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

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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!)

The multi-barrier system for the storage of HLW

1) container with HLW

2) bentonite

3) host rock

- 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!
Thermodynamics

$E_h$

e$^-$ donors in bentonites

organic C  H$_2$  H$_2$S  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$_2$S  Fe$^{2+}$  organic acids

Properties of materials ?

Performance ?

$\text{H}_2\text{O}$  $\text{O}_2$  C-source  pH  T
A tiny, microbial world – microcosms

Addition of energy-sources
(Lactate, Acetate, Metals and/or H₂)

processed Bentonite

anaerobic, synthetic pore water solution

No additional inoculation of microorganisms

incubation of microcosms at defined temperatures

30°C  60°C
37°C  90°C

days/months/years

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

- **Oxygen (O₂)**
- **Redox potential (Eh)**
- **pH**
- **Iron (Fe(II)/Fe(III))**
- **Acetate/Lactate**
- **Gas**
- **Sulfate (SO₄²⁻)**
- **Corrosion**

Isolation of DNA and sequencing via MiSeq Illumina
Somehow something happens…

Formation of:
- Gases
- Fractures
- Precipitates

Analyses of geochemical parameters (30 °C)

**H₂**

- **Eₜ [mV]**
- **pH**

**Lactate** (10 mM)

- **Eₜ [mV]**
- **pH**

**Metabolites [mM]**

- **Fe(II)**
- **Fe(III)**
- **SO₄²⁻**
- **Acetate**
- **Lactate**

**H₂** ⇌ **SO₄²⁻**

2**H⁺** ⇌ **H₂S**

- **d = 238**
- **d = 181**

Analysis of microbial diversity (30 °C)

Dominance of spore-forming, sulfate-reducing bacteria!
– resistant to harsh conditions for many years –

The relevance of thermophiles!? 

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

Thermophiles dominate, independent from the presence of substrates! 
Effect of metabolic activity on the tested materials?

Analyzing the microbial influence on canister materials (I)

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

Influence on corrosion?

- Cast iron
- Copper
- Hydrogen ($H_2$)
- Lactate

$$
\begin{align*}
\text{Cast iron} & \quad \text{c} \\
\text{Copper} & \quad \text{c} \\
\text{Hydrogen} & \quad H_2 \\
\text{Lactate} & \quad \text{Lactate}
\end{align*}
$$
Analyzing the microbial influence on canister materials (II)

- Incubated with H\textsubscript{2} for 30 days at 37 °C.

- Cast iron-containing bentonite microcosms

- 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

Summary

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