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Electron microscopic investigation of bacterial cell structure fossil preservation in response to mineral precipitation in deep ocean hydrothermal systems

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Structural polymers of all bacterial cells, including those that thrive in deep ocean hydrothermal systems, contain an abundance of reactive acidic functional groups that give rise to net negative surface charge values at pH $\geq$ 4. This accounts for the behavior of bacteria as distinct minute geochemically reactive solids. Hydrothermal fluids are, in turn, characterized by high concentrations of dissolved mineral-forming elements, which can sustain oversaturated solutions. Under such conditions, chemical interactions between bacterial structural polymers and dissolved chemical species foster heterogeneous mineral nucleation and precipitation. Resulting mineral phases range from poorly ordered hydrous iron-manganese oxides to crystalline iron-silicates. These bacteriogenic minerals generally occur on the cell wall and in association with extracellular material, but can also be present inside the cells. The external sheaths and capsular material around bacterial cells undergo mineralization first, and this leads to thickly coated mineral encrusted microcolonies or individual cells. Bacteria that lack an external sheath or capsule are susceptible to encrustation by mineral precipitates that develop directly, perhaps even in an epitaxial manner on their cell wall. Upon mineral precipitation, bacterial cells can burst open and provide additional nucleation sites for intracellular mineral formation. Precipitates that form inside cells tend to be extremely fine-grained and poorly ordered possibly because of the presence of cytoplasmic polymeric material. From these electron microscopic observations, there appears to be at least 3 mineralization steps involved in the formation of bacterial microfossils. The first step relates to reactions between cell surface polymers and dissolved chemical species around individual cells, followed by nascent mineral precipitation. Subsequent crystal growth and ripening, i.e., maturation, contributes to complete encrustation of both encapsulated and non-encapsulated cells. The final step occurs when cells lyse and undergo intra-cellular mineralization to form relic bacteria micro-fossils.