The fidelity of paleomagnetic records carried by magnetosome chains

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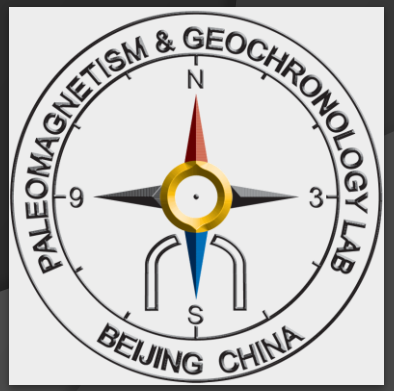
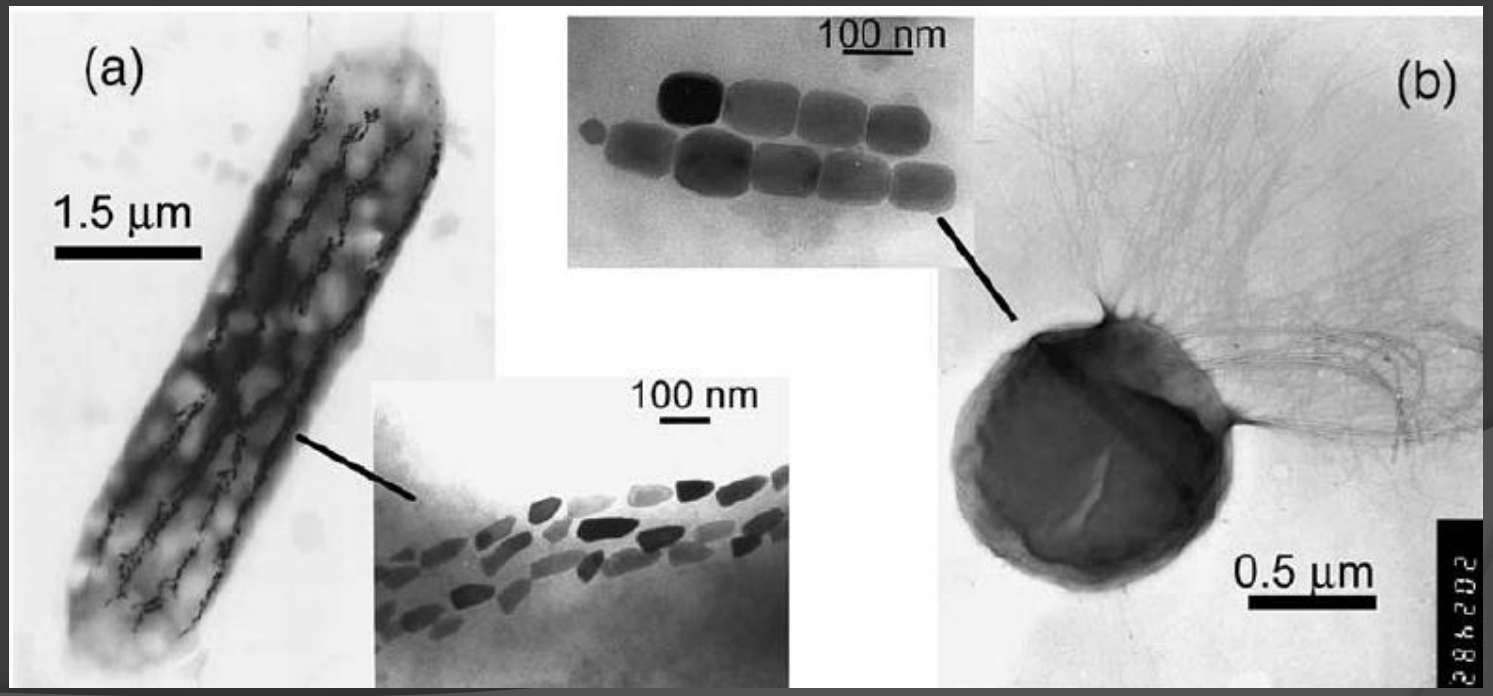


What are MTB?

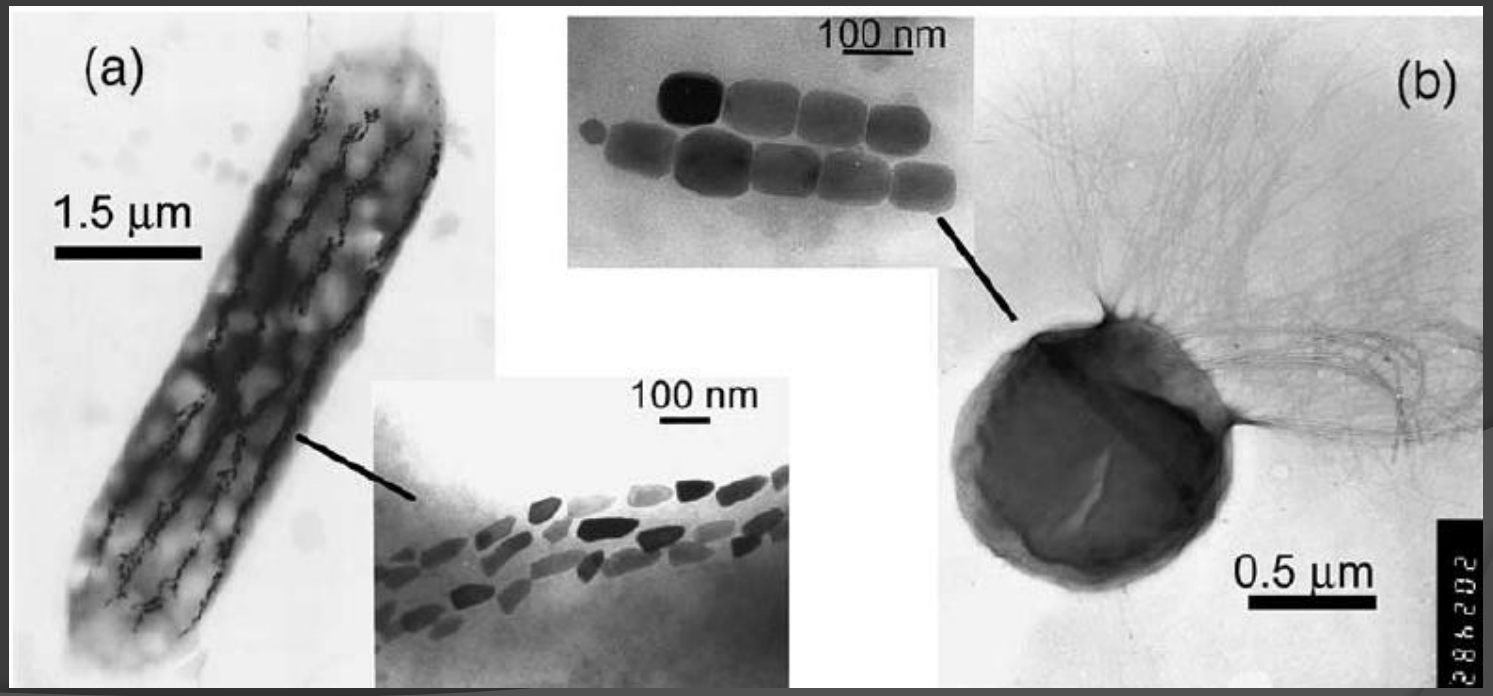
- Magnetotactic bacteria (MTB) use magnetic particles to navigate
  - Live within sediments



***Pan et al.* (2005; EPSL)**

What are MTB?

- Form SD magnetite particles
  - 30-120 nm
  - Elongate chains

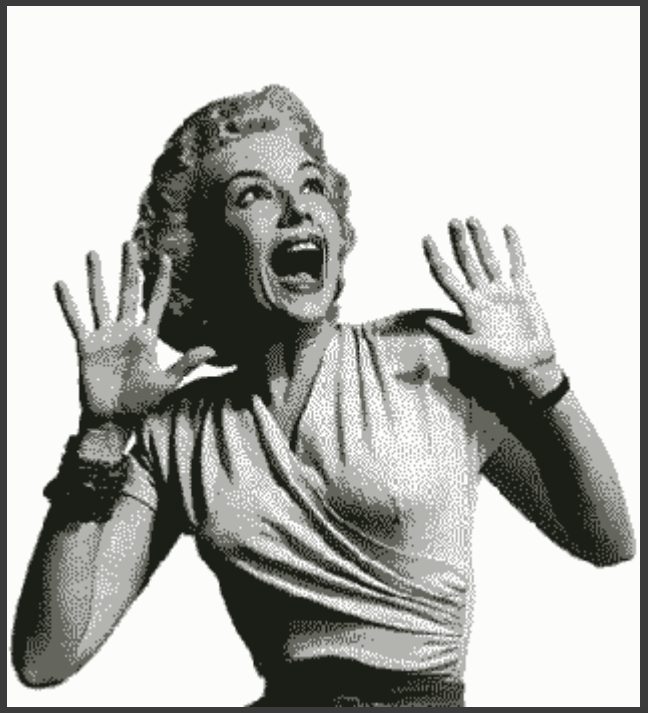


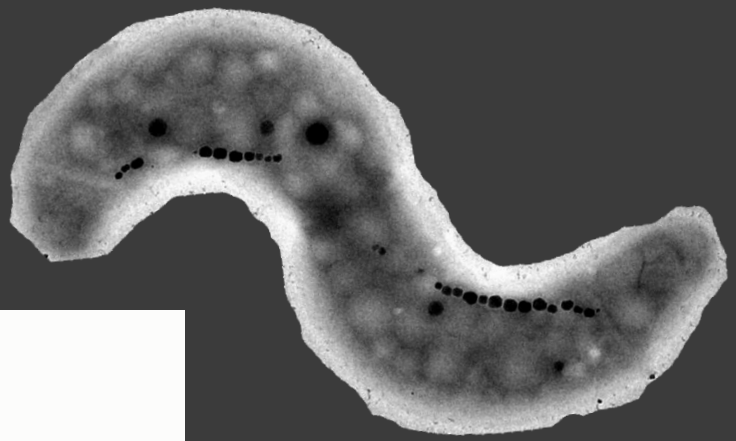
***Pan et al.* (2005; EPSL)**

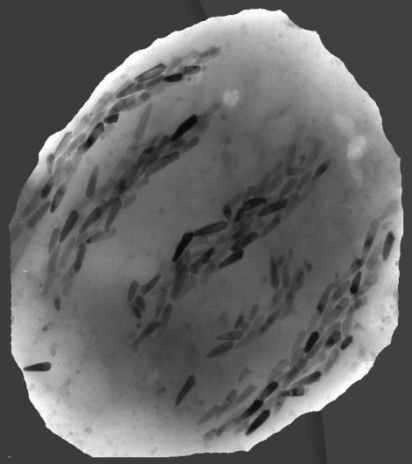
Why care about bacteria?

- When they die magnetosomes contribute to sedimentary magnetization
- Sedimentary paleomagnetic records are high resolution
  - Backbone of geomagnetic reconstructions
  - Reversal and excursions
  - Climatic information
- MTB play a key role

Invasion of the MTB!!!







Invasion of the MTB!!!

