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Biomineralization in natural environments: the effect of microorganisms inhabiting hot spring water and biomats on mineral formation

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Bacterial mineralization or biomineralization is a common and widespread phenomenon occurring in various geothermal systems. The important role of microorganisms in the formation of modern hydrothermal deposits was denoted. Bacteria are very small ($\sim$ 1.5 μm^3), but have the largest surface to volume ratio of any life form. Therefore, they provide a large contact area that can interact with metals in the surrounding environments. Microbial activity is responsible for the transformation of at least one third of the elements in the periodic table. In chemolithotrophic environments, the microbial abundance (or biomass) and the types of bacterial activities (or production) reflect the biological components of the biogeochemical processes occurring in the ecosystem.

The main objective of the present study was to investigate hot spring water, biomats and deposits in order to observe microorganisms that could be actively involved in biogenic mineral formation. Samples of water, green biomats and modern hydrothermal deposits were collected from two sampling areas namely Lake Baikal, Siberia and Kamchatka Peninsula, Russia. Water, biomats, and deposits collected from hot springs were analyzed with methods of hydrochemistry, mineralogy, and microbiology.

An *in situ* visualization of the fossilized microorganisms in the green biomats and deposits of the Kotelnikovsky hot springs located on the northwest coast of Lake Baikal, Russia, allowed to show the important role of microorganisms during fossilization processes of the modern hydrothermal deposits. It was concluded that silicification and calcification of the microorganisms extensively appeared in the biomats and deposits under pH 8.0 hydrothermal conditions. Chemical process has been proposed for cal-

cite deposition from bicarbonate-rich water with adequate supply of calcium ions. But this process might be catalyzed biologically due to removal of CO_2 during metabolic activity of thermophilic microorganisms and/or photosynthesis of cyanobacteria. Additionally, the silicification process of bacterial cells in the environments with high content of silicon at slightly alkaline pH might occur on the surfaces through a cationic bridging mechanism.

The waters of the Vilyuchinskie hot springs, namely V3 site, Kamchatka Peninsula, Russia had a high iron concentration, and ferric iron predominated over the ferrous form at a ratio of 52:7 in the brown biomats. It was concluded that at the V3 site Fe(II) oxidation is extremely enhanced. Moreover, the waters of the Vilyuchinskie springs are rich in silicic acid and there is a rapid rate of silicification during water discharge and cooling. These processes take place simultaneously. Observation of the microbial communities inhabiting the biomats revealed that brown biomats consist primarily of bacteria with mineral-encrusted cells. A positive correlation was found between the activity of Fe-bacteria in the hot spring water, their presence in the hot spring biomats, and the chemical content of hot spring water and deposits. The accelerated processes of iron oxidation, silicification, and deposition of Fe-Si-minerals that occur in the brown biomats of the Vilyuchinskaya hydrothermal system can be attributed to the impact of rod-shaped bacteria inhabiting the hot spring waters and biomats.