The role of microorganisms in the bentonite barrier of high-level radioactive waste repositories

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M ND Microbiology In Nuclear waste Disposal
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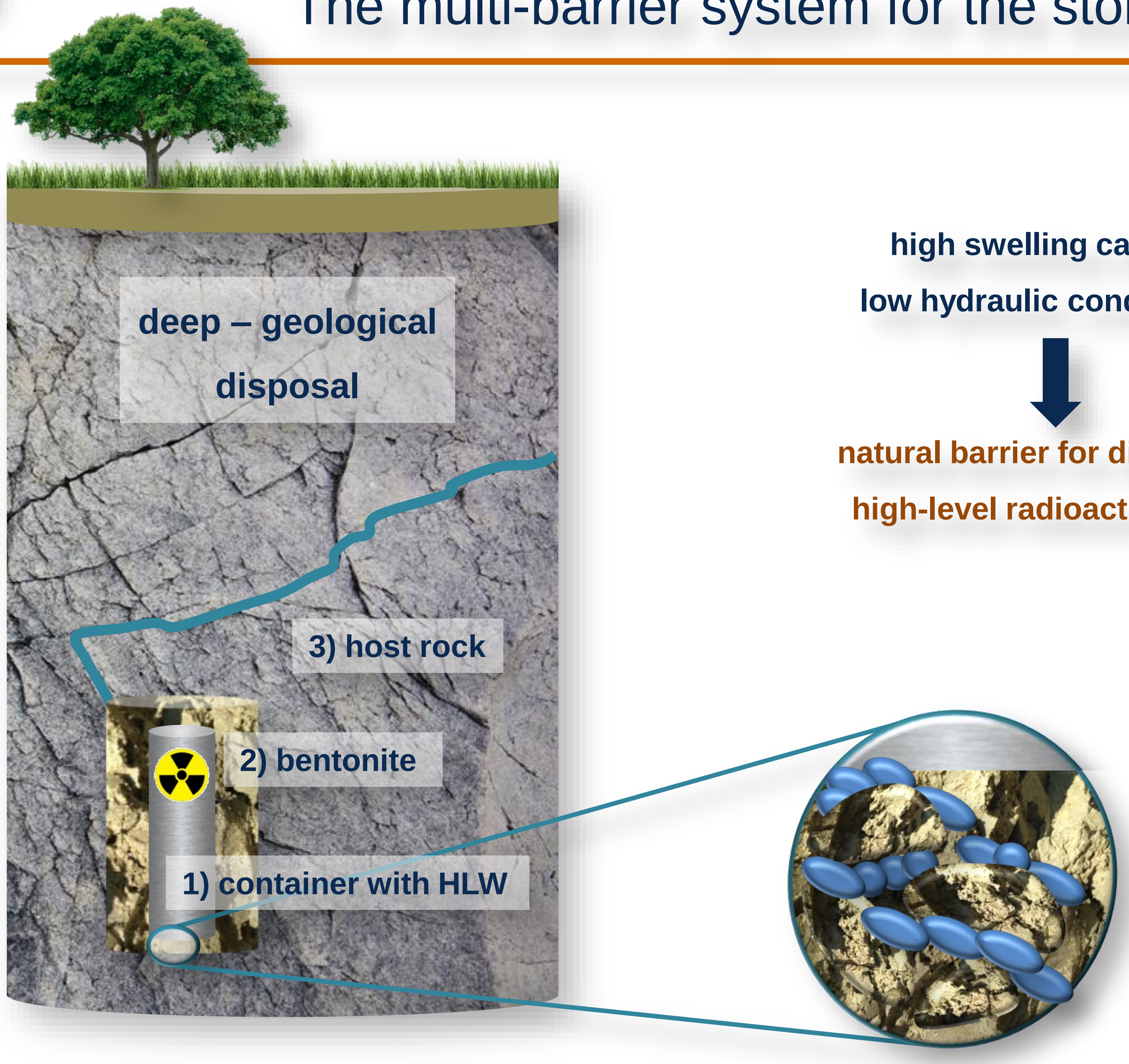
How to deal with all the waste?

