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Bacterial-Paleontological Study of Early Precambrian Weathering Crusts

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Abstract

Existence of diverse microorganisms, bacteria (? Cyanobacteria) in the Early Precambrian (Archaean and Early Proterozoic) weathering crusts is determined. Presence of eukaryots can't be excluded also. So it is possible to speak about the colonization of land by microbes already at that time and about existence of single series from weathering crusts (primitive soils) to real soils.

Keywords: eukaryotes, prokaryotes, bacteria (? Cyanobacteria), Archaean, Proterozoic, Precambrian, weathering crust, paleosoles, Greenstone Belt

1. Introduction

The study of the origin and early evolution of life on Earth are fundamental scientific problems. These problems embrace investigation of ancient life both in marine and land conditions. The only reliable evidences of continental conditions existence are weathering crusts. Often they are the only source of information about exogenous processes and subsequently about conditions under which the development of biosphere occurred in Early Precambrian. Sediments, formed under the influence of weathering, are known from the earliest stages of the Earth geological development (Golovenok, 1975; Rozanov et al., 2008). Weathering profiles in all geological settings are reliable witnesses of continental regimes and in the Precambrian structures they often give unique information about continental features which led to biosphere development (Rozanov et al., 2008). Complex of diverse fossil microorganisms in ancient weathering crusts was discovered in result of electronic-microscope investigations, and conclusion about possibility of land colonization by microbes from the very beginning of geological annals was made (Rozanov et al., 2008; Rozanov & Astafieva, 2009; Astafieva et al., 2009).

The prokaryotic community that was the first to catalyze the system of biogeochemical cycles served as a basis for further evolution. It is possible to reconstruct the geobiological systems of the past using geochemical products of metabolism of prokaryotes that are preserved in the host rocks. The prokaryotic biosphere became a basis for the further evolution of life. Hence, the expansion of our knowledge on the evolution of the geo-biosphere in the Precambrian is a very important geological and biological task.

Most ancient organisms were found in rocks of 3.8 Ga age (Schidlowski, 1988, 2001) which means that even in the Archean age biomineralization was possible. The exact role of biota in autogenic mineralization is not clear. Clayey mineral formation is possible either with or without bacteria interaction. Modern investigations show that the final weathering product - clayey minerals, either biogenic or abiogenic, practically can't be recognized by structure and chemical composition (Tazaki, 1997; Kawano & Tomita, 1999). So, geochemical criteria of separation (division) of biogenic clayey minerals from abiogenic ones are absent.

Moscow Carboniferous basin white clays (collected by P. Kabanov) could be a nice example. These clays for a long time considered to be terrigenic. Bacterial-paleontological study of these clays (Figure 1) shows, that they are not terrigenic, but autigenic, i.e. most likely they were formed due to biological factor influence. The fact that core roundness, clearly seen on the picture, because of their small sizes (<<200 μm), cannot be due to rounding, serves as basis for such conclusion. We remind you that grains less 200 μm (0.2 mm) in sizes cannot become roundish under water influence, remaining angular. Our "balls" are about 5 μm in size. It means that their origin is biogenic, i.e. "balls" are fossilized coccoidal bacteria.

