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PHYSICAL AND MAGNETIC MICROSTUCTURE OF BACTERIAL MAGNETITE FROM ELECTRON HOLOGRAPHY

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Introduction

Magnetite crystals in magnetotactic bacteria are typically organized in chains and have specific crystal morphologies within each cell type. In some bacterial strains, the crystals are cuboctahedra comprised of {100} and {111} forms. In other bacterial strains, the crystals are elongated along a [111] axis parallel to the chain direction and have idealized habits comprising {100}, {111}, and {110} forms. In these habits, the six, eight, and twelve symmetry-related faces of the respective forms expected for the face-centered (Fd3m) spinel structure are not equally developed (DEVOUARD et al., 1998). The elongated magnetite crystals are typically ca. 40 to 100 nm long, within the permanent, single-magnetic-domain size range.

Magnetotactic bacteria collected from a brackish lagoon at Itaipu', located on the coast of Brazil north of Rio de Janeiro, contain chains of magnetite crystals with lengths up to 200 nm (FARINA et al., 1994; LINS et al., 1994). As the magnetic single-domain to multi-domain transition dimension in magnetite is not well understood and varies with axial ratio (DUNLOP & OZDEMIR, 1997), it is uncertain whether the magnetite crystals in the Itaipu' bacteria are permanent single domains or metastable single domains resulting from magnetostatic interactions between crystals in the magnetosome chains. Here we report on a study of the micromagnetic structure and crystal morphology of magnetosome magnetite crystals in the magnetotactic bacteria from Itaipu' by off-axis electron holography (EH), high-resolution transmission electron microscopy (HRTEM), and electron diffraction (ED).

Methods

Two strains of coccoid magnetotactic bacteria, IC-1 and IC-2, were collected and whole cells, or magnetosomes extracted from disrupted cells, were deposited on TEM grids. EH, HRTEM, and ED measurements were carried out as previously reported (DUNIN-BORKOWSKI et al., 1998; DEVOUARD et al., 1998).

Results and Conclusions

IC-1 cocci contain two chains of large magnetosomes with quasi-rectangular planar crystal projections. IC-2 cocci have smaller magnetosomes with elongated rectangular projections. From HRTEM and ED, it was inferred that the idealized habit of the crystals in IC-2 cocci consists of combinations of {100}, {111} and {110} forms, with pseudo-hexagonal prisms of six elongated (110) faces. This morphology is consistent with the electronic contribution to the EH phase deviations in [110] and [112] zones perpendicular to the [111] elongation axis, which show a (110) face (flat top) perpendicular to the beam, and an intersection between adjacent (110) faces (tent-top) perpendicular to the beam, respectively (figure 1). The corner faces of the crystals in IC-1 cocci are less

prominent, but the HRTEM, ED, and EH data show that these crystals also have idealized habits consisting of pseudo-hexagonal prisms comprising six slightly elongated (110) faces. This is the first report in which three-dimensional information obtained by EH has been used to confirm the morphology of bacterial magnetites derived from two-dimensional projections.

Based on the magnetic contribution to the EH phase deviations, the crystals in IC-2 cocci are true single-magnetic domains. The crystals from IC-1 cocci are also single magnetic domains when in a chain configuration. A fortuitous configuration was also found in the crystals extracted from disrupted cells that comprised three large crystals and three elongated crystals, from IC-1 cocci and IC-2 cocci, respectively, with the large crystals forming a right angle. Analysis of the magnetization before and after application of a magnetic field greater than the coercive field indicate that the large crystals can support domain walls. Hence the large crystals in magnetosome chains in IC-1 cocci from Itaipu' are metastable single-magnetic domains.

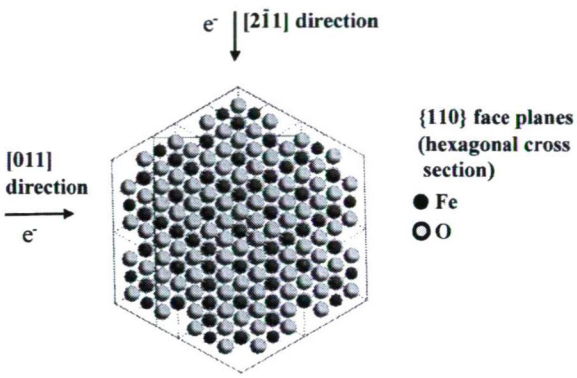

Figure 1. Model of a cross-section of the magnetite structure viewed along the [111] axis of elongation in which six [110] face planes are seen edge-on.

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