proteinspotlight
> ONE MONTH, ONE PROTEIN <

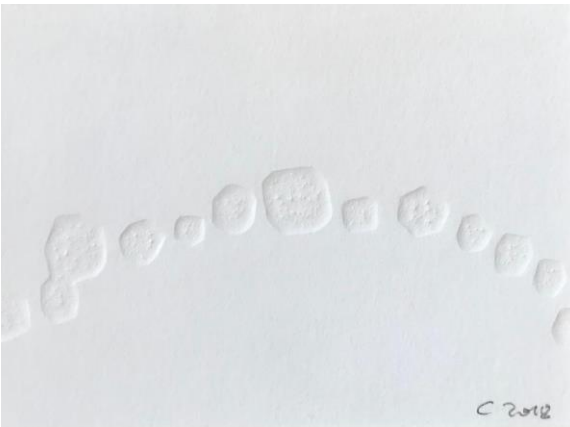
Issue 217, September 2019

www.proteinspotlight.org

a sense of direction

Vivienne Baillie Gerritsen

Survival depends on cues, mobility and a medium to evolve in. Cues – such as scents, sounds or colours for example – will attract organisms towards food, mating grounds and an environment in which they feel protected and are happy to stay. Thanks to them, organisms usually head off in a direction they expect will be to their advantage, using the means of locomotion they have, to cross all sorts of media. Some organisms make use of additional systems to reach a given destination. An example? Magnetotactic bacteria have learned to use the Earth's magnetic field as a speedy highway to travel to nutrients of interest. They do this by way of minute iron-rich pouches – or magnetosomes – that are aligned along their middle and act much like a compass would. Many macromolecules are required to model this fascinating system. One of particular interest is a protein known as MamB which is at the heart of magnetosome initiation. Magnetosomes have also long intrigued those behind the microbiology blog *Small Things Considered*, and this article echoes a lovely piece on magnetotactic bacteria and their navigation skills written by Christoph Weigel earlier this week, and whose artwork is shown below.



frottage on paper by Christoph Weigel

Courtesy of the microbiologist/artist

Magnetotactic bacteria proliferate in freshwater sediments but also in brackish, marine and hypersaline environments all over the world. In the late 1950s, an Italian doctor, Salvatore Bellini, observed for the first time a group of bacteria which all seemed to be heading in the same direction: northwards. He termed them magnetosensitive bacteria and described what he had seen in an article published in 1963. Though a short summary was translated into several languages, including English, his findings were given little to no attention at all. Seemingly unaware of Bellini's findings, in the mid-1970s Richard Blakemore, then a graduate student in microbiology, also observed bacteria that were using the Earth's magnetic field to navigate. Thanks to electron microscopy, Blackmore was able to go a step further and distinguish the chain of magnetosomes within the bacteria. Blakemore coined the bacteria's mode of transit 'magnetotaxis' – which is the term used ever since.

Why use the Earth's magnetic field to direct movement? Speed and efficiency may well be the answer. If you use our planet's magnetic field as a multi-lane highway, you are travelling in one plane only. Instead of dashing off in random directions – which costs energy – you follow a single direction. Fair enough, but why would this lead you to where you need to go, you may ask. How do bacteria know that what they are looking for lies along the Earth's magnetic field? It is a cunning system. Magnetotactic bacteria such as the spiral-shaped *Magnetospirillum gryphiswaldense* propel themselves forward by way of two flagella – one at each of their ends. They use very little oxygen and "know" that the best place for them to find nutrients is in a zone known as the oxic-anoxic transition zone (OATZ) of water. This particular zone is sandwiched between two layers of water: an upper oxygen-rich (oxic) layer supplied by the atmosphere and aqueous photosynthesis, and a lower oxygen-free (anoxic) layer. The anoxic layer releases all sorts of fermentation products that drift into OATZ while oxygen is fed into it thanks to the oxic layer. As a result, OATZ is an ideal feeding place for *Magnetospirillum*, and one of the fastest and most convenient ways of getting there is by hitching a ride on the geomagnetic field.

