Biogenic Magnets

Amanda L. Eckermann Literature Seminar November 3, 1998

Mankind has long marveled at the ability of birds to navigate over extremely long distances (up to 6000 km)[1] to wintering and breeding grounds. The identification of a ferrimagnetic material, magnetite, Fe_3O_4, in tissues of various migratory animals including pigeons, yellowfin tuna, and sea turtles[1] gave credibility to the idea that these creatures possess a magnetic compass sense. In 1975, bacteria that navigate along magnetic field lines were discovered.[2] These magnetotactic bacteria aided studies tremendously as the magnetic field effects on their behavior are highly reproducible.

Magnetotactic bacteria contain nanoscale particles of magnetite (Fe_3O_4)[3], greigite (Fe_3S_4)[4-5], or both[6-7] minerals. These particles are called magnetosomes[8] and are typically arranged in chains within the bacterial cells as seen in Figure 1. These mixed-valence materials share the inverse spinel structure and the metal centers are ferrimagnetically coupled. [1,9]

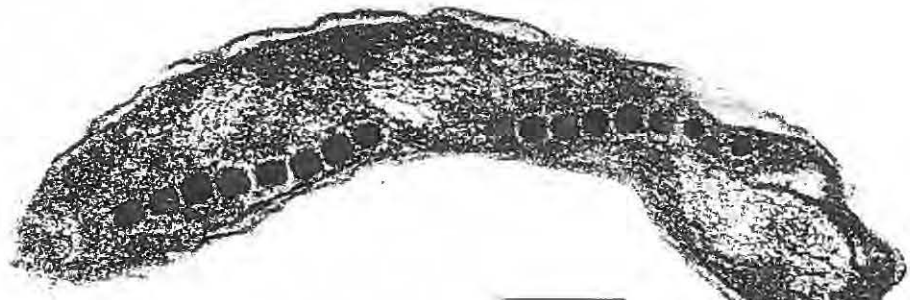

Figure 1

Techniques used in the characterization of magnetosomes include M^ssbauer spectroscopy, TEM and HRTEM as well as EDXA and SAED.[2-8,10-14] Transmission electron micrographs of entire cells show that within a bacterial species, magnetosomes have a narrow size distribution.[12-13] Magnetite and iron oxides were positively identified in some species of bacteria using M^ssbauer spectroscopy.[3] Greigite and other iron sulfides were identified in other species using EDXA and electron diffraction techniques.[4-5,14] TEM and HRTEM results have identified three species-specific morphologies: cubo-octahedra, elongated cubo-octahedra, and hexagonal prisms.[10-13] Magnetic characterization techniques show the particles are ferrimagnetic and have characteristic single-domain properties.[15]

In magnetotactic bacteria, the magnetosomes are formed within the cell, and inorganic precursors have been identified.[16] In magnetite-producing cells, ferrihydrite $5Fe_2O_3 \cdot 9H_2O$ has been identified and is believed to be the precursor to Fe_3O_4.[17] Besides greigite, cubic FeS and mackinawite have been identified in iron-sulfide containing bacteria.[14] Mackinawite is a tetragonal phase of FeS with the PbO structure. Studies have shown cubic FeS and mackinawite to be precursors to greigite.[18-19] Previous reports of pyrite (FeS_2)[20] within cells are probably inaccurate.[14]

Each magnetosome is enclosed in a membrane, which is believed to play a significant role in the biosynthesis of the magnetic materials. The membrane comprises neutral lipids, glycolipids and sulpholipids, and phospholipids in the ratio 1:4:6.[16] Three proteins unique to the magnetosome membrane have been isolated, but their specific functions have not been determined.[15] Because elongated crystal morphologies are observed, it has been postulated that the membrane either strictly controls the direction of ion flow or inhibits growth of certain faces and thus controls the direction of crystal growth.[5,7,11]

Many aspects of biogenic magnets inspire questions for future research. One goal is the elucidation of the biosynthetic pathway that includes the specific mechanism of iron uptake and transport by the cell, control of nucleation and subsequent crystal growth. Perhaps most interesting is the mechanism by which the magnetosome couples to cell movement. Further research in this area may illuminate the role of magnetosomes and magnetosensitivity in other organisms, including humans.

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