Nanoscale magnetic properties of iron minerals in bacteria Mihály Pósfai[a*], Takeshi Kasama[b,c], Edward T. Simpson[c], Ryan K.K. Chong[c], Rafal E. Dunin-Borkowski[c,b], [a]*Dept. of Earth and Environmental Sciences, University of Veszprém, Hungary.* [b]*The Institute of Physical and Chemical Research, Hatoyama, Japan.* [c]*Dept. of Materials Science and Metallurgy, University of Cambridge, UK.*
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We have used a combination of advanced transmission electron microscopy techniques to study the physical and chemical properties of intracellular ferrimagnetic magnetite (Fe_3O_4) and greigite (Fe_3S_4) nanocrystals inside magnetotactic bacteria that were collected from lakes and streams. The relative orientations and the morphologies of magnetic nanocrystals in magnetosome chains were identified using electron diffraction, high-resolution electron microscopy and high-angle annular dark field electron tomography. Whereas magnetite chains were found to be analogous to beads on a string, in which biological control set the [111] magnetocrystalline easy axes of the crystals parallel to each chain axis, greigite crystals had more random orientations. Within each bacterial strain, magnetite magnetosomes were observed to have distinct and well-controlled morphologies. In contrast, greigite crystals appeared to have more irregular shapes. We used off-axis electron holography to record magnetic induction maps from the magnetosome chains. The magnetic signal was dominated by inter-particle interactions and by the shapes of the individual crystals. Magnetite nanocrystals were found to be uniformly magnetized, parallel to the magnetosome chain axes. In contrast, the disordered three-dimensional arrangement of multiple chains of greigite crystals resulted in the magnetic field following a meandering path between adjacent crystals. 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. Our results are useful for obtaining an insight into biomineralization processes, and for studying the fundamental effects that influence the magnetic properties of closely-spaced nanoscale magnets.

Keywords: biomineralization, magnetism, advanced electron microscopy