Magnetotactic bacteria use their magnetosomes to do just this. Scientists have been looking into these singular vesicles since the 1970s and, though knowledge is still scant, they are beginning to understand magnetosome biogenesis at the molecular scale. Several magnetosomes – up to 60 in *Magnetospirillum* – form simultaneously, and independently, by invagination of the bacterial membrane. As invagination occurs, a host of magnetosome-specific proteins, known as Mam proteins, rush to the site. Once formed, the vesicles align along the bacteria's middle held stable by an underlying actin-like cytoskeleton. Meanwhile, membrane-bound magnetite (Fe_3O_4) crystals nucleate and mature inside each magnetosome – typically one perfect cubo-octahedral crystal per magnetosome in *Magnetospirillum*. From the bending of the bacterial membrane and its invagination to magnetosome formation, iron transport, the shape, size and number of magnetite crystals and the final alignment of the magnetosomes, every stage is controlled by different Mam proteins, of which there are many.

One essential protein for magnetosome initiation in particular is MamB. MamB seems to play an important part in two stages of magnetosome formation: membrane invagination and magnetite nucleation. In the process of invagination, MamB may act as a landmark protein by forming a complex with other Mam proteins which, together, bend the membrane by sheer physical force to form a vesicle. Concomitantly, though iron ions may float passively from the cytoplasm into the forming magnetosomes, there is reason to believe that MamB is actively involved in their transport and triggers off magnetite nucleation. It is difficult, however, to talk about mamB without mentioning MamM, which has a stabilizing effect on MamB and is necessary for its correct function.

MamB and MamM belong to the cation diffusion facilitator (CDF) family. CDFs are found throughout all domains of life where they transport divalent metal cations from the cytoplasm into the extracellular space or indeed into intracellular compartments like magnetosomes. MamB and MamM are transmembrane proteins and share very similar structures; V-shaped, they probably form homodimers and interact with each other via their cytoplasmic regions. Both are needed for magnetosome invagination and magnetite nucleation although it seems that MamB has a more central role as MamM keeps it stable.

Magnetite biocrystals are very pure as opposed to their geocrystal equivalents which can harbour foreign inclusions. As a consequence, applications of magnetotactic bacteria and magnetosomes are currently being considered to resolve medical and environmental issues. Magnetosomes would be more effective contrast agents than their current chemical counterparts for magnetic resonance imaging (MRI) for instance. They could also be tailored to target malignant cells to which a magnetic field is applied thus inducing heat induction and cell disruption. On the environmental front, besides iron, magnetotactic bacteria are also capable of absorbing other metals such as cadmium, selenium, cobalt, manganese and copper. Engineered, magnetotactic bacteria could then be used to clean up toxic waste. Certainly, the applications seem promising and endless, but it is this faculty nature has of devising such sophisticated and unlikely ways of surviving which is the most intriguing. Magnetotactic bacteria have been around since the Cretaceous at least and are thought by a few to even exist on Mars but it is this capacity some living beings have of knowing how to sculpt inorganic crystals which is thought-provoking.

Cross-references to UniProt

Magnetosome protein MamB, *Magnetospirillum gryphiswaldense*: V6F510
Magnetosome protein MamM, *Magnetospirillum gryphiswaldense*: V6F235

References

1. Uebe R., Keren-Khadmy N., Zeytuni N. *et al.*
   The dual role of MamB in magnetosome membrane assembly and magnetite biomineralization
   Molecular Microbiology 107:542-557(2018)
   PMID: 29243866

2. Uebe R., Schüler D.
   Magnetosome biogenesis in magnetotactic bacteria
   Nature Reviews Microbiology 14:621-637(2016)
   PMID: 27620945

3. Dieudonné A., Pignol D., Prévéral S.
   Magnetosomes : biogenic iron nanpoarticles produced by environmental bacteria
   Applied Microbiology and Biotechnology 103:3637-3649(2019)
   PMID: 30903215