- Found in lacustrine and marine environments
  - Often at the oxic-anoxic transition zone

Modern day

↓

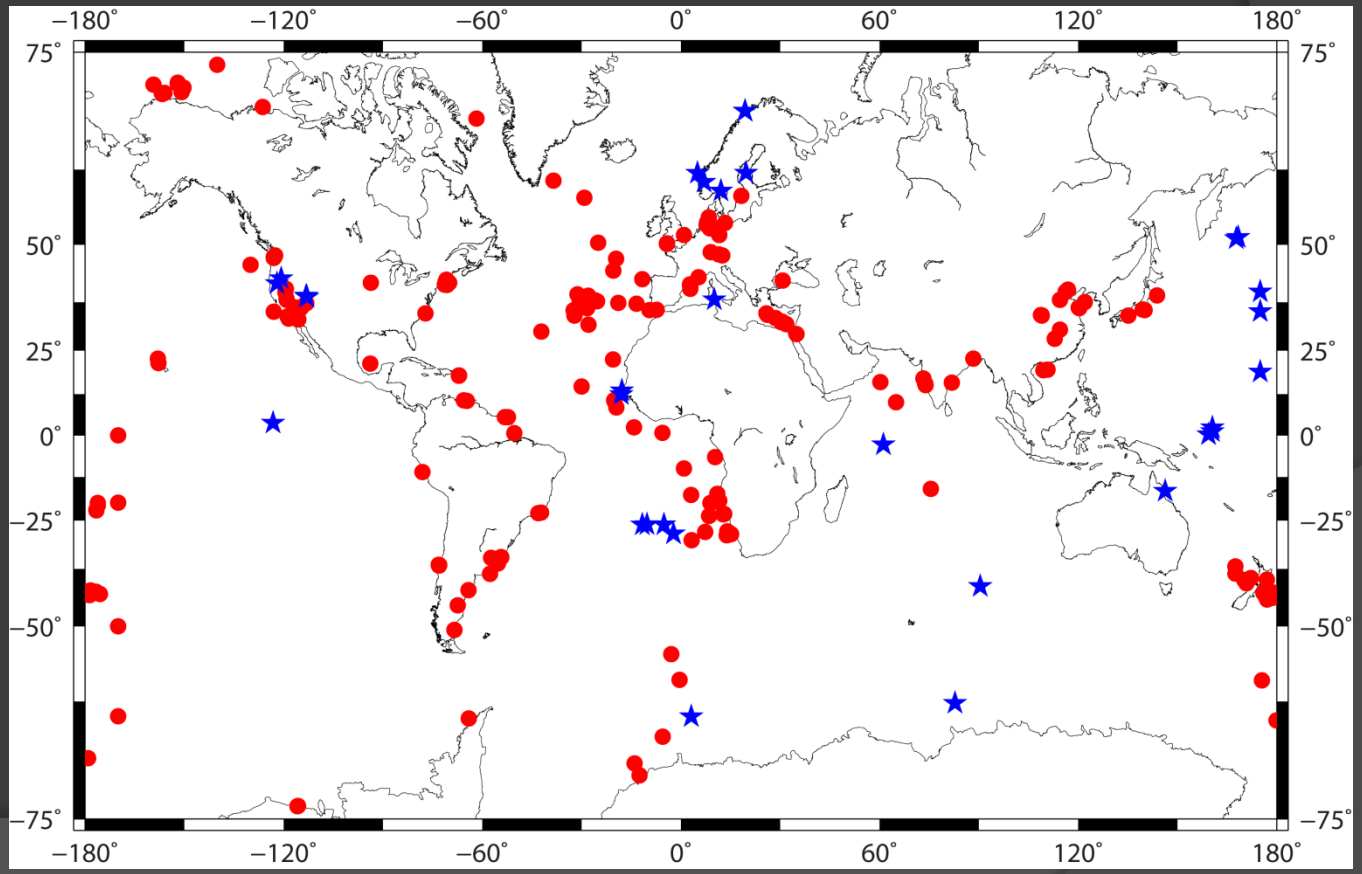
Eocene

↓

Cretaceous (?)

↓

Precambrian (??)



Invasion of the MTB!!!

- How much do MTB contribute to sediment magnetization?
  - Living cells contribute ≥ 10 % to NRM

- Are MTB good recorders?
  - **???**
  - Not good for relative paleointensity (RPI)?
    - Roberts et al. (JGR, 2011)

Relative paleointensity

- Sediment magnetization is controlled by
  - **Geomagnetic variation**
  - Concentration
  - Composition

  } **Need to normalize these factors**

- Anhysteretic magnetization (ARM)
  - SD particles
    - (But also magnetic interactions)
- Saturation isothermal magnetization (SIRM)

Relative PINT bias?

- Requirements for RPI

? • Consistent NRM mechanism

✓ • Magnetite

? • Small concentration variations

✘ • Grain size 1-15 μm

The paper

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The fidelity of paleomagnetic records carried by magnetosome chains

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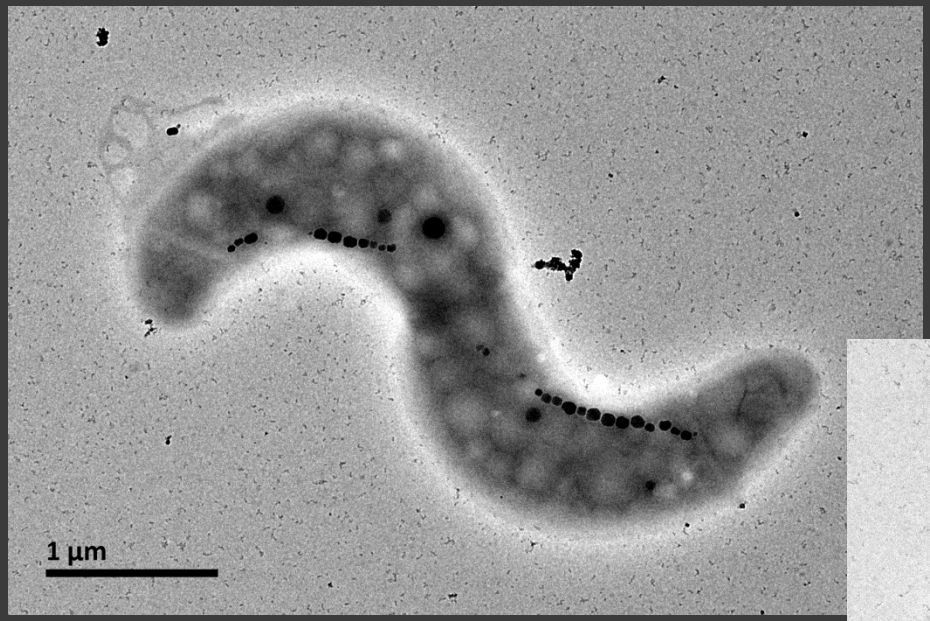
ABSTRACT

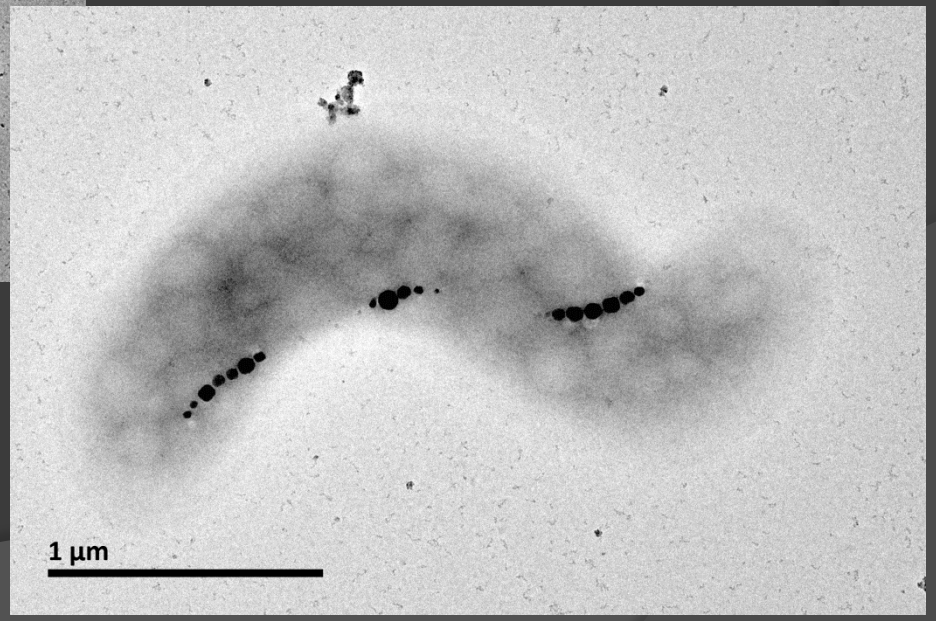
Magnetotactic bacteria (MTB), which use aligned chains of magnetosomes (magnetic crystals) as a navigation tool, are found in a wide range of modern day marine, river and lacustrine environments and their fossilized remains are being increasing recognized in geological records. Despite an increasing realization

The bacteria

- Used cultured bacteria



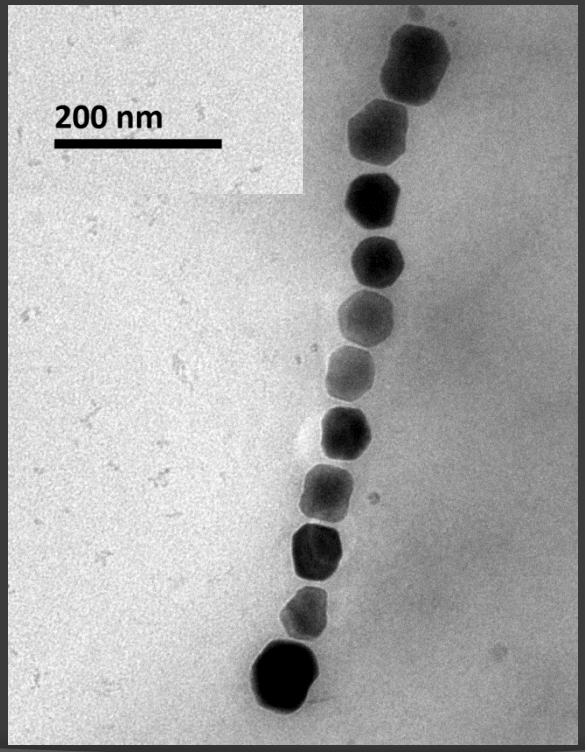
Magnetospirillum magneticum (AMB-1)



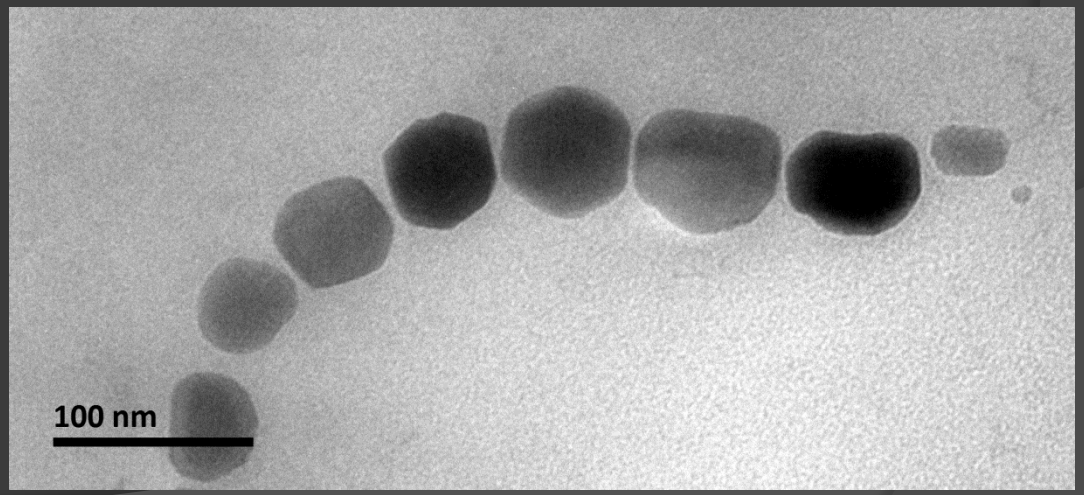
Fragmental magnetosome chains (4-15 grains per chain)

