Goldschmidt 2023 Abstract
https://doi.org/10.7185/gold2023.17566

Establishing trace and minor element incorporation into magnetite as a tool for the identification of fossil magnetotactic bacteria

MATTHIEU AMOR[1], J. FREDERICK W. MOSSELMANS[2], ERNESTO SCOPPOLA[3], CHENGHAO LI[3], DAMIEN FAIVRE[4] AND DANIEL M. CHEVRIER[5]

[1]Ecole Normale Supérieure de Lyon
[2]Diamond Light Source
[3]Max Planck Institute of colloids and interfaces
[4]Aix-Marseille Université, CEA, CNRS, BIAM
[5]CEA/CNRS/Aix-Marseille University/BIAM

Presenting Author: matthieu.amor@ens-lyon.fr

There are longstanding and ongoing controversies about the abiotic or biological origin of nanocrystals of magnetite (Fe_3O_4). Magnetotactic bacteria (MTB) are the only known microorganisms synthesizing intracellular nanoparticles of magnetite in a genetically controlled manner. They are ubiquitous in modern aquatic environments, and may represent some of the most ancient biomineralizing organisms on Earth. Identifying their mineralogical remains preserved in ancient rocks and corresponding to their fossil magnetite nanoparticles would provide strong constrains on the origin and evolution of early life. However, determining the biological or abiotic origin of fossilized magnetite remains extremely challenging. The elemental composition of magnetite has been proposed as a tool for distinguishing magnetite produced by MTB from its abiotic counterpart: the incorporation of trace and minor elements was observed to be dramatically decreased in biological magnetite. However, the mechanisms leading to such elemental depletion have never been clearly identified. Here, we use a combination of theoretical modeling (lattice and crystal field theories) and experimental evidence (high-resolution inductively coupled plasma−mass spectrometry and X-ray absorption spectroscopy) to demonstrate that element incorporation into abiotic magnetite nanoparticles is controlled principally by cation size and valence. Elements from the first series of transition metals (Cr to Zn) constituted exceptions to this finding, as their incorporation appeared to be also controlled by the energy levels of their unfilled 3d orbitals, in line with crystal field mechanisms. We finally show that element incorporation into biological magnetite nanoparticles produced by MTB cannot be explained by crystal−chemical parameters alone, which points to the biological control exerted by the bacteria over the element transfer between the MTB growth medium and the intracellular environment. This screening effect generates biological magnetite with a purer chemical composition in comparison to the abiotic materials formed in a solution of similar composition, thus establishing trace element partitioning as a tool for identification of MTB fossils preserved in ancient rocks.