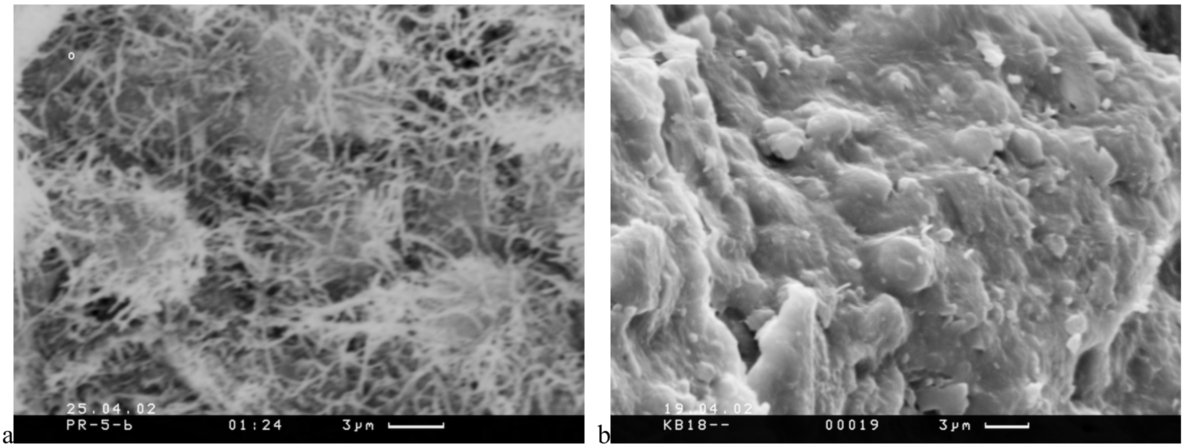

Figure 1. Thread-like nannobacteria (? glycocalyx) surrounding coccoidal bacteria in the Lower Carboniferous clays of Moscow basin (a – quarry Priokskiy: specimen PIN, no. 5081/22, image 124; b – quarry Peski: specimen PIN, no. 5081/23, image 019)

Other evidence of bacterial participation in rock formation, earlier considered to be terrigenic, is siltstones with clay interlayers (illite) of Kola Peninsular (Imandra-Varzuga Greenstone Belt, Tominga Formation, collected by N.A. Alfimova and V.A. Matrenichev). Siltstones are known as classic terrigenous rocks. But rather numerous and diverse microfossils – threadlike, coccoidal, etc. forms – were found in studied siltstones (Figures 2-3). It is the evidence of biogenic factor (to some degree) in these siltstones formation.

It means that it is impossible to judge about rock genesis (including clayey ones) without bacterial-paleontological studies.

Earlier suggestions about life existence during the Early Precambrian cratons were made only on the basis of investigations of elemental and isotopic ratios of C, H, N and P in the rock matter. So it is confirmed the presence of microbial mat on the rock surface as far as 2.7-2.6 Ga (Watanabe et al., 2000; Sergeev et al., 2007). But fossil remains of the Precambrian land microorganisms have not been found yet.

This article aims at evaluation of bacteria role in an ancient weathering process.

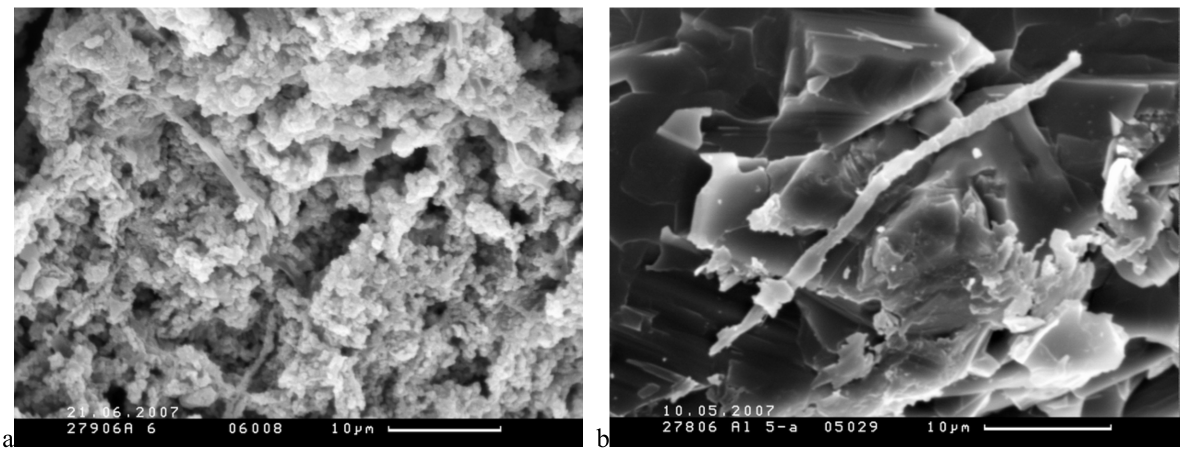

Figure 2. Thread-like microfossils (a – threads submerged in glycocalyx) from Lower Proterozoic siltstones with clayer interlayers (illite) of Imandra-Varzuga (Kola Peninsular) Tomingskaya Formation (~2.0 Ga), specimen PIN, no. 5081/10, image 0608; b – single thread from Lower Proterozoic siltstones of Imandra-Varzuga (Kola Peninsular) Tomingskaya Formation (~2.0 Ga), specimen PIN, no. 5081/11, image 0529