The magnetosomes

- Cuboctahedral grains
  - Magnetite

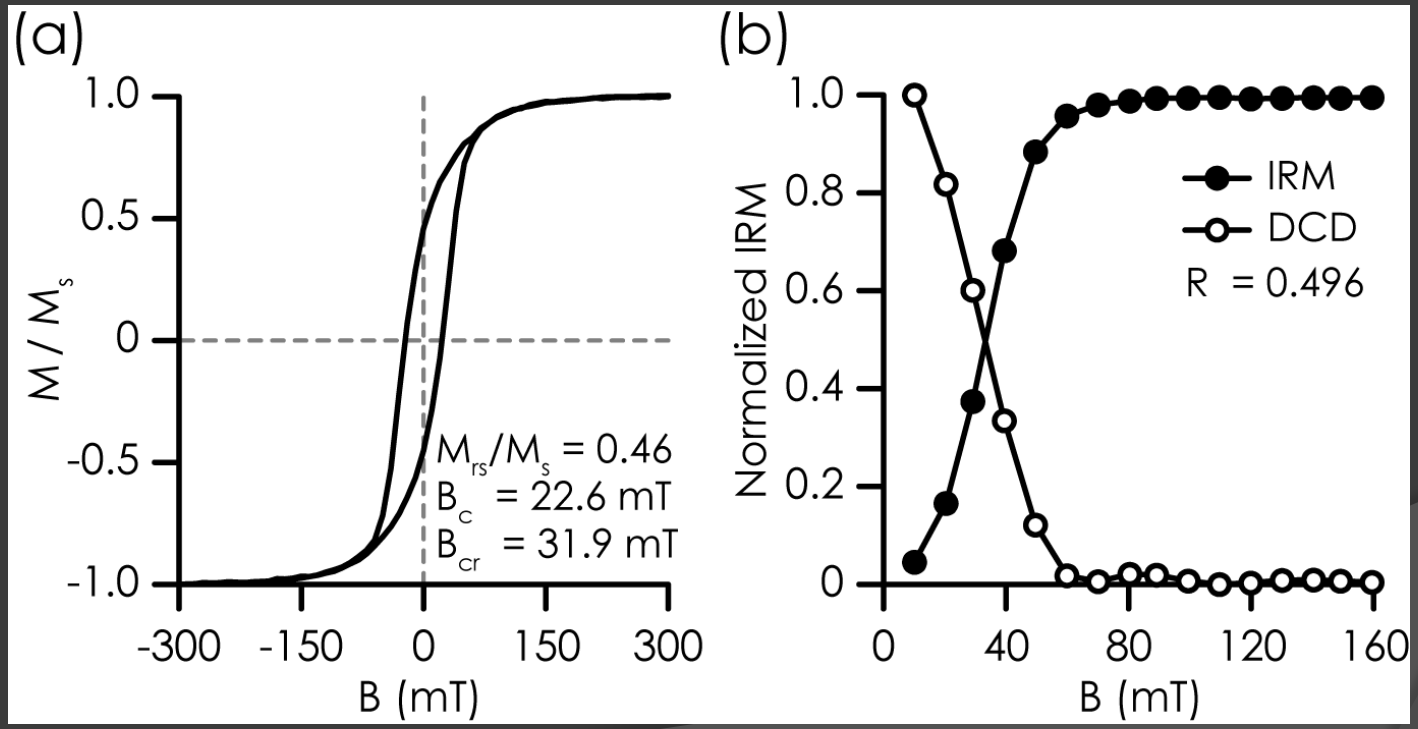


Grain size 52.2 ± 13.5 nm
Shape factor 0.85 ± 0.16
(N = 118)



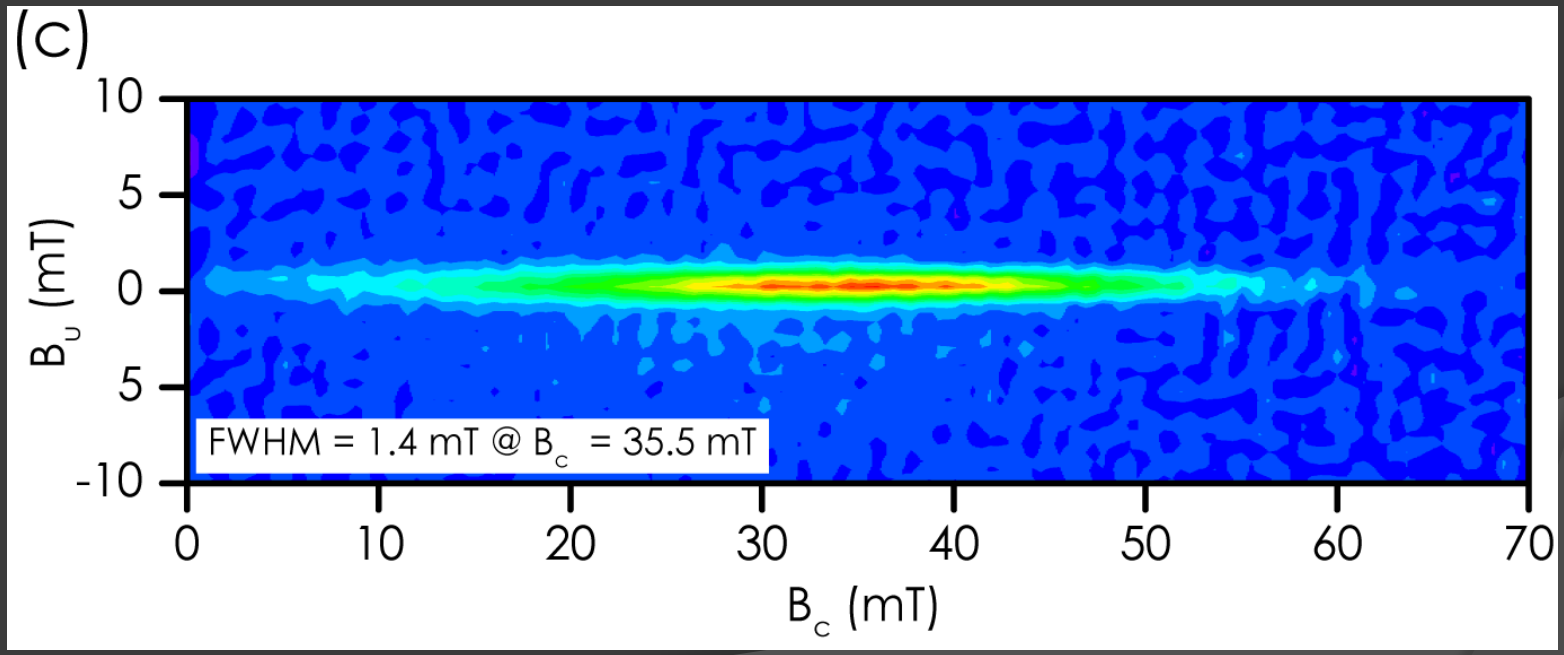
Rock magnetism

- Hysteresis & IRM
  - Non-interaction SD grains



Rock magnetism

- FORC diagram
  - Non-interaction SD grains
    - Typical MTB behaviour

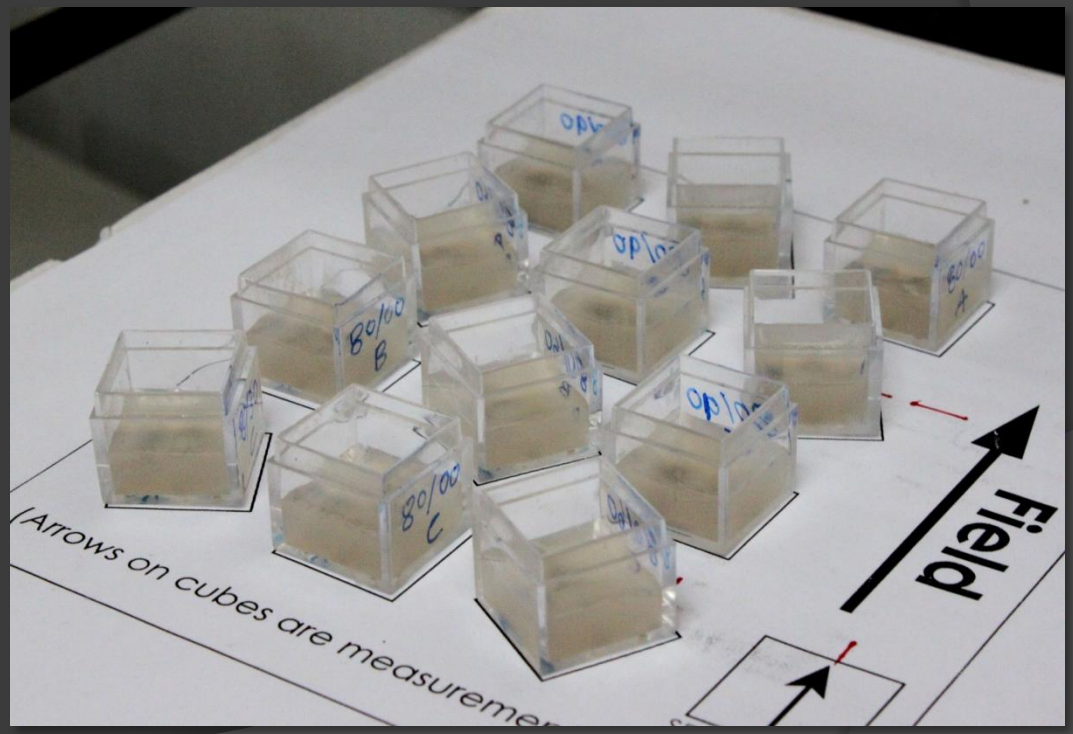


The field coils

- Two-axis Helmholtz coils
  - 6 fields up to 120 μT
    - Zero-field, < 200 nT
  - Field control < 0.15 μT
  - Zero inclination
    - ≤ 1.3% vertical component

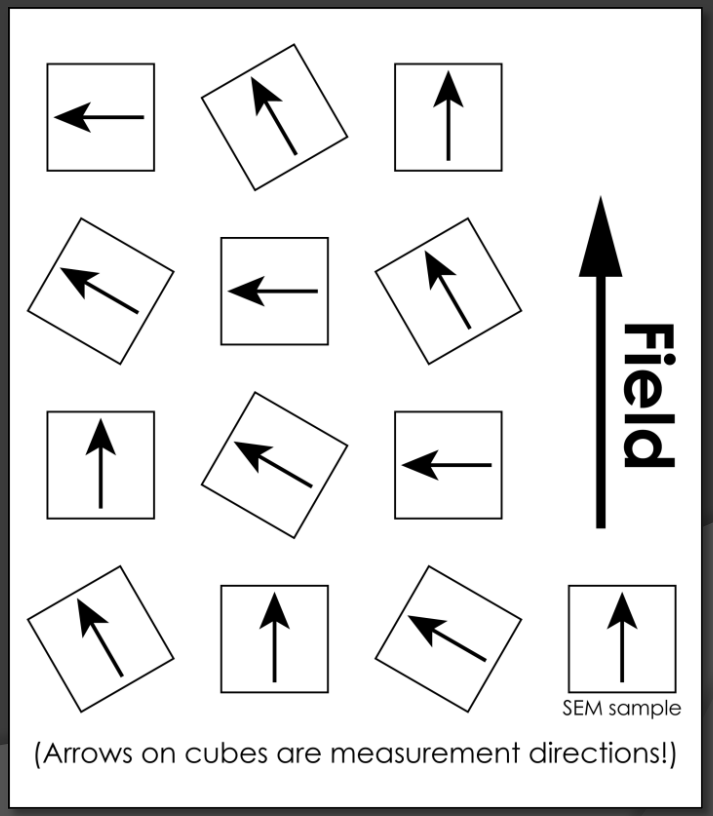
The samples

- Deposit 2 mL of bacterial solution
  - Allow to dry over 5-6 days
- Cells will experience a magnetic torque
  - Align with the applied field



