Magnetotactic bacteria: biology, diversity and biotechnology

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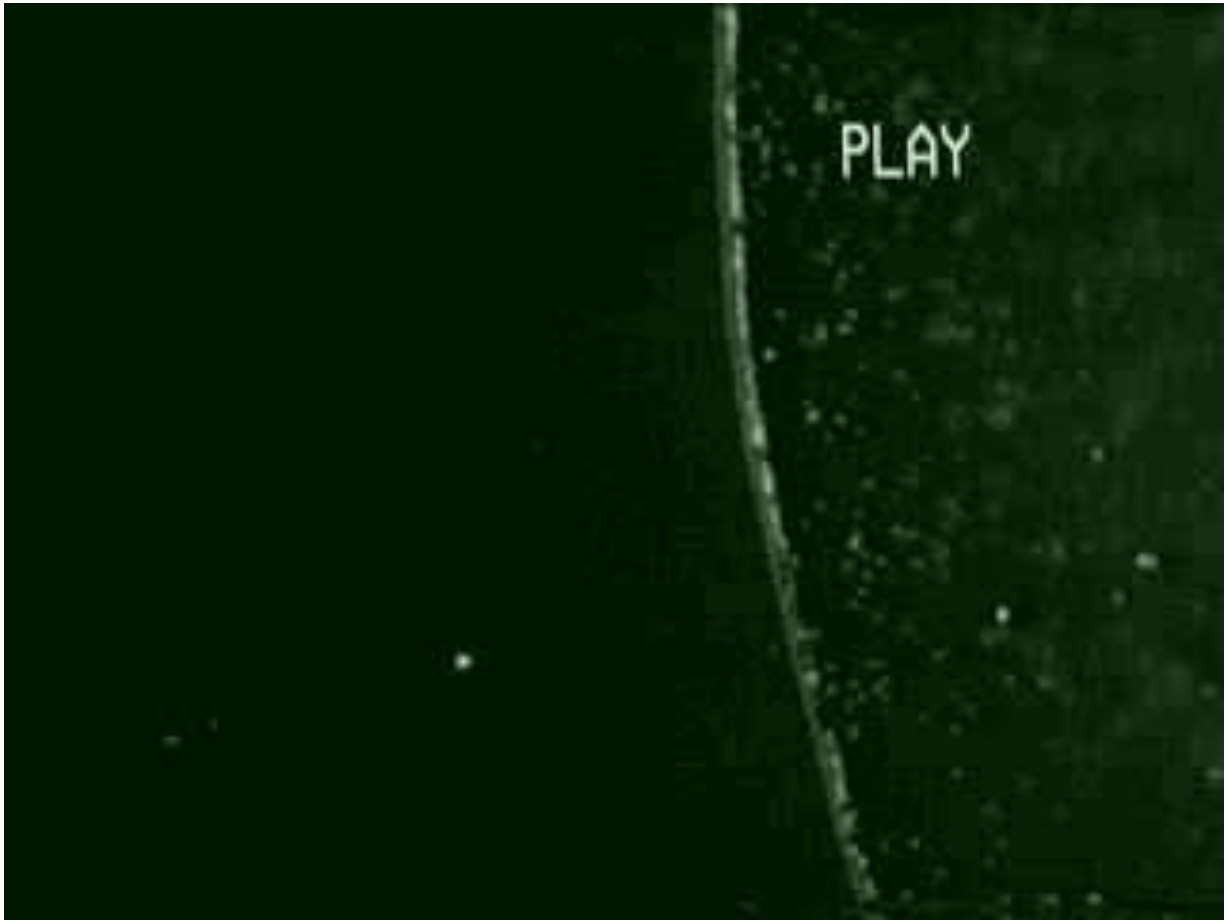
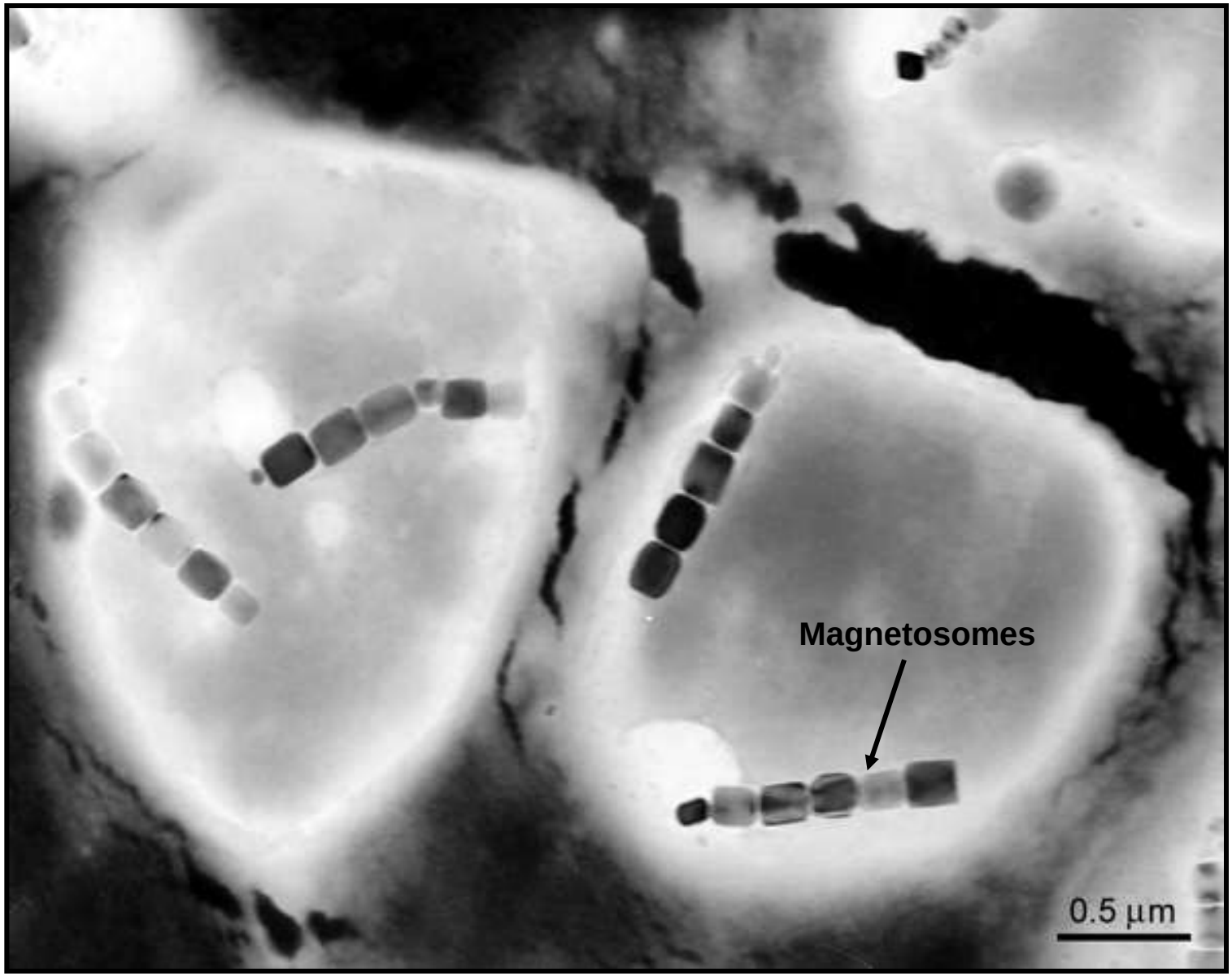
BIOTA – FAPESP 2014

Magnetotaxis

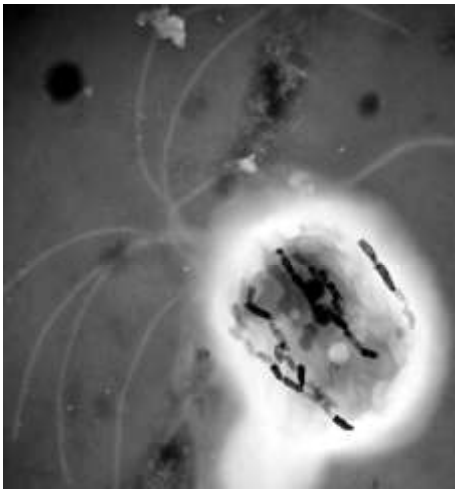


Ability of some bacteria to orientate and navigate along magnetic field lines

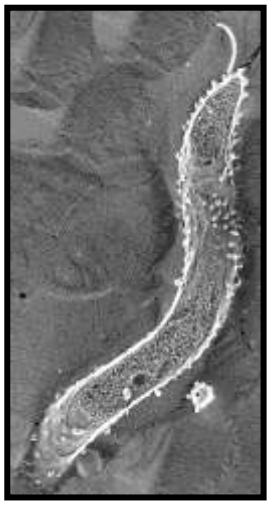
Magnetotactic bacteria orientate along filed lines because of magnetosomes



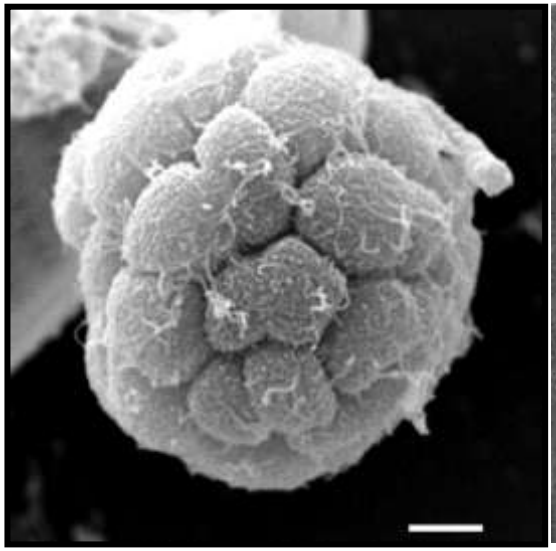
Morphology, phylogeny and metabolism



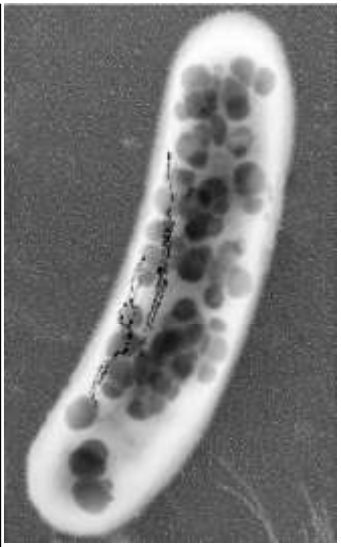
Cocci



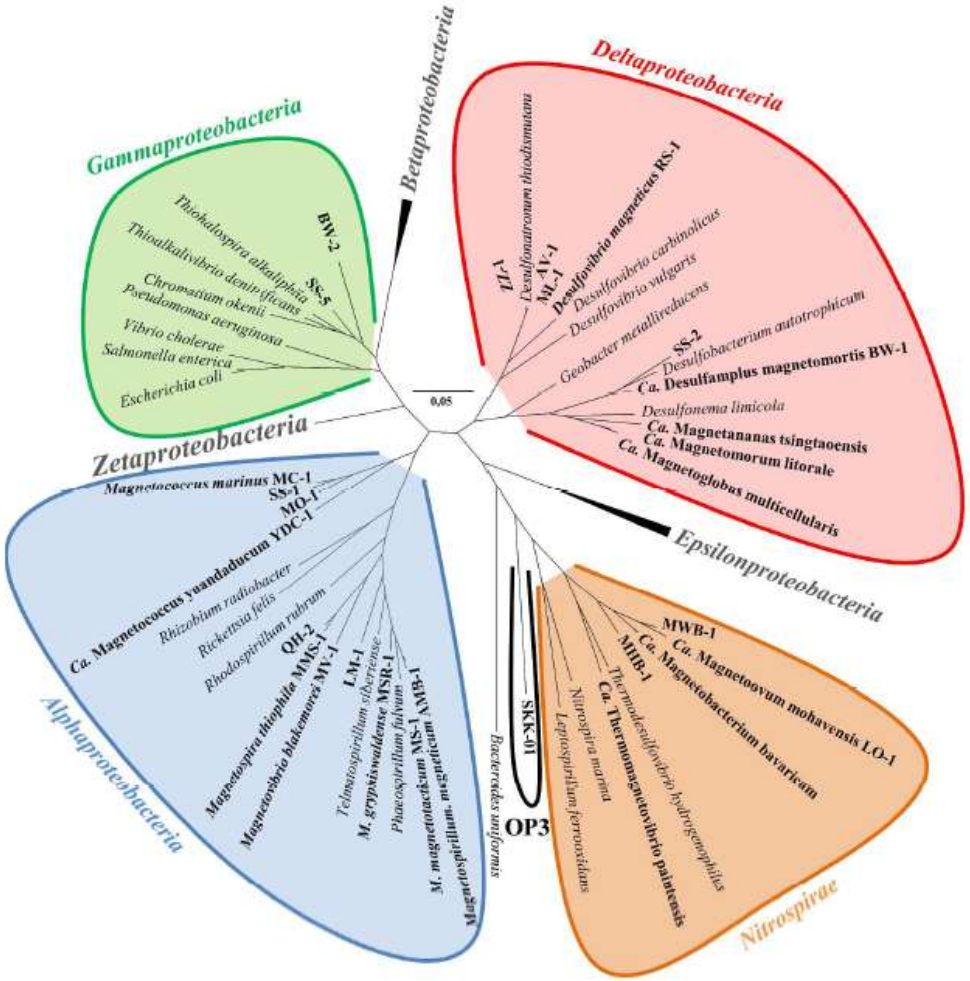
Spirilla



Multicellular

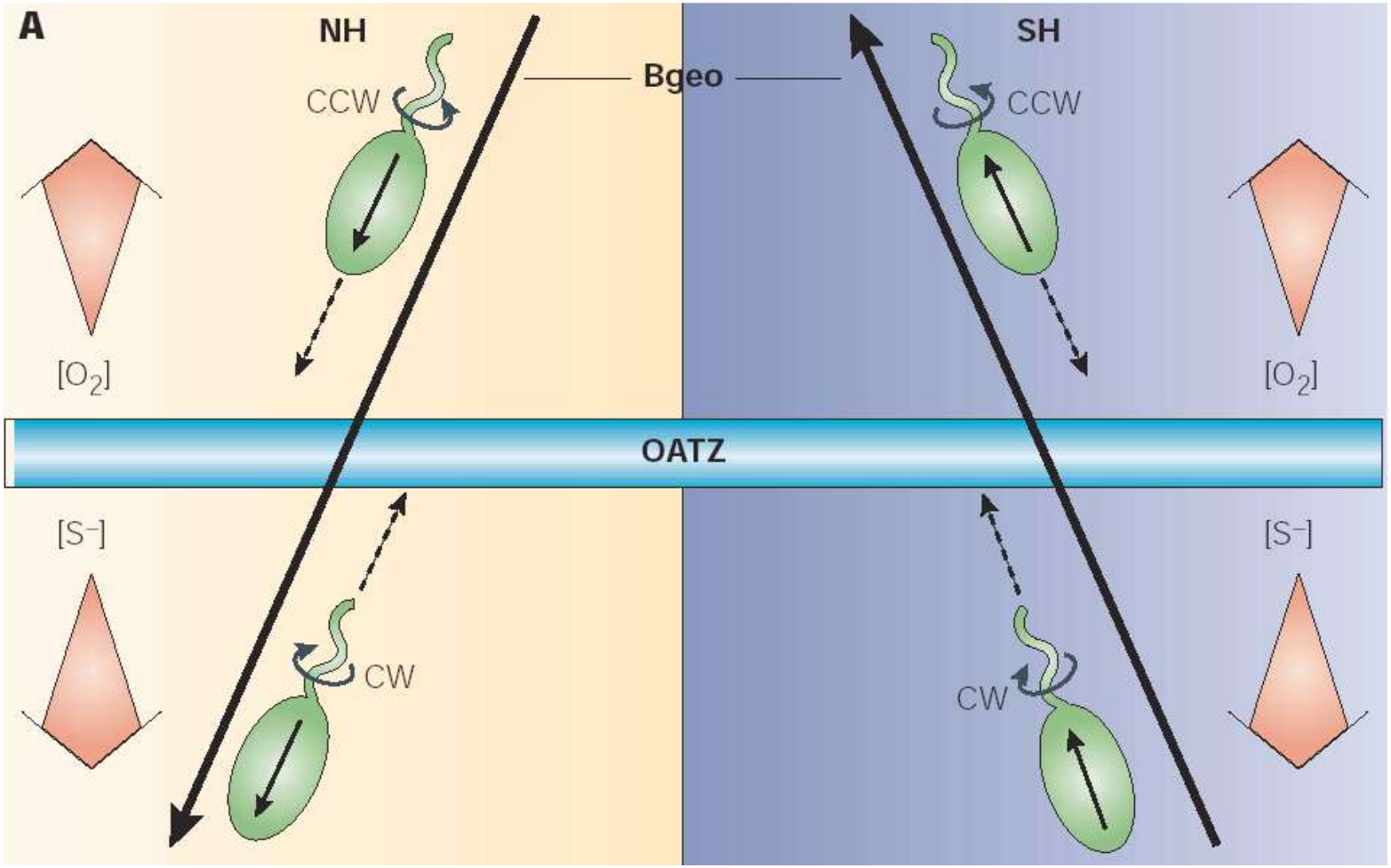


Rod-shaped



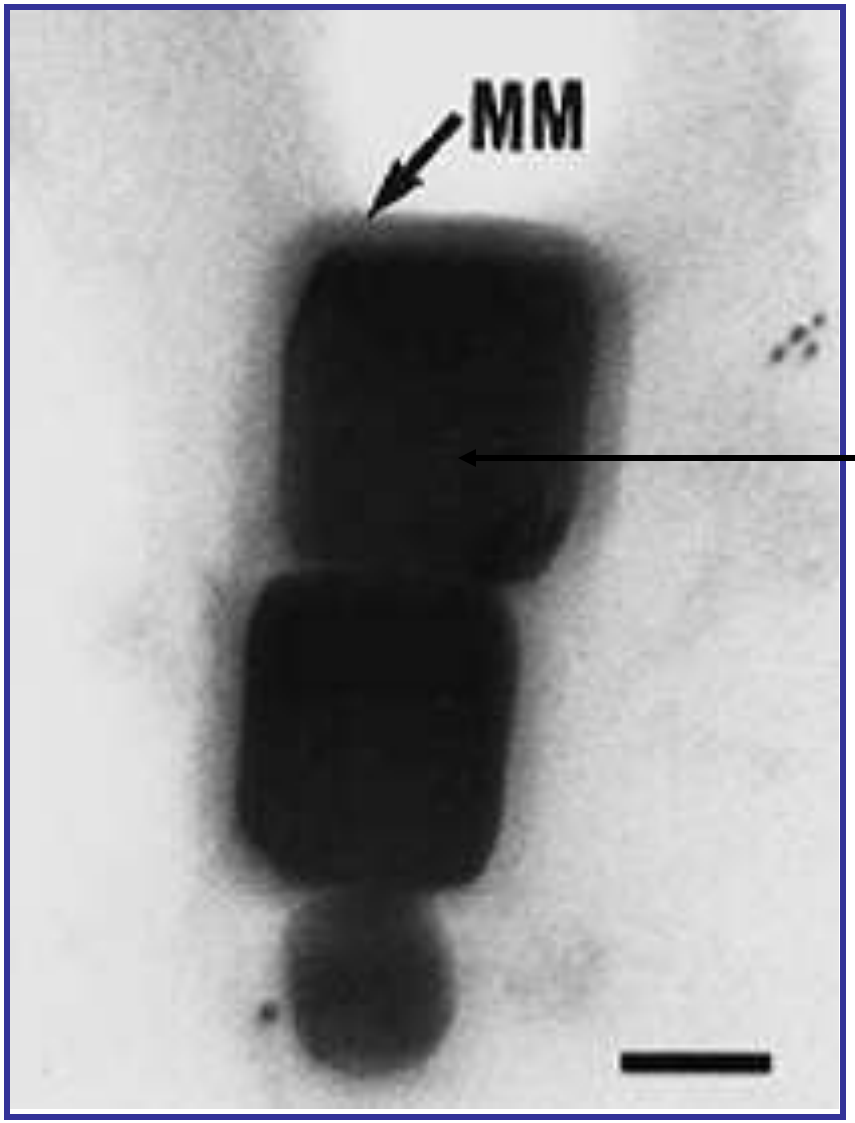
They are microaerophilic or anaerobes

Function of magnetotaxis



To help bacteria to orientate and navigate along the geomagnetic filed lines and towards more favorable regions

