MULTICELLULAR MAGNETOTACTIC PROKARYOTE AS A TARGET FOR LIFE SEARCH ON MARS.

A.F. Davila[1], M. Winklhofer[2], C. McKay[1].
[1] NASA Ames Research Center. M.S. 245-3. Moffett Field, Ca. 94087 (E-mail: afernandez-davila@arc.nasa.gov)
[2] Dept. of Earth and Environmental Sciences. LMU Muenchen. Germany

Introduction: It is now widely accepted that if life ever existed on Mars it probably did not evolve beyond a relatively simple level of organization similar to unicellular organisms on Earth. This hypothesis relies on models for the early evolution of Mars that propose a seemingly short time window (i.e. 1Gyr) during which the planet's surface possessed the chemical and physical conditions that would enable the appearance and evolution of life, thereby hindering the appearance of more complex cell structures and body architectures in a putative Martian biosphere.

Recent studies conducted on an intriguing type of magnetotactic organisms on Earth [1], suggest however that an intimate type of multicellularity is possible among relatively simple prokaryote cells. The so-called Multicellular Magnetotactic Prokaryote (MMP) consist of tens of Gram-negative, flagellated cells, characterized by an undisrupted multicellular life cycle, coordinated motion, a very simple level of cell differentiation, intercell communication and ultrastructural features that suggest a complex level of multicellular organization [1, 2]. We suggest that following a similar strategy, multicellularity may have evolved as well on Mars.

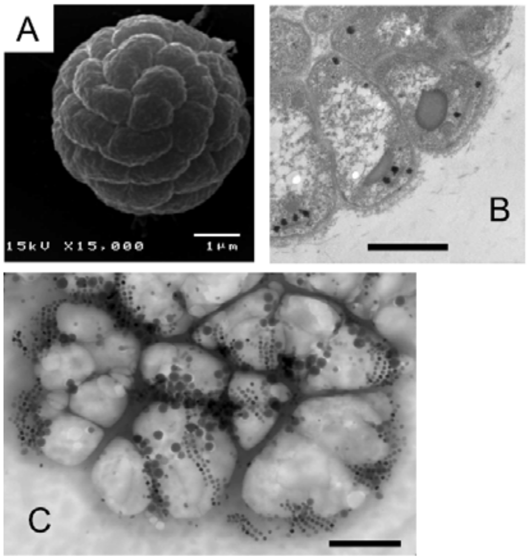

Fig 1. A. SEM picture showing the spherical arrangement of cells in the MMP. B. Thin section of a MMP, showing the natural radial arrangement of cells and magnetosomes (dark). C. Arrangement of the magnetic crystals in the form of double or multiple chains. Bars 1μm. From (1).

The Multicellular Magnetotactic Prokaryote: Depending on the location and maturity level, an MMP consists of between a dozen and not more than 45 Gram-negative, flagellated cells, and measures between 4 and 9.5 μm in diameter [1, 3] (Fig. 1A). The cells have an approximately pyramidal shape and are distributed radially about an acellular compartment [3]. Each cell contains up to 50 magnetosomes (i.e. intracellular magnetic crystals) arranged in chains and usually composed of the iron sulfide greigite ($Fe^{2+}Fe^{3+}S_4$) (Fig. 1B, C). The flagellar movement of the cells is highly coordinated and allows the MMP to swim along magnetic-field lines, a behavior commonly known as magnetotaxis. Up to this day no viable unicellular stages have been observed during the MMP life cycle, and each of its constituent cells is incapable of individual development.

Exploiting the magnetotactic response of the MMP, Winklhofer et al. [1] have shown that despite its rather complex cell organization, the MMP is highly optimized from a magnetotactic point of view. This observation is based on experiments designed to estimate the degree of magnetic optimization (DMO) of the MMP. The DMO is defined as the magnitude of the net magnetic moment of an individual MMP, with respect to the maximum remnant magnetic moment that the same organism can possibly acquire, after it has been treated with a brief, strong magnetic pulse that magnetically saturates the organism. The authors showed that MMPs in their natural state are optimized above an 80% indicating that the formation of intracellular chains of magnetosomes is highly controlled. In the same study, the authors showed that each generation of MMPs cannot be formed through agglomeration of individual cells, and still show a high DMO at the population level. Instead, they suggested that a continuously multicellular life style is necessary for the MMP to preserve its magnetically optimized state during reproduction, and to retain its capability to swim along magnetic field lines, as already suggested in previous studies [1, 3, 4] (Fig. 2). According to these results, the optimization of the magnetotactic response, and the need to transfer efficiently the magnetic polarity during division, may have been a major selective force towards multicellularity among magnetotactic prokaryotes [1].