The samples

- Multiple samples and orientations
  - For averaging
- 4 angles
  - 0, 30, 60, 90°
- 3 replicates



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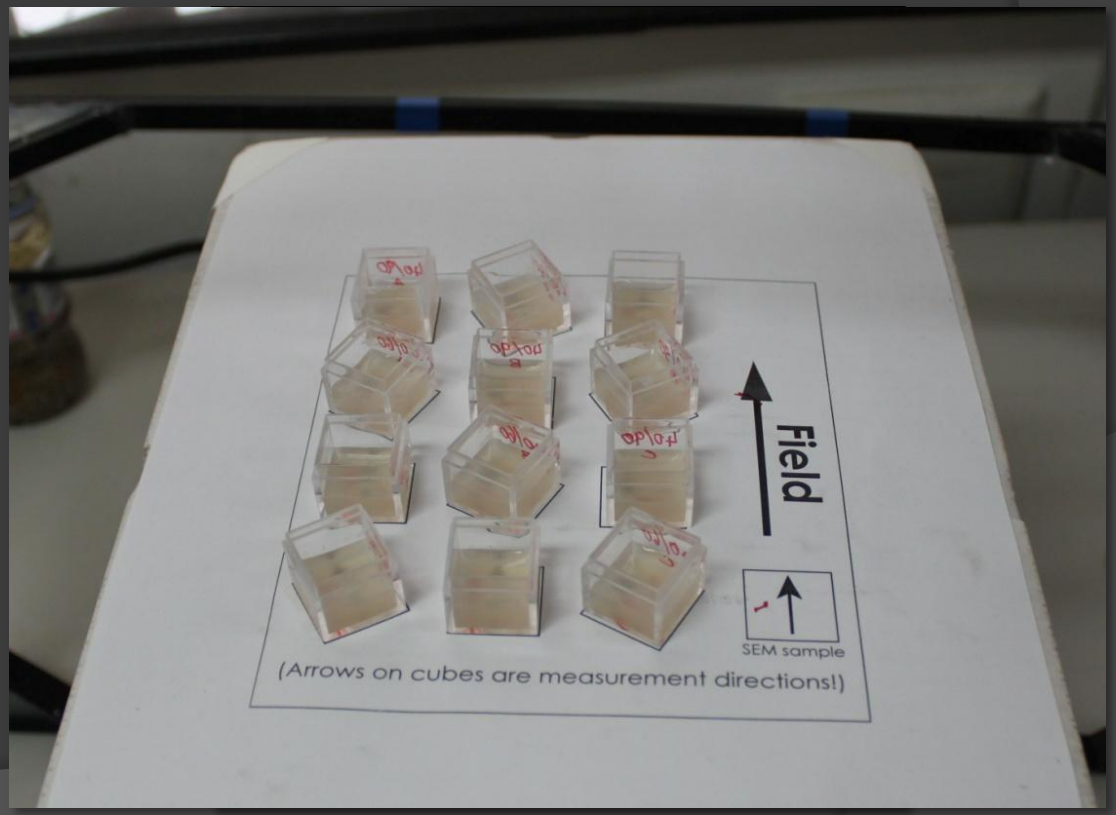
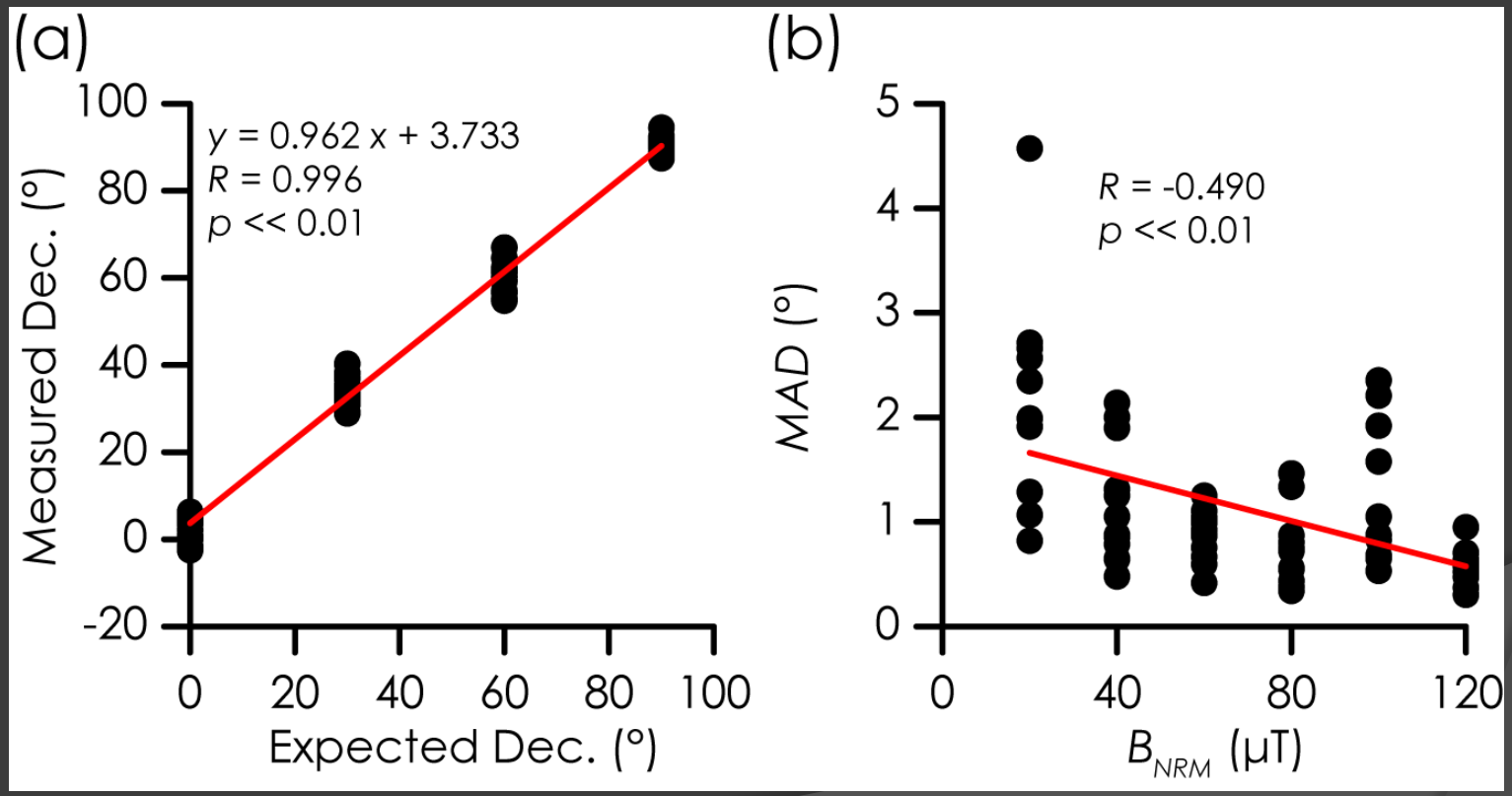


The measurements

- AF demag of…
  - NRM
  - ARM (60 μT @ 80 mT AF peak)
  - SIRM (1 T)
- Anisotropy of ARM and SIRM
- ARM and SIRM acquisition
- VSM based rock mag.