Magnetosomes

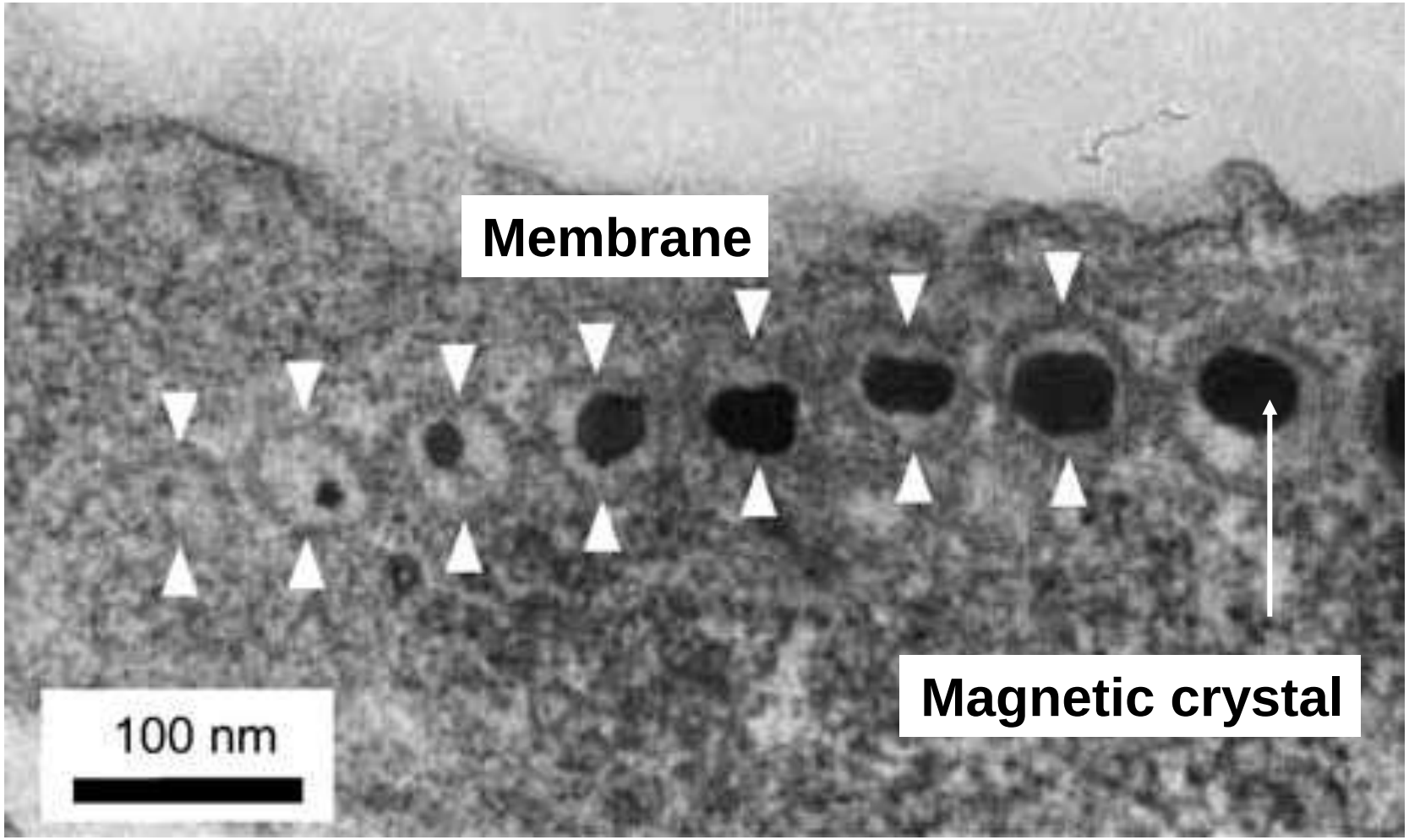


Magnetic crystal

Magnetite (Fe_3O_4)

Greigite (Fe_3S_4)

Magnetosomes

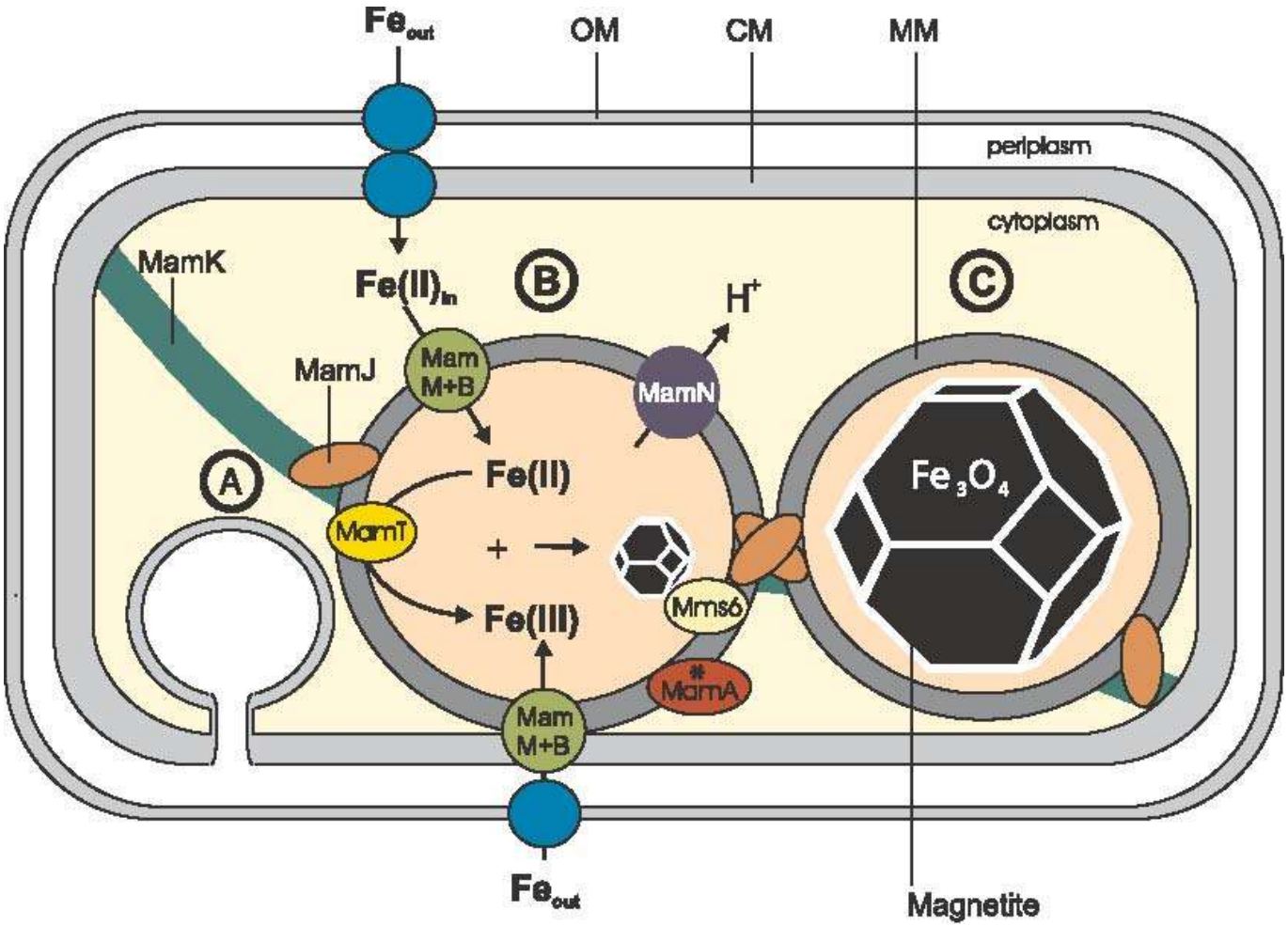


- **Magnetosomes consist of a magnetic crystal enveloped by a lipid-protein membrane**

Magnetosomes and biological control

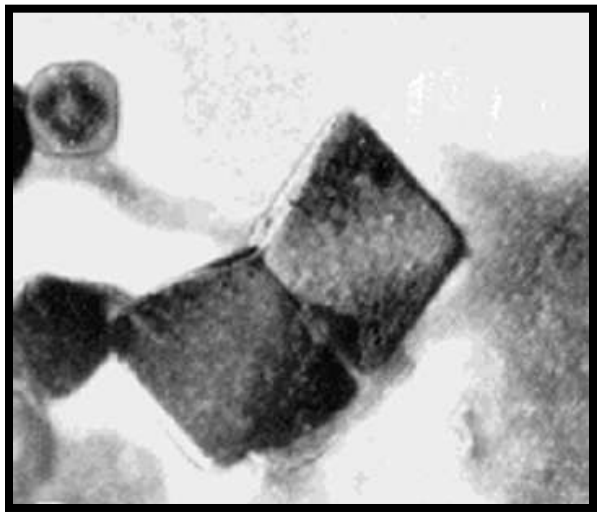
- The membrane defines a region of the cytoplasm where bacteria control **growth, size and purity** of the crystals through the proteins.

- The iron atoms are transported from the environment to the magnetosome vesicle where the crystal is nucleated and grows.

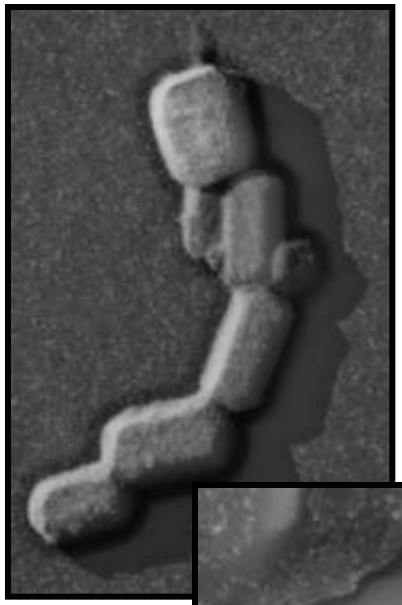


Magnetosomes and controlled morphology

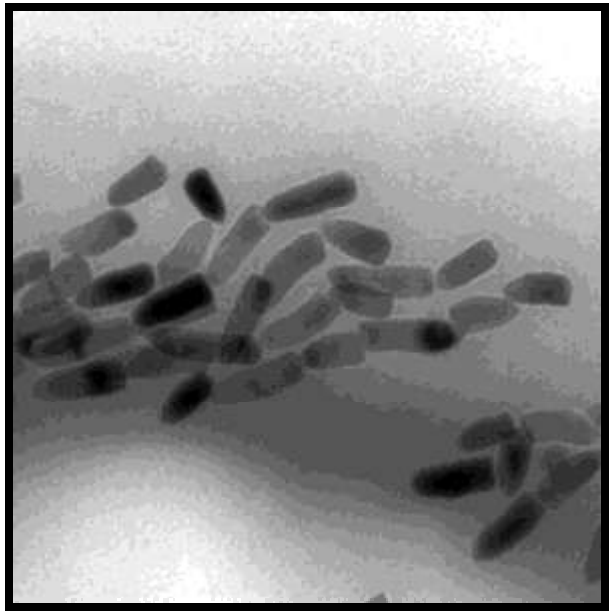
Inorganic magnetite



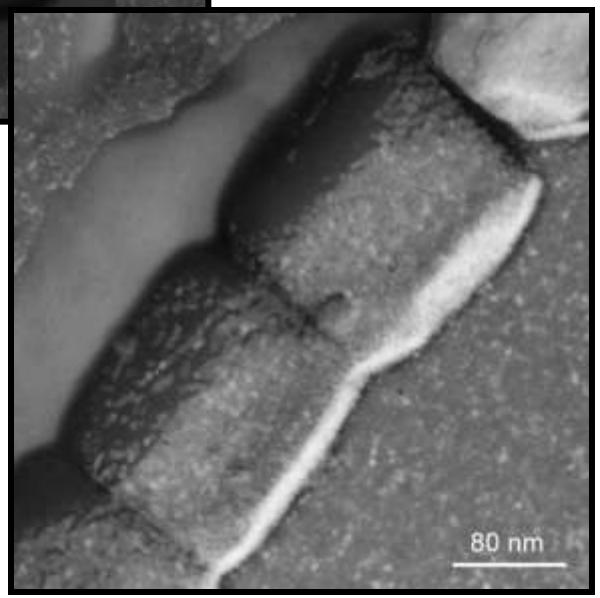
Cubo-octahedra



Prismatic

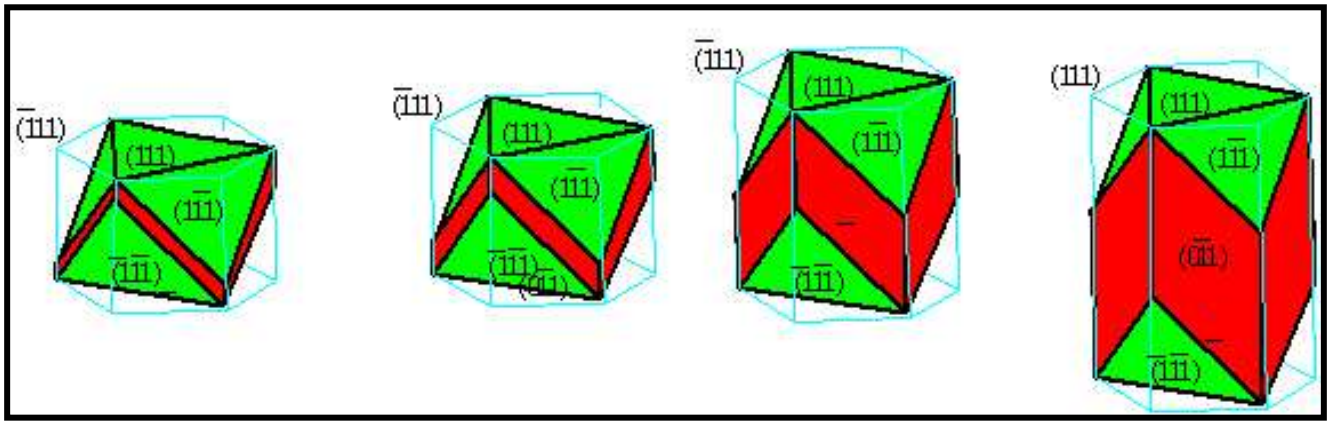


Bullet-shaped

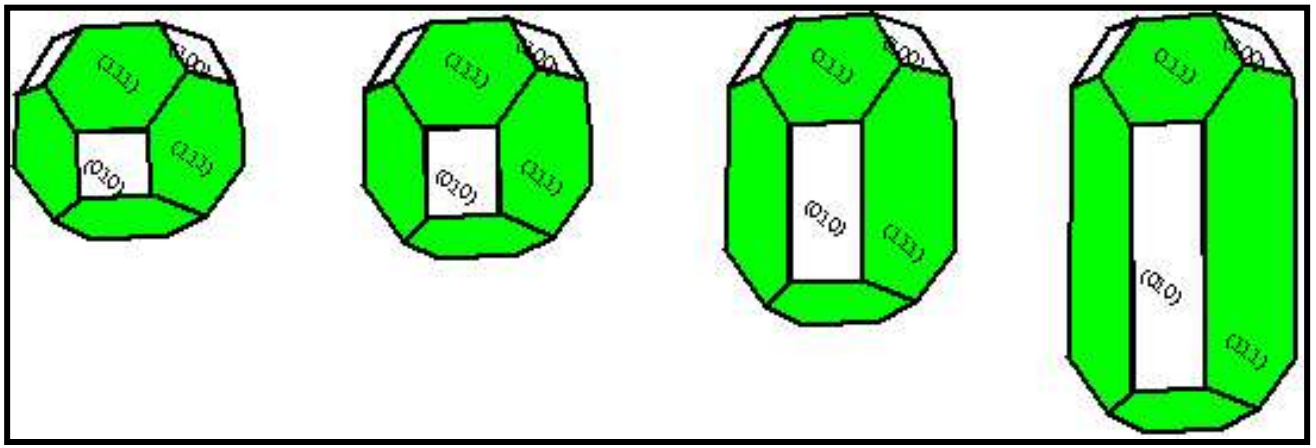


Morphology produced by bacteria

Magnetosomes and morphology



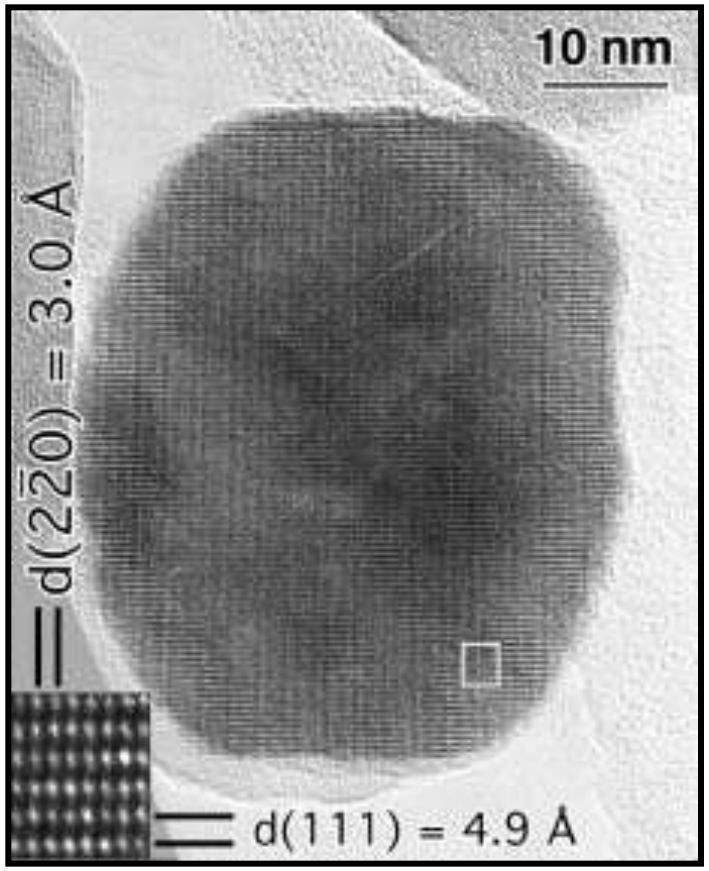
Inorganic magnetite



- Bacteria control the morphology of the magnetosomes.
- They facilitate the growth of specific faces to modify the morphology.
- If we understand the control mechanism we can try to mimic it.

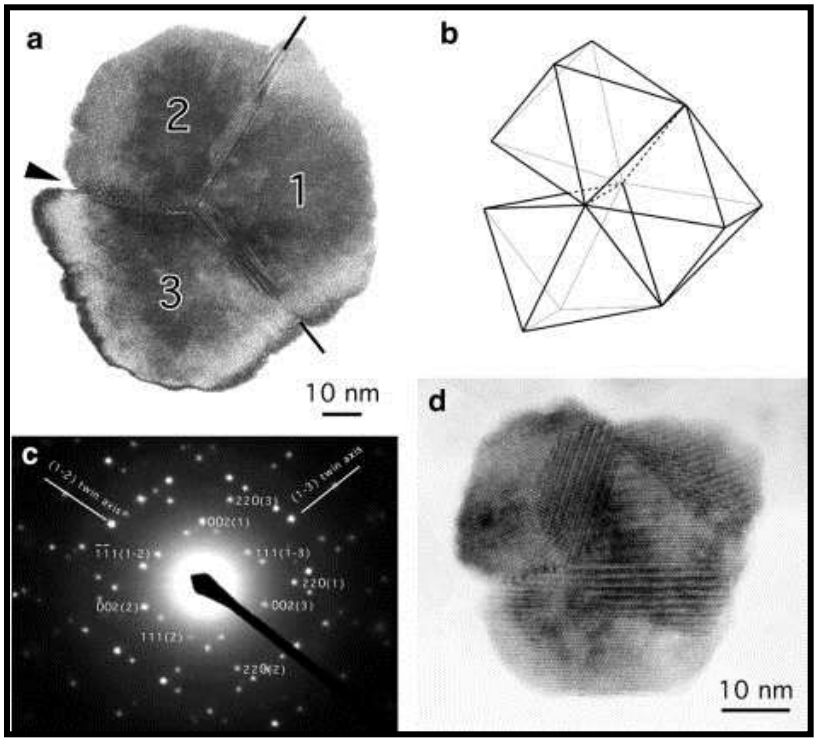
Magnetosomes and defects

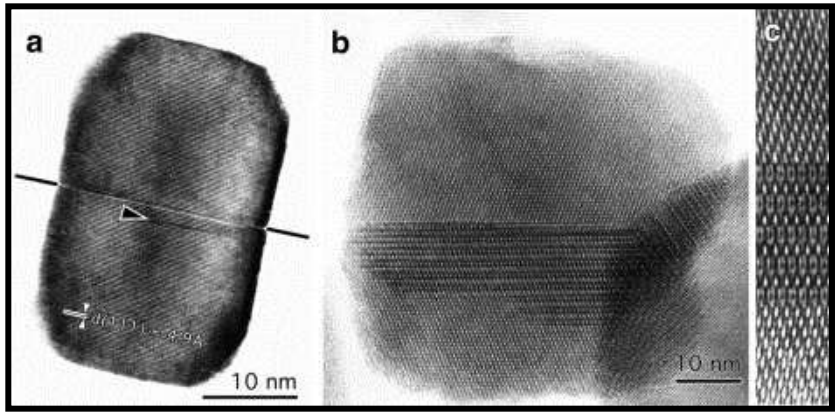
Magnetite: Fe_3O_4



Magnetosomes

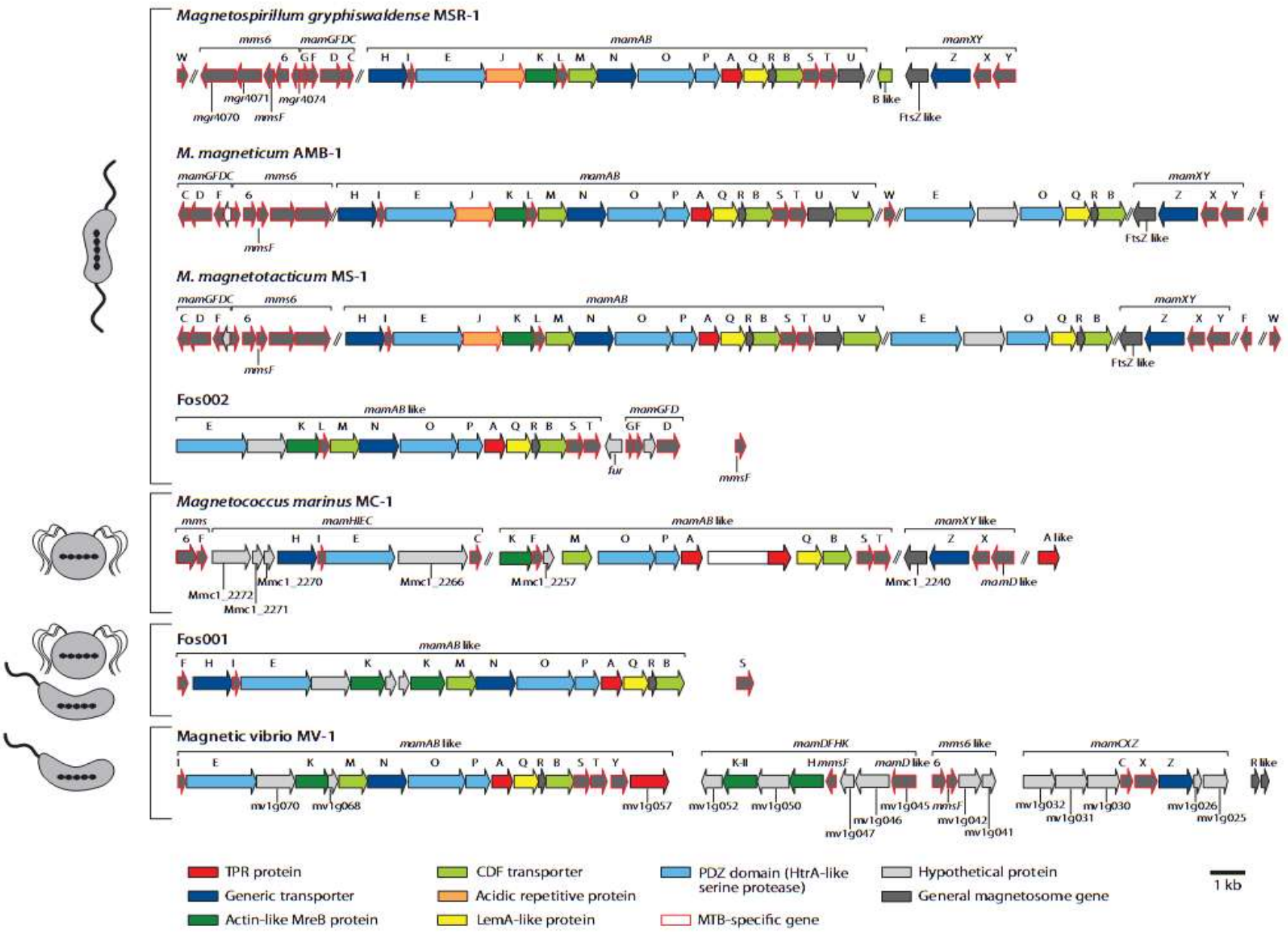
- Few crystalline defects are observed in magnetosomes



