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Iron sulfides from magnetotactic bacteria: Structure, composition, and phase transitions

MIHÁLY PÓSFAI,[1,*] PETER R. BUSECK,[1] DENNIS A. BAZYLINSKI,[2] AND RICHARD B. FRANKEL[3]

[1]Departments of Geology and Chemistry/Biochemistry, Arizona State University, Tempe, Arizona 85287, U.S.A.
[2]Department of Microbiology, Immunology and Preventive Medicine, Iowa State University, Ames, Iowa 50011, U.S.A.
[3]Department of Physics, Californa Polytechnic State University, San Luis Obispo, California 93407, U.S.A.

ABSTRACT

Using transmission electron microscopy, we studied the structures and compositions of Fe sulfides within cells of magnetotactic bacteria that were collected from natural habitats. Ferrimagnetic greigite (Fe_3S_4) occurred in all types of sulfide-producing magnetotactic bacteria examined. Mackinawite (tetragonal FeS) and, tentatively, sphalerite-type cubic FeS were also identified. In contrast to earlier reports, we did not find pyrite (FeS_2) or pyrrhotite ($Fe_{1-x}S$). Mackinawite converted to greigite over time within the bacteria that were deposited on electron microscope grids and stored in air. Orientation relationships between the two minerals indicate that the cubic-close-packed S substructure remains unchanged during the transformation; only the Fe atoms rearrange. Neither mackinawite nor cubic FeS are magnetic, and yet they are aligned in chains such that when converted to magnetic greigite, the probable easy axis of magnetization, [100], is parallel to the chain direction. The resulting chains of greigite are ultimately responsible for the magnetic dipole moment of the cell. Both greigite and mackinawite magnetosomes can contain Cu, depending on the sampling locality. Because bacterial mackinawite and cubic FeS are unstable over time, only greigite crystals are potentially useful as geological biomarkers.