We produce 300 million tonnes of toxic waste per year (poisonous chemicals, medical waste, coal dust)

- **97,000 tonnes of nuclear waste** (0.03 % of all toxic waste)
  - LLW (Low Level Waste)
  - ILW (Intermediate Level Waste)
  - HLW (High Level Waste) → **12,000 tonnes HLW (highly radiotoxic for 200,000 years!)**

[1] background modified from: http://sitn.hms.harvard.edu/flash/2018/looking-trash-can-nuclear-waste-management-united-states/

The multi-barrier system for the storage of HLW



high swelling capacity

low hydraulic conductivity

↓

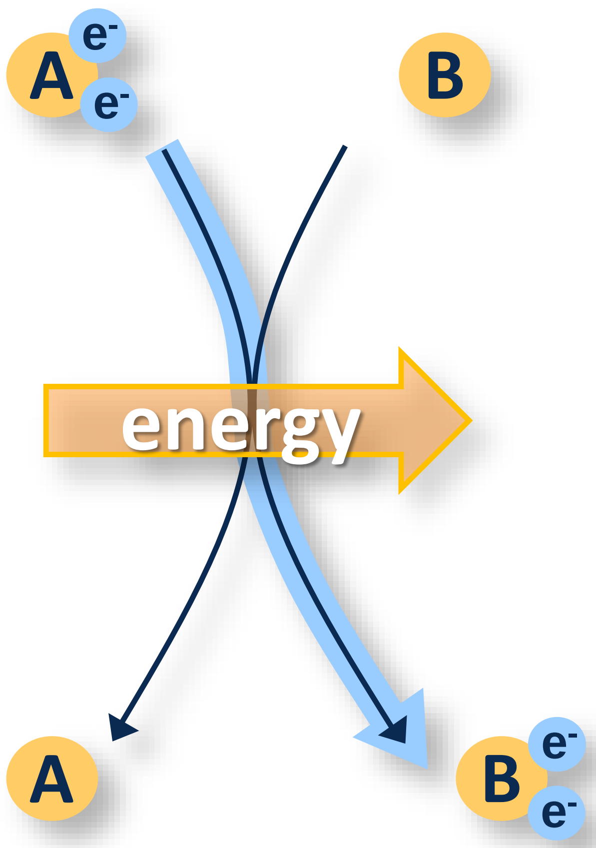
natural barrier for disposal of high-level radioactive waste

Active microorganisms at the interface in between the container and the bentonite?

Looking for life…

Life in simple words:

electron transport from an electron donor to an electron acceptor!



H_2O O_2 p C-source pH T

Thermodynamics

E_h

e⁻ donors in bentonites

organic C H_2 H_2S NH_4^+ Fe^{2+} Mn^{2+} CH_4 CO

e⁻ acceptors in bentonites

O_2 Mn^{4+} Fe^{3+} NO_3^- SO_4^{2-} S^0 CO_2

Formation of metabolites due to anaerobic, microbial metabolism

CH_4 H_2S H_2 CO_2

Fe^{2+}

organic acids

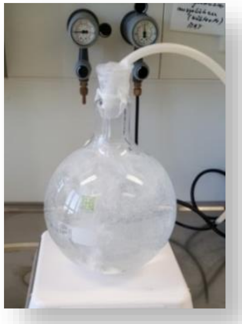
Properties of materials ?

Performance ?

A tiny, microbial world – microcosms

processed Bentonite[2]

+



anaerobic, synthetic pore water solution

Addition of energy-sources (Lactate, Acetate, Metals and/or H_2)

→

No additional inoculation of microorganisms

incubation of microcosms at defined temperatures

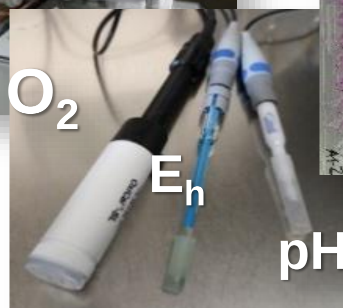
30° C	60° C
37° C	90° C

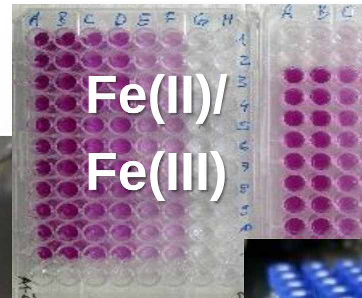
days/months/years

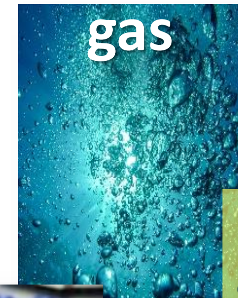
t_0 — t_1 — t_2 — t_3 — t_4 — t_5

[2]: Bentonite B25 powder was provided by Stephan Kaufhold (BGR, Hannover, Germany)