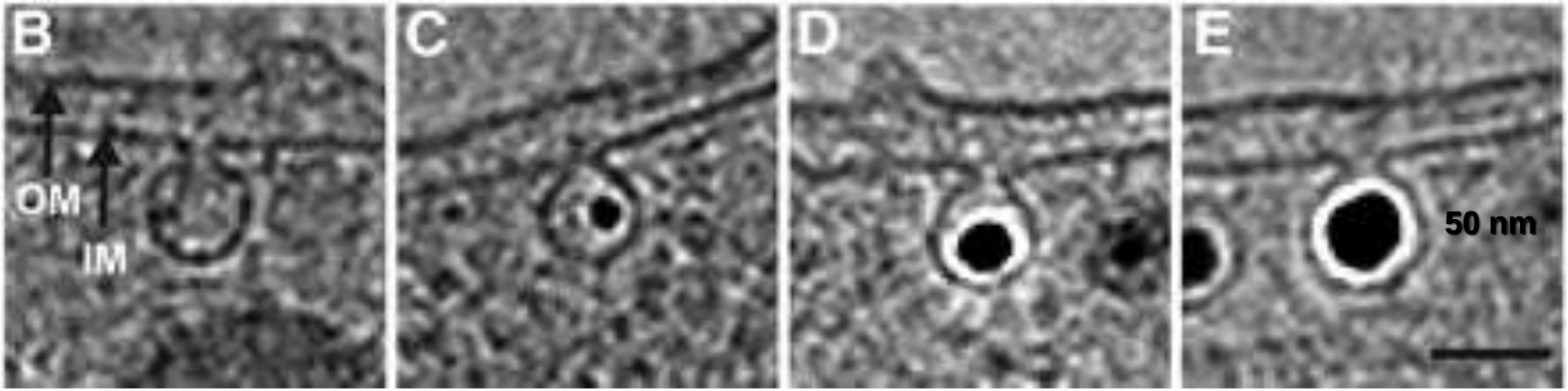


Crystal defects

Magnetosome genomic island



A membrana do magnetosomo é uma invaginação da membrana plasmática



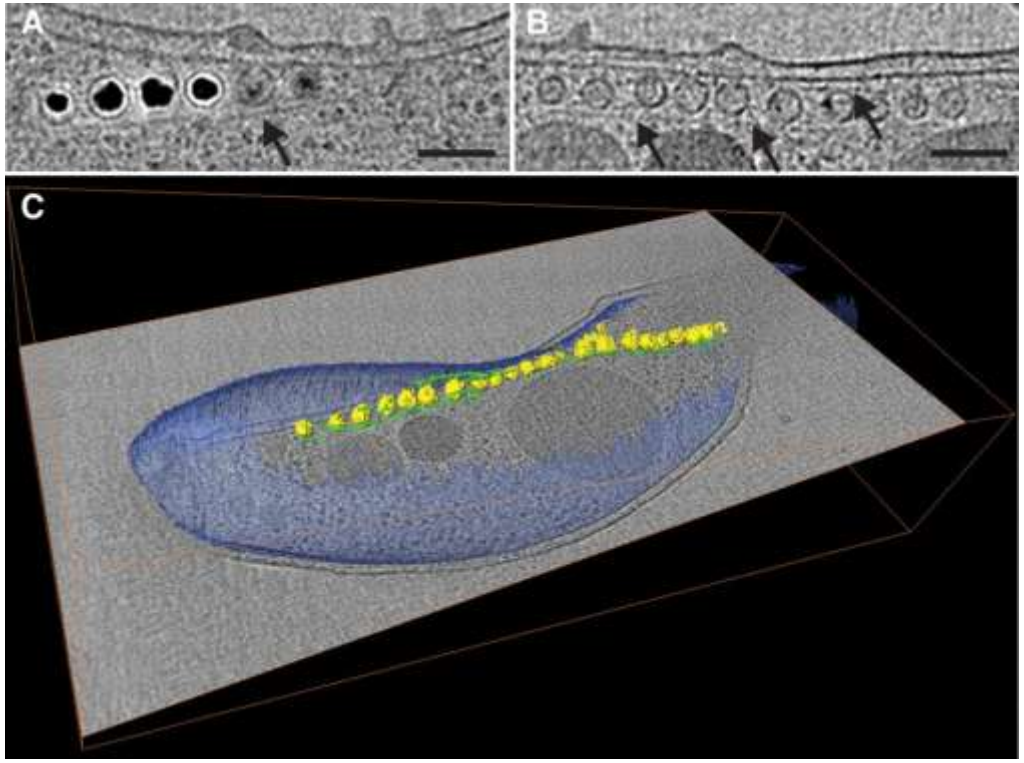
Magnetospirillum magneticum

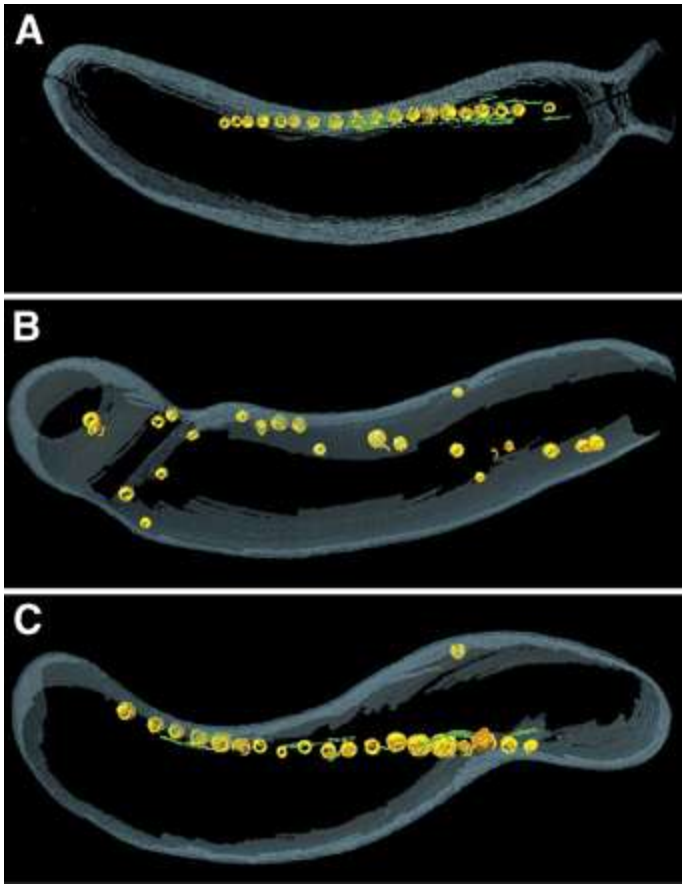
From: Komeili et al., Science 2006

Protein function in the control of the magnetosome chain

MamK – actin-like protein similar to MreB

It is essential for the formation of the chain





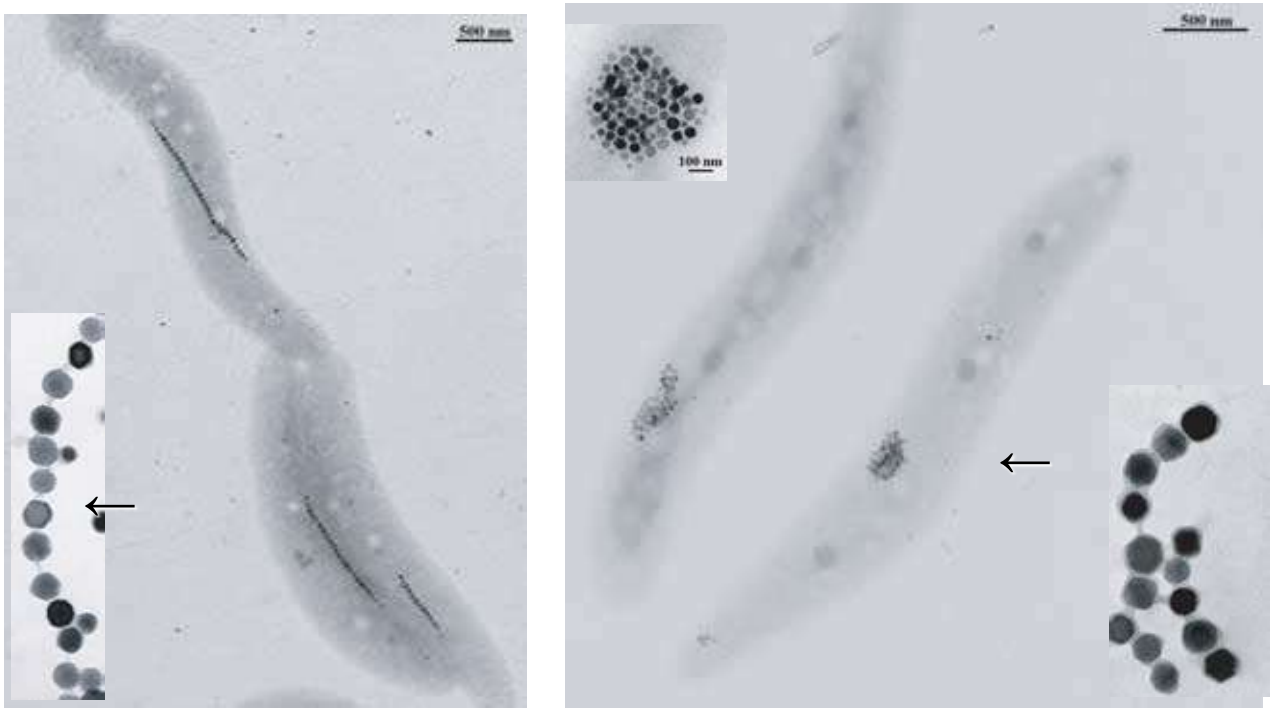
Magnetospirillum magneticum

From: Komeili et al., Science 2006

Protein function in the control of the magnetosome chain

MamJ – acidic protein associated with the filamentous structure (MamK)

From:
Scheffel et al., Nature 2006

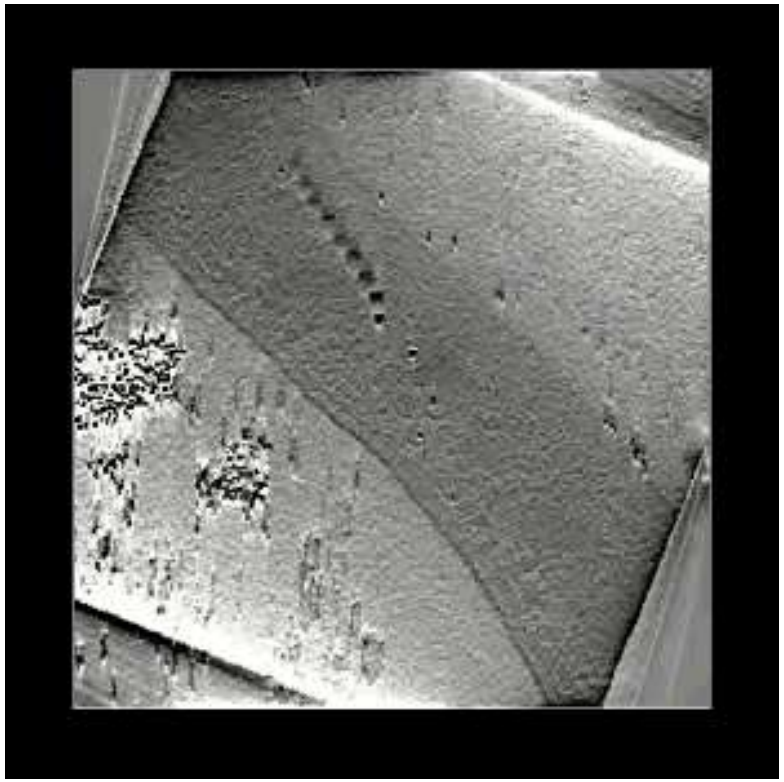


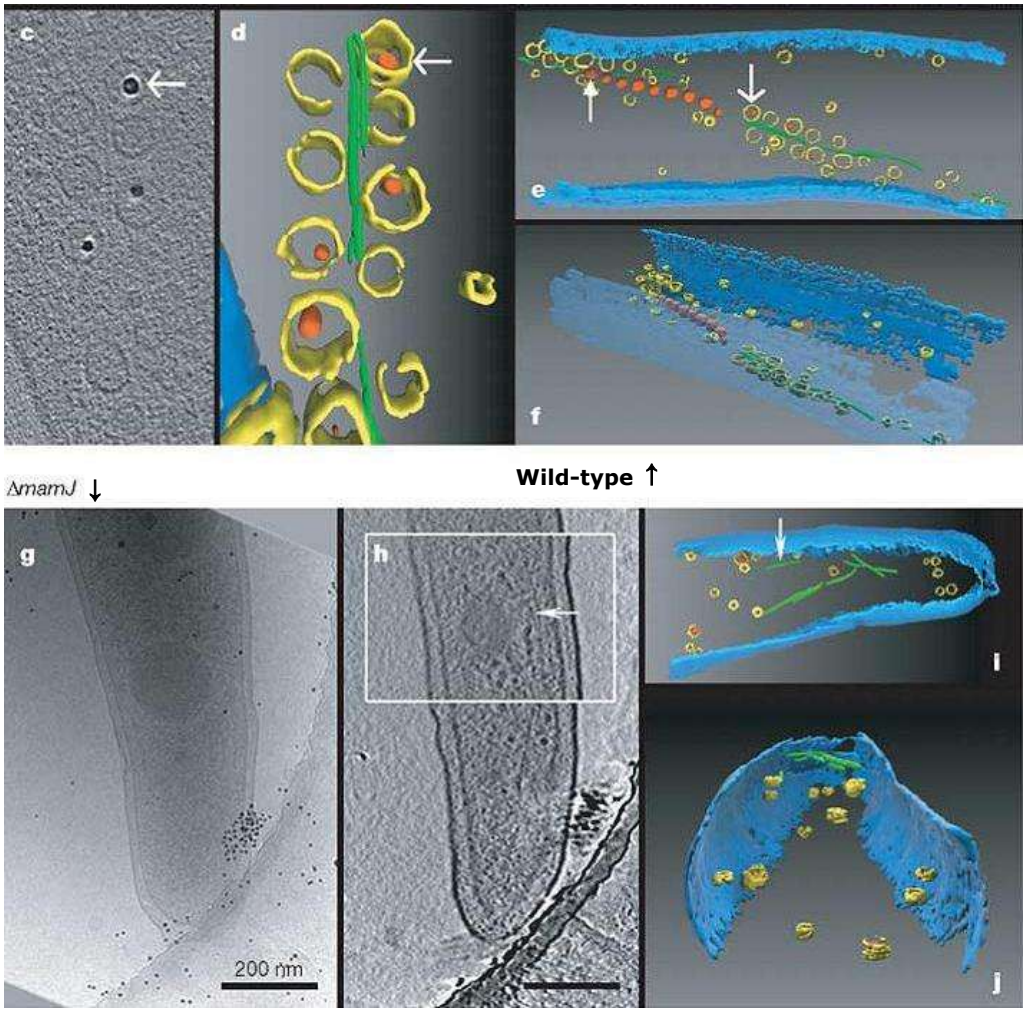
Wild-type **Δ*mamJ* Mutant**

Magnetospirillum gryphiswaldense

MamJ

From: Scheffel et al., Nature 2006

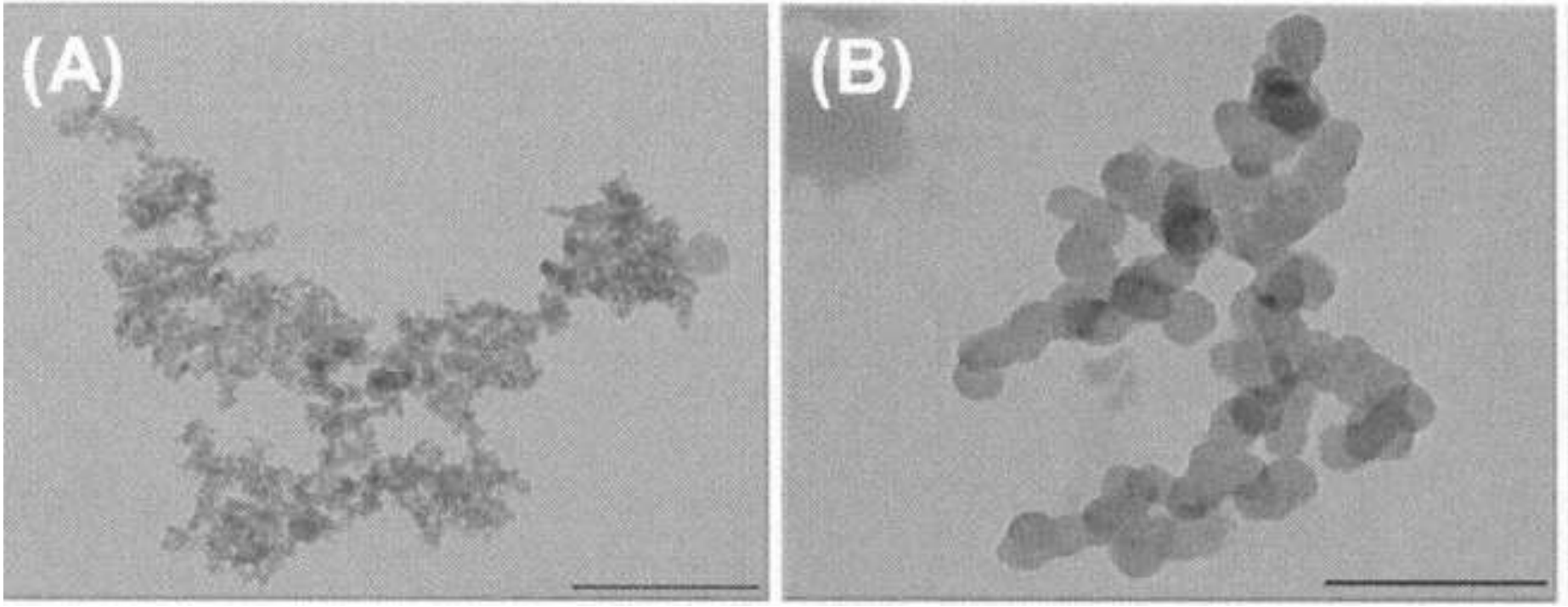




Blue: Cell Membrane
Red: Magnetite Crystal
Yellow: Magnetosome Membrane
Green: "Filamentous Structure" (MamK)