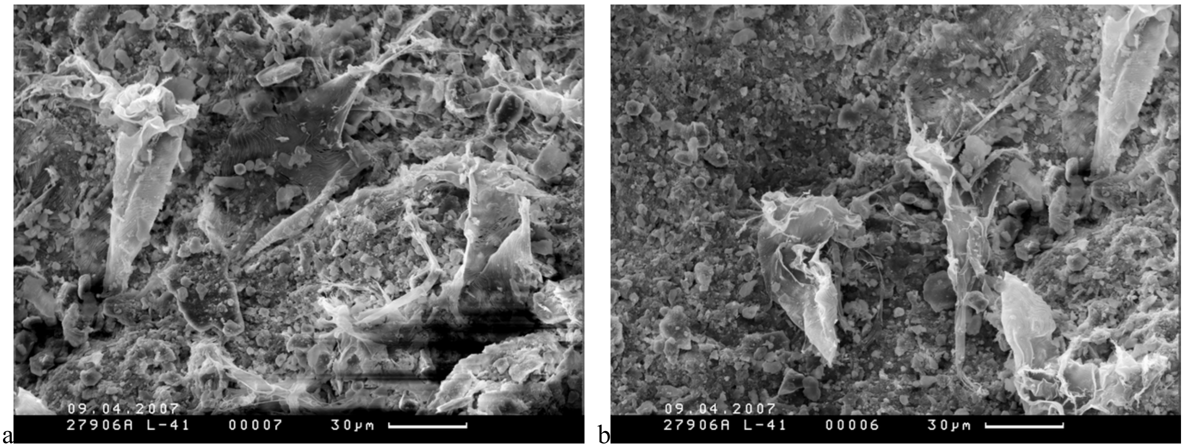

Figure 3. a-b Flattened ?cyanobacterial sheaths from Lower Proterozoic siltstones with clayer interlayers (illite) of Imandra-Varzuga (Kola Peninsular) Tomingskaya Formation (~2.0 Ga). Specimen PIN, no. 5081/12, images 07, 06

2. Repository

Main objects of this paper are Early Proterozoic and Archaean weathering crusts of Karelia and Kola Peninsular (Plate 1, Figure 4). All samples are housed in the Paleontological Institute, collection number no. 5081.

Plate 1. Stratigraphic position of the studied weathering crusts (according to data by Akhmedov et al., 1996; Rozanov et al., 2008; Kheiskanen, 1990)

