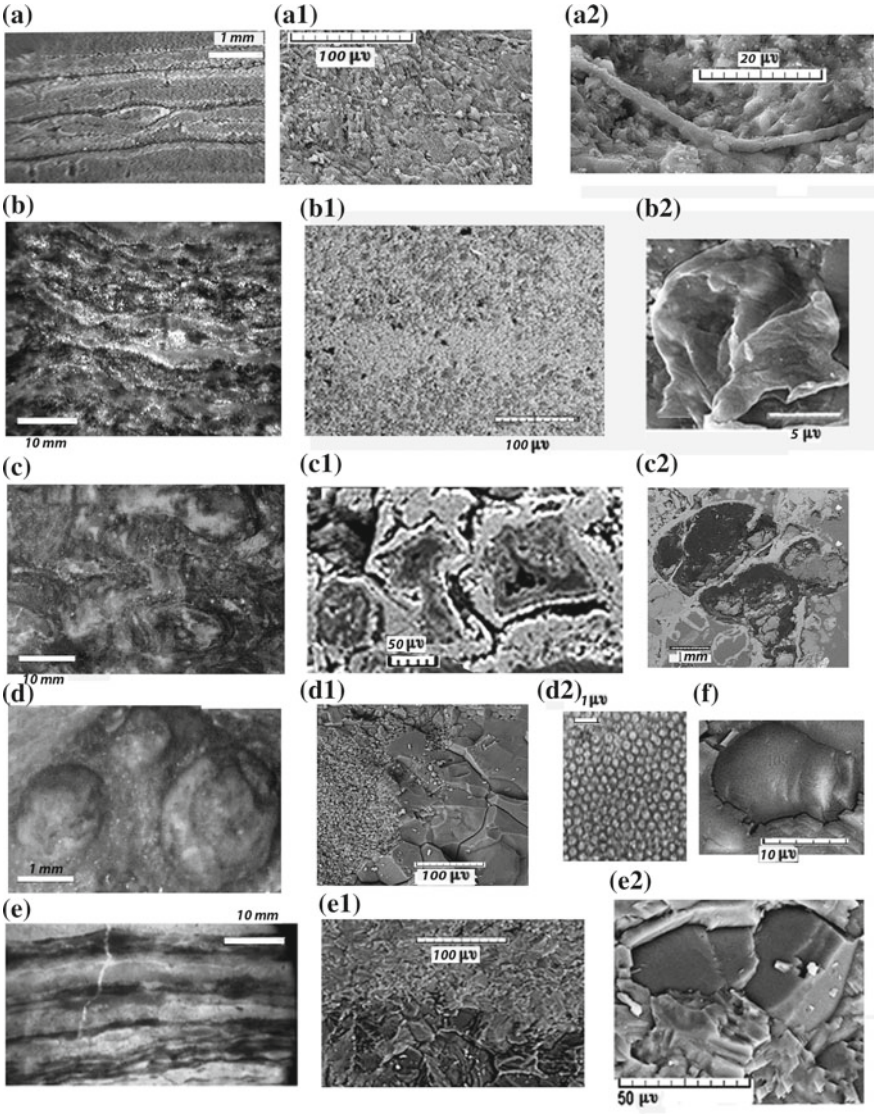

Fig. 12.2 Microstructure and its builders: *Colonnella Laminate*: **a**, $\mathbf{a_1}$ linear micro- and unlrtamicrostructure, $\mathbf{a_2}$ theread cyanobacterium; *Colonnella Kyllachii*: **b**, $\mathbf{b_1}$ clotty micro- and ultramicrostructure; $\mathbf{b_2}$ coccoidal cyanobacteriaum; Sundia: **c** random concentric microstructure, $\mathbf{c_1}$, $\mathbf{c_2}$ concentric biogenic ultramicrostructures; *Colenia Olenica*: **d** nodular microstructure, $\mathbf{d_1}$ inner structure of a nodule, $\mathbf{d_2}$ accumulation of biogenic nanometer-sized particles; *Colonnella Fomich*: **e** unequally lenticular microstructure with swell features in dark layers; **e** contact between mineral and organogenic layers at different magnifications; $\mathbf{e_2}$ biogenic ultramicrostructures, lateral binary fission of a cell; **f** cyanobacterium. Note: **a**, **b**, **e** Northern Anabar area, Fomich River, Early Riphean; **c**, **d** Karelia, Sundozero Lake, Southern Olenii Island, Paleoproterozoic

largely as a consequence of the vital activities of thread bacteria (Fig. 12.2a_2). They gradually give way to another colonella species: *C. kyllachii Shapovalova* (Krylov et al. 1968). The latter are characterized by a clotty microstructure seen at any level of studying (Fig. 12.2b). The organogenic layer of this taxon is made up of relatively large isolated biogenic ultramicrostructures.

