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Probing Magnetic Polarities of Magnetotactic Bacteria by X-ray Magnetic Circular Dichroism in a Scanning Transmission X-ray Microscope

X.H. Zhu,[1] A.P. Hitchcock,[1] T. Tyliszczak,[2] D.A. Bazylinski[3]

[1] Chemistry & Chemical Biology, McMaster University, Hamilton, Canada L8S4M1
[2] Advanced Light Source, LBNL, Berkeley, CA, USA 94720
[3] Life Sciences, University of Nevada, Las Vegas, NV, USA 89154

Magnetotactic bacteria (MTB) are a group of fascinating organisms that can biomineralize chains of nano-scale (~50 nm) single crystals of magnetite (Fe_3O_4) or greigite (Fe_3S_4), known as magnetosomes [1]. The magnetosome chain passively aligns the magnetotactic bacteria with the Earth's geomagnetic field lines, a behaviour called magnetotaxis. This, along with oxygen chemotaxis, is believed to give MTB an evolutionary advantage as it reduces the search for their optimum ecological niche (the oxic-anoxic boundary) from 3D to 1D. Previous studies showed that northern hemisphere MTB swim preferentially towards the north magnetic pole (north-seeking, NS), whereas southern hemisphere MTB swim towards the south magnetic pole (south-seeking, SS) [1]. This behavior can be explained if the orientation of the magnetic polarity relative to the motile apparatus is reversed between NS and SS MTB (**Figure 1**) [2]. Alternatively, that orientation could be fixed and the sense of preferred motion reversed through some unspecified mechanism. Some MTB, such as *Magnetovibrio blakemorei* strain MV-1, feature a single flagellum for motion (**Figure 2**). In such species, if the flagellum and the magnetic polarity of the magnetosome chain are measured at the single cell level, direct experimental insights about magnetotaxis may be obtained. X-ray Magnetic Circular Dichroism (XMCD) measured in a Scanning Transmission X-ray Microscope (STXM) provides a means to measure magnetic moments and spatial orientation at the single magnetosome level [3-5]. Recently we used STXM-XMCD to show that a significant sub-population of MV-1 have anomalous magnetosome chains in individual cells in which there are gaps separating sub-chains of opposite magnetic orientation [5]. These results contradict previous understanding that all the magnetosomes in a chain have the same magnetic alignment. Why do a sub-set of MV-1 MTB synthesize two sub-chains with opposite magnetic directions?

Here, we report a new study that uses TEM imaging and STXM-XMCD to determine the magnetic polarities of magnetosome chains in individual cells of MV-1 magnetotactic bacteria. Our results show that, in some cases, different MV-1 MTB cells from the Northern Hemisphere can have different magnetic polarities (**Figures 2 & 3**). These results are consistent with Torres de Araujo's model [2] that some south-seeking bacteria are produced in the Northern Hemisphere and that North-seeking and South-seeking bacteria have opposite magnetic polarities in their magnetosome chains (Figure 1). A new theory is proposed to explain our previous results. Further studies including measurements of the magnetic polarity of northern hemisphere and southern hemisphere MV-1, as well as North-seeker and South-seeker cells isolated from a northern hemisphere culture will be reported. [6]

References:
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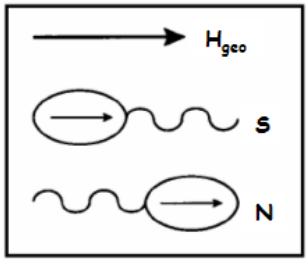

Figure 1. Schematic representation of South-seeking (Polarity type S) (top) and North-seeking (polarity type N) (bottom) magnetotactic bacteria, as per the Torres de Arujo model [2].

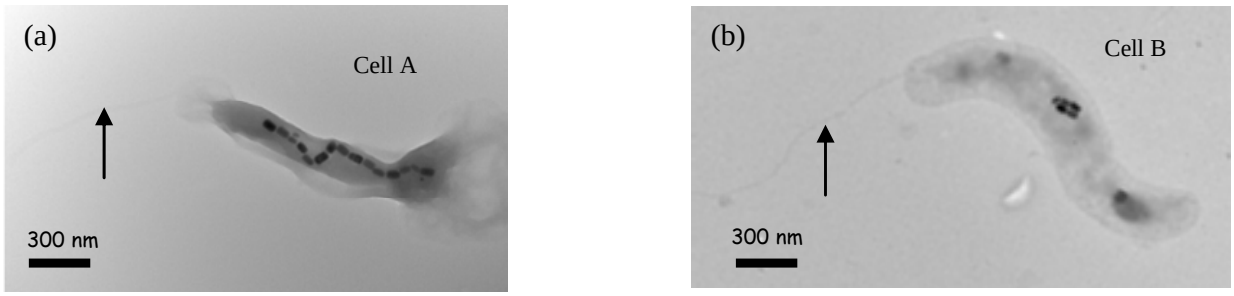

Figure 2. (a) and (b), TEM images of two MV-1 MTB cells in the Northern Hemisphere. The arrow indicates the flagellum of each bacterium.

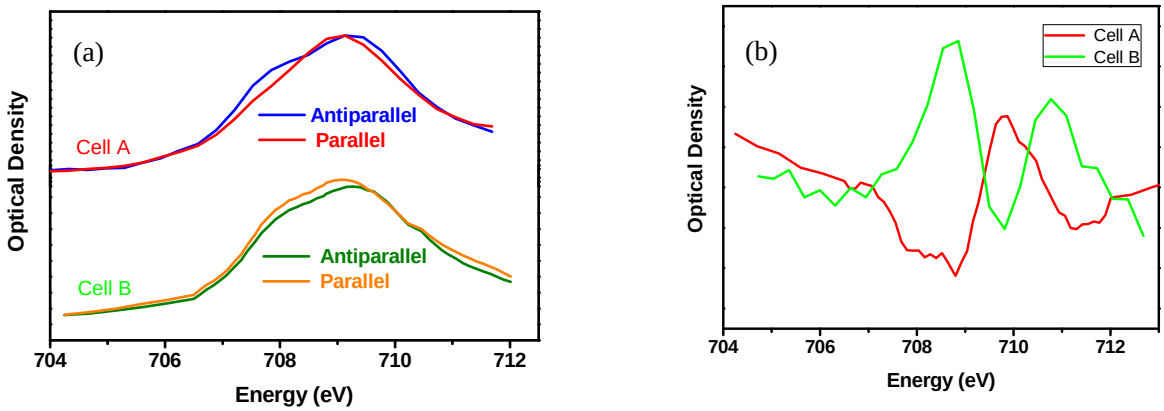

Figure 3. (a). Fe L_3 X-ray Absorption Spectra (XAS) of two MV-1 MTB cells in Figure 2 recorded with Left Circularly Polarized Light (LCP) and Right Circularly Polarized Light (RCP); (b). Derived XMCD spectra (difference spectra between LCP and RCP spectra in Figure 3a.) of the two MV-1 MTB cells from the Northern Hemisphere. The XMCD show that these two cells have opposite magnetic polarities relative to their flagellum, even though both cells are taken from a Northern Hemisphere culture.

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