<table>
<tr><th colspan="4">General stratigraphic scale</th><th>Age Ga</th><th>Climate</th><th>Weathering crusts</th></tr>
<tr><td rowspan="5">PROTEROZOIC
PR</td><td rowspan="5">LOWER PROTEROZOIC
(KARELIAN)</td><td>Upper Karelian K_2</td><td>Jatulian</td><td>2.1</td><td>Nival</td><td><u>Jatulian</u>
Chapanshari Island,
Segozero Lake
(Centr. Karelia)</td></tr>
<tr><td rowspan="4">LowerKarelian K_1</td><td>Sariolian</td><td>2.3</td><td>Arid</td><td><u>Prejatulian</u>
Pechenga Green-stone Belt (Kola Peninsular);
Maly Janisyarvi Lake
(Northern Ladoga region)</td></tr>
<tr><td></td><td>2.4</td><td>Nival</td><td><u>Presariolian</u>
Vatulma Lake, Lekhta structure (Karelia);
Paanayarvi Lake
(Northern Karelia)</td></tr>
<tr><td>Sumian</td><td>2.45</td><td rowspan="3"></td><td><u>Sumian</u>
Imandra-Varzuga structure (Kola Peninsular)</td></tr>
<tr><td></td><td>2.5</td><td><u>Presumian</u>
Tsipringa structure
(Northern Karelia)</td></tr>
<tr><td>ARCHAEAN
AR</td><td>UPPER
ARCHAEAN
(LOPIAN)</td><td colspan="2">Upper Lopian L_3</td><td>2.8</td><td><u>Archaean</u>
Voronye Lake, Lekhta structure (Karelia);
Khizovaar structure
(Northern Karelia)</td></tr>
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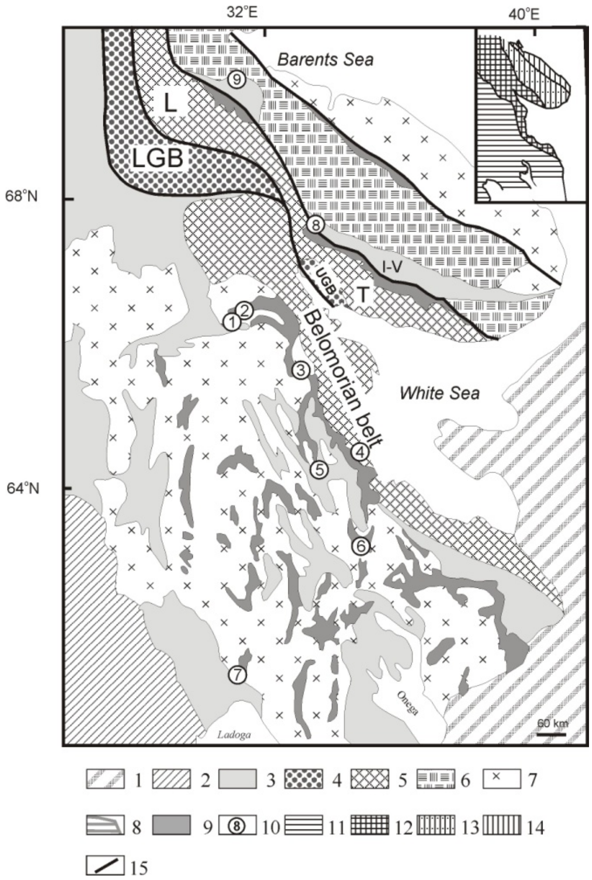

Figure 4. Geological scheme showing sample localities

Legend: 1 – Upper Proterozoic-Paleozoic Platform sheath; 2-5 – main Lower Proterozoic structures: 2 – svekophennids, 3 – sedimentary-volcanogenic structures (P – Pechenga, I-V – Imandra-Varzuga), 4 – Lower Proterozoic Laplandian (LGB)-Umbian (UGB) granulite belt, 5 – intermediate labile belts (Belomorian and Terrian-Lottian (T – Terrian, L – Lottian) fragments); 6 – Central-Kola granulite belt; 7 – granitoid (tonalite-trondhjemite-granodiorite, TTG) gneiss migmatite basement of granite-greenstone regions; 8 – Vodloserian block; 9 – greenstone belts; 10 – sample localities:1 – Paanayarvi Lake, Northern Karelia; 2 – Tsipringa structure, Northern Karelia; 3 – Khizovaar structure, Northern Karelia; 4 – Voronye Lake, Lekhta structure, Karelia; 5 – Vatulma Lake, Lekhta structure, Karelia; 6 – Chapanshari Island, Segozero Lake, Central Karelia; 7 – Maly Janisyarvi Lake, Northern Ladoga region, Karelia; 8 – Imandra-Varzuga structure (hole 1A) , Kola Peninsular; 9 – Pechenga Green-stone Belt, Kola Peninsular (hole 5A)

3. Methods

Bacterial paleontological studies have been done by CamScan-4 with microprobe Link-860. Only fresh chips of rocks were studied, selected samples were washed in spirit and were dried in muphel-stove.