The diverse species of the microorganisms and their quantitative proportions in each individual taxon made up fairly diverse and often complicated microstructures. The dominant organisms, and hence, the microstructure itself, were replaced gradually. Moreover, the structural–textural features of the rock may have been complicated as a result of the changing sedimentation conditions and, later, under the effect of secondary processes. All of these factors can be analyzed using an electron microscope.

The Lower Proterozoic stromatolites of Karelia notably differ from other Precambrian stromatolite structures and are practically not compatible with the formalized classification of these rocks. The taxon *Sundia Butin* (Butin 1966) has a random–rounded texture and an analogous microstructure (Fig. 12.2c). The study of this taxon under an electron microscope has shown that a dominant role in its origin was played by excellently preserved fossilized endolithic algae (Litvinova 2018). They enveloped the walls of round holes, which were formed by these algae themselves, and developed them (Fig. 12.2c_2). If young individuals have no time to occupy a hole completely, carbonate sediment gradually filled the space between the many-fold twisted thallome (Fig. 12.2c_1). This follows from the notably higher carbon concentration in the dark layers, with the pale one made up of carbonate material. Later recrystallization produced rounded–layered textures in the holes. Data on samples recovered by the superdeep borehole confirmed their presence. Endolithic algae produced small unequal columns and other round microstructural features of this taxon by dissolving the sediment and filling holes favorable for reproduction and vital activities with the thallome material (Fig. 12.2c_1, c_2, c_3). These conditions provided protection against direct sun rays and water currents, which is important for algae because they have no root systems.

On Southern Olenii Island in Onega Lake, Karelia, Russia, other stromatolite structures were found: these were *Colenia Olenica Ryabinin* (Ryabinin 1941). They have a nodular texture and an analogous microstructure (Fig. 12.2d). Studies of this taxon under an electron microscope have shown that the nodule has a concentric inner structure, as seen in its cross section (Fig. 12.2d_1). Its core contains an accumulation of round biogenic nanostructures (Fig. 12.2d_2). This indicates that the morphological features of this taxon were formed by the vital activities of coccoid bacteria, which reworked the carbonate silt and built round mounds. As the sediment was gradually dehydrated and the nutrients were exhausted, the organisms had to extend their habitat and form a new nodule nearby. As a resultsromatolite *Colenia Olenica* includes (as seen in outcrops) closely spaced randomly oriented nodules.

An unusual microstructure was found in stromatolites *Colonnella Fomich Litvinova* in the northern Anabar area (Litvinova 2014b, R_1). They are characterized by alternating mineral and organogenic microlayers with sharp contact between them and with crenulated dark layers with swells (Fig. 12.2e). The former consist of

pelitomorphic carbonate material, and the latter show diverse complicated ultrastructures of dominantly biogenic character (Fig. 12.2e$_1$). The organogenic layers are characterized by the presence of round structures, ranging from 10 to 30 μm across (Fig. 12.2e$_1$), with notably elevated carbon concentrations. The community of organisms in the latter resemble a beehive in which each bacterium occupied its own cell or was coated with a thin protective biofilm of polysaccharide composition. The binary fission of the cells (Fig. 12.2e$_2$), which occurred in a single plane, resulted in chains of unicellular individuals, which thus built up the colony. Accumulations of a number of such rows defined the unequally lenticular structure, and the round morphologies of the organisms were responsible for the crenulation of the microlayers. Single round biogenic structures are occasionally found in the chemogenic layer, in which they are devoid of the protective shell. The organism likely tried to get out of the overlying sediment but failed and was buried in the chemogenic layer without acquiring a protective shell.

