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Self-assembled nano-structured minerals as signatures of bacterial mineralization activities

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In general, minerals with unusual shapes, such as small spherical, rod-shaped, and filament-like calcite and amorphous silica minerals, are considered as fossils of bacteria or nanobacteria. However, the internal structures of fossilized bacteria is difficult to study. As a result, morphologies and shapes are not sufficient to differentiate between abiotic and microbiological mediated precipitation. Some spherical minerals may be biologically mediated, but the spheres apparently are not fossil or microbes. McKay et al. (1996) first suggested that the carbonate globules in the meteorite ALH84001 contained the fossil remains of Martian microbes. Many studies have concentrated on possible mineral signatures as microbial existence, especially on crystal morphology of magnetite nanocrystals in magnetotactic bacteria and the Martian meteorites. Although a few results show possible biosignatures of magnetite in the Martian meteorite, several results show inorganic origin of magnetite and potential terrestrial contamination of the meteorite. Systematic crystallographic study of magnetite from magnetotactic bacteria and the meteorite indicated that existing crystallographic and morphological evidence is inadequate to support the inference of former life on Mars. Therefore, careful investigation is needed to identify fossils bacteria or nano-bacteria.

In this paper, we will focus on minerals formed through self-assembling of inorganic components (silica, Ca-carbonate) and surfactant-like organic components that are released from bacteria (such as, fatty acids). Lipids, including fatty acids, are components of bacterial cell membrane. When bacteria die, the lipids are released. Fatty acids and lipids derived from bacteria, are common organic compounds in soils. By carefully comparing the minerals prepared in the presence and absence of the organic compounds with the natural mineral samples, we hope to be able to understand how the organics affect the mineral formation. This information will help resolve some of the controversies and uncertainties when the mineral morphologies and structures are used to interpret the bacteria activities.

We use a co-polymer (P123) and a positively charged surfactant CTAB with hydrophilic heads and hydrophobic tails (as chemical analogs for lipids) to synthesize amorphous silica and calcite from the solutions containing the organics. Figure 1 shows synthesized nanoporous (nano-channel-like) silica having a rod-like morphology (Fig. 1A) precipitated from silicate solution, and onion-like silica spheres (Fig. 1B) precipitated from Al-bearing silicate solution. Figure 2 show nanoporous and nano-crystalline calcite from natural dust deposit (Fig. 2 A) and precipitation products of a solution containing surfactant CTAB. SEM image (Fig. 2C) shows cube-like shape of the calcite. TEM image and electron diffraction pattern (Fig. 2D) show the cube-like calcite is composed of nano-bricks of calcite crystals. It can be inferred that unusual shaped minerals with self-assembled nano-structures can be used as signatures for bacterial activities. Such kinds of minerals do not have to be replacement products of bacteria, i.e., micro bacterial or nano-bacteria fossils. We expect naturally derived biological organic compound (such as lipids) may also template mineral precipitation, which will also leave finger prints of the nano-structures in minerals. This research is supported by NSF (EAR02-1082). E-mail: hfxu@unm.edu

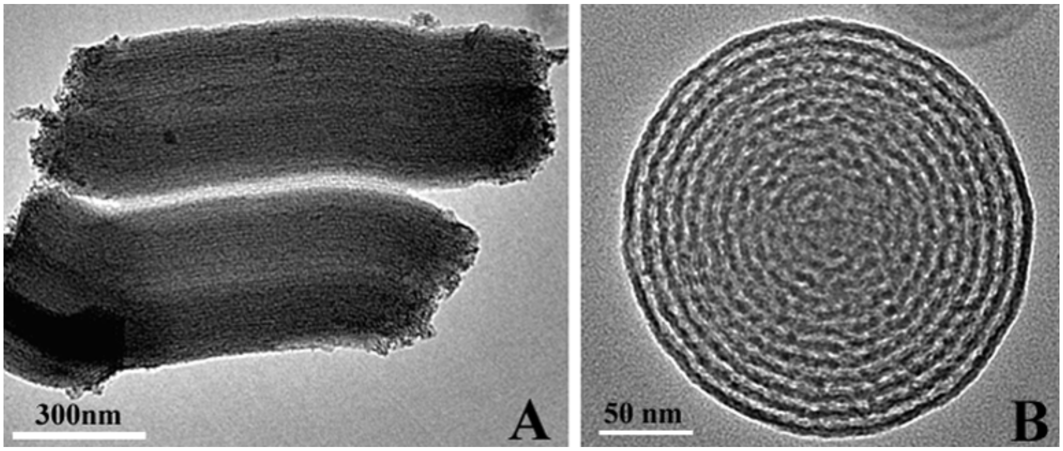

Figure 1: TEM images showing rod-like silica (A) and silica sphere (B) with self-assembled nano-structures.

