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Opinion

Iron Biomineralization Performed by Iron-Cycling Bacteria and Magnetotactic Bacteria

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Abstract

Iron is regarded as an essential element for organisms in earth. Iron-cycling bacteria (ICB) including iron-oxidizing bacteria (IOB) and iron-reducing bacteria (IRB), and magnetotactic bacteria (MTB) can mineralize iron to functional biocomposites which have potential for biomedical and environmental use. Generally, biologically induced mineralization (BIM) mainly occurs in ICB and biologically controlled mineralization (BCM) primarily exists in MTB. Iron biomineralization is a complex process and is affected by various environmental factors.

Keywords: Iron-Cycling Bacteria; Magnetotactic Bacteria; Biologically Induced Mineralization; Biologically Controlled Mineralization

Iron is the fourth most abundant chemical element by weight in the earth's crust and exists in the forms of ferrous Fe(II) and ferric Fe(III) [1]. Its cycling on our planet is an extremely complex process involving both abiotic and biotic components [2]. As important members in biotic cycling of iron, iron-cycling bacteria (ICB) including iron-oxidizing bacteria (IOB) and iron-reducing bacteria (IRB), and magnetotactic bacteria (MTB) can convert iron to biocomposites such as oxides, hydroxides [4-6].

Thus, biomineralization is the process by which living organisms transform environmental metallic elements into inorganic or functional organic-inorganic biominerals [2]. Biomineralization is of great interest for geologists, biologist, medical scientist, environmentalists and astronomer science it connects the living word of organisms with inanimate words of minerals [7]. There are two types of iron biomineralization, i.e., biologically induced mineralization (BIM) and biologically controlled mineralization (BCM) [3]. BIM is documentedly governed by environmental factors such as pH, temperature, dissolved oxygen, and redox potential, whereas BCM is controlled by itself.

BIM can be observed at the surface of ICB cells and the extracellular iron oxides or/and hydroxides are formed. Some neutrophilic IOB such as *Gallionella* sps., *Mariprofundus ferrooxydans, Leptothrix* sps. produce distinctive mineralized Fe-oxyhydroxide-encrusted stalk and sheath [4]. Other neutrophilic IOB including *Sideroxydans paludicola, Ferritrophicum radicicola, Siderocapsa* sps. are found to form particulate iron oxyhydroxides with amorphous morphotype. The precipitation of iron minerals may not only alter cellular ultrastructures but also catalyze the production of free radicals, which are potentially lethal for bacterial cells [8]. However, these neutrophilic IOB can leave large areas of the cells free of precipitates via localizing iron biomineralization at a distance from the cells [9]. The acidophilic IOB such as *Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans, L. ferriphilum* are able to synthesize iron biomaterials including jarosite, schwertmannite, and akaganeite under the specific condition [10,11]. BIM also discover in the IRB like *Shewanella* sps., *Geobacter* sps. and *Thermoanaerobacter ethanolicus* [3]. It has been documented that the amorphous to poorly ordered iron (oxyhydr) oxides (e.g. ferrihydrite), more-crystalline Fe(III) oxides (e.g. hematite and magnetite) are the preferred sources of solid-phase ferric iron for these IRB [12]. It can be found that the amount of magnetite depends on the inorganic phosphate titer and Fe(III) availability in medium [3].

BCM can be observed in MTB such as *Magnetospirillum gryphiswaldense, M. magnetotacticum* and *Desulfovibrio magneticus* [4]. The nanometer-sized, membrane-bound crystals of the magnetic iron minerals magnetite (Fe_3O_4) or greigite (Fe_3S_4), i.e. magnetosomes are mineralized by MTB [5]. Generally, magnetosomes along the long axis of the cells are arranged in one, two or multiple chains in the majority of MTB [5]. Various morphologies of magnetosomes are observed including cubooctahedral, bullet-shaped, elongated prismatic, and rectangular morphologies [2,5,6]. Mature magnetosomes typically fall within a narrow size range of about 35–120 nm which is just in stable range of a single magnetic domain crystal and permanently magnetic at ambient temperature [5, 6]. The location, size, nucleation, morphology, and arrangement of magnetosomes are strict controlled by the *mam* and *mms* genes organized within a genomic island [13]. Up till now, more than 40 genes related to the synthesis of magnetosomes were found and characterized [5, 6]. These genes are organized in four gene clusters mostly located in a specific chromosome section [6]. Formation of magnetosomes generally involves vesicle formation, extracellular iron uptake, iron transport and genetically controlled magnetosome mineralization [6]. The magnetosomes are also produced by acidophilic IOB including *A. ferrooxidans* and *L. ferrooxidans* [5]. For MTB, the magnetosome chain mostly orients bacteria and magnetosomes can also be used as a potential storage of iron. For magnetosome-producing acidophilic IOB, the magnetosomes dispersed in cells should only be considered as a potential storage of elastic energy.

The products of iron biomineralization are form under green conditions without loss of functionalities. Therefore, they have potential application in cell isolation, tumor hyperthermia, drug delivery, medical imaging, information storage, wastewater treatment and ground water remediation, biological catalysis [1,5].

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