4. Results

As a result of study of many rock samples, it was discovered that the absence of correlation between microfossil diversity and the abundance and the age of weathering crusts comprising these microbial remains. In all (for exeption of Khizovaar) weathering crusts it was revealed that the complex of diverse fossil remains of thread-like (filament), coccoidal (diameter up to 5 μm), larger ball-shaped (diameter > 10 μm) forms, fossil biofilms, etc. are present. Rather often rock fragments practically entirely consist from destroyed cocci, dumbbell-like forms and thread ravels (Figure 5).

1) Thread-like (filament) forms are the most abundant. Often they comprise whole organic rock (Figure 6).

2) By the most part threads are long diameter as a rule from 1 to 3 μm, sometimes up to 5-6 μm, some samples resemble crumpled sheaths of cyanobacteria Microcoleus (Zhegallo et al., 2000) (Figure 7).

3) Coccoidal forms are not so numerous. Discovered cocci have diameter about 2 μm (Figure 8). There are both single cocci and cocci met in clusters. Their surface often uneven and rough. Sometimes numerous traces of cocci are noted, probably the rock was literally comprised of coccoidal structures.

4) Rather large ball-shaped forms with diameter 15-30 μm with uneven rough surface (Figure 9). These structures are semidestroyed, but it is seen that they were heterogenous. The nature of construction and sizes allow to suppose possible reference of these forms to eukaryots. The possibility of these cocci accumulations to be a colony of small coccoidal bacteria associated by single envelope still exists.

5) Biofilms (Figure 10).

6) Peculiar rounded structures looking like cocci envelope (Figure 11). They situated close by each other.

Study of the youngest (2.1 Ga) weathering crusts among investigated - weathering crust of Chapanshari Island (Segozero Lake) – gave opportunity to trace microfossil distribution along different zones: quartz-sericite rocks, aleurites (siltstones) and amphibolites from contact zone of weathering crust and superposed rocks (dolomites).

Microfossils are rather abundant and diverse in these zones, filament forms dominate. But fossil bacteria met much more rarely in aleurites (siltstones) than in quartz-sericites and amphibolites. Fossil microbes are not found in the superposed dolomites. So revealing of distributional trends in different weathering crust zones is supposed subject for future study.

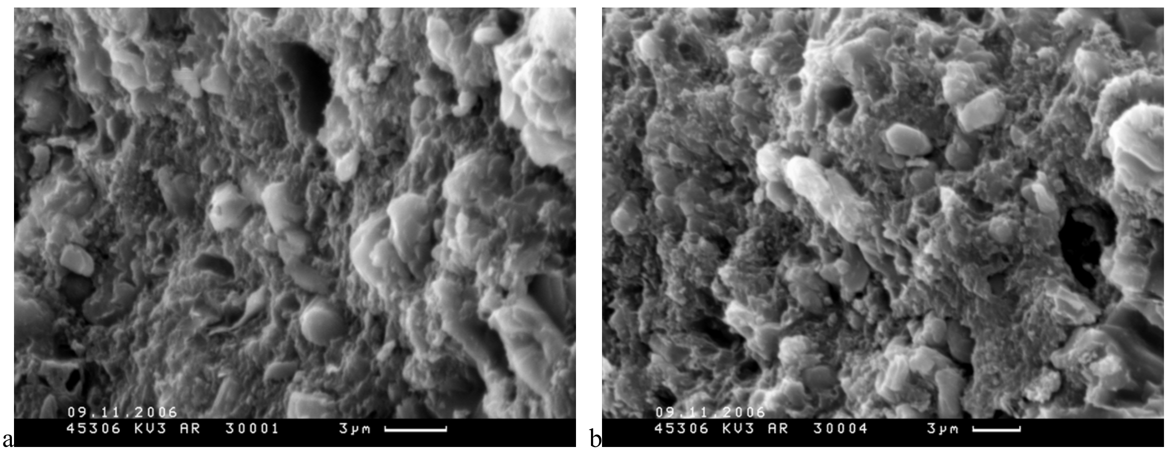

Figure 5. a-b Presariolian, Paanajarvi Lake, microfossils comprising Precambrian weathering crusts. Specimen PIN, no. 5081/13, images 301, 304