Analyzing microcosms

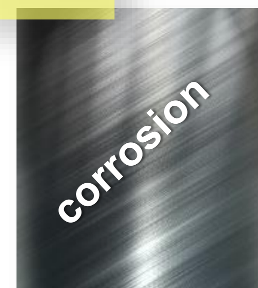




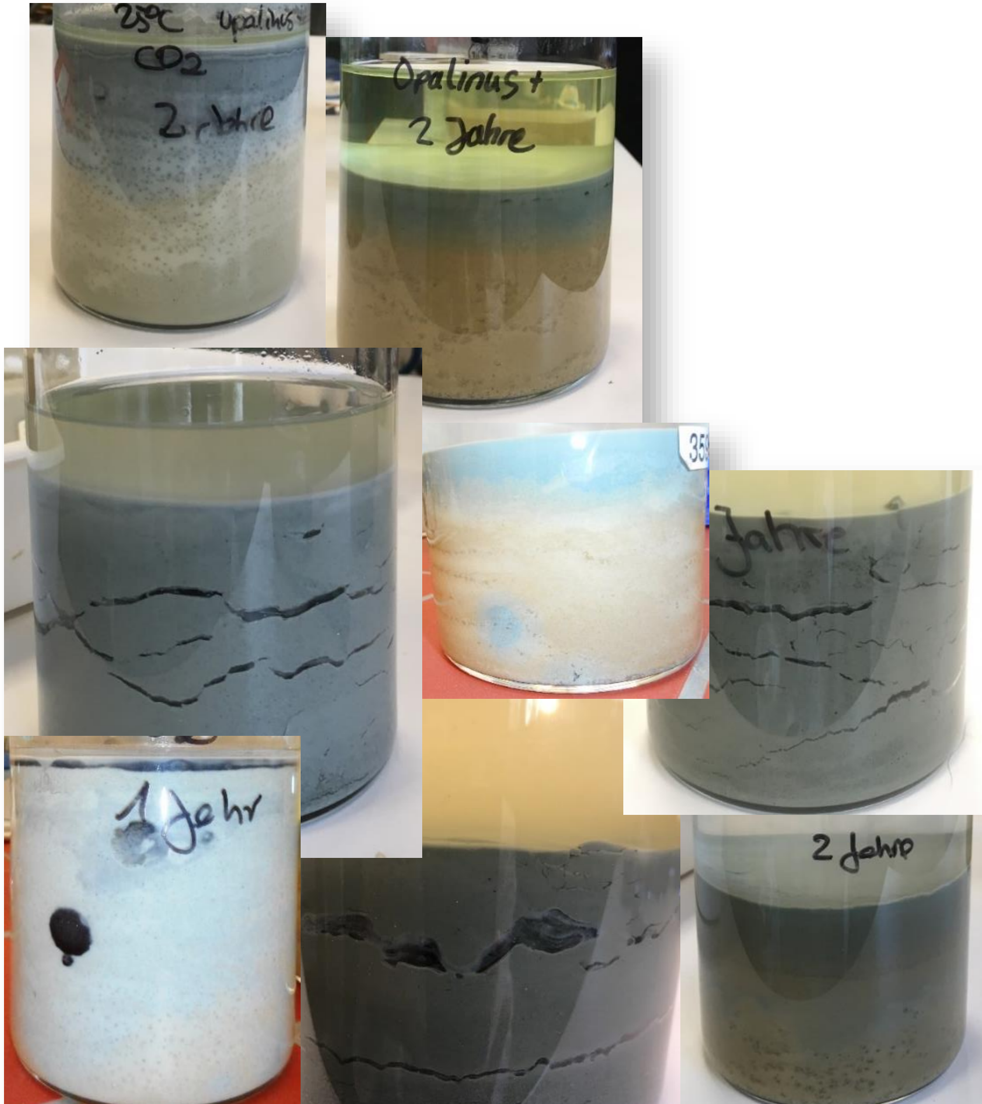


K Na
Mg Fe Cu
Ca Si

SO_4^{2-}



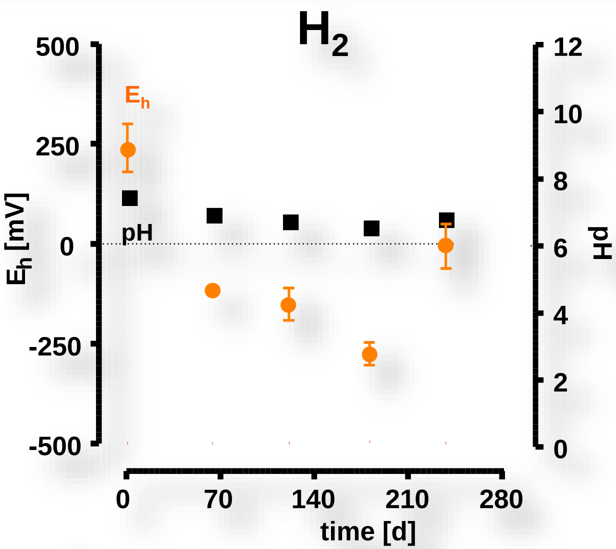
Somehow something happens…