Magnetospirillum gryphiswaldense

Mms 6 protein role in the morphology of magnetosomes

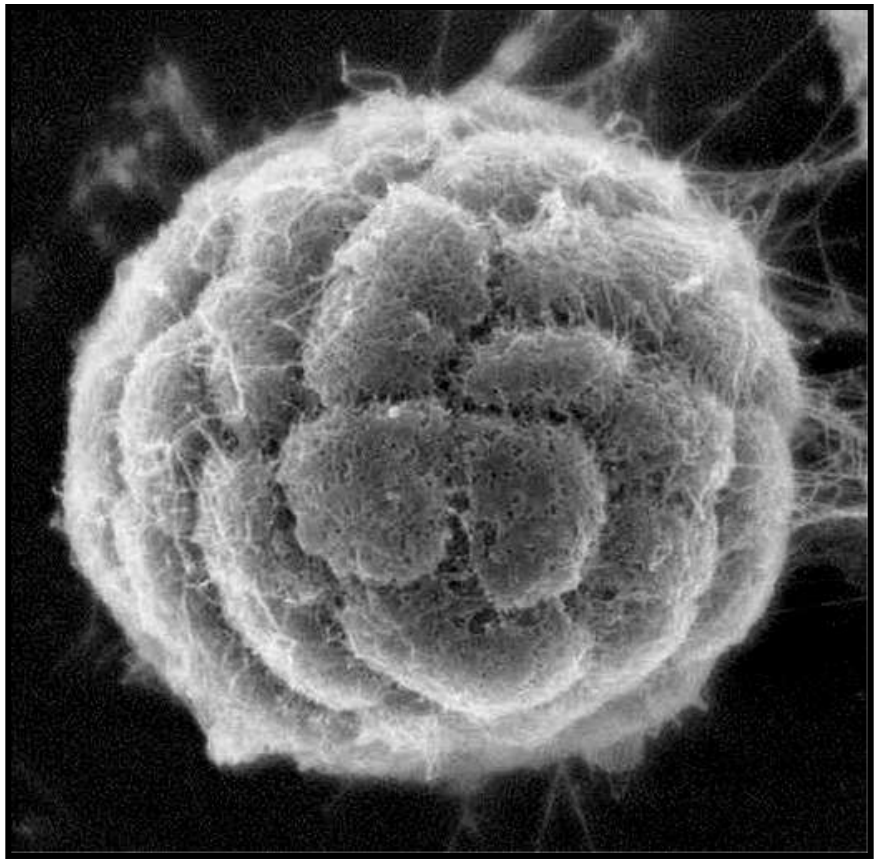


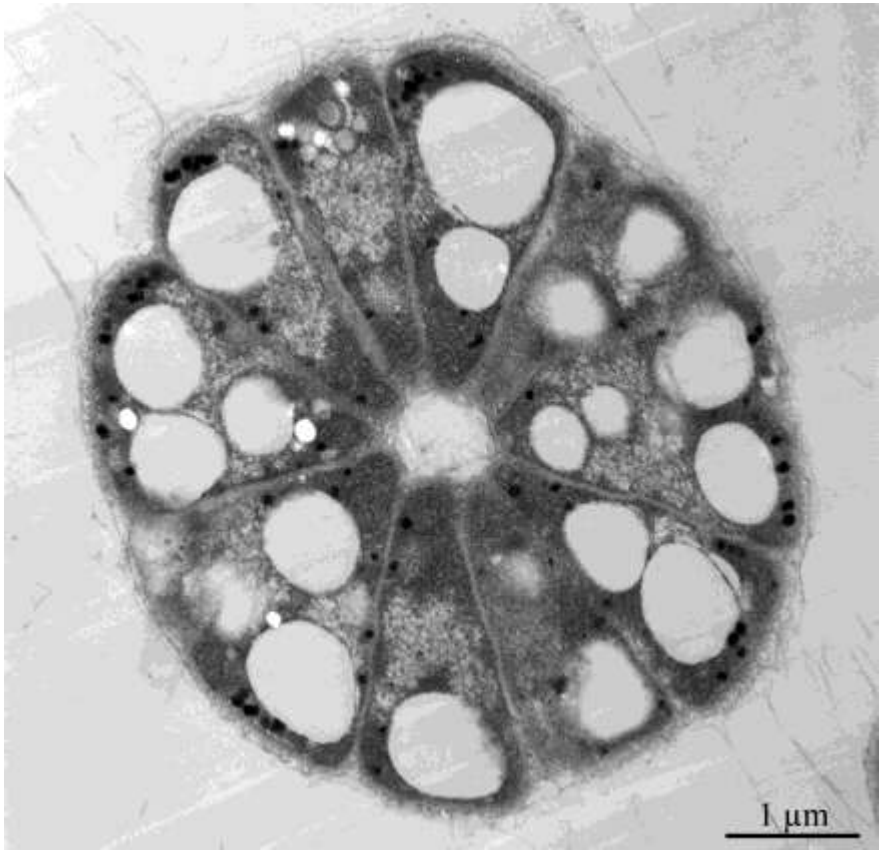
Scale bars = 200 nm

From: Prozorov, Mallapragada, Narasimhan, Wang, Palo, Nilsen-Hamilton, Williams, Bazylinski, Prozorov, & Canfield, Adv. Funct. Mater. 2007

- ***Optimization and cultivation of magnetotactic bacteria***
- ***Diversity and evolution of magnetotaxis***
- ***Applications of magnetosomes***

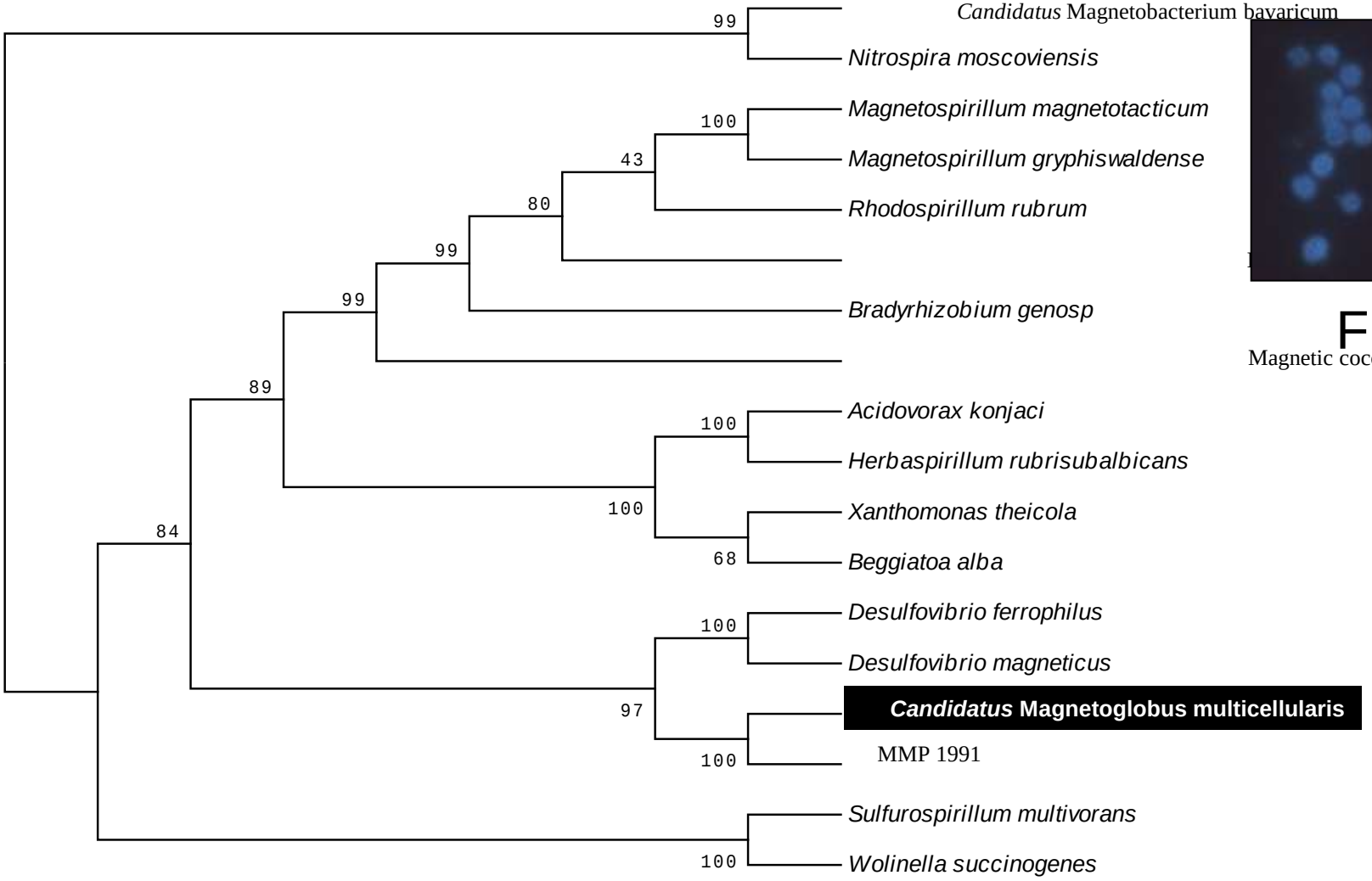
Candidatus Magnetoglobus multicellularis

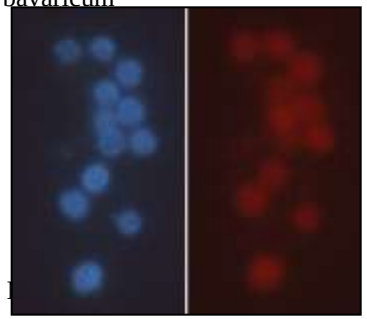




Keim *et al.*, 2004

16S rRNA gene sequencing for *Candidatus* Magnetoglobus multicellularis





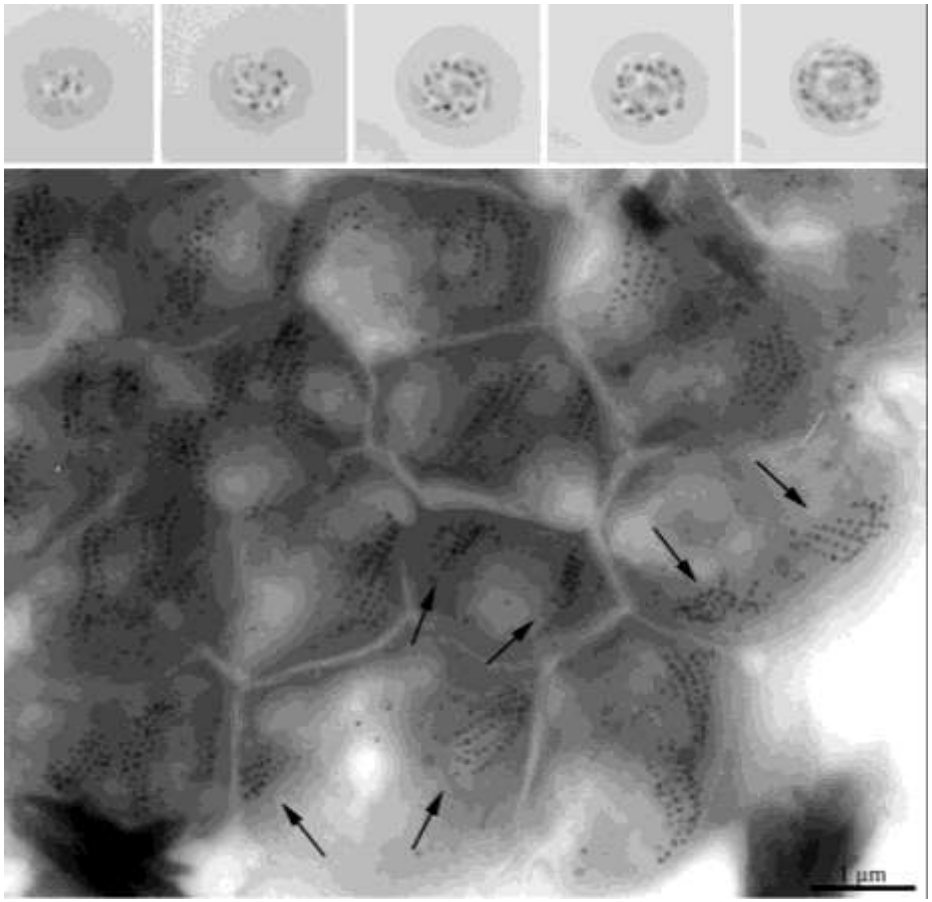
FISH

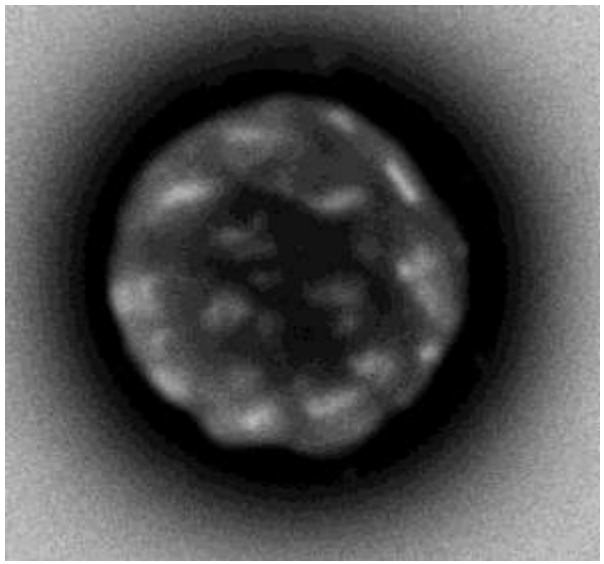
Magnetic coccus

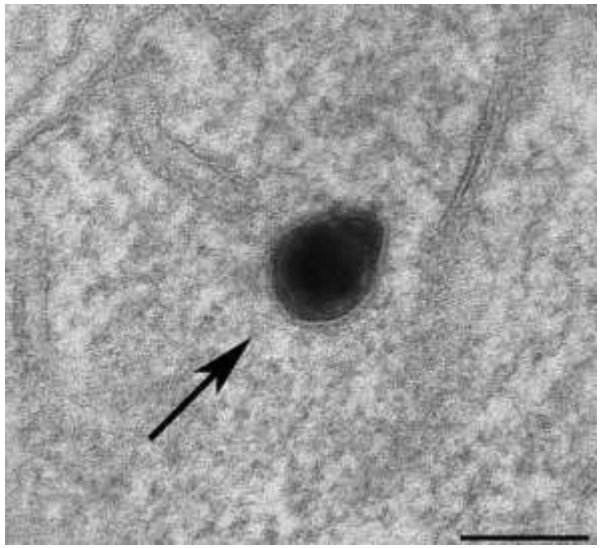
Abreu *et al*., 2007

Candidatus Magnetoglobus multicellularis

- **Each cell contains 60-100 greigite (Fe_3S_4) magnetosome**







Abreu *et al*., 2008

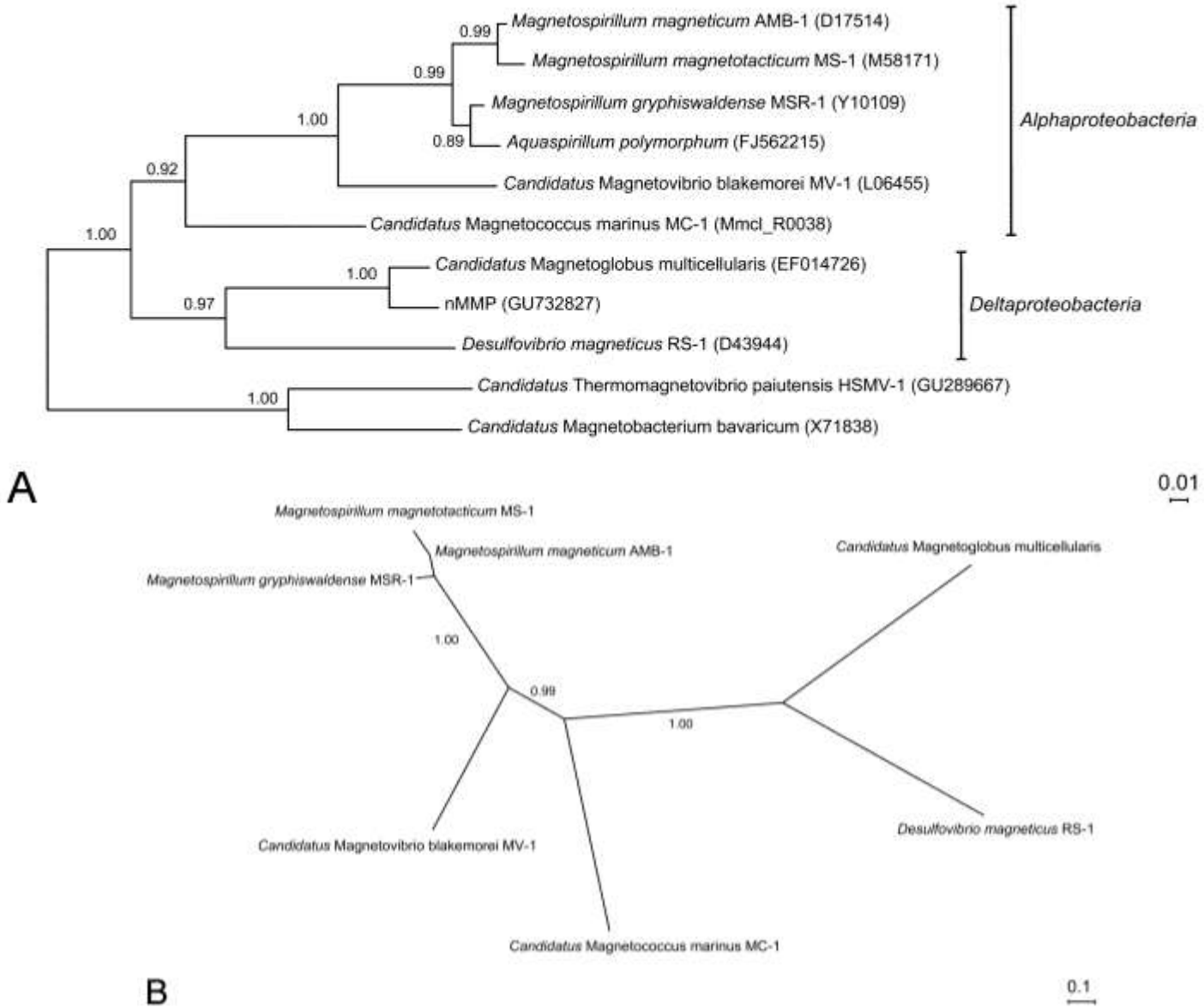
Genome *of Candidatus* Magnetoglobus multicellularis

What to do with all these data?

Genome coverage	23x
Length (bp)	12.459.246
G+C content (%)	37.27
Coding density (%)	77%
Average of ORF length (bp)	914
Number of Contigs	3.706
Total number of ORFs	10.639
Number of known protein ORFs	2.792
Number of partial ORFs	26
Number of truncated ORFs	140
Number of hypothetical ORFs	7520
rRNA	3
rRNA 16s	1
rRNA 23s	1
rRNA 5s	1
tRNA	46
KEGG matches	71%
InterPro matches	77%

- Understand ecology to....
- Develop a culture medium

Genomic "island"



Abreu et al. ISME J (2011)

Genomic "island"

