Crystal growth of bullet-shaped magnetite in magnetotactic bacteria of the Nitrospirae phylum

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1. INTRODUCTION

Magnetotactic bacteria (MTB) are known to produce single-domain magnetite or greigite crystals within intracellular membrane organelles and to navigate along he Earth's magnetic field lines. MTB have been suggested as being one of the most ancient biomineralizing metabolisms on the Earth and they represent a fundamental model of intracellular biomineralization. Moreover, the determination of their specific structure and morphology is essential for paleoenvironmental and ancient-life studies. Yet, the mechanisms of MTB biomineralization remain poorly understood, although this process has been extensively studied in several cultured MTB strains in the Proteobacteria phylum. Here, we present a comprehensive transmission electron microscopy (TEM) study of bullet-shaped magnetites produced by the uncultured strain MYR-1 belonging to the Nitrospirae phylum, a deeply branching phylogenetic MTB group. High resolution TEM, electron tomography, electron holography and aberration corrected STEM-HAADF imaging have been used to investigate the magnetic and structural properties down to atomic scales of biomineralized magnetites.

We observed a multiple-step crystal growth of MYR-1 magnetite: initial isotropic growth forming cubo-octahedral particles, subsequent anisotropic growth and a systematic final elongation along [001] direction. During the crystal growth, one major {111} face is well developed and preserved at the larger basal end of the crystal. The basal {111} face appears to be terminated by a tetrahedral–octahedral-mixed iron surface, suggesting dimensional advantages for binding protein(s), which may template the crystallization of magnetite. This study offers new insights for understanding magnetite biomineralization within the Nitrospirae phylum.

2. RESULTATS

2.1 Experiments

MYR-1 bacteria have been collected from Lake Miyun near Beijing (China) and selected using magnetic separation. Whole cells and isolated magnetite have been observed using various TEM methods including HREM, electron tomography, atomic resolution STEM-HAADF and electron holography.

2.2 Growth sequence of MYR-1 magnetosomes

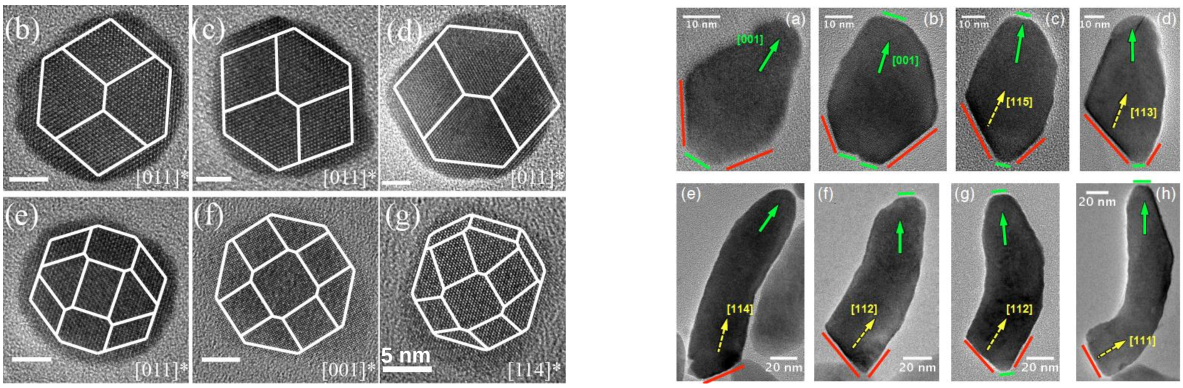

Figure 1. Growth sequence of intracellular magnetite.
Left panel: initial isotropic growth forming cubo-octahedral particles
Right panel: subsequent anisotropic growth and systematic final elongation along [001] direction

2.3 3-D shape of magnetosomes / Atomic structure of the {111} basal plane

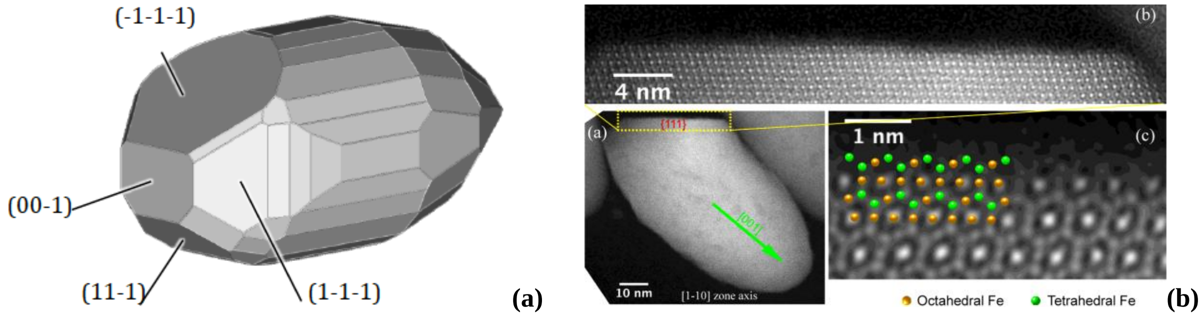

Figure 2..
(a) idealized morphology of magnetosome deduced from electron holography and STEM-HAADF contrast analysis
(b) STEM-HAADF observation revealing the atomic structure of the magnetosome {111} basal plane.

3. CONCLUSION

This study reveals a multiple-step crystal growth of magnetite that leads to forming highly elongated and kinked magnetosomes within MYR-1. Despite varieties in the elongation direction at the initial stage of anisotropic growth, the final elongation is uniformly along [001] crystal direction of magnetite. The offset between the initial and final elongation directions results in the formation of various kinked shapes of magnetite crystals. During the anisotropic crystal growth, one major {111} face at the basal end is well developed and preserved, and it appears to be made of dense monolayer of iron from mixed tetrahedral and octahedral sites. The elongating, kinking crystal growth and the well-defined basal f111g end face together indicate a unique biologically controlled mineralization mechanism for bullet-shaped magnetite in MTB of the *Nitrospirae*, which is distinctive from that for cubo-octahedral and prismatic magnetites in the Proteobacteria, at least from crystallographic point of view. To determine the molecular mechanisms of the bulletshaped magnetosome formation and evolution of the magnetosome biomineralization for magnetotaxis, more biological and geological studies are needed on modern MTB and ancient magnetofossils, respectively..

REFERENCES

[1] Li J., Menguy N., Gatel Ch., Boureau V., Snoeck E., Patriarche, G., Leroy, E. and Pan, Y. *J. R. Soc. Interface* DOI: 10.1098/rsif.2014.1288 (2015)