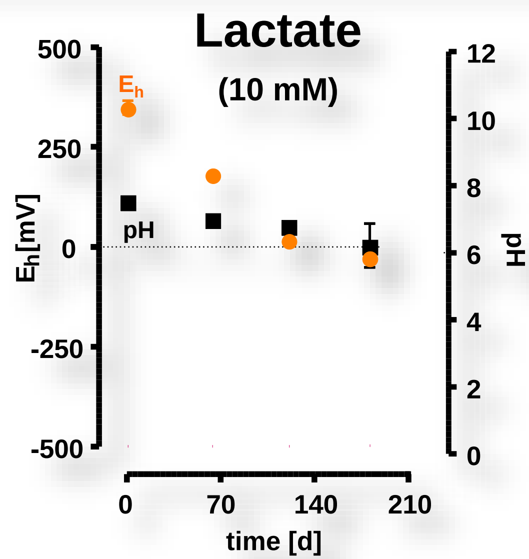
Formation of:
- Gases
- Fractures
- Precipitates

[3] Modified from Matschiavelli *et al.* 2019a, scientific report, HZDR-103

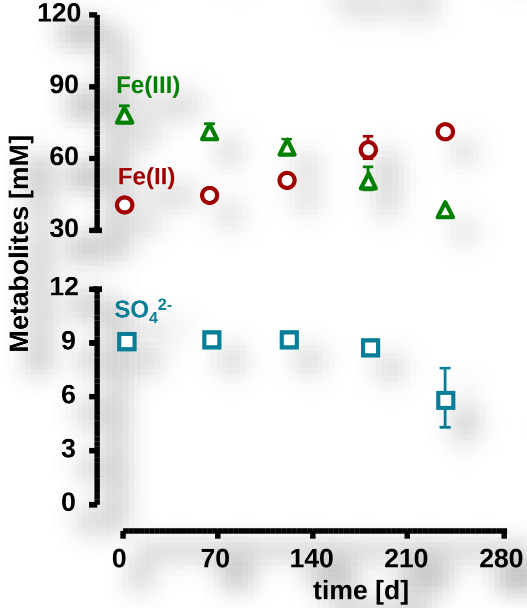
Analyses of geochemical parameters (30 °C)