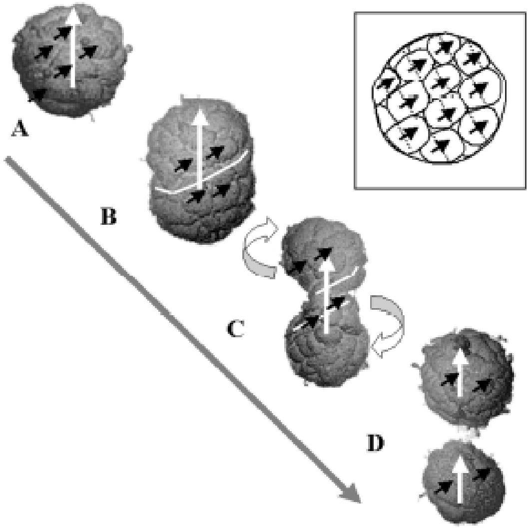

Fig 2. Postulated reproduction mechanism of the MMP in a continuously multicellular life cycle resulting in two equal organisms with the same general cell arrangement and direction of total magnetic moment (white arrows) as the parental one. From [1]

Ecology and Phylogeny of the MMP: The Ecology of the MMP remains mostly unstudied, but all MMPs reported thus far have been found in marine environments and are abundant in slightly sulfidic sediments, suggesting that MMP's thrive in poorly oxygenated and anoxic environments. Simmons and Edwards [5] have sequenced the 16S rDNA genes from a natural population of MMP and found five lineages separated by at least 5% sequence divergence. Furthermore, all cells in each aggregate expressed identical SSU rRNAs, suggesting that the aggregates are composed of a single MMP phylotype. The authors concluded that the MMP should be considered a separate genus in the δ-proteobacteria rather than a single species as previously thought, and that the MMP is comprised of clonal cells which reproduce by binary fission of the aggregate, supporting the models advocating for a continuous life cycle for the MMP.

Currently it is not known how long MMPs have been on Earth. The few genetic studies conducted thus far on MMPs have placed this type of organism in the Delta subgroup of the proteobacteria, which is not a deeply branching evolutionary line in the domain Bacteria, and therefore this group is not generally considered to be ancient groups of bacteria. More studies are required to elucidate the history of the MMP on Earth.

Multicellular Magnetotactic Prokaryotes on Mars: The possibility that magnetotactic organisms may have evolved on Mars has received increasing attention since the putative finding of magnetosome-like particles in the ALH84001 Martian meteorite [6, 7]. Taking the biochemistry and ecology of all known magnetotactic organisms on Earth as a reference, then the development of magnetotaxis on early Mars essentially required the presence of liquid water habitats and a planetary magnetic field. That Mars possessed a magnetic field early in its history has been clearly established by orbiter measurements [8]. Additionally, the recent NASA Mars Rovers Missions have provided conclusive evidence of aqueous sedimentation or aqueous alteration on the Martian surface [9], a finding consistent with models of liquid water near the surface [10], coexistent with an active Martian magnetic field [11, 12].

If magnetotaxis evolved on Mars, then evolution and natural selection may have facilitated the appearance of multicellular forms such as the MMP. Such body architectures have important advantages with respect to single cell organisms, including access to resources and niches that require a critical mass and cannot effectively be utilized by isolated cells; collective defence against agents that can effectively damage isolated bacterial cells but are ineffective against dense or organized populations of the same bacteria and optimization of population survival by differentiation into distinct cell types [13]. Finally, the hypothesis that multicellularity may have evolved on Mars is supported by the apparent preference of MMPs of anoxic and micro-oxic conditions in marine sediments, a type of environments that has also been suggested for early Mars, where O_2 was never massively accumulated as can be tested by the weak isotopic oxygen anomaly in the contemporary atmosphere [14]. If multicellularity ever evolved on Mars, it would have added a higher level of cell and body complexity to the Martian biosphere, opening the door to more complex and sophisticated life forms not considered until now.

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