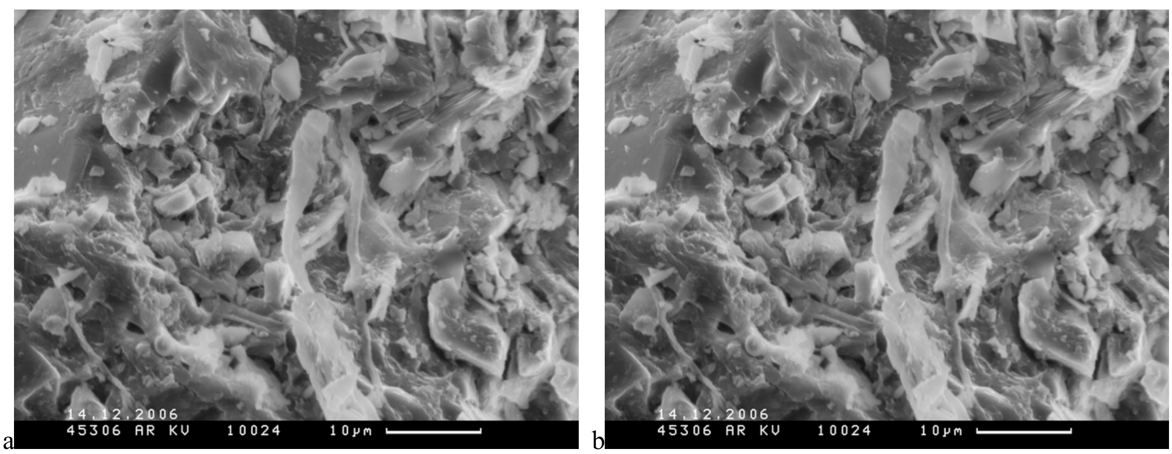

Figure 6. Tread-like forms comprising weathering crusts almost entirely: a – Presariolian (Paanajarvi Lake: specimen PIN, no. 5081/14, image 124); b – Prejatulian (Maly Janisjarvi Lake: specimen PIN, no. 5081/15, image 1503)

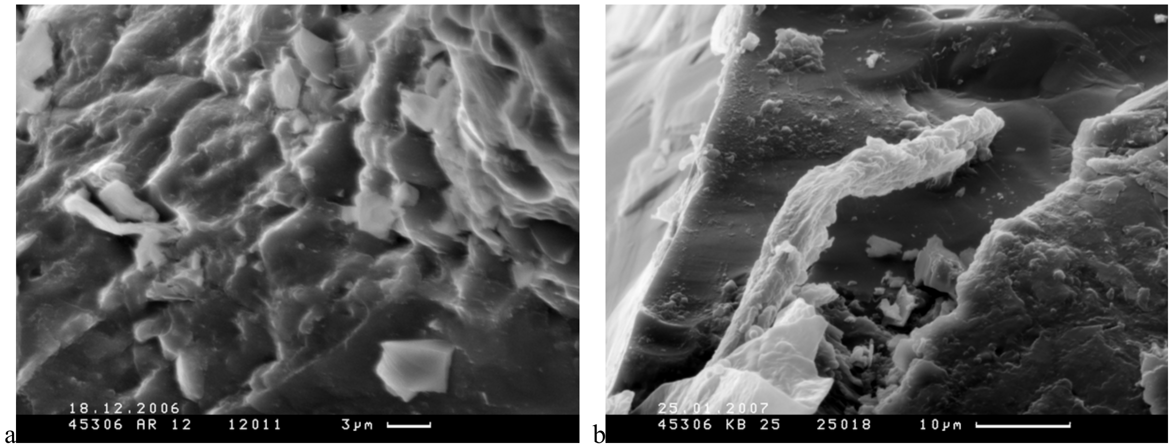

Figure 7. Presariolian (Paanajarvi Lake) filament microfossils: a - single filament: specimen PIN, no. 5081/16, image 1211; b - single filament looking like crumpled cyanobacteria Microcoleus envelope (Zhegallo et al., 2000). Specimen PIN, no. 5081/17, image 2518