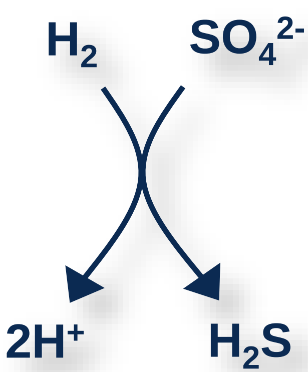


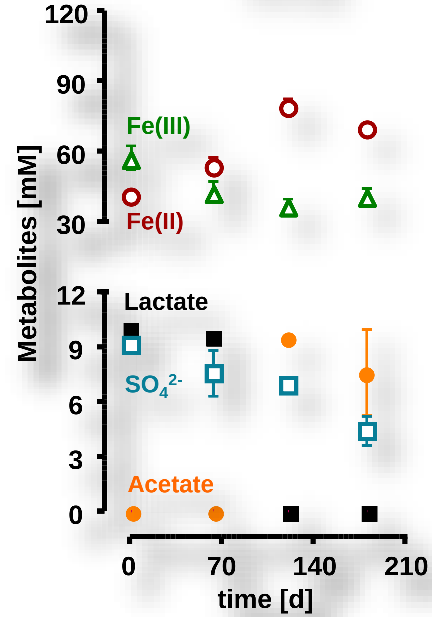
d = 238

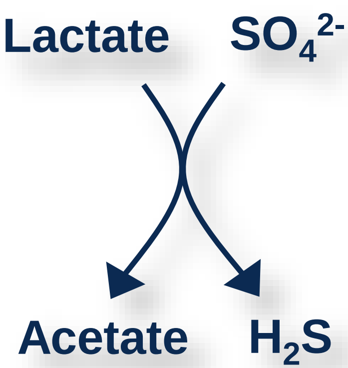


d = 181



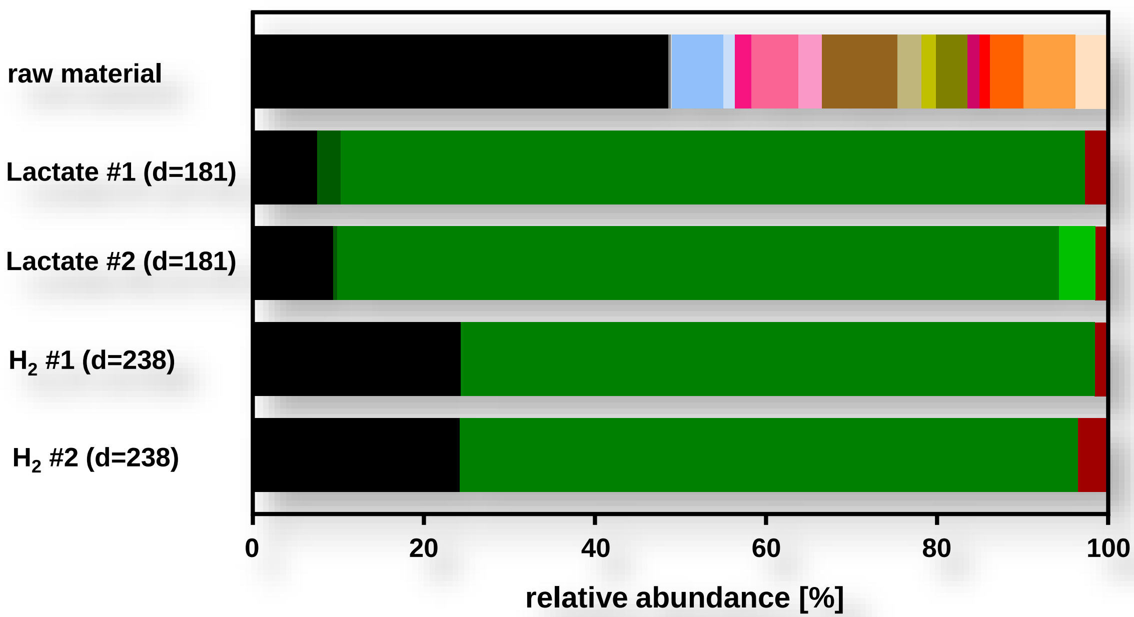


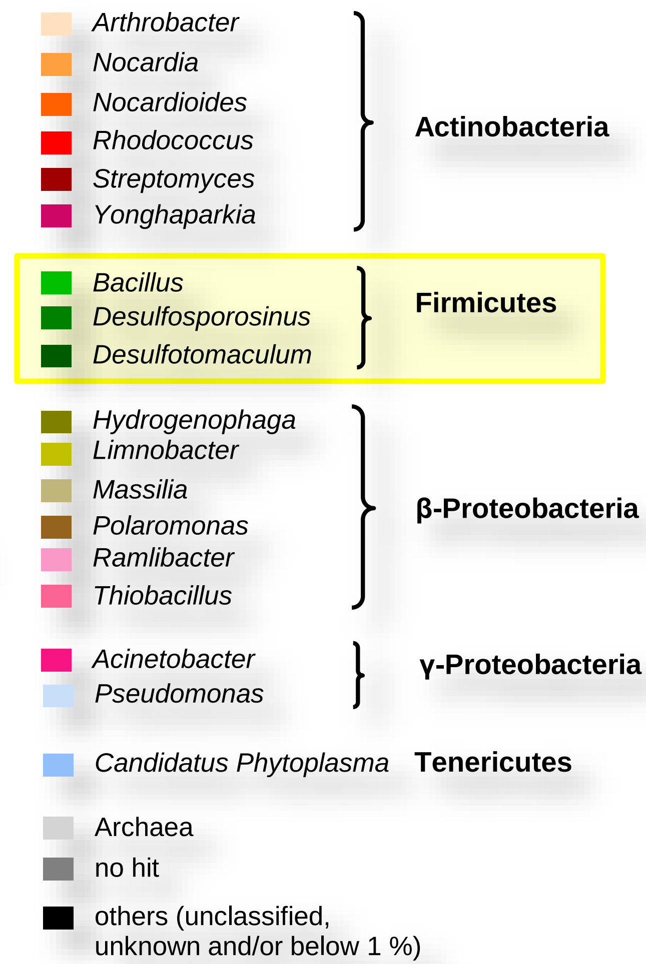