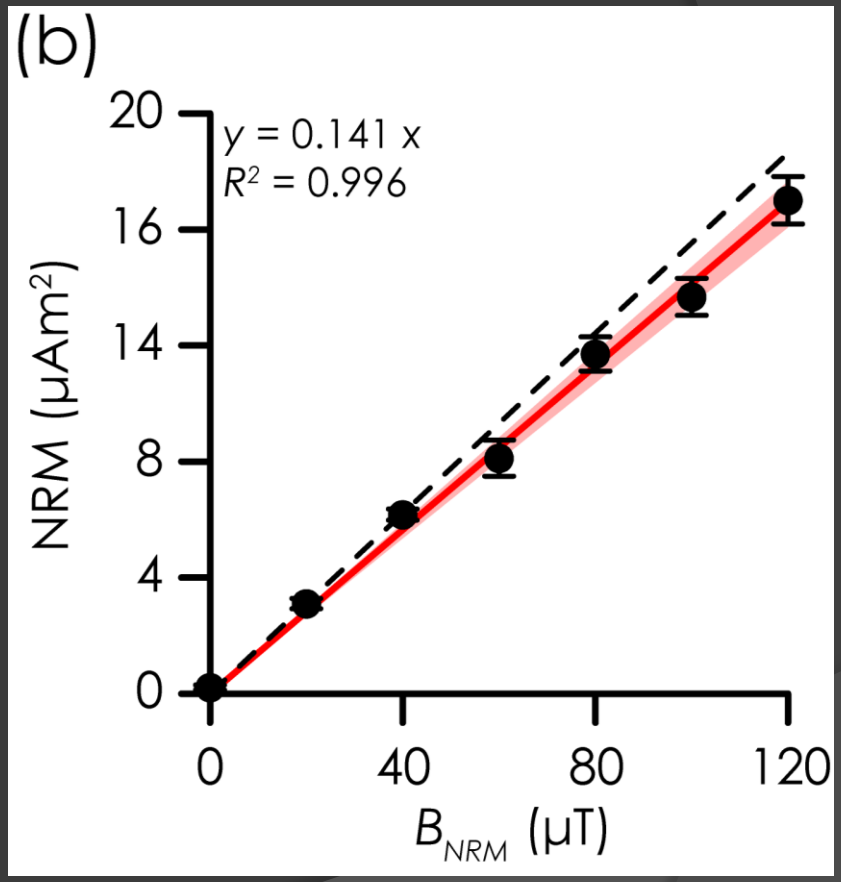
NRM behaviour

- Excellent directional behaviour



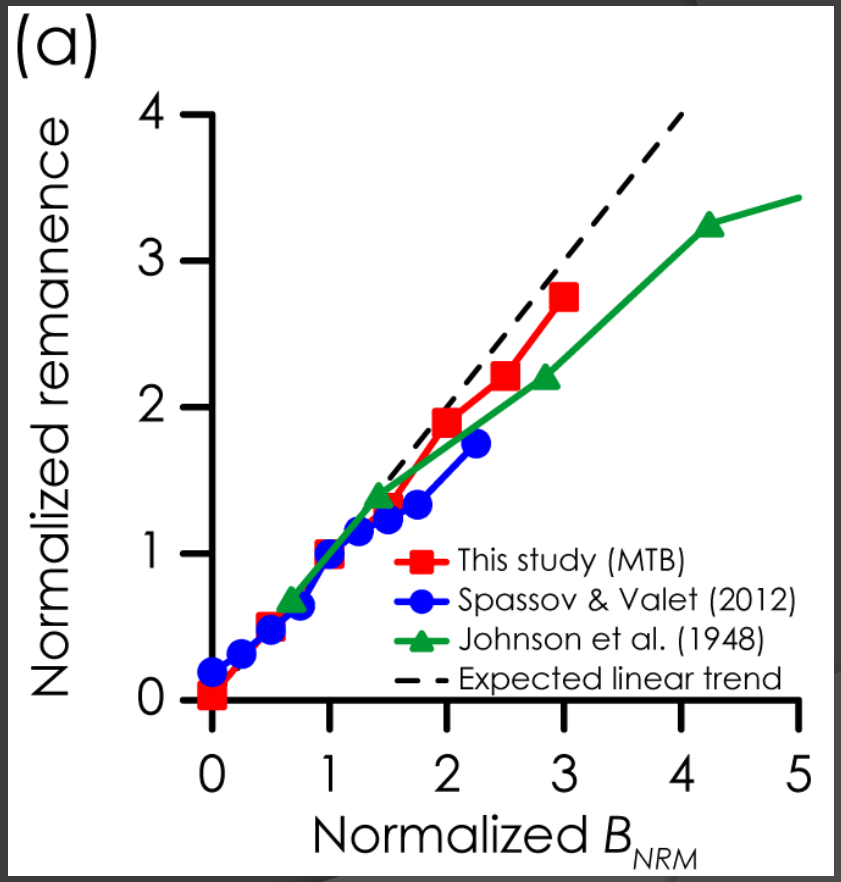
NRM behaviour

- NRM is near linear with applied field
  - Small deviation from expected trend



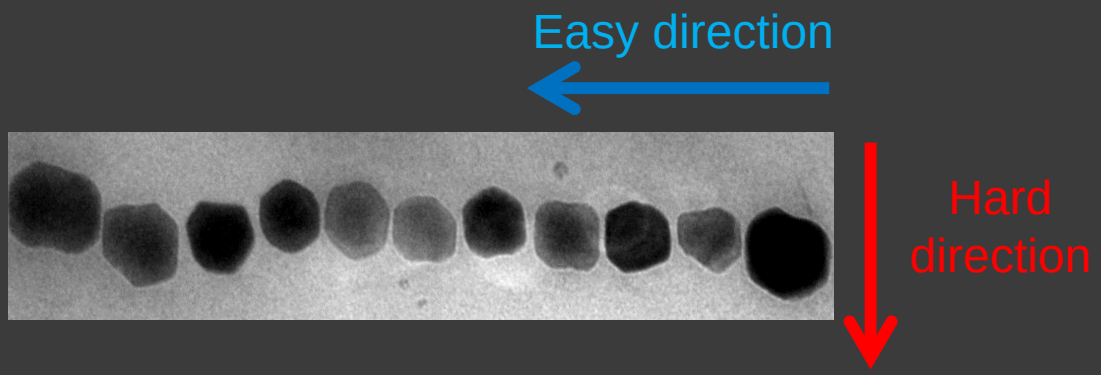
NRM behaviour

- NRM is near linear with applied field
  - Small deviation from expected trend
- As good as or better than detrital records



Anisotropy?

- Magnetosome chains are elongate
  - Anisotropy may be large for ARM and SIRM



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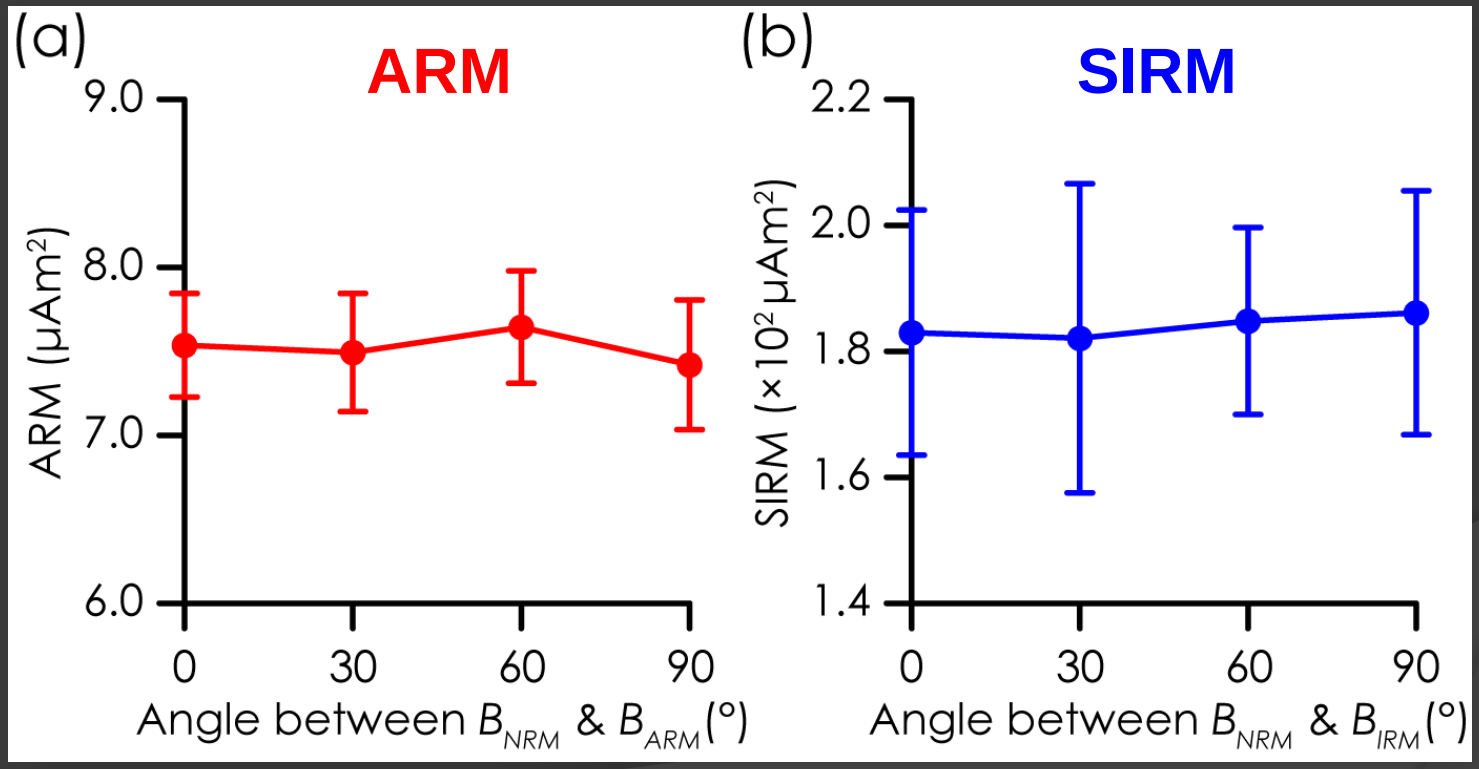
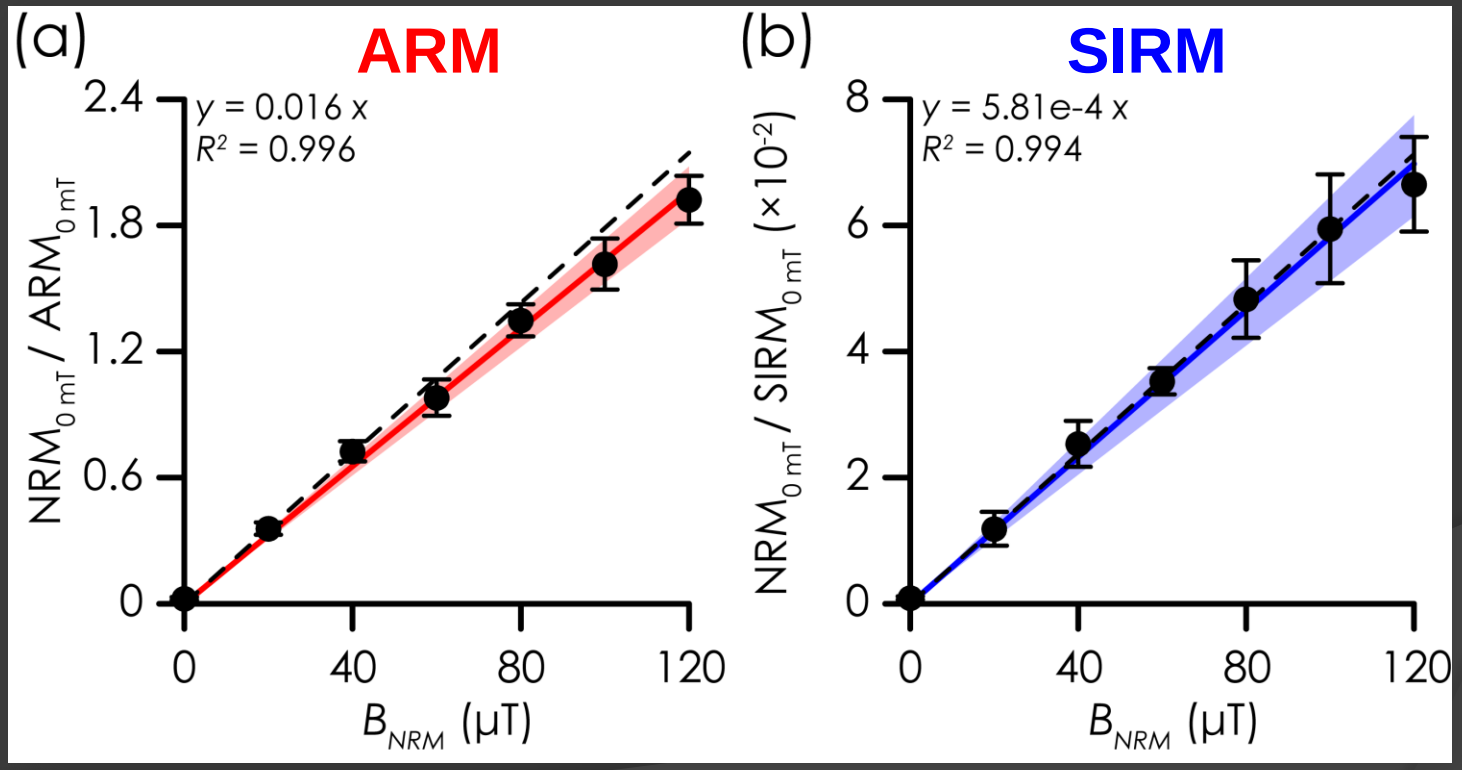


Relative paleointensity

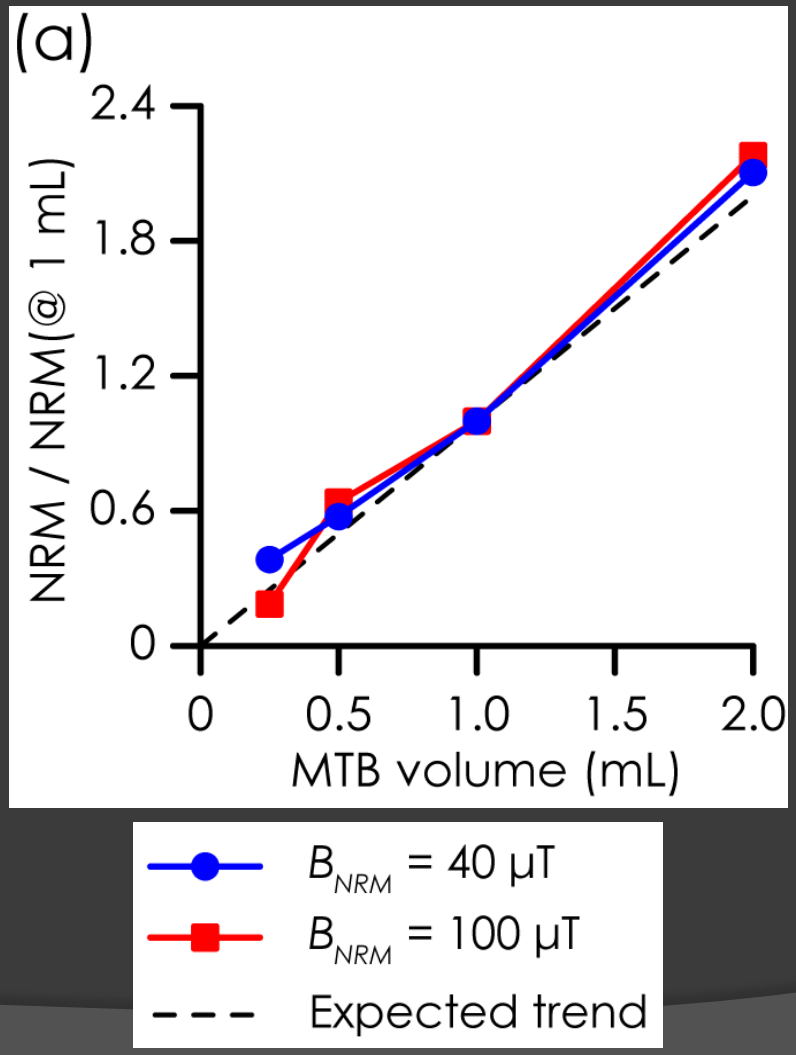
- Relative paleointensity (RPI) behaves well
  - Near expected linear trend