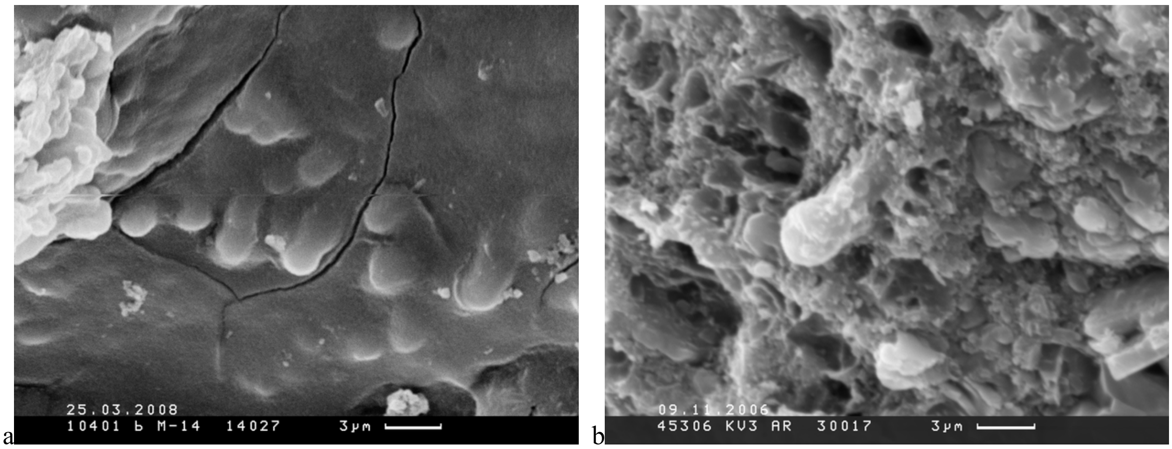

Figure 8. Cocci: a – numerous cocci in glycocalyx: Archaean weathering crust (Voronye Lake): specimen PIN, no. 5081/18, image 1427; b – coccoidal form with uneven surface, probably all the rock was covered by biofilm consisted from such cocci: Presariolian weathering crust (Paanajarvi Lake): specimen PIN, no. 5081/13, image 0317

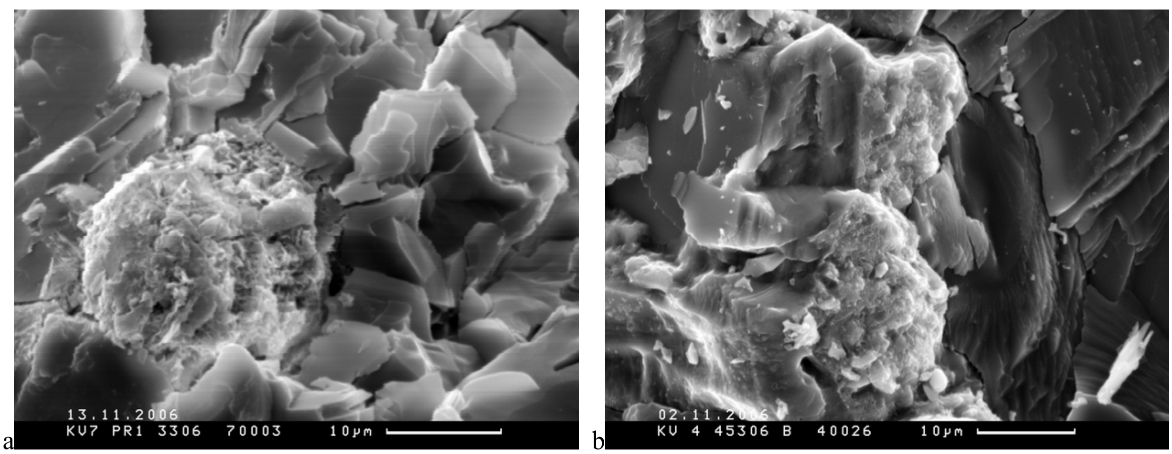

Figure 9. Large ball-shaped forms (diameter 15-30 µm) with uneven bumpy surface: a – Prejatulian weathering crust (Maly Janisjarvi Lake): specimen PIN, no. 5081/20, image 0703; b – Presariolian weathering crust (Paanajarvi Lake): specimen PIN, no. 5081/19, image 0426