The living conditions of the cyanobacteria, analysis of the restructurings of the community of the biosystem, fossilization specifics of the organisms, the morphology, composition, and distribution of biological ultramicrostructures within the organic layers, their changes under the effect of secondary processes, i.e., almost all constituents of the mechanism that formed the microstructures can largely be reproduced using electron microscopic data. The suggested method enables the researcher not only to estimate the final result of the vital activities of cyanobacteria that built a given microstructure of a rock but also to trace the reasons for the degradation of the columns of the structure (Naugol'nykh and Litvinova 2014) and analyze the evolution of the stromatolite system as a whole (Litvinova 2014b, 2016), i.e., to understand how and why the various structures of these rocks were formed and degraded.

Studies of stromatolites of various age and sampled at different localities made it possible to distinguish four groups and fourteen types of the biogenic ultramicrostructures based on their morphological features (Litvinova 2016). They await their classification and elucidation of their spatiotemporal distribution, which can be compared with those of cyanobacteria described in Precambrian rocks. At a wider application of electron microscopy, they may play an important role in determining the age of the rocks.

12.4 Currently Available Complementing and Testing Techniques

The studies can be significantly facilitated by examining stromatolites in thin sections under a powerful modern microscope to allow the researcher confirm the conclusion and to obtain new or refine preexisting data (Litvinova and Sergeev 2018). Although the resolution power of optical microscopy is incomparable with that of an electron microscopy, the former traditionally employs technique that make it possible to gain extensive experience in studying microfossils and utilize them to date rocks.

Studies of Phanerozoic and modern stromatolites and their comparison with Precambrian biogenic ultramicriostructures helps the researcher in understanding the specifics of fossilization of the organisms and their changes in the course of overprinted alterations. Observations of the development of modern stromatolites and determining the chemical parameters of the habitats of cyanobacteria make it possible to understand many details of the process and its rate, and this, in turn, allows the researcher to interpret the ancient fossil structures and their genetic nature and to compare their living conditions.

Interesting material, which provides evidence of a biogenic origin of the rock and demonstrates that organisms can be reserved in it, can be obtained with the application of electron spin resonance (ESR) methods. Parameters of the signals of carbon-bearing radicals can be used to identify OM remnants of both protein (bacterial) and floral (algae) types and the magmatic grade of the rocks (Leonova et al. 2014).

Much interesting information can be derived from experimental data on the role of the bacterial film and behavior of organisms during sediment supply (Gerasimenko et al. 2007; Krylov and Orleansky 1988; Orleansky et al. 2000 and others) and on step by step changes during fossilization. This provides help in revealing biogenic structures that are otherwise hard to identify, as well as in unbiased estimation of the role of the organisms in the formation of stromatolites.

All of the methods listed above, or results obtained with these methods, were used by the author, confirmed the integrity and reliability of the data obtained using an electron microscope, and helped the author to interpret the electron-microscopic data.

12.5 Conclusion

The application of an electron microscope equipped with an energy dispersive spectrometer helps in solving the following problems:

(1) Determining the morphology, composition, and relative arrangement of stromatolite-building organisms, even if they are smaller than one micrometer. Identifying the dominant stromatolite-building organisms in each of the taxons of stromatolites and determining their functions in forming the structure of the rock.
(2) Determining the role of secondary alterations that occurred in the rock during and/or after the reef was formed, and estimating the effects of these processes on changes in the textural and structural features of the stromatolites.
(3) Analyzing the reasons why some dominant microorganisms within a given stromatolite reef give way to others. Characterizing the evolution of this process in each given stromatolite structure and in the Precambrian as a whole.
(4) Studying the growth conditions, lifetime, and reasons for the degradation of a given stromatolite structure. Determining how its shape depended on the evo-

lutionary changes and ecological conditions under which stromatolite-building cyanobacteria lived.

The suggested technique enables the researcher to monitor the physicochemical and biological parameters of the origin of a stromatolite reef and to suggest more geochemical criteria of biogenic sedimentation. Because of this the method can play an important role in solving more general problems, such as determining direct and feedback relationships between components of a biosystem. The use of this method can help the researcher to suggest criteria for determining climatic, geological, and other geological circumstances in which the reef was formed. The method offers interesting possibilities of studying interactions in stromatolites and other complicated biological systems.

Currently most of the aforementioned problems are analyzed mostly visually because it is still not possible to rely on any physical material on the biocenosis involved in the origin of stromatolites.

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