THE MINERALOGY OF MAGNETOSOMES

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Magnetosomes are intracellular, membrane-bound nanocrystals produced by magnetotactic bacteria. The mineralogical identity of the inorganic particles in magnetosomes has been the subject of many studies since the discovery of magnetotactic bacteria. After thirty years of research the major inorganic constituents of the magnetosomes are known to be magnetite (Fe_3O_4) and greigite (Fe_3S_4). However, questions remain about the presence of possible precursors and transformation products. We used conventional and advanced transmission electron microscopy techniques to study the structure, composition and magnetic properties of magnetosomes from various types of magnetotactic bacteria, some grown under controlled culture conditions and others obtained from environmental samples. We also studied synthetic nanocrystals, in order to better understand the transformations of biogenic iron oxides and sulfides.
Even though previous studies reported the presence of ferrihydrite and hematite as possible precursors to magnetite, in freshly-nucleated magnetosomes we identified only magnetite. However, maghemite was present in the cells of strain RS-1, an anaerobic sulfate-reducing magnetotactic bacterium, likely as a result of the oxidation of the original magnetite. In synthetic maghemite we found that various vacancy ordering schemes can be present within single nanoparticles, producing a domain structure. Under prolonged exposure to the electron beam, the vacancies in maghemite disorder, and the electron diffraction pattern becomes indistinguishable from that of magnetite. Therefore, maghemite could be easily overlooked if present in magnetosomes. In iron sulfide-producing magnetotactic bacteria initially non-magnetic mackinawite (FeS) forms and then converts to greigite. Synthetic mackinawite is poorly crystallized and forms ribbon- and sheet-like units. In aged mackinawite, islands appear that have a disordered greigite structure, similar to the defect structures that are observed in magnetosomes. Some of the above results, particularly those that concern phase transformations, are likely to be also relevant to complex magnet-bearing sensory systems that are known to occur in birds and fishes.

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