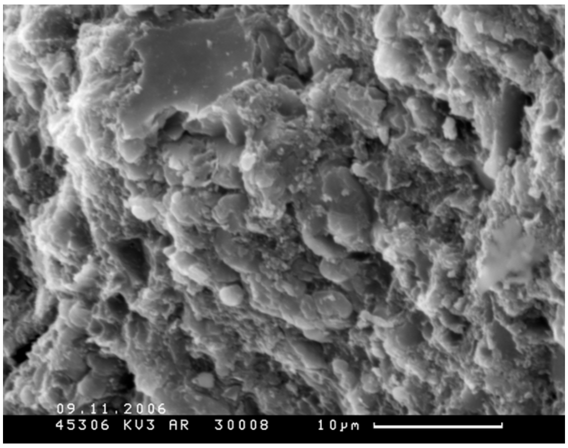

Figure 10. (?) Biofilm: Presariolian weathering crust (Paanajarvi Lake): specimen PIN, no. 5081/13, image 0308

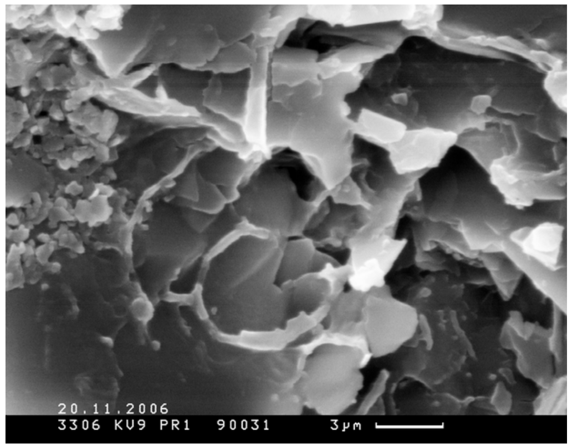

Figure 11. Peculiar rounded structures: Prejatulian weathering crust (Maly Janisjarvi Lake): specimen PIN, no. 5081/21, image 931

5. Discussion

Ancient weathering crust investigations are of higher priority for determination of continental sedimentation conditions during earliest stages of Earth development. At the same time climatic conditions dominated over the territory of the Baltic shield during formation of the objects under investigation were strictly different. Nival conditions of sedimentation are reconstructed on the basis of wide spreading of moraine rock associations for the interval 2.4-2.3 Ga (Akhmedov et al., 1996). Predominance of arid climatic conditions is suggested for Jatulian time (2.3-2.1 Ga) judging by presence of evaporates and red colored sediments in the sequences (Kheiskanen, 1990). Besides, some caliche are described for this period (Sochava et al., 1975), this fact also points to the arid climate conditions. According to the provided investigation, weathering crusts, formed both under nival and arid conditions, are characterized by the same peculiarities of geological structure and chemical composition. It causes doubts concerning leading role of climate for the process of formation of hypergene objects in the Early Precambrian.

Chemical composition of microfossils of the described complex in all cases is identical to the chemical composition of rock matrix and is represented by the main rock forming oxides of Si, Al, Fe, K and Mg. It serves as indirect confirmation, that microbiological complex is even-aged with the host rocks. More likely, microorganisms fixed in the rocks played role of catalyst – decay (decomposition) of minerals, comprising rocks, and their transformation into clayey minerals happened under bacterial participation (Rozanov et al., 2008). Perhaps, uncial weathering crusts of the Early Precambrian were formed due to interaction between peculiar specific composition of microorganisms and conditions of hypergene transformations.

6. Conclusions

As a result of investigations it is ascertained that the diversity of bacterial forms of life existed as early as the Early Precambrian. Bacterial founds in the objects of hypergene origin testify to the exogenous nature of studied objects.

In the Early Precambrian microorganisms, bacteria (? Cyanobacteria), and may be even eukaryots accompanied and promoted formation of weathering crusts. So it is possible to speak about colonization of land by microbes at this time and about existence of a single series from weathering crusts (paleosoles) to real soils.

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