The effects of concentration

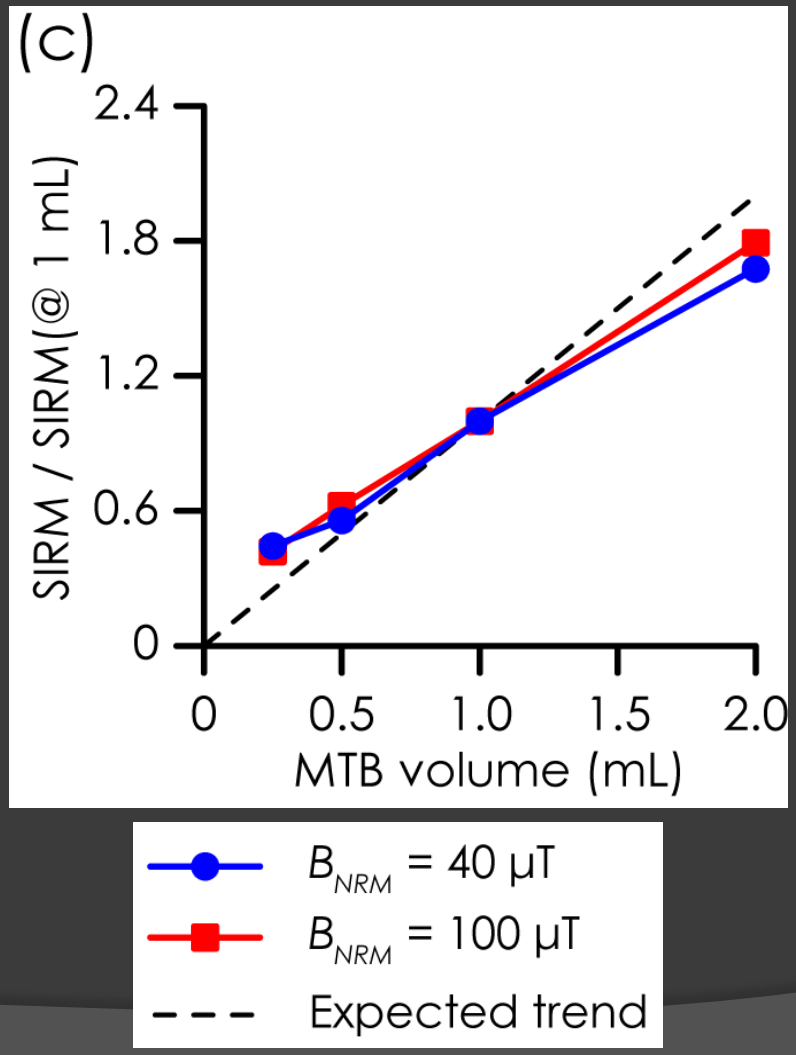
- Four concentrations
  - 0.25, 0.5, 1, and 2 mL of solution
    - Total volume always 2 mL
- Two fields
  - 40 and 100 μT
    - All samples parallel to applied field
- Two replicates

The effects of concentration



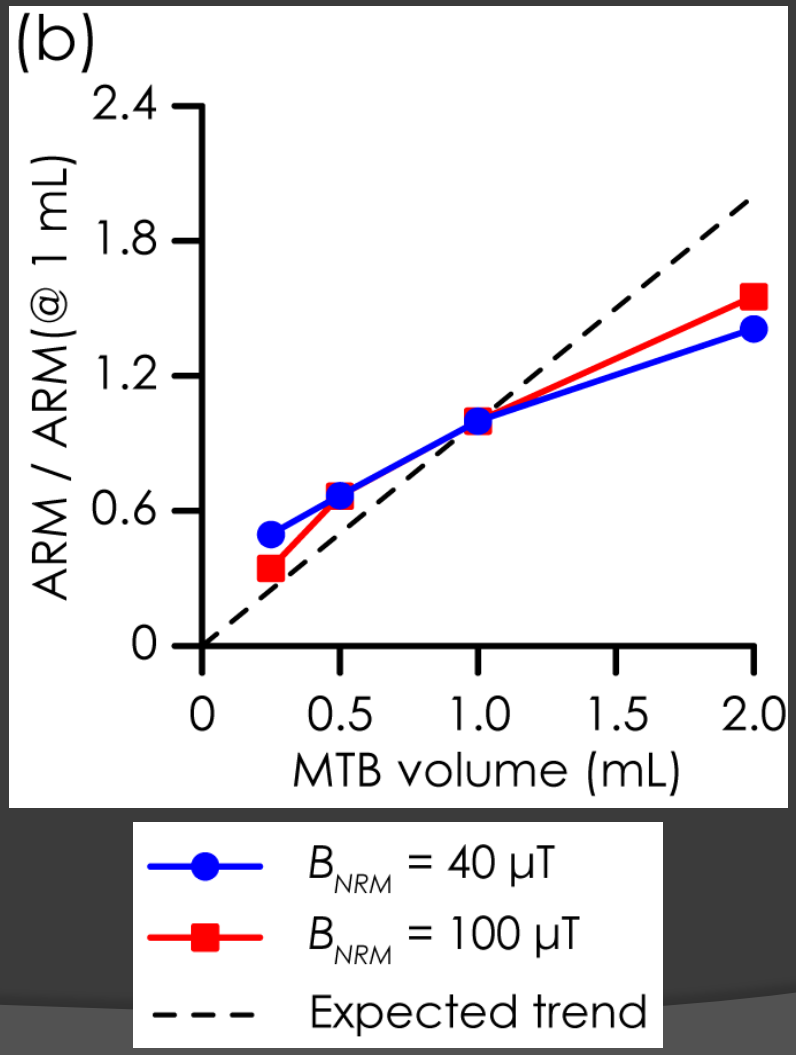
- NRM
  - 2 x conc. = 1.97 x NRM

The effects of concentration



- NRM
  - 2 x conc. = 1.97 x NRM
- SIRM
  - 2 x conc. = 1.76 x SIRM

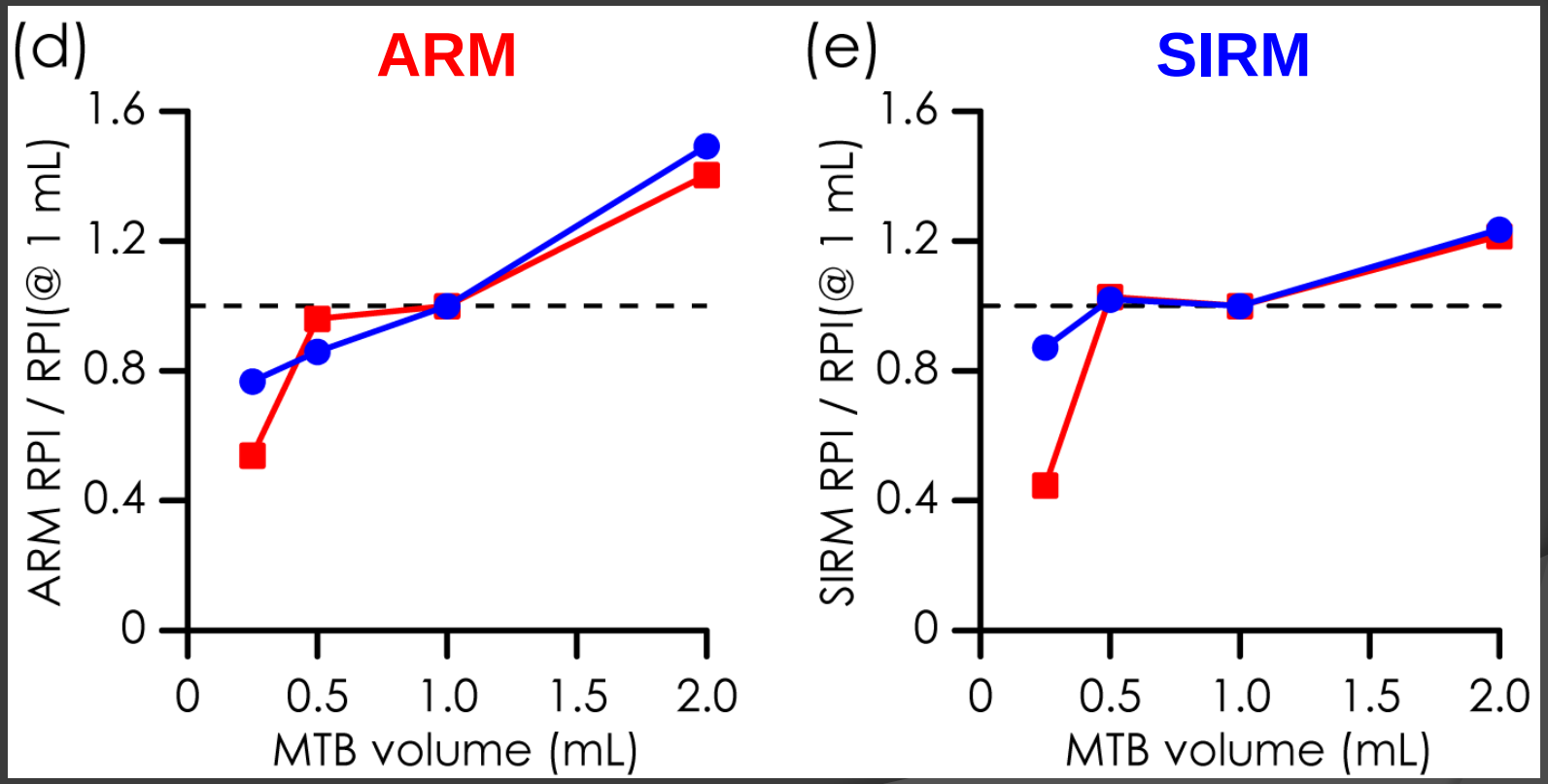
The effects of concentration



- NRM
  - 2 x conc. = 1.97 x NRM
- SIRM
  - 2 x conc. = 1.76 x SIRM
- ARM
  - 2 x conc. = 1.63 x ARM