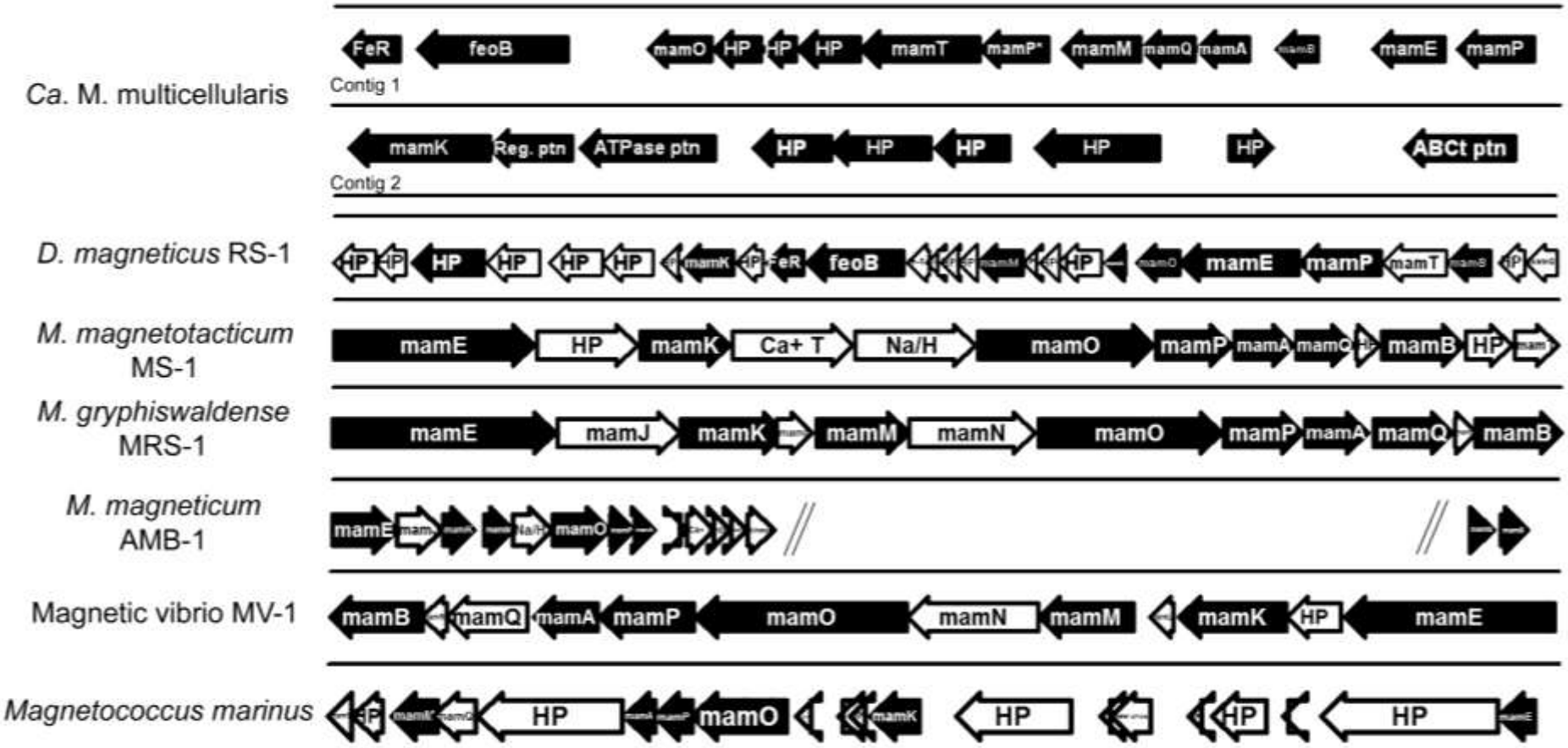
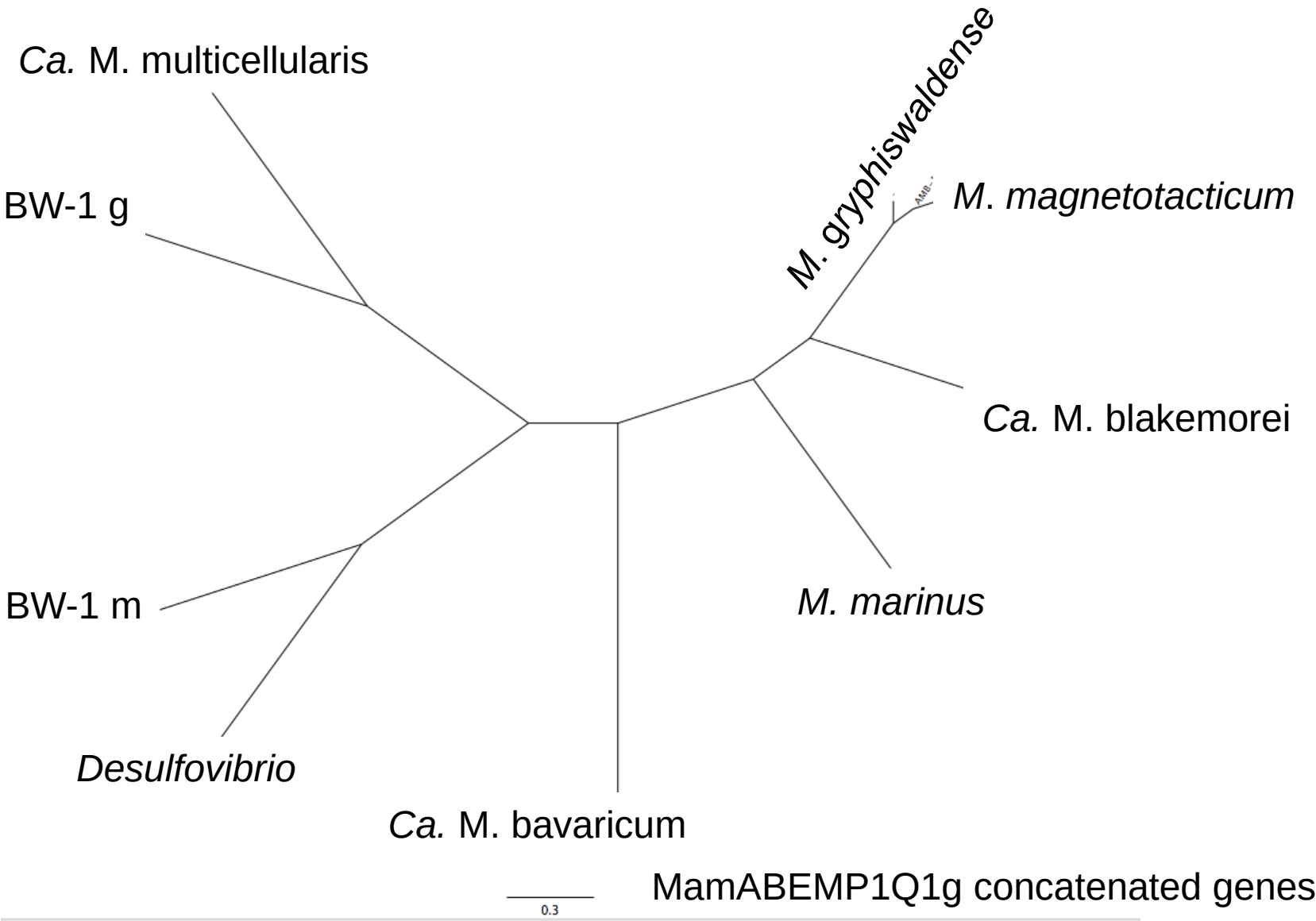
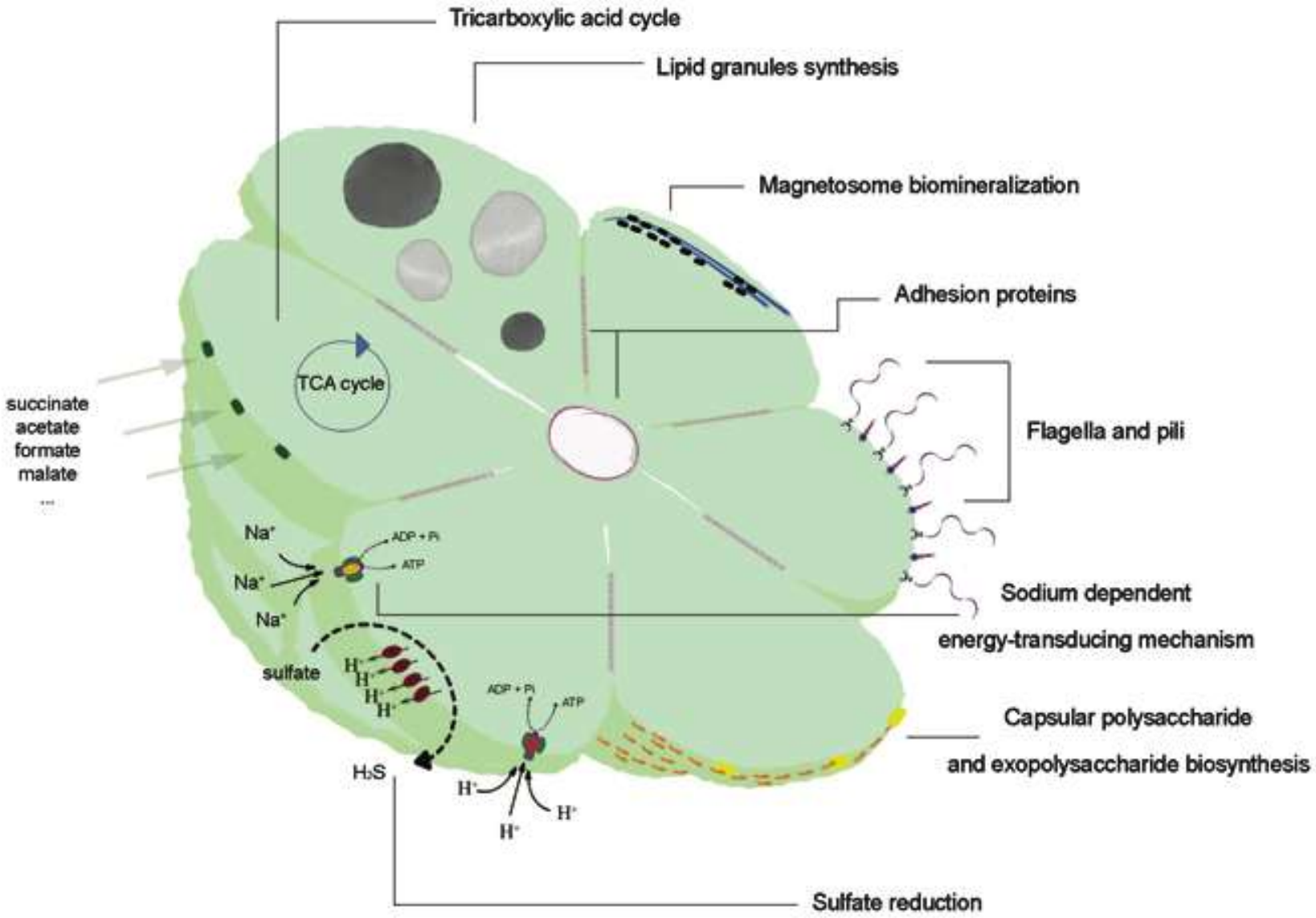


Figure: ORFs organization in two contigs containing putative MAI related genes in *Candidatus* Magnetoglobus multicellularis and MAI homologous regions in cultivated MTB. MTB genes with homologous sequences in *Ca*. M. multicelullaris are represented in black and genes without homology in white.

Magnetosome biomineralization

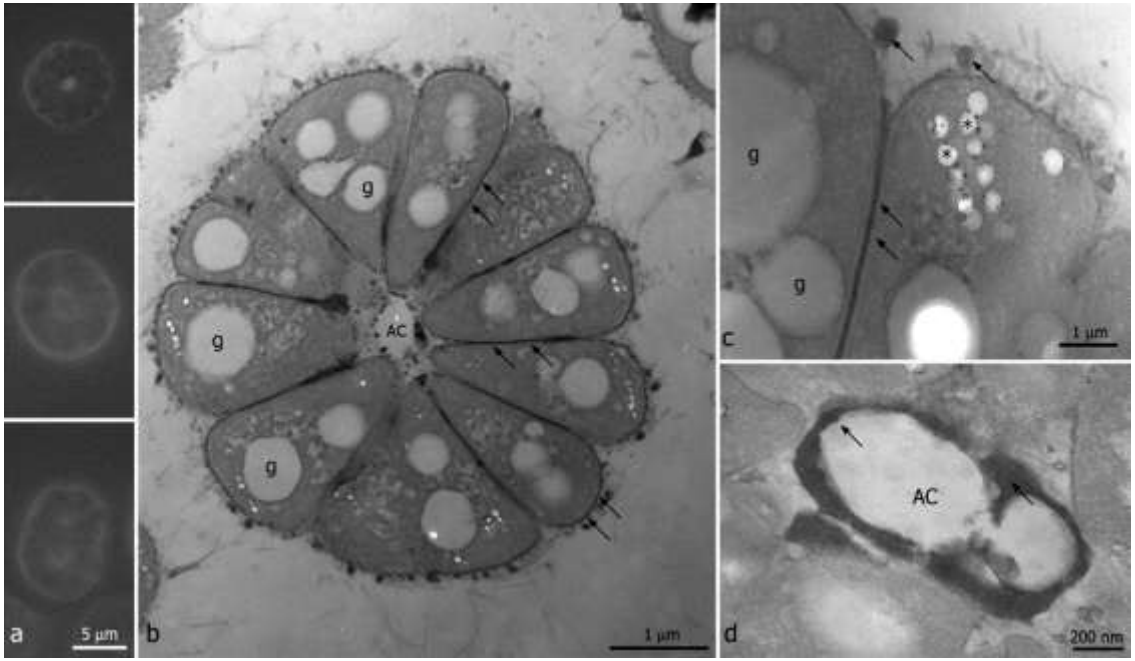


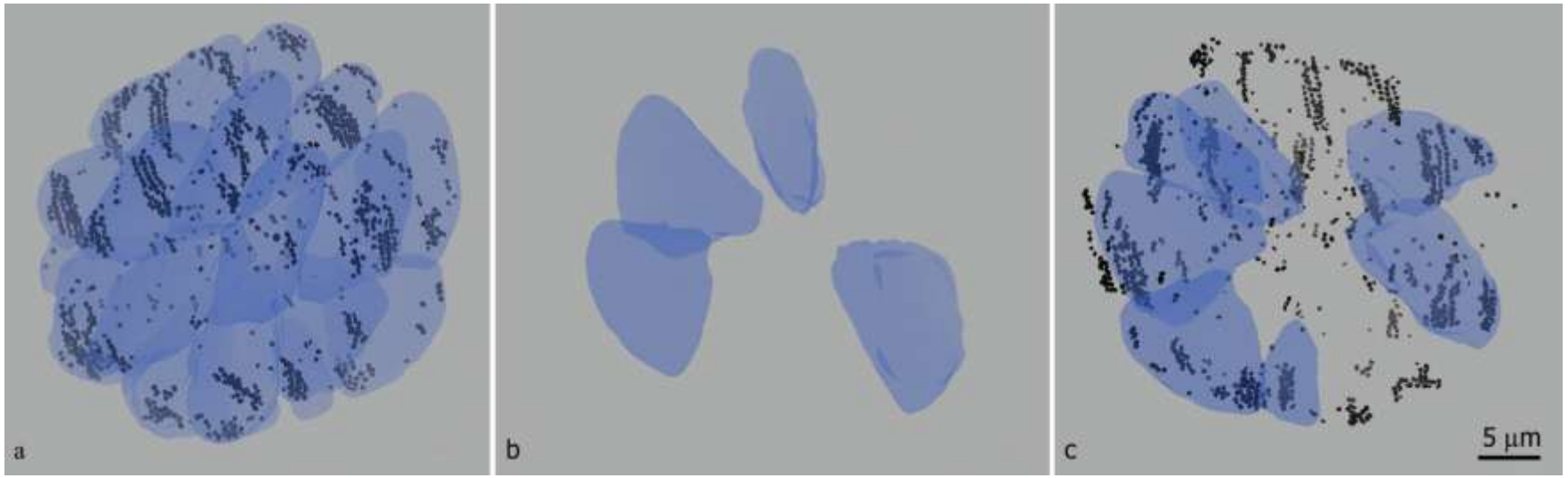
Genome of *Candidatus* Magnetoglobus multicellularis



Abreu et at. ISME J (2014)

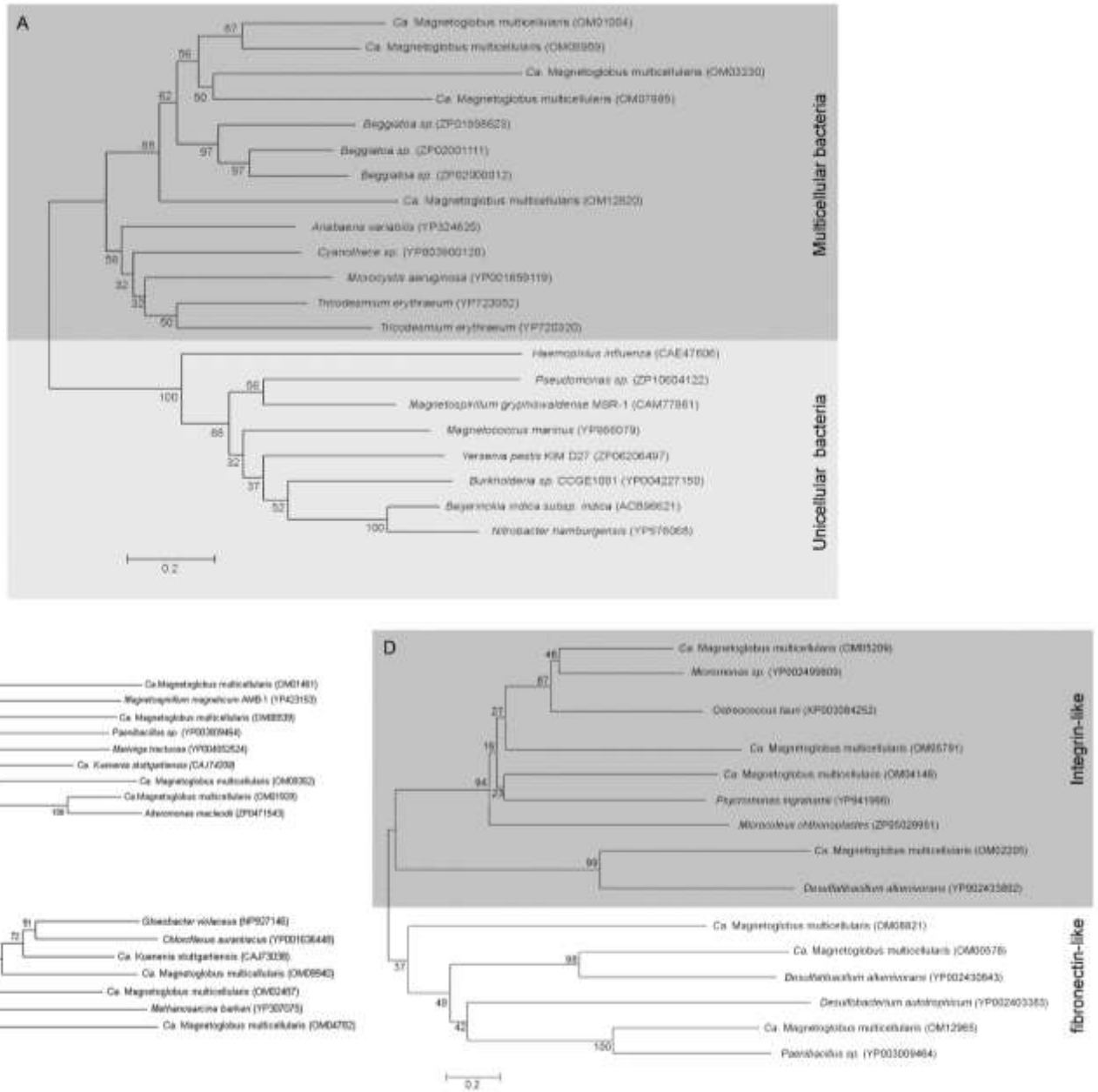
Cell adhesion molecules and magnetosomes distribution





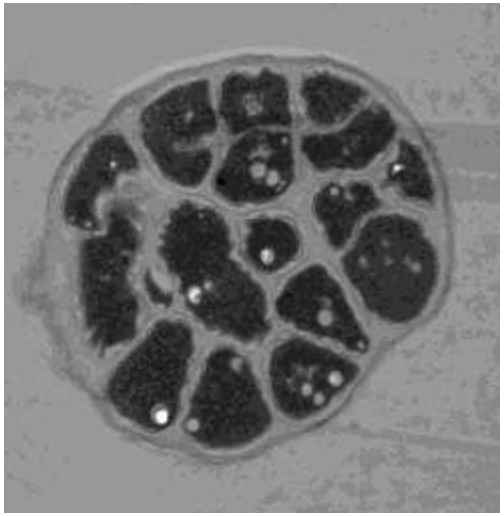
Abreu et al. Microsc. Microanal 2013

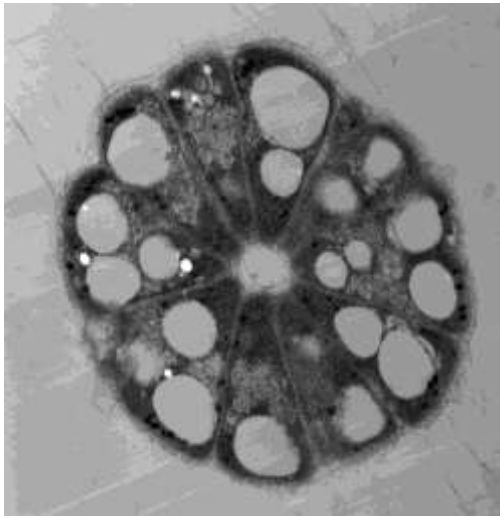
Cell adhesion molecules and phylogeny



Abreu et at. ISME J (2014)

Cultivation



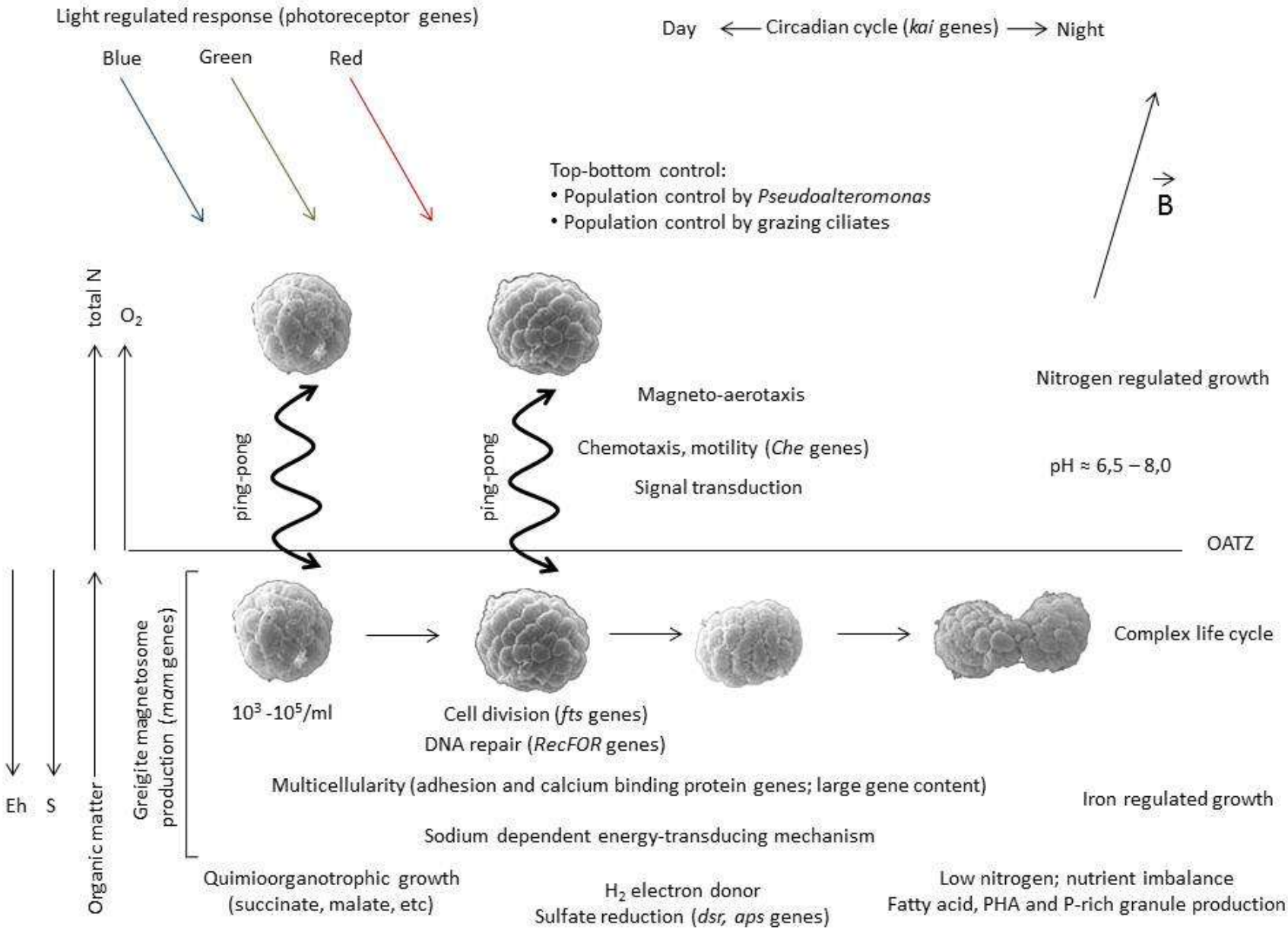


Enrichment cultures

Abreu et at. ISME J (2014)

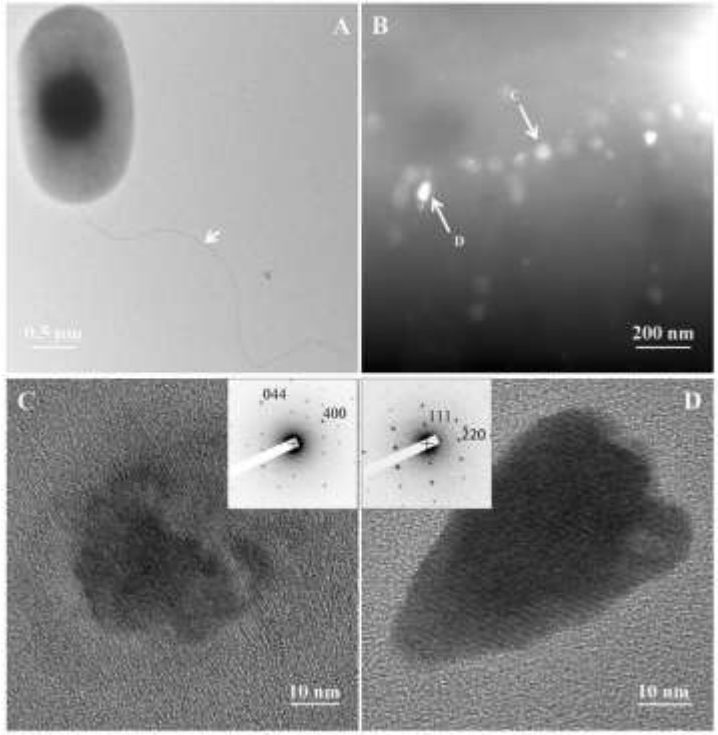
Culture of 'Candidatus Magnetoglobus multicellularis'

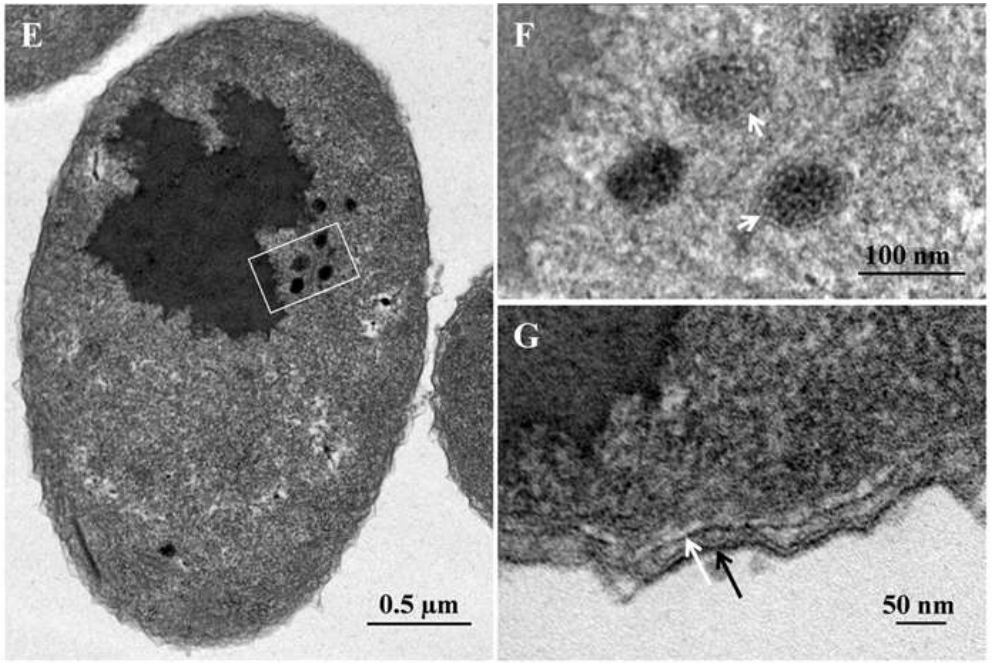
Ecological role

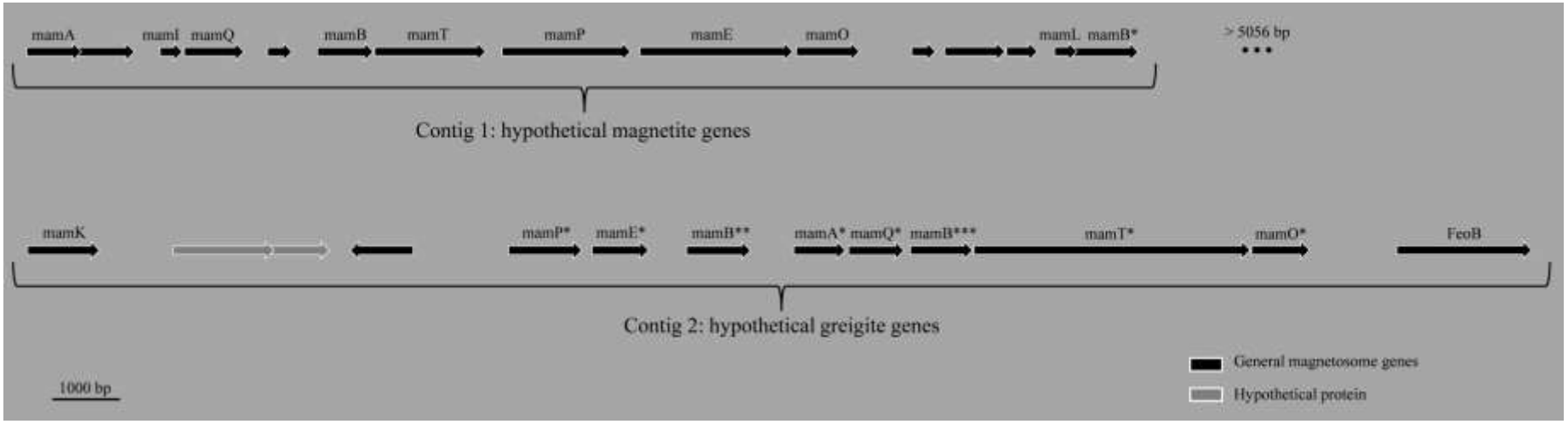


Abreu et at. ISME J (2014)

Genes for magnetosomes in strain BW-1



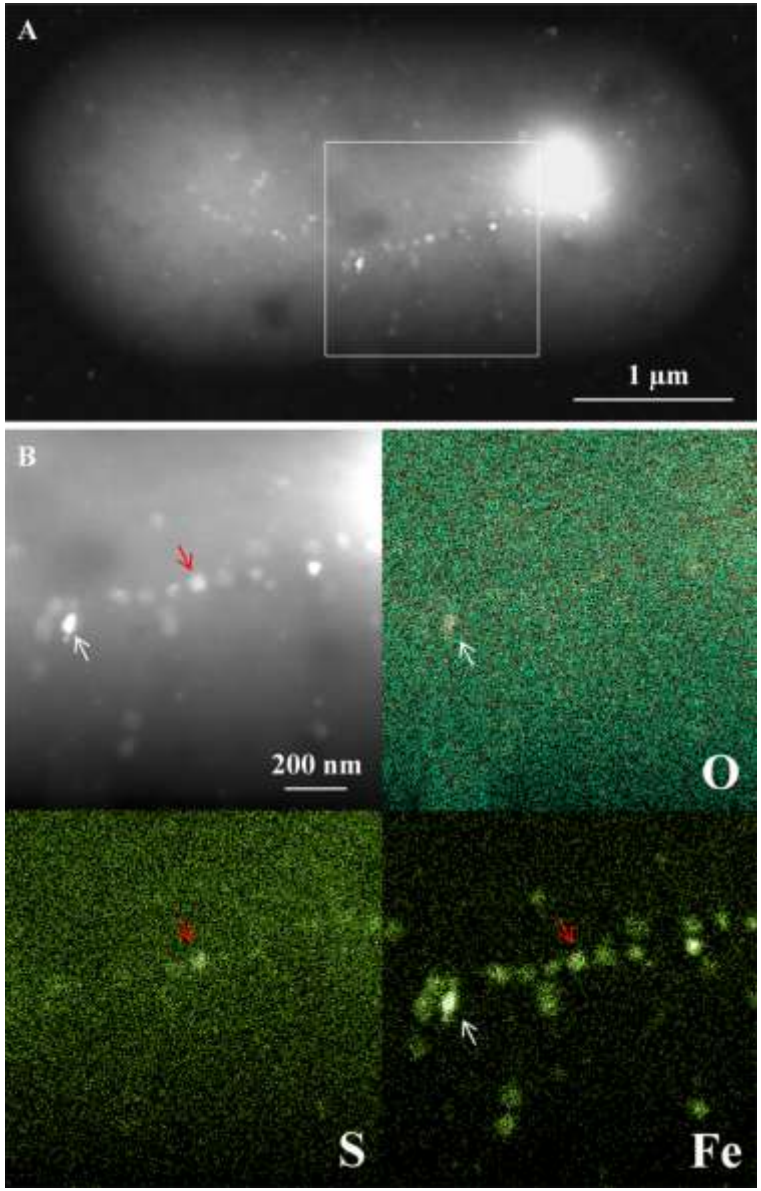


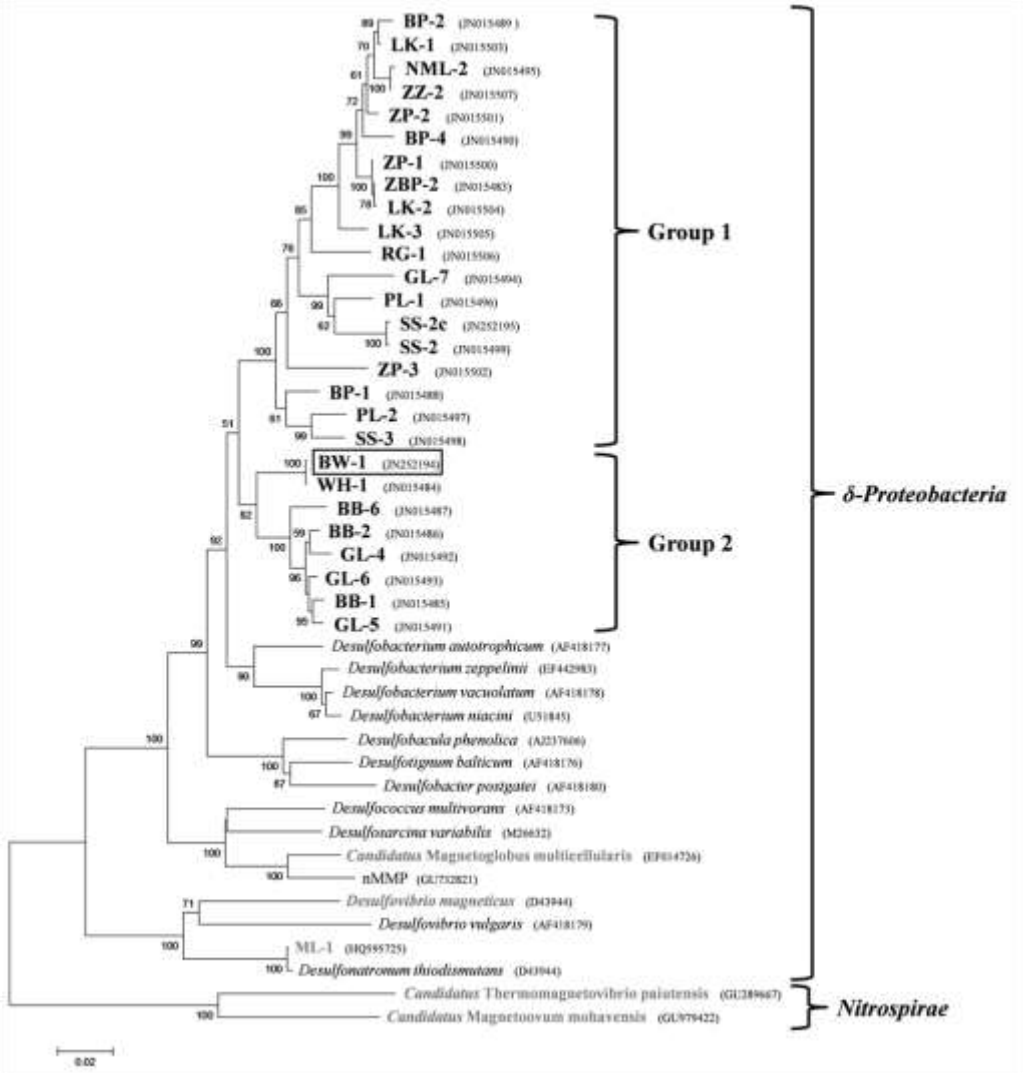


Lefevre et al., Science 2011

Desulfamplus magnetomortis strain BW-1

Produce greigite and magnetite

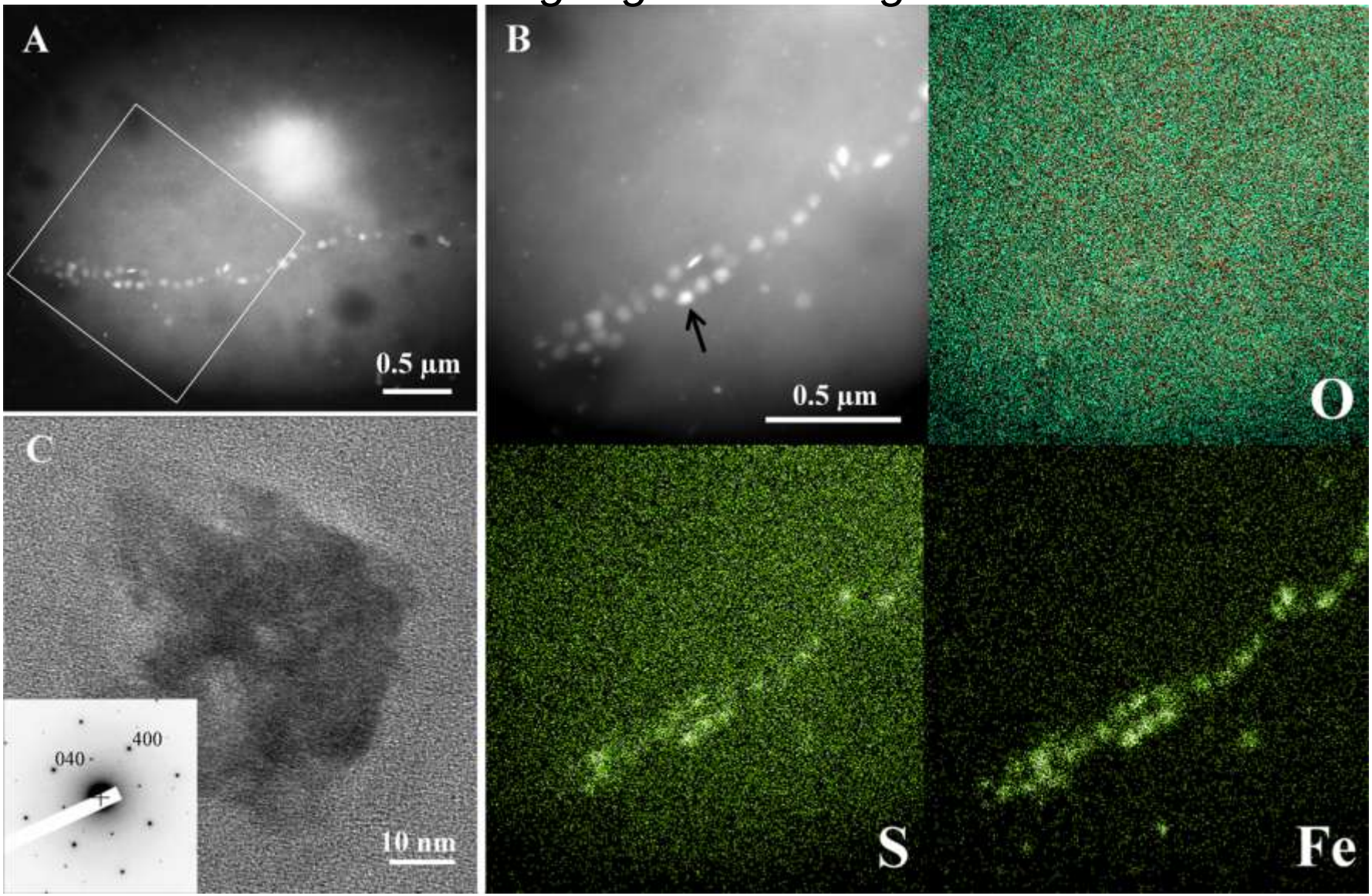




Lefevre et al., Science 2011

Desulfamplus magnetomortis cepa BW-1

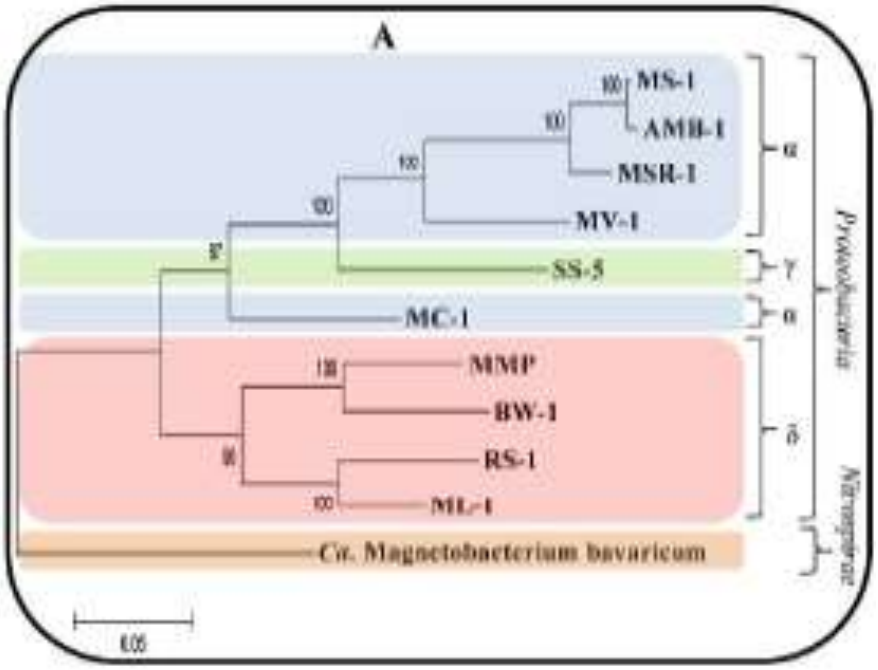
Produce greigite and magnetite

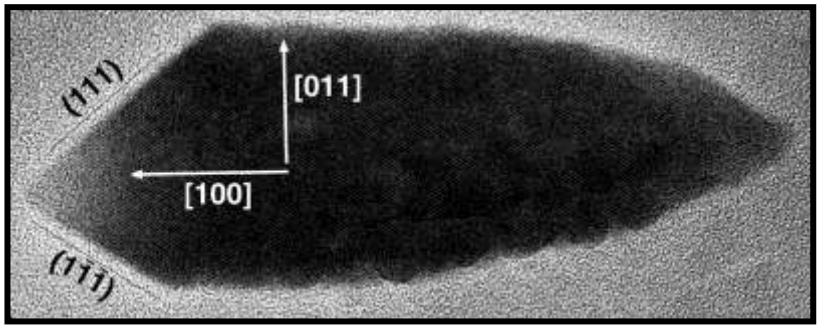


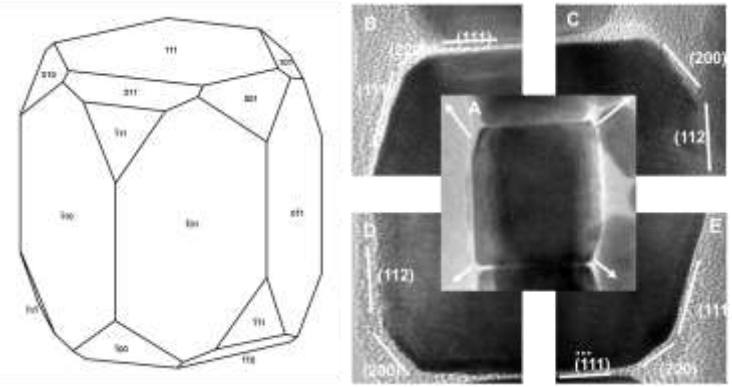
Lefevre et al., Science 2011

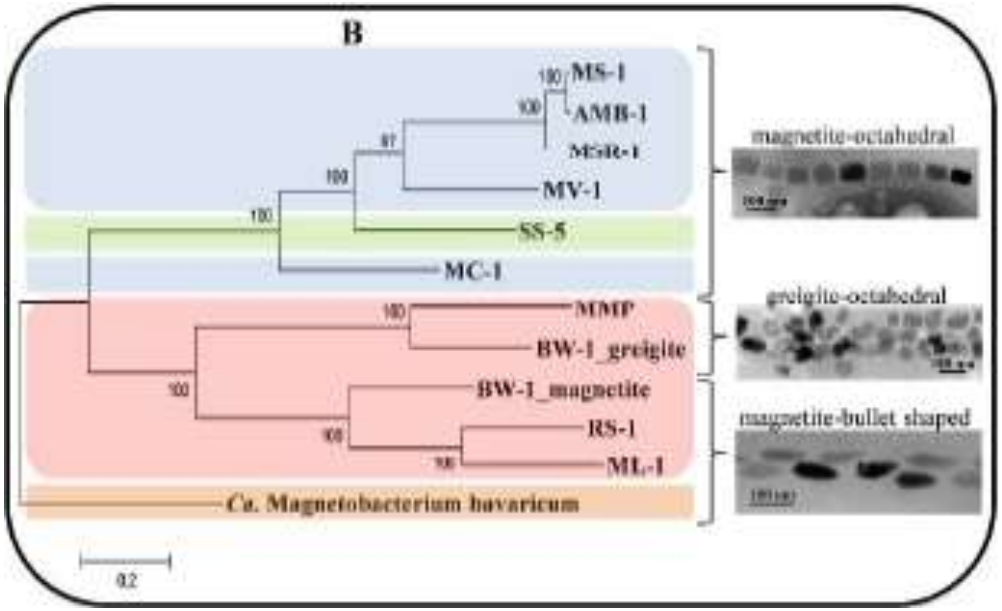
- ***Optimization and cultivation of magnetotactic bacteria***
- ***Diversity and evolution of magnetotaxis***
- ***Applications of magnetosomes***

Monophyletic origin of magnetotaxis







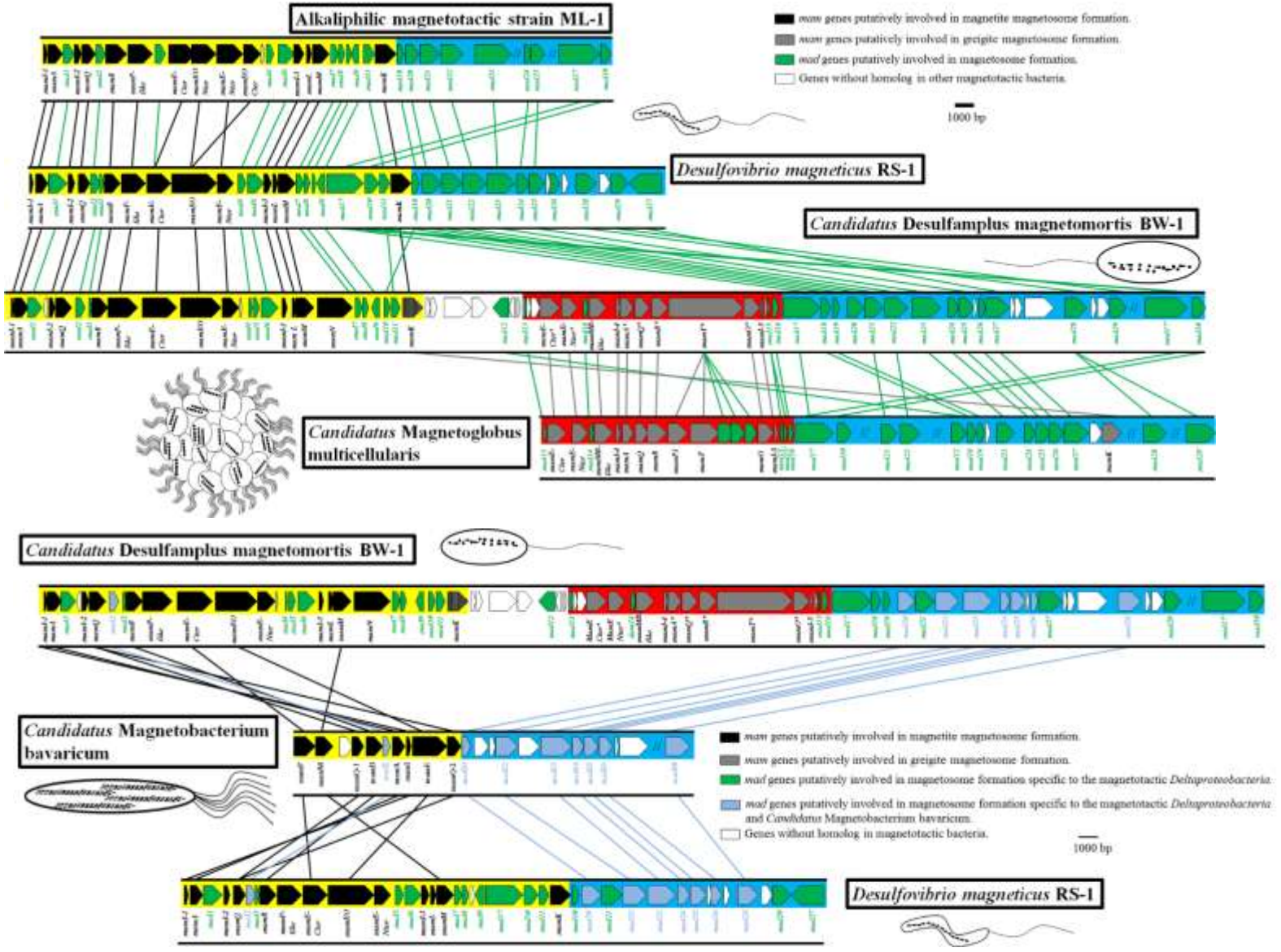


Phylogenetic trees based on 16S rRNA gene sequences reflecting the evolution of MTB (A) and on concatenated magnetosome protein sequences (MamABEIKMPQ and FeoB) reflecting the evolution of magnetotaxis (B).

Lefevre et al., Environm Microbiol 2013a

Genes for greigite magnetosomes in Deltaproteobacteria

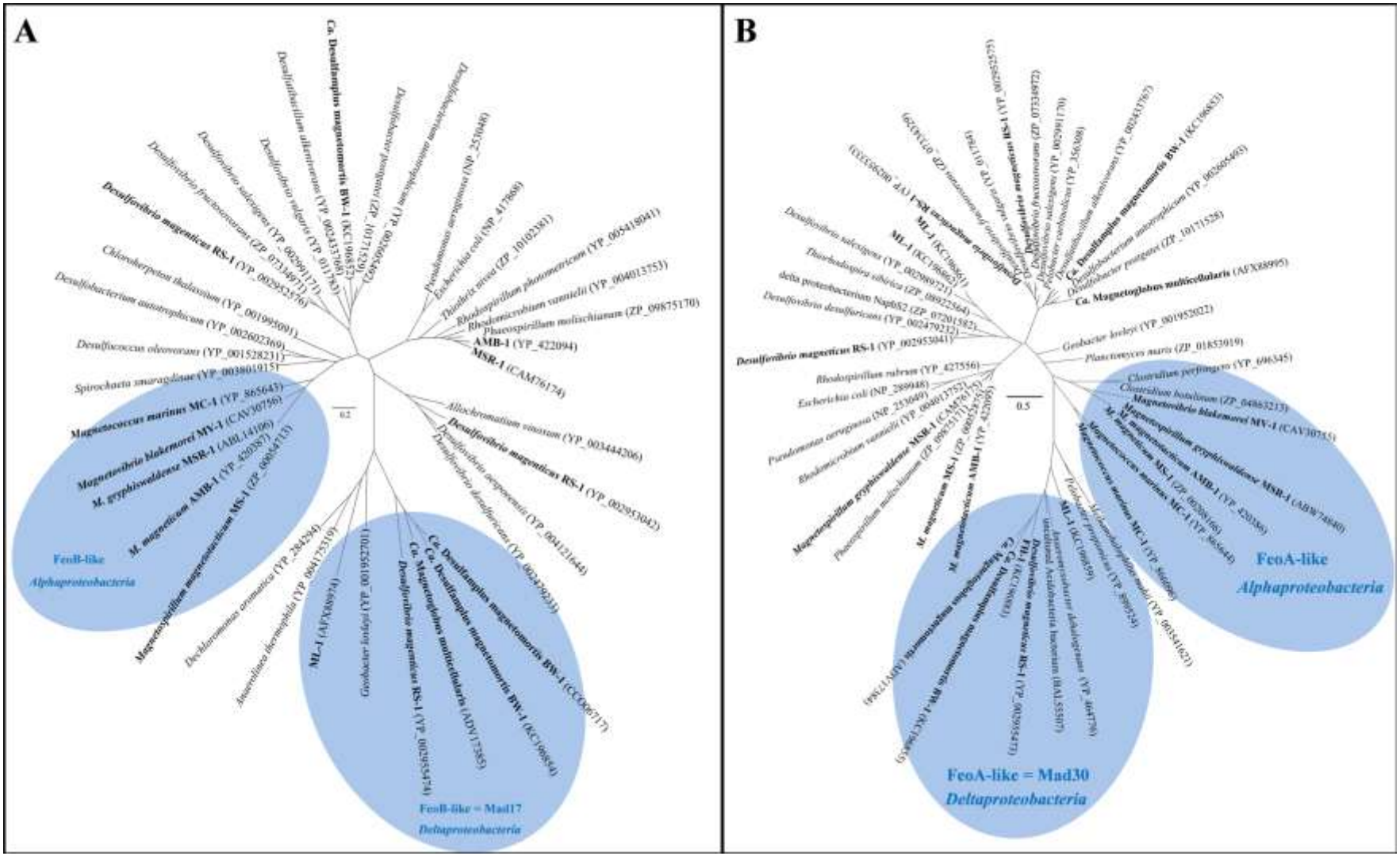
Magnetosome Associated Deltaproteobacteria



Lefevre et al., Environm Microbiol 2013b

Feo transport genes

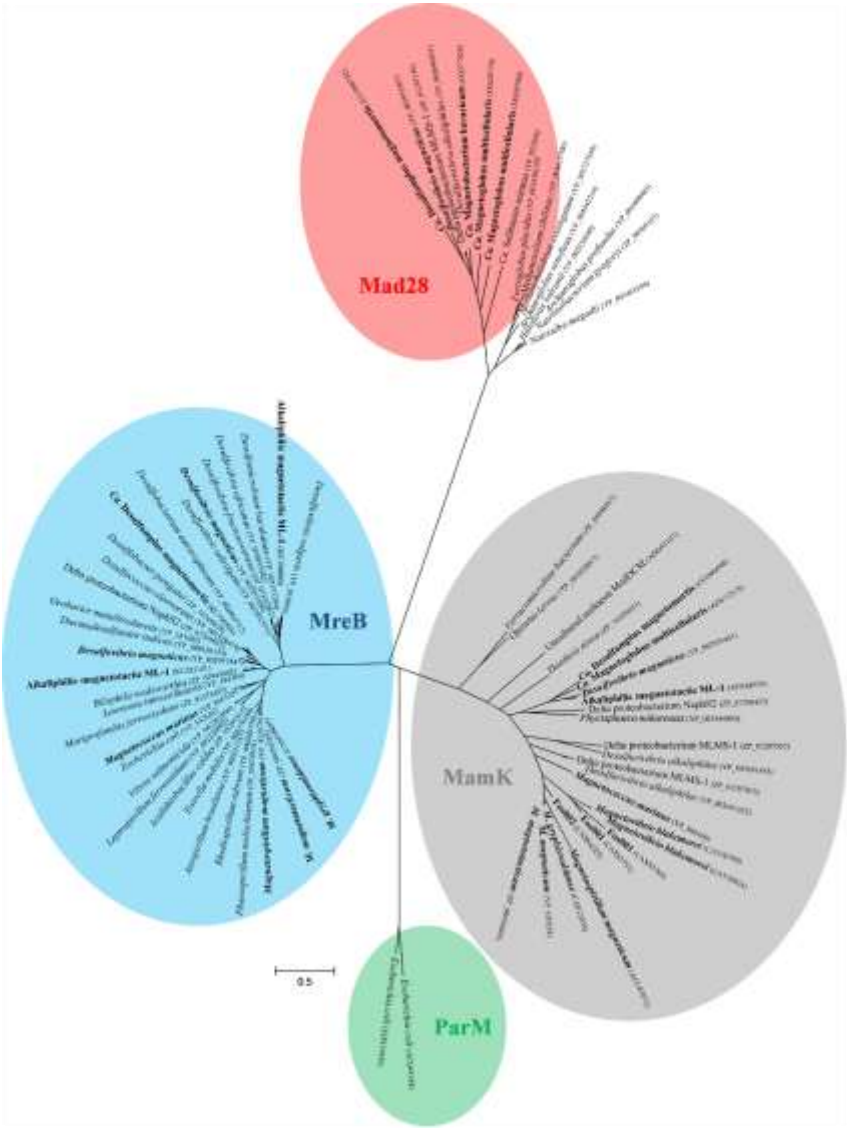
Magnetosome Associated Deltaproteobacteria

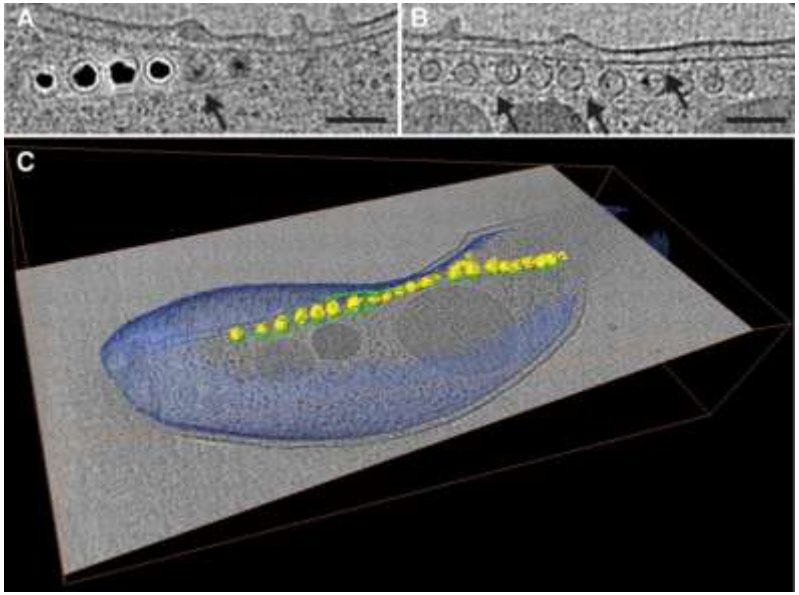


Lefevre et al., Environm Microbiol 2013b

Cytoskeleton

Magnetosome Associated Deltaproteobacteria





Magnetospirillum

Lefevre et al., Environm Microbiol 2013b

- ***Optimization and cultivation of magnetotactic bacteria***
- ***Diversity and evolution of magnetotaxis***
- ***Applications of magnetosomes***

Features that make magnetosomes interesting in biotechnological applications

Advantages:

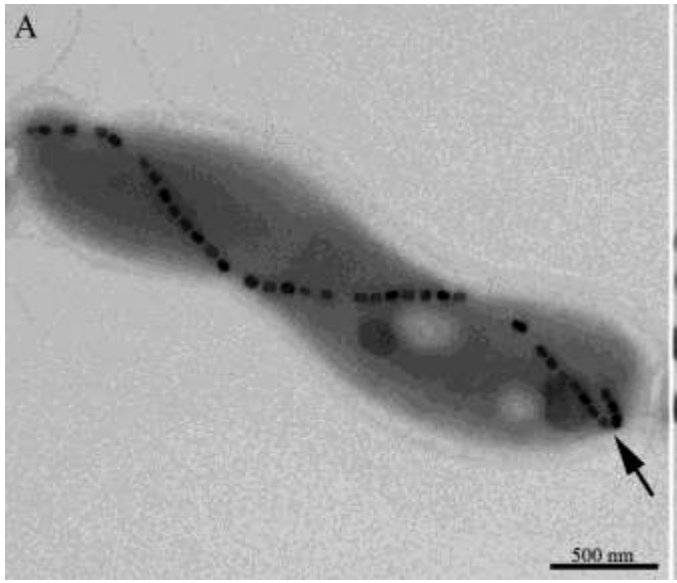
- **Controlled size:** magnetosomes are nanoparticles with highly controlled size range (less than 10% variation depending on growth conditions)
- **Controlled morphology:** bacteria control and modify the morphology of magnetosomes and each strain produce a specific type of crystal.
- **Chemical purity:** magnetosomes are chemically pure; rarely they contain metal contaminants.

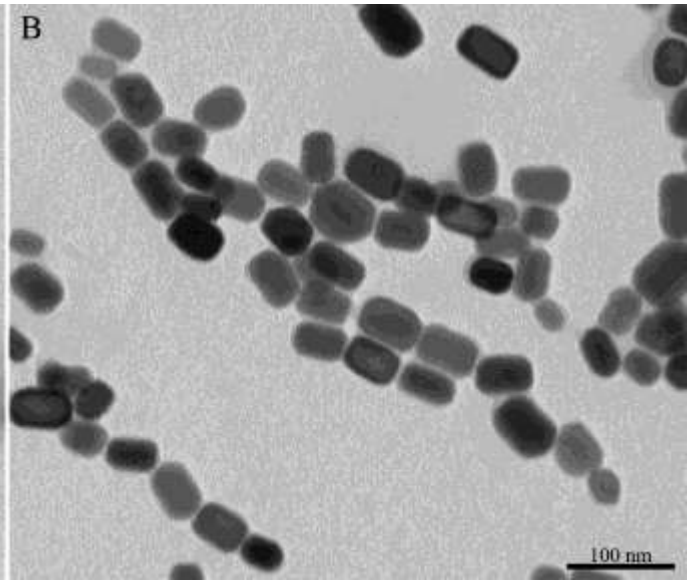
Disadvantages:

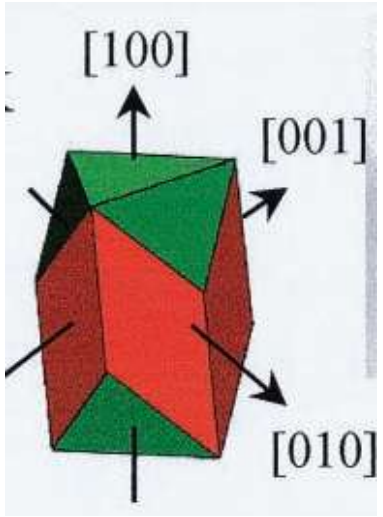
- **Cultivation:** magnetotactic bacteria are fastidious and difficult to isolate.
- **Cost:** to produce magnetosomes is expensive (bioreactors)

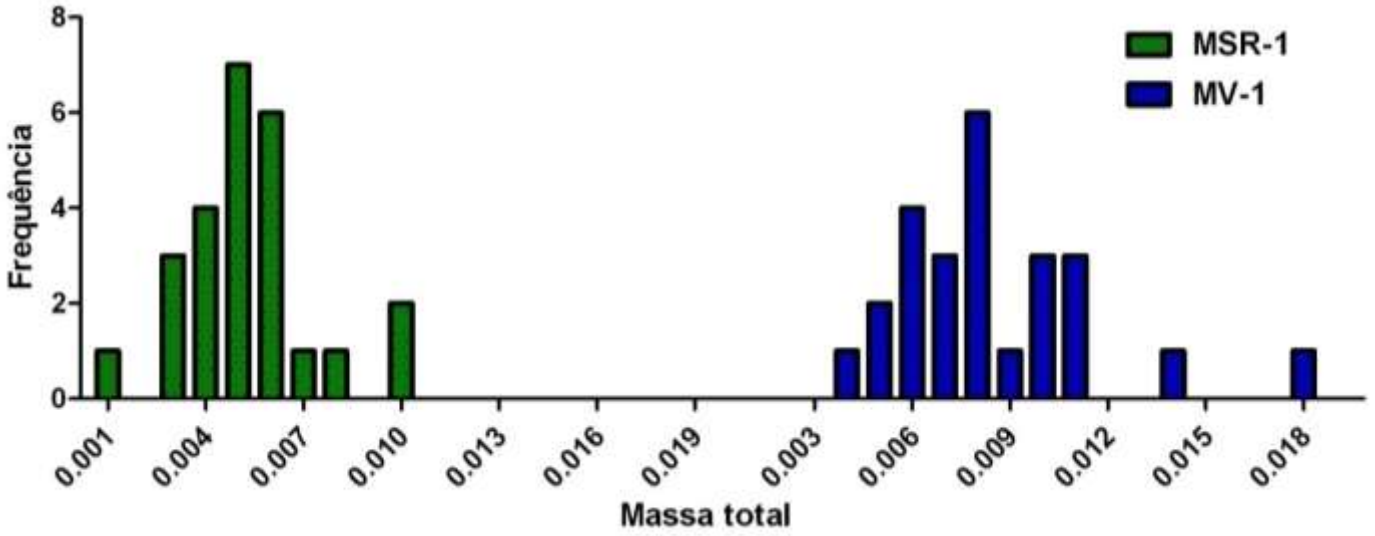
Magnetovibrio blakemorei strain MV-1

Marine vibrio with a polar flagellum and a single chain of elongated magnetite magnetosomes

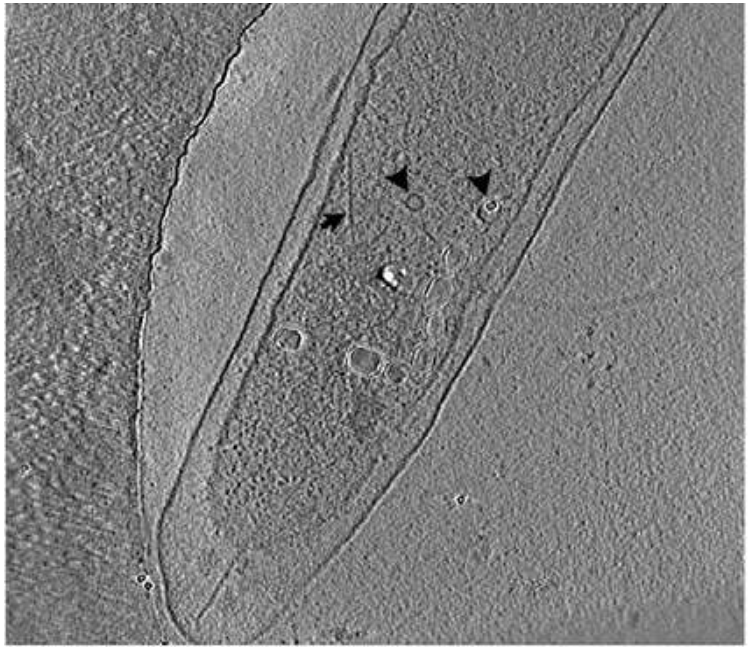


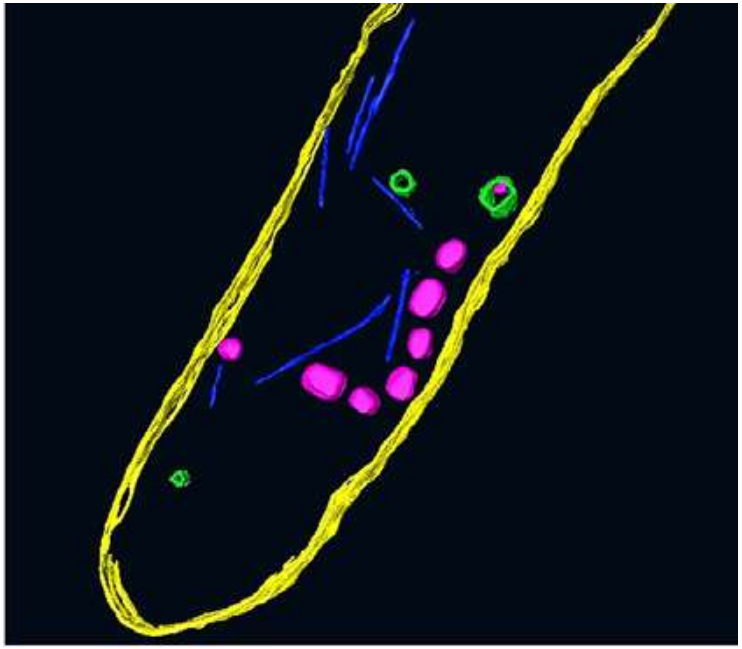


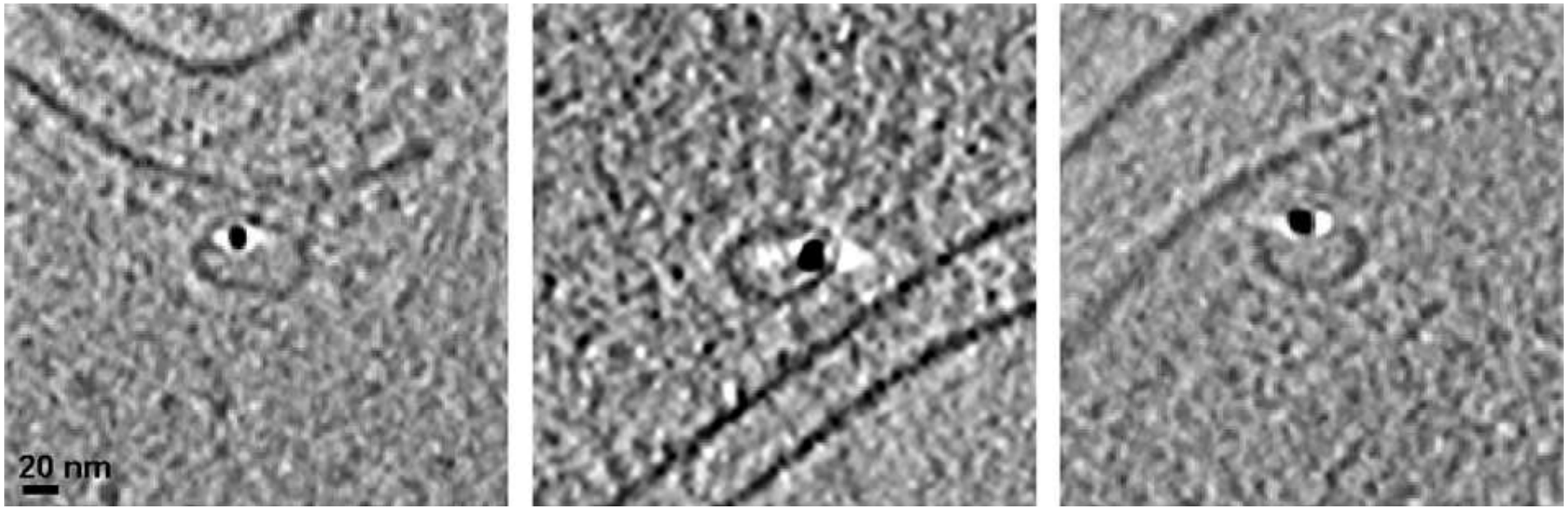




Cryo-electron tomography of *Magnetovibrio blakemorei* MV-1







Abreu et al. (2013) J. Struc. Biol.

Magnetovibrio blakemorei strain MV-1

Optimization of growth

Silva et al. (2013) Appl Environm. Microbiol.

Statistical experimental design (DCCR)

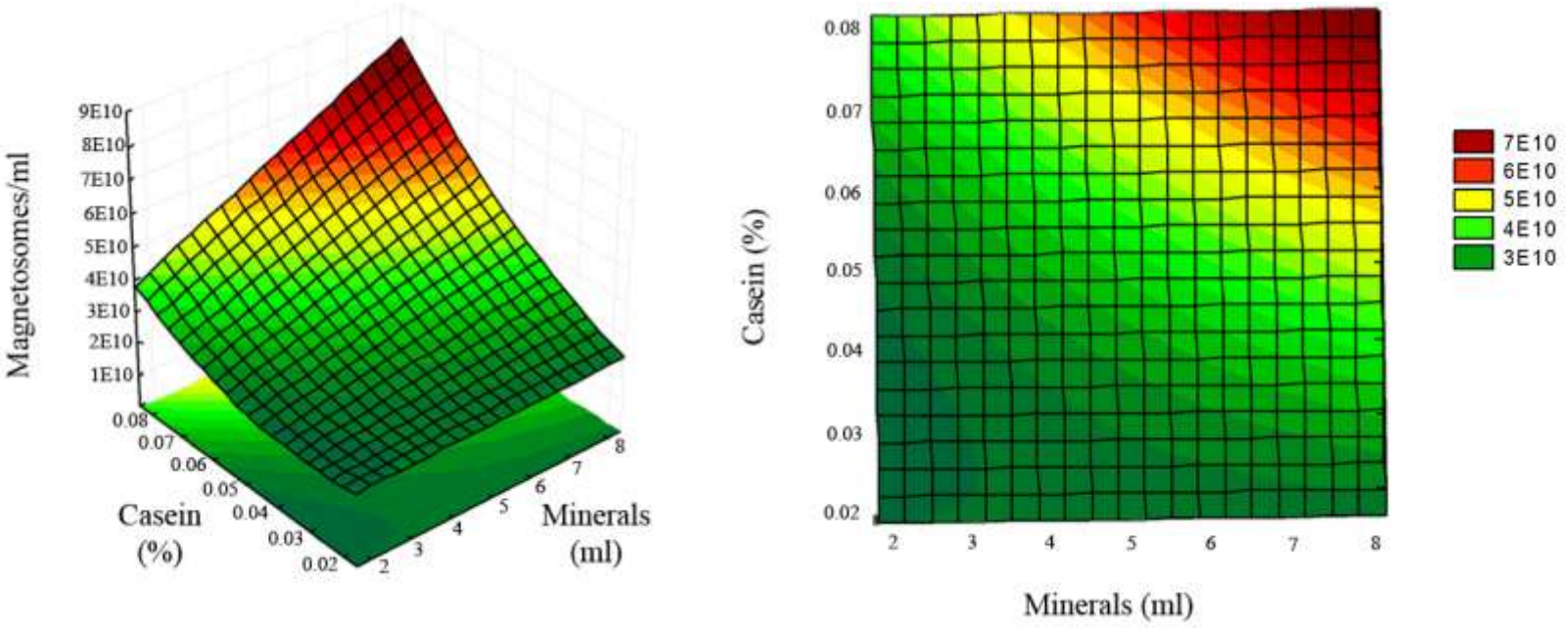


TABLE 1 Maximum magnetite production and productivity of *M. blakemorei* in batch culture in flasks

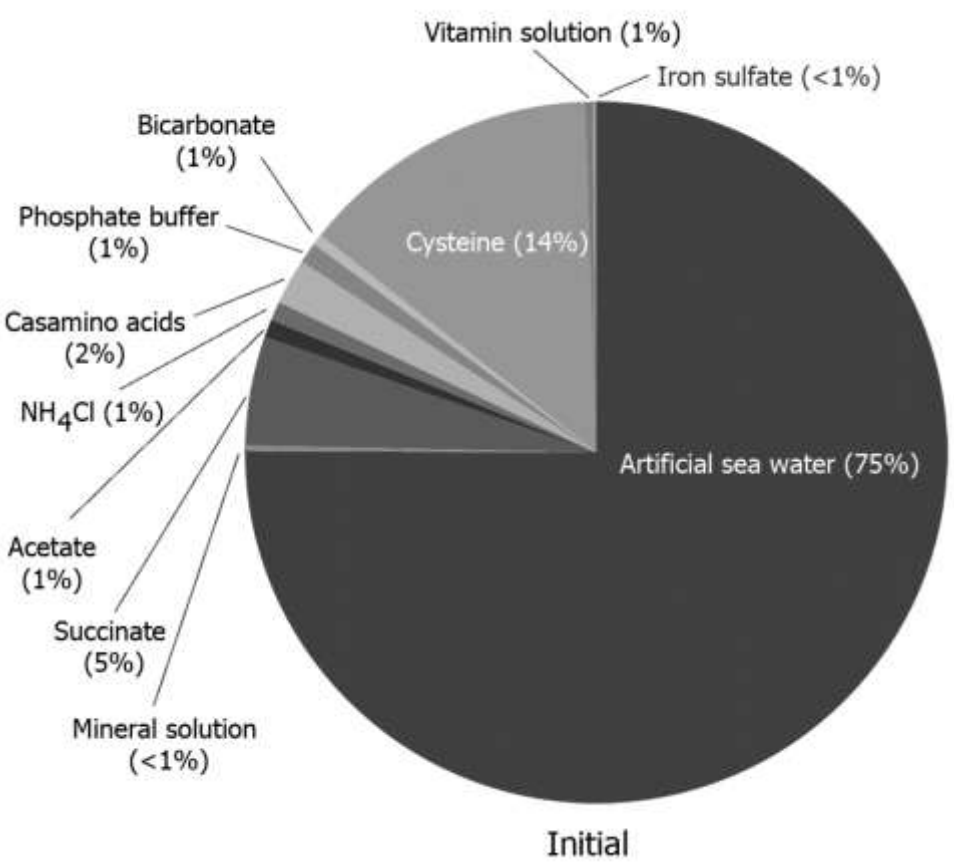
Medium	Time (h)	Avg no. of cells/ml (SD)[a]	Avg no. of magnetosomes/cell (SD)[a]	No. of magnetosomes/ml	Magnetite concn (mg/liter)	Magnetite production (mg/liter/day)
Initial	72	1.85×10^9 (1.41×10^7)	15.34 (4)	2.83×10^{10}	15.14	4.98
Optimized	96	7.82×10^9 (3.85×10^7)	13.68 (4)	1.07×10^{11}	64.35	16.09

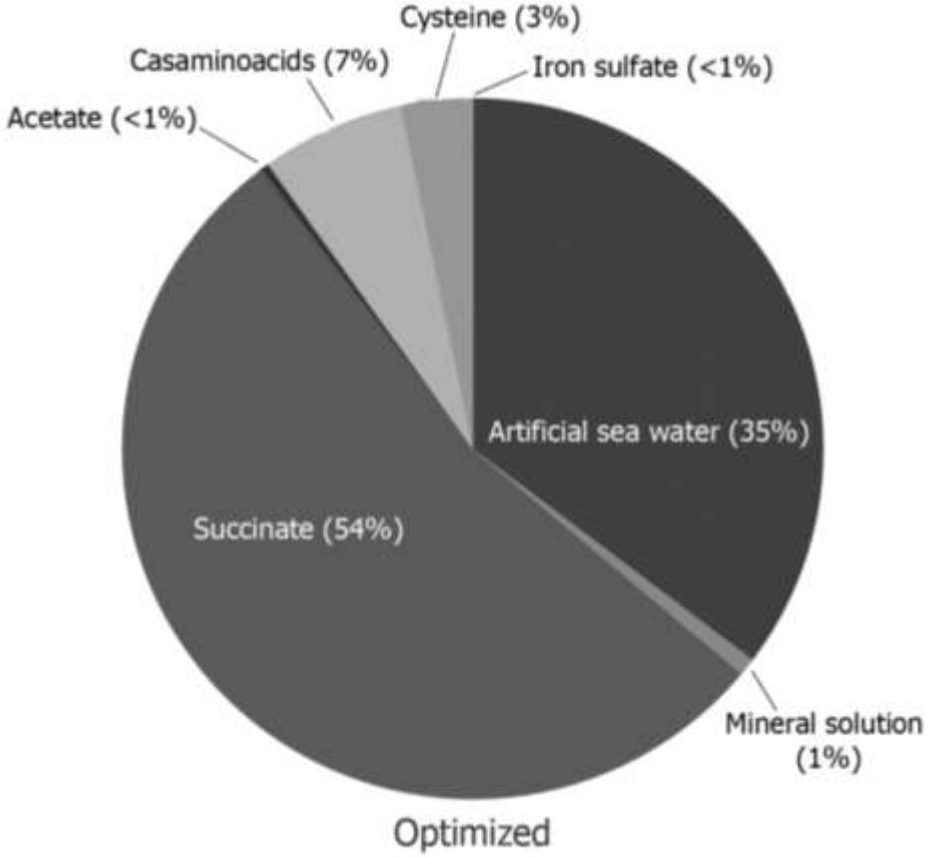
[a] Results are from two replicate experiments.

Increase in production by about 8 x

Silva et al. (2013) Appl Environm. Microbiol.

Cost analysis



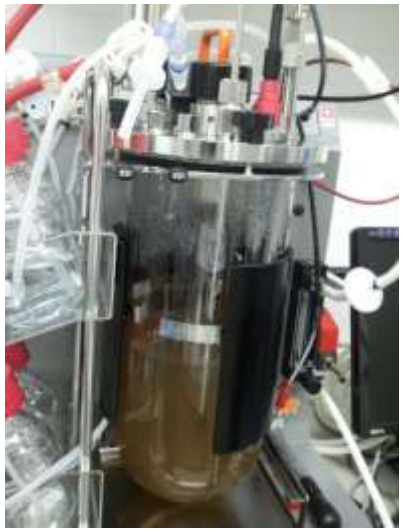


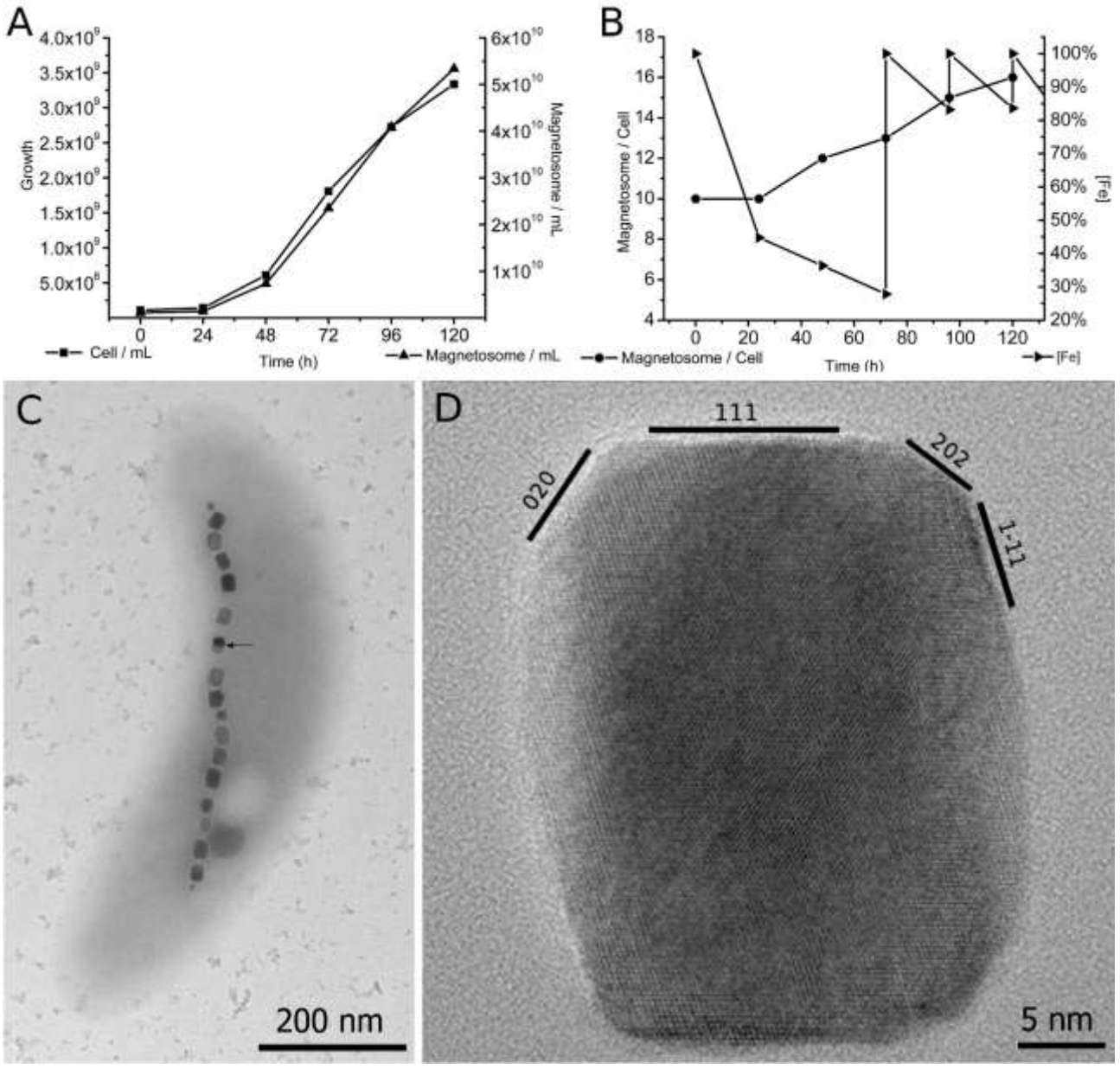
Increase in cost by about 2 x

Net increase in production/cost by about 4 x

Silva et al. (2013) Appl Environm. Microbiol.

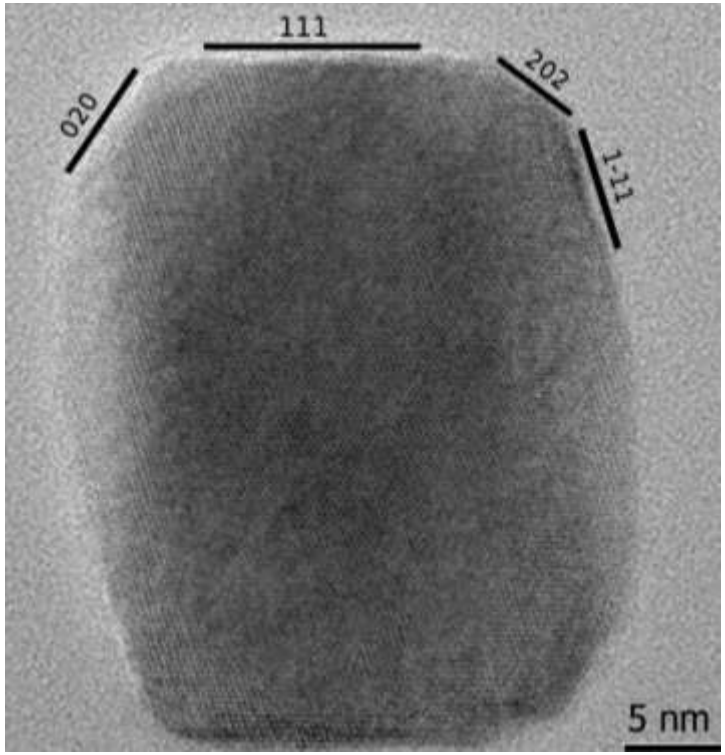
Growth in Bioreactor

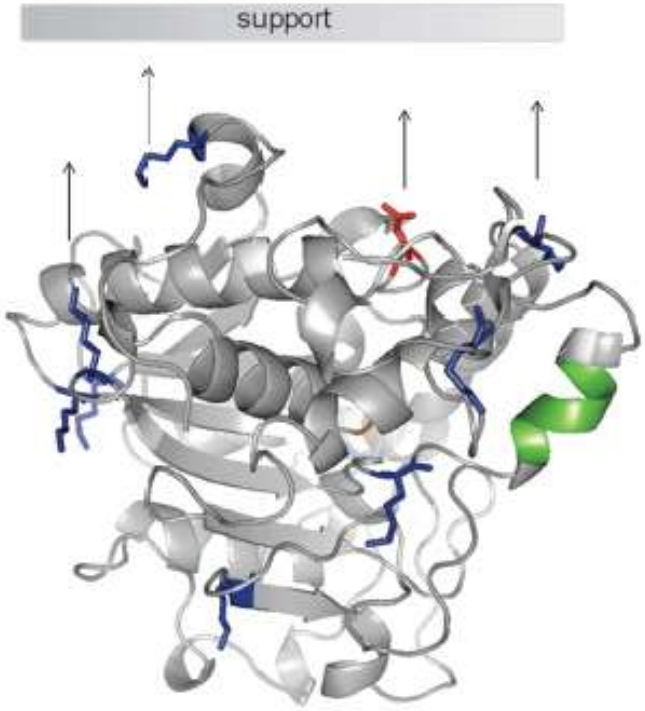




Silva et al. (2013) Appl Environm. Microbiol.

Immobilization of lipases





Lipase from *Rhizomucor miehei*

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Master students
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