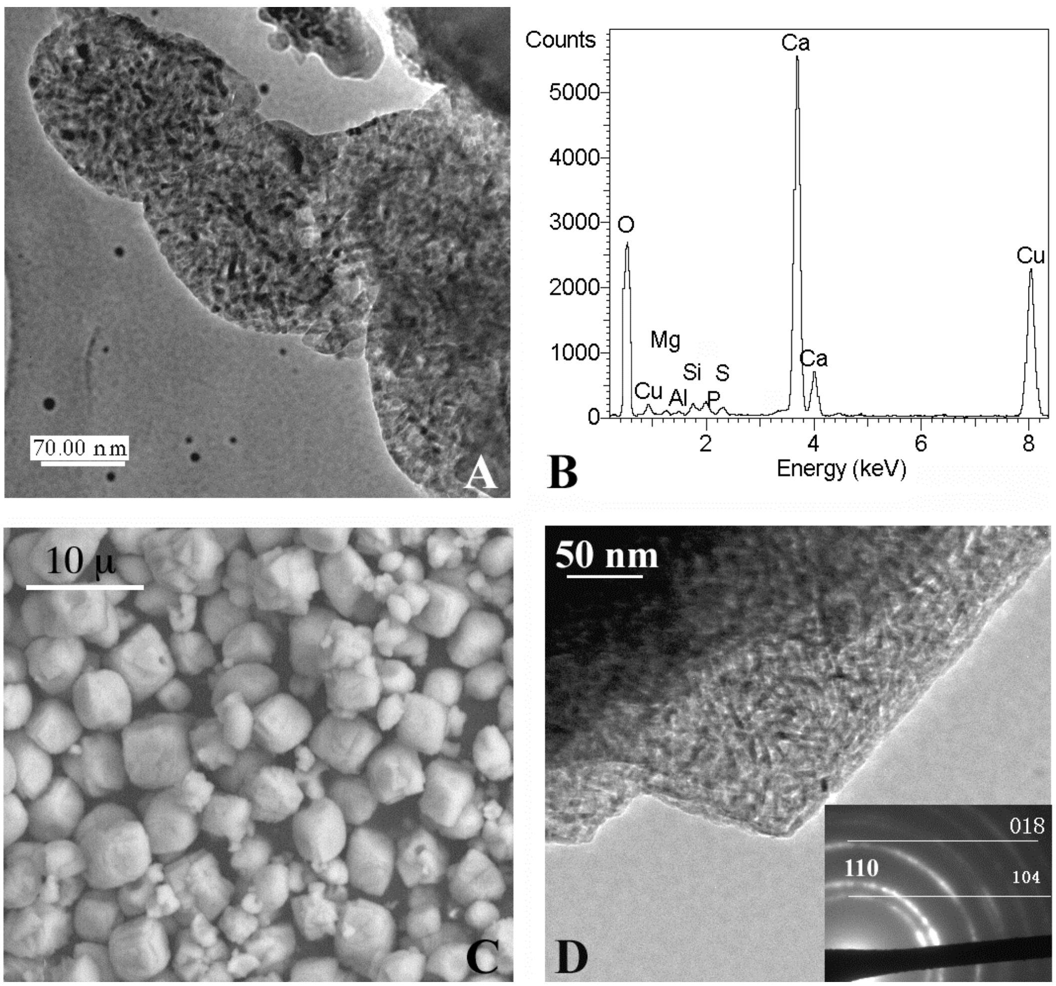

Figure 2: (A) TEM image and (B) EDS spectrum from a nano-porous calcite in a dust deposit. P and S in the nanoporous calcite may be from lipid-like organics inside the nanopores. (C) SEM image of cube-like calcite grains. (D) TEM image and selected-area electron diffraction pattern of the synthesized nano-structured calcite crystals precipitated from a surfactant-bearing solution.

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