[4] Modified from Matschiavelli *et al.* 2019b, *Environ. Sci. Technol.* 53: 10514-10524

Analysis of microbial diversity (30 °C)





Dominance of spore-forming,

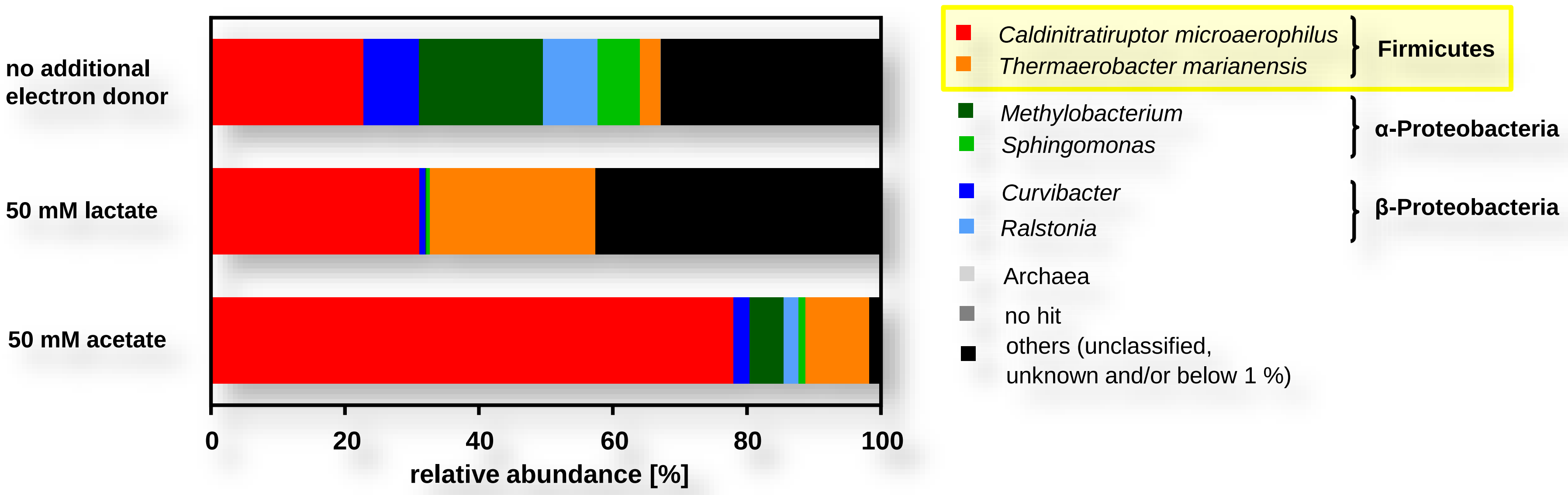
sulfate-reducing bacteria!

