RELATIONSHIPS BETWEEN THE PROPERTIES OF FERRIMAGNETIC NANOCRYSTALS AND BIOLOGICAL CONTROL OVER CRYSTAL GROWTH IN MAGNETOTACTIC BACTERIA

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We have used several advanced transmission electron microscopy techniques to study the physical and chemical properties of intracellular ferrimagnetic magnetite (Fe_3O_4) and greigite (Fe_3S_4) crystals in magnetotactic bacteria that had been collected from lakes and streams. Our measurements provide indirect information about mechanisms of biomineralization.

The orientations and morphologies of magnetite crystals in a double magnetosome chain were identified using electron diffraction, high-resolution electron microscopy and high-angle annular dark field electron tomography. Each of the two chains is analogous to beads on a string, in which biological control appears to be stricter in setting the [111] magnetocrystalline easy axis of the crystals to be parallel to the chain axis than in constraining their orientation about this direction. We used off-axis electron holography to record magnetic induction maps from the same particles. The magnetic signal was dominated by inter-particle interactions and by the shapes of the individual crystals.

We studied the diversity of magnetosomes in bacteria collected from Lake Balaton. In stained thin sections of *cocci*, magnetite crystals appear to be anchored to the inner cell membrane. They are enveloped by stained material, which may correspond to the magnetosome membrane. The sections contain no detectable iron outside the magnetite magnetosomes.

The shapes, orientations, microstructures and magnetic properties of iron sulfide nanocrystals in magnetotactic bacteria that had been collected from salt marshes were also studied. Rod-shaped cells were found to contain multiple chains of greigite magnetosomes with random shapes and orientations. Many of the greigite crystals appeared to be only weakly magnetic, presumably because their magnetic induction direction was almost parallel to the electron beam. The disordered three-dimensional arrangement of the crystals in a multiple chain resulted in the magnetic field in the chain following a meandering path between adjacent crystals. Nevertheless, the magnetosomes were observed to collectively comprise a permanent magnetic dipole moment that is sufficient for magnetotaxis. Over a three-year period, with the sample stored in air, each greigite crystal developed an amorphous iron oxide shell and its magnetic moment decreased. When taken together, these results provide a better understanding of magnetotaxis in sulfide-producing cells, and they have implications for the interpretation of paleomagnetic signals recorded from greigite-bearing sedimentary rocks.