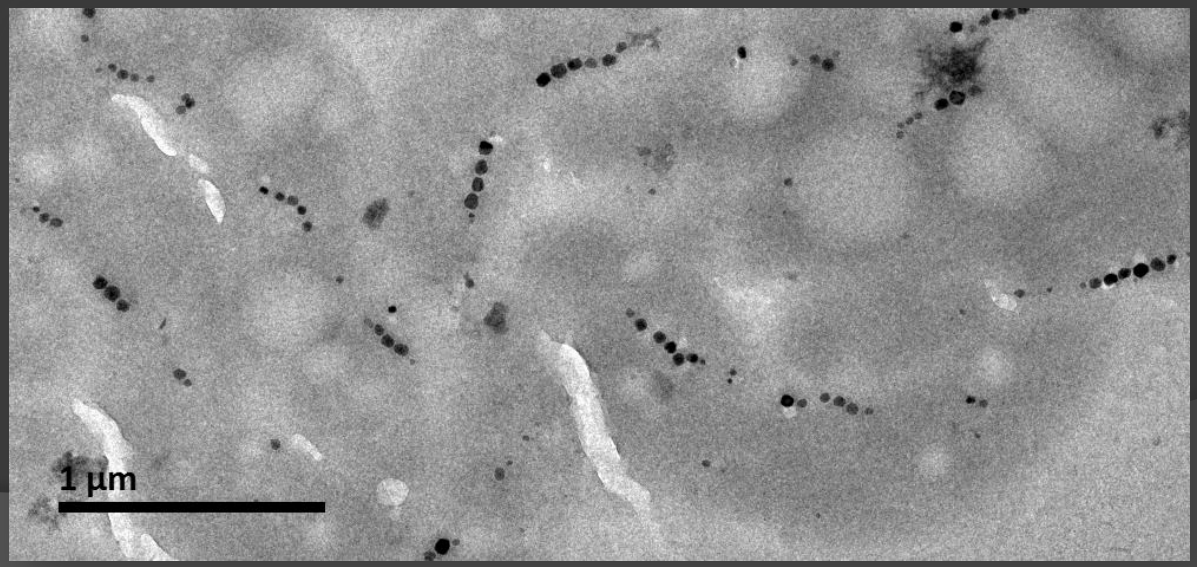
The effects of concentration

- RPI should be constant



Magnetic interactions

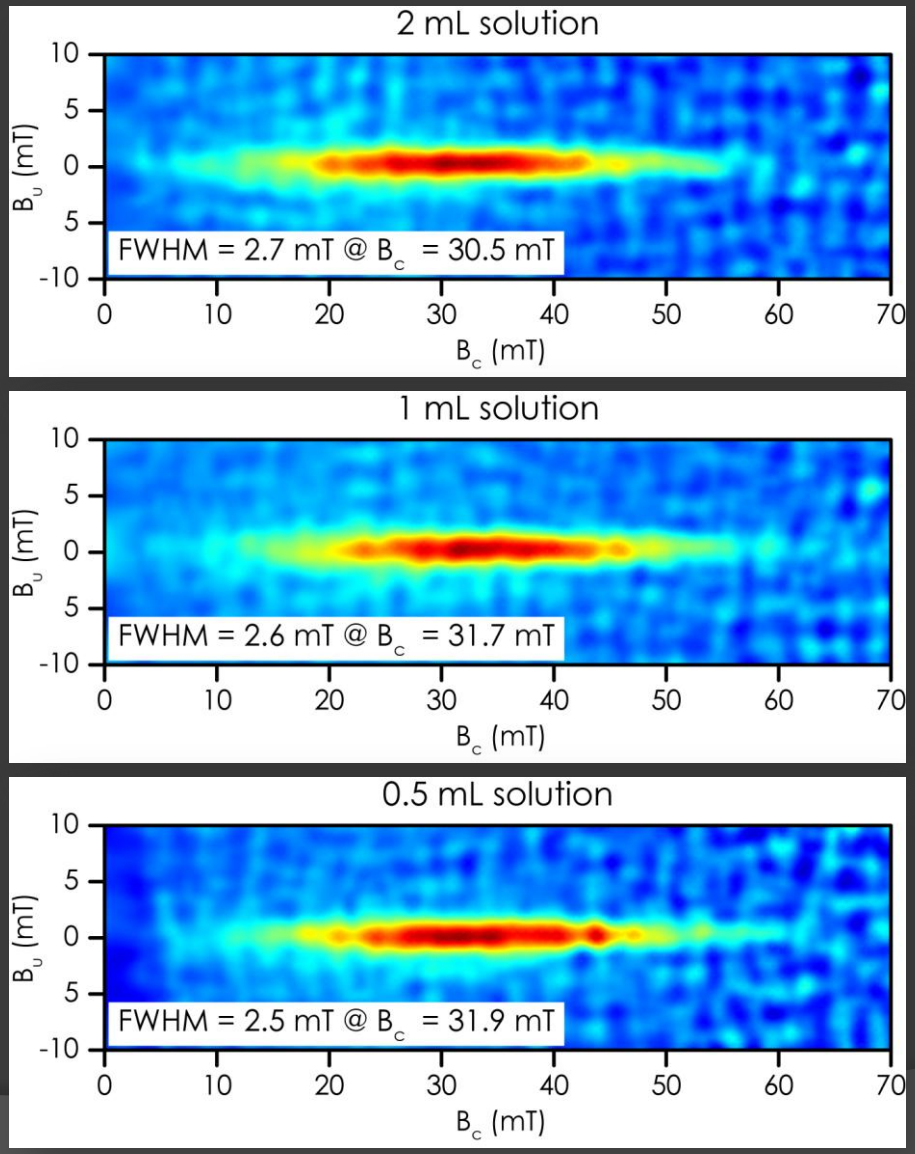
- Densely packed sample
- Interactions affect
  - IRM @ ~3 grain diameters (~0.3 μm)
  - ARM @ ~30 grain diameters (~3.0 μm)



Inter-cell interactions influence ARM

(and SIRM)

Magnetic interactions

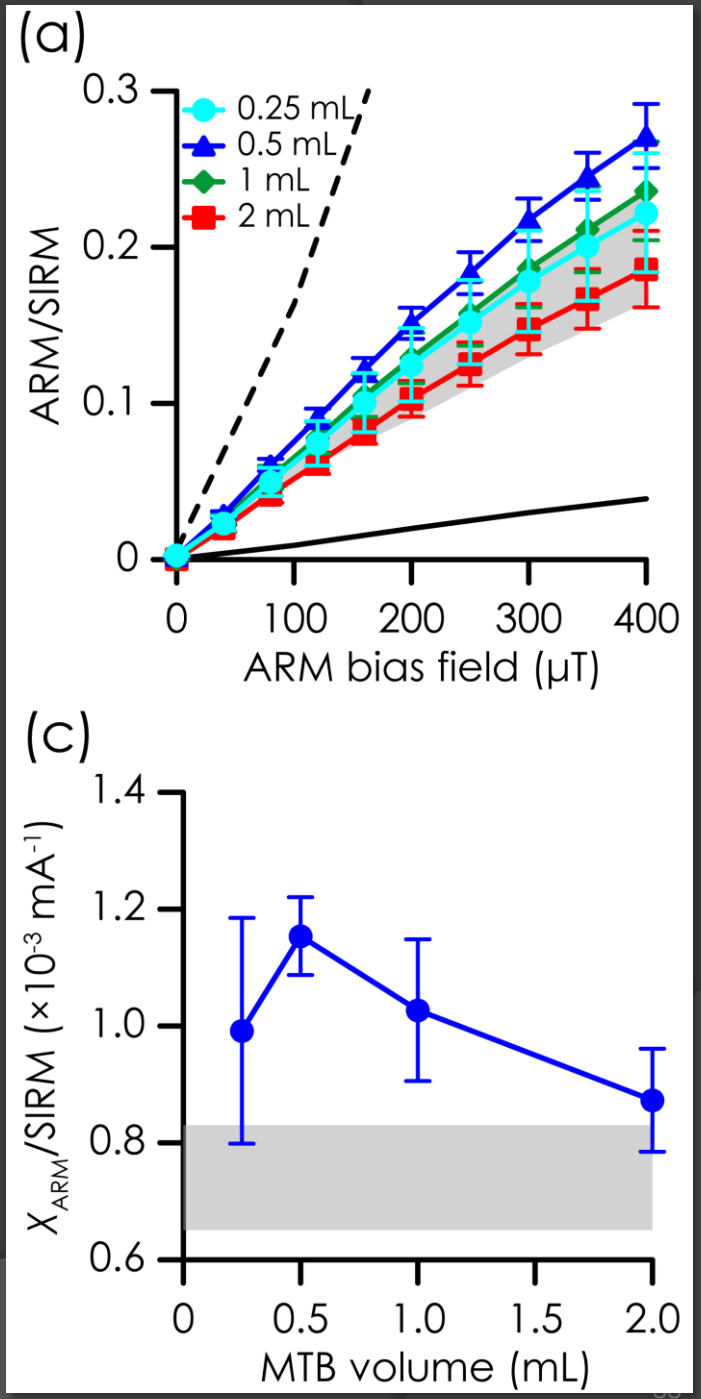


- FORCs are non-interacting
  - Paleomagnetic interactions are not seen
- May be more common than we think