– resistant to harsh conditions for many years –

[4] Modified from Matschiavelli *et al.* 2019b, *Environ. Sci. Technol.* 53: 10514-10524

The relevance of thermophiles!?

Microbial diversity in bentonite microcosms after 323 days incubation at 60 °C



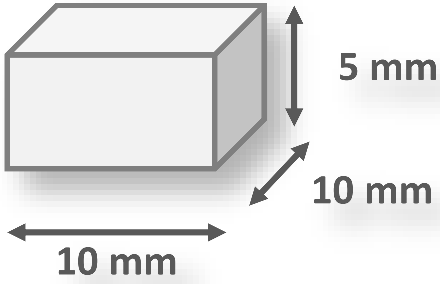
Thermophiles dominate, indepent from the presence of substrates!

Effect of metabolic activity on the tested materials?

[4] Modified from Matschiavelli *et al.* 2019b, *Environ. Sci. Technol.* 53: 10514-10524

Analyzing the microbial influence on canister materials (I)

cast iron **copper**



H_2

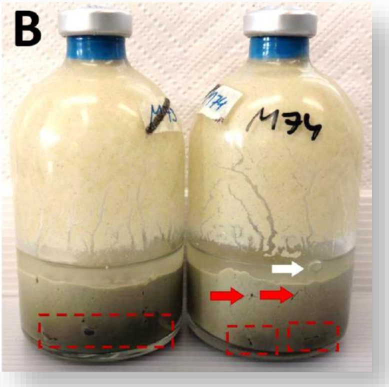
Lactate

Influence on corrosion?

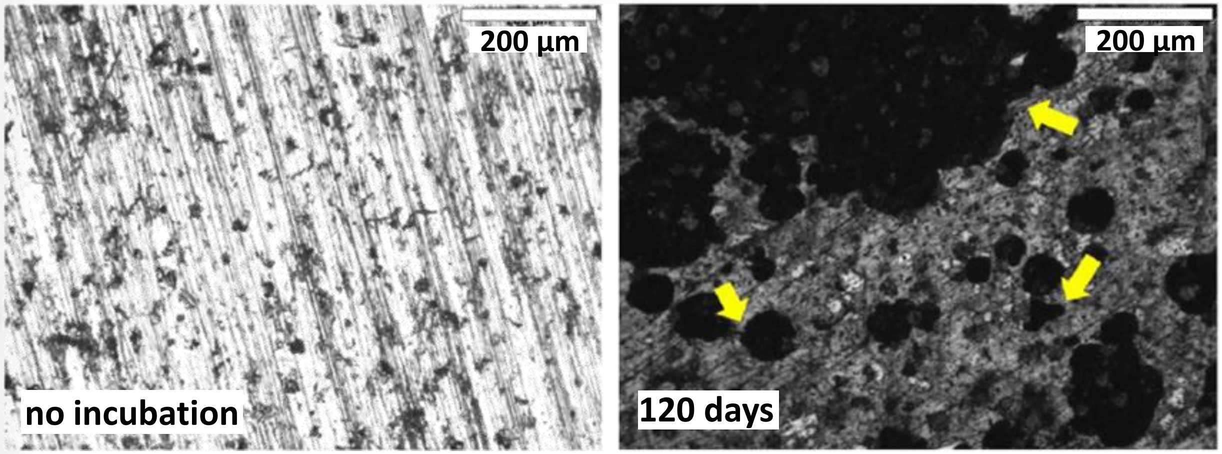
[5]: Cast iron and copper plates were provided by Artur Meleshyn (GRS, Braunschweig, Germany)

Analyzing the microbial influence on canister materials (II)

cast iron-containing bentonite microcosms



Incubated with H_2 for 30 days at 37 °C.



