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Microbial interactions with steel and bentonite

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Abstract

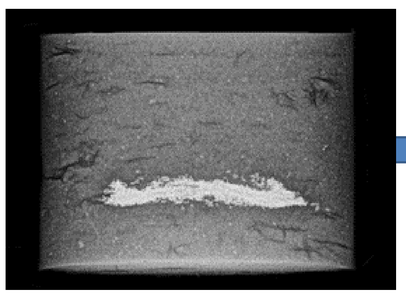
Microbial activity has been implicated in the corrosion of steel and alteration of bentonite clays used in geological disposal facilities for radioactive waste. To understand the limits on microbial growth, and the potential for microbial activity in this environment to affect the swelling behaviour of the bentonite and metal corrosion, a suite of laboratory experiments is being conducted. Experiments conducted in the MIND (Horizon2020) project have been designed to simulate in situ repository conditions by preparing compressed, hydrated bentonite samples (dry density 1200-1400 kg m^{-3}), with embedded steel. These samples were housed in a Constant Volume Axial Flow (CVAF) vessel. A hydraulic gradient was applied using two high pressure pumps. Preliminary results show evidence of corrosion in all experiments and XRD data show an increase in the basal spacings of smectites in the zone immediately surrounding the steel. SEM examination showed that samples inoculated with a sulphate reducing bacterial enrichment culture had evidence of calcium precipitation and calcite crystal formation, accompanied by differences in the iron phases.

These experiments simulate the in situ conditions well, but the complex nature of this experimental design reduces the practicality of performing many repeat experiments and varying the environmental conditions. Therefore, to complement these investigations, a low-tech solution has been implemented with unpressurised, hydrated bentonite batch experiments. The simpler nature of this set-up allows for investigation of more parameters. The freezing of fluid used in the MIND set-up was modelled and formed the basis of a groundwater representative of 'permafrost' conditions. The effect of incubation temperature is also being investigated. This combination of high- and low-tech investigations aims to provide insight into microbial behaviour under variable realistic conditions. Combined, these experiments will help to understand the influence of microbes in geological disposal facilities and how their behaviour may change by external parameters.

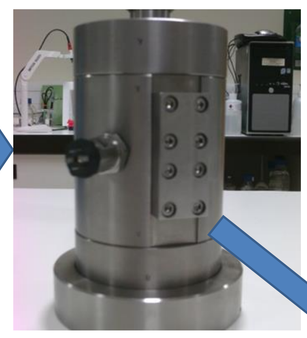
Methods

MIND. Compacted bentonite samples containing 5g steel filings near the inlet end were prepared and placed in a titanium constant volume axial flow cell (CVAF). After hydrating with groundwater at 1000 kPa for approximately 25 days, a hydraulic gradient was applied by increasing injection pressure to 2500 kPa, maintaining a 1000 kPa backpressure.

Batch. Bentonite mixed with fluid in 3 to 1 ratio by mass, left overnight to hydrate in anaerobic environment before filling containers. Steel was cleaned with 3% DECON 90 and acetone, weighed, sterilised by UV then placed upright in containers. Sacrificial experiments were assembled to monitor changes.



Steel embedded in compressed bentonite (50mm diameter, ~48 mm length)



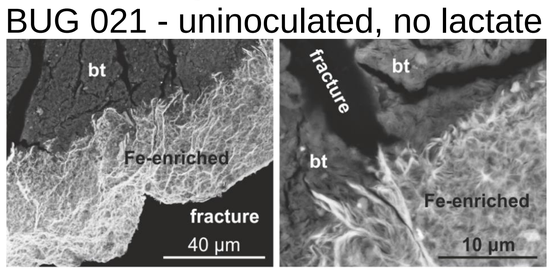
CVAF with radial and axial load cells

Incubator with MIND rig containing two HPLC pumps, sample holder and data logger

Condition	MIND experiments	Batch experiments
Steel	Unalloyed DH-SE21-14	Mild steel
Flow	Yes	No
Groundwater	Artificial 'Grimsel' groundwater (± lactate)	'Grimsel' and 'permafrost'
Dry density (kg m^{-3})	1200-1400	251-276
Clay	Bentonite (NAGRA)	Bentonite (NAGRA)
Duration (days)	147-152	180 (planned)
Temperature (°C)	35	4, 20, 35 and 50
Uninoculated / inoculated	Gamma irradiated / enriched inoculum	Gamma irradiated / natural community