SF = 3; ΔB = 3.1 mT

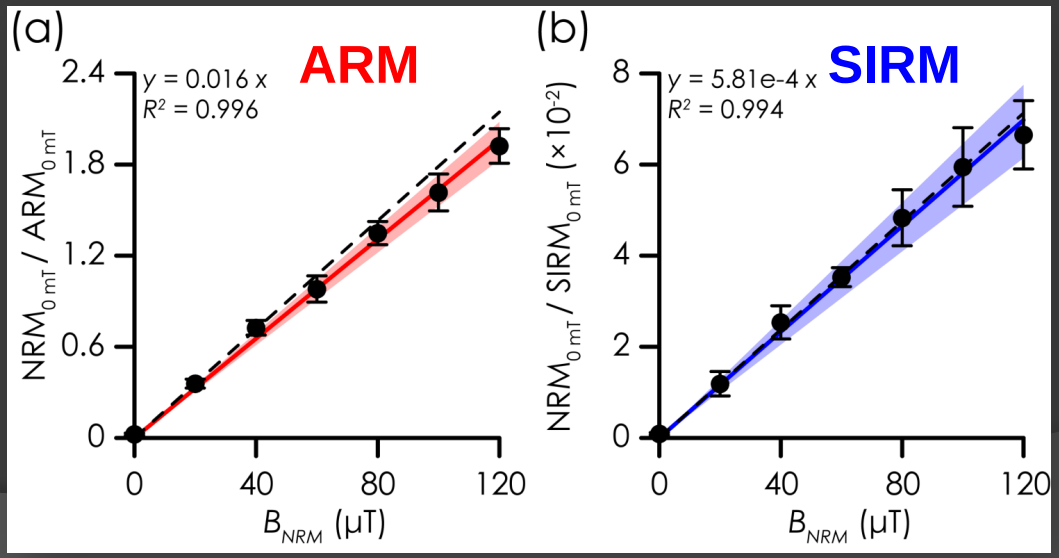
Interactions

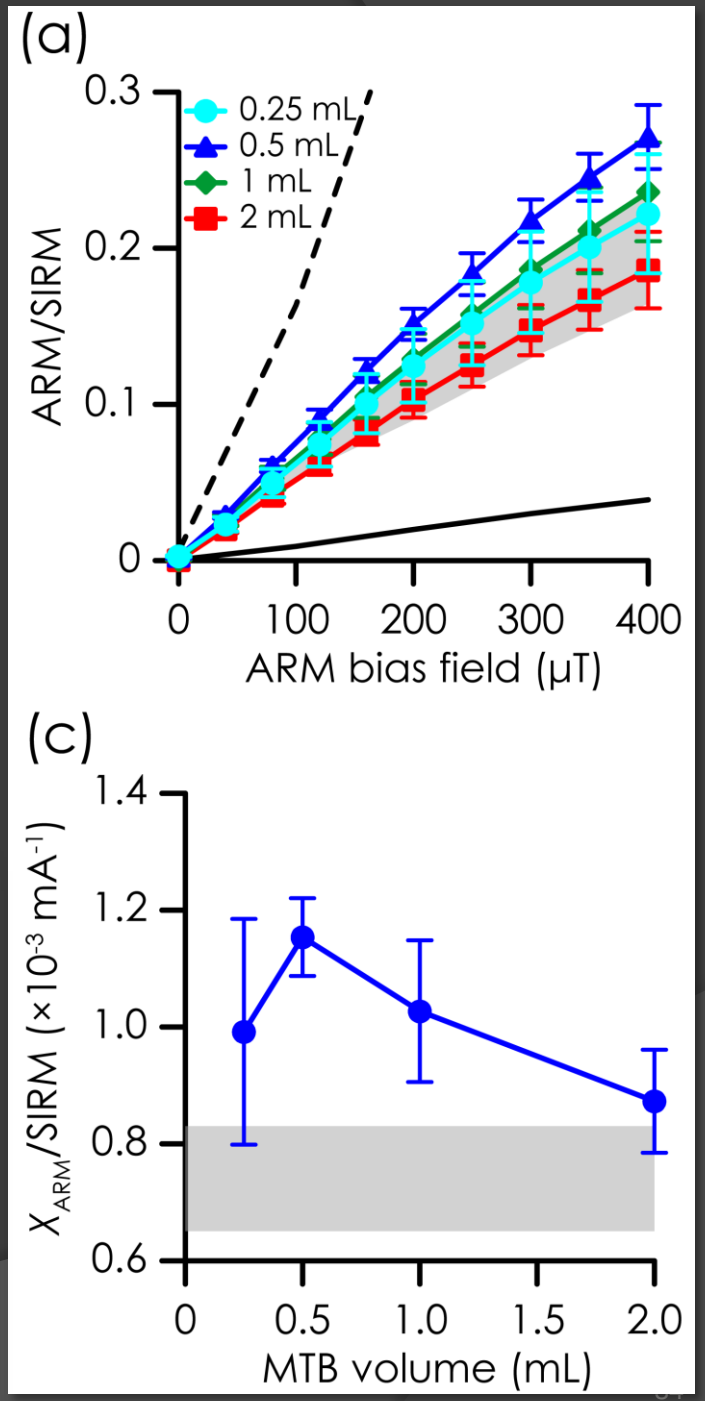
- Remanence methods may be better



Interactions

- Remanence methods may be better
- Grey shaded area gave us…





Relative paleointensity

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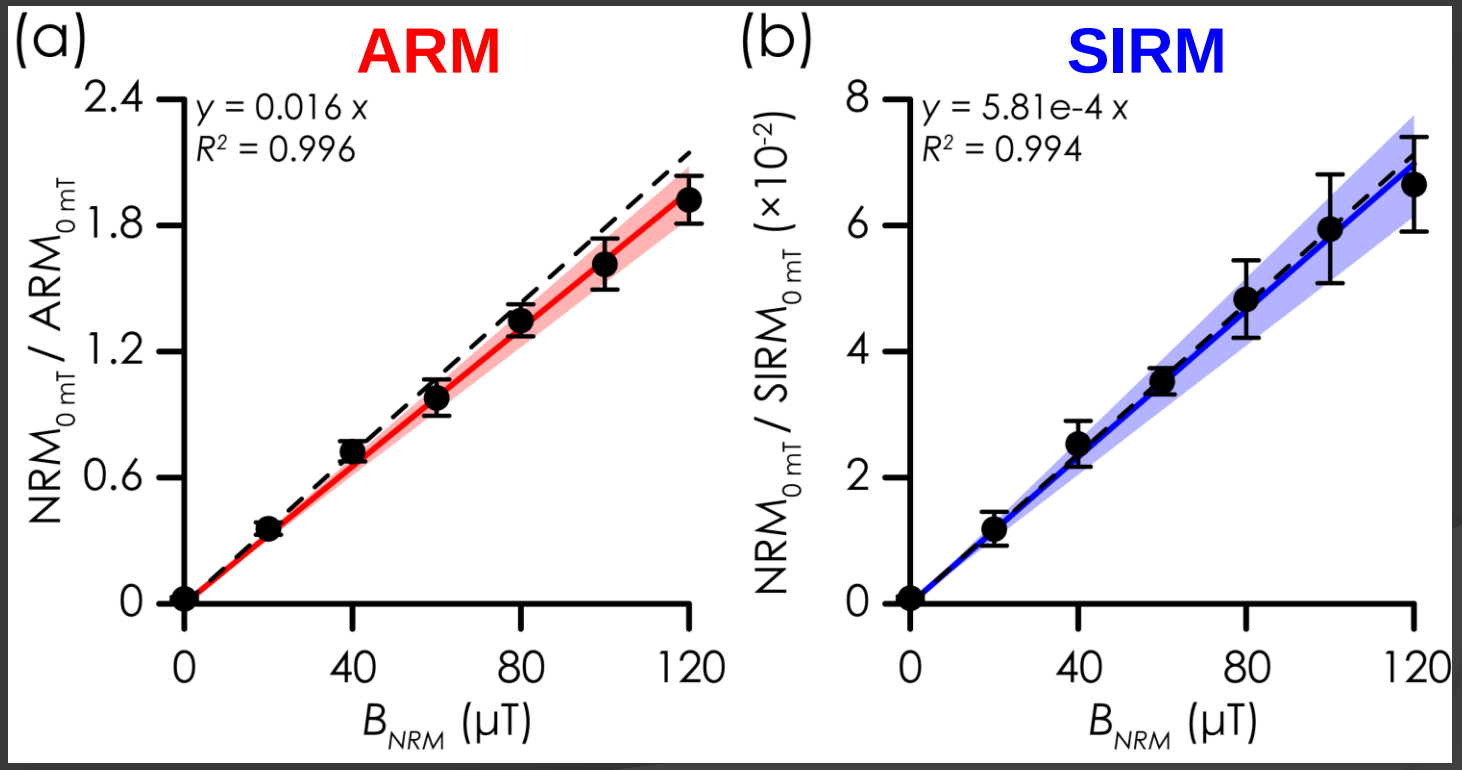
  - Near expected linear trend



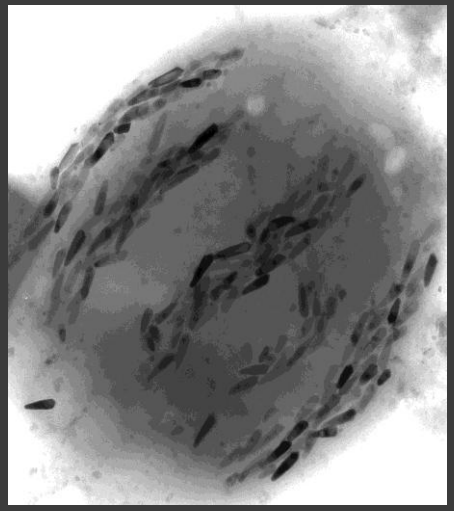
Summary

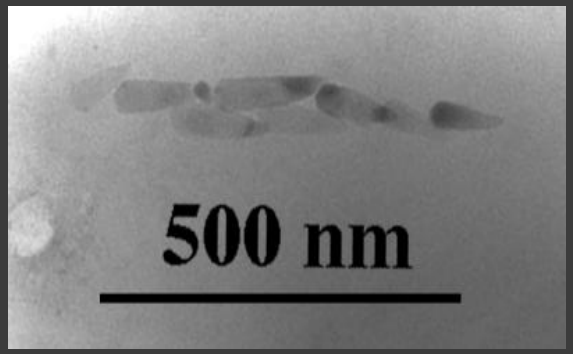
- MTB are good recorders of the geomagnetic field
  - NRM is linear with field
  - NRM responds to concentration
- RPI is recoverable
  - With no concentration change
- Normalizers can fail to correct for concentration
  - Magnetostatic interactions

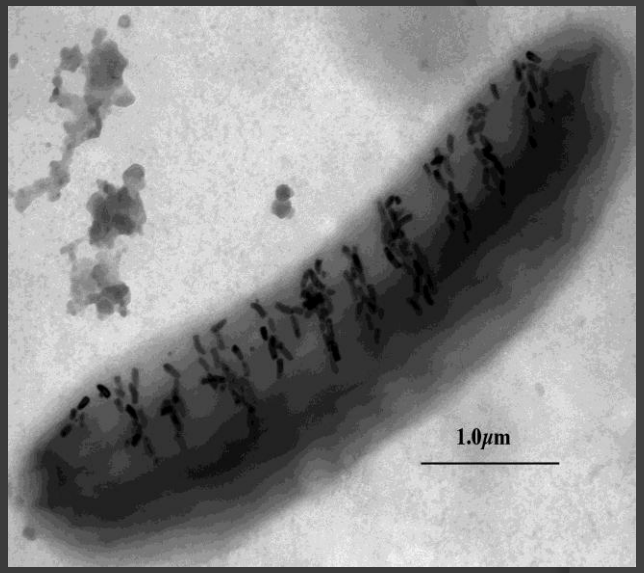
The future

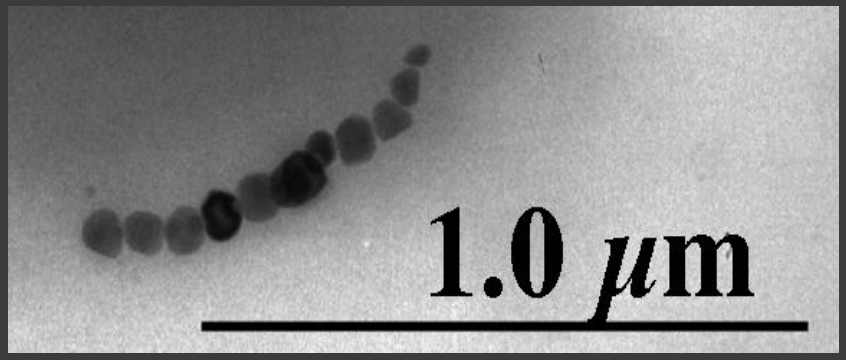
- Tip of the iceberg!
  - First-order behaviour
- More realistic experiments
- Numerical models?

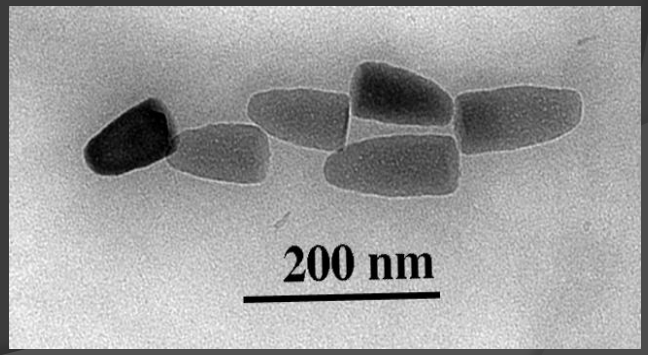
MTB are diverse





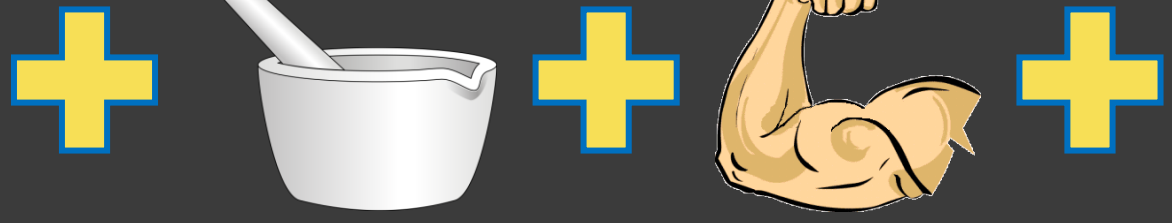
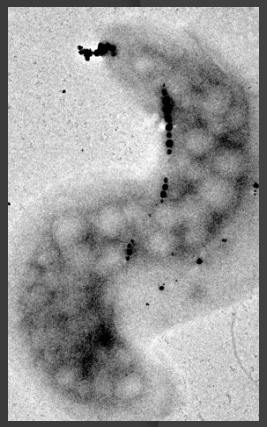






MTB are not alone!

- Always some mixing with detritus

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