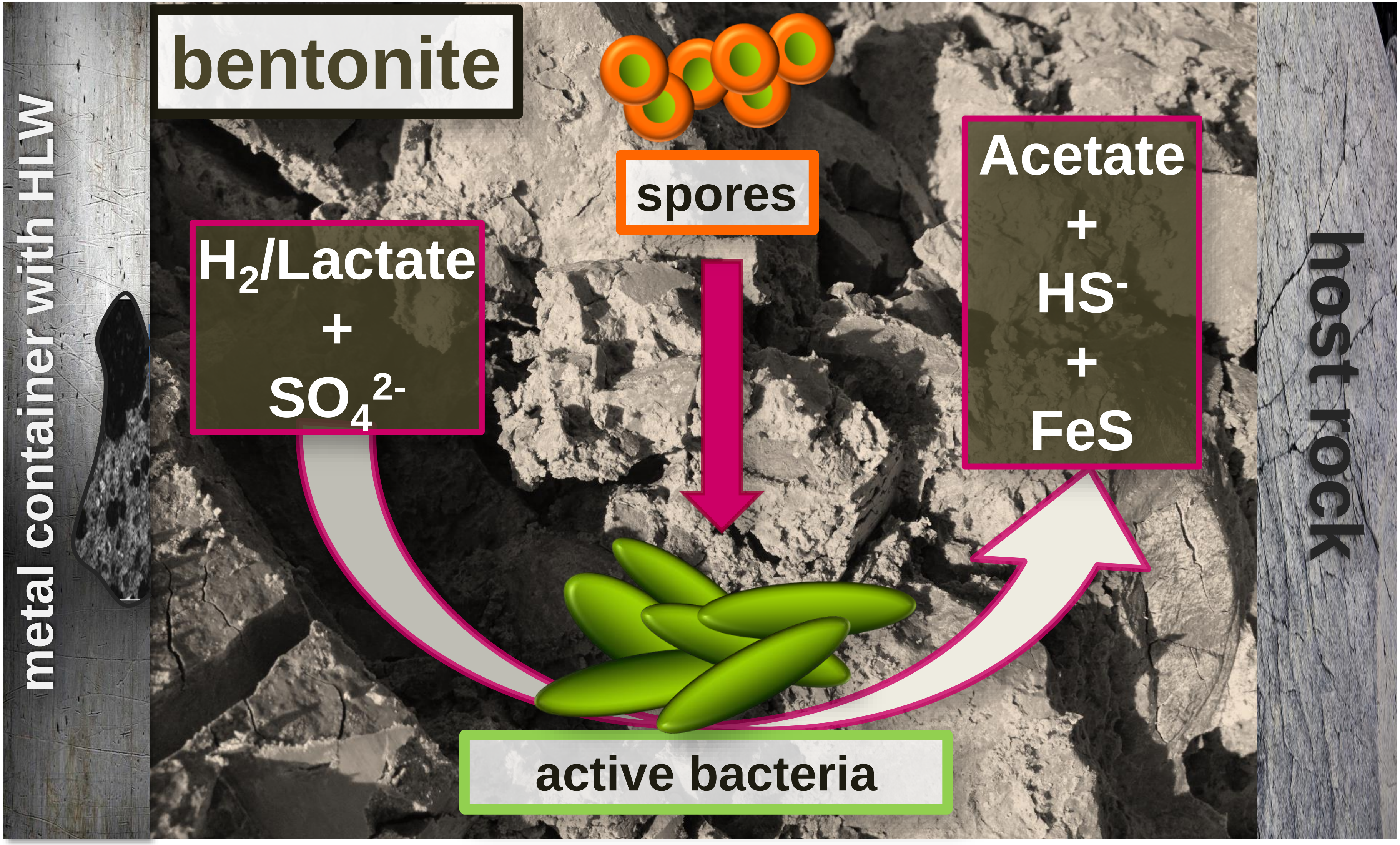
Light microscopic surface analysis of incubated cast iron plates

Isolation of new sulfate-reducing and spore-forming *Desulfotomaculum spec.* from cast iron containing microcosms.

Detailed analysis by introducing this bacterium into (heavy-) metal-containing microcosms

[6] Modified from Magdalena Dressler, Master`s thesis, University of Greifswald 2019

Summary



[4] Modified from Matschiavelli *et al.* 2019b, *Environ. Sci. Technol.* 53: 10514-10524

Thank You!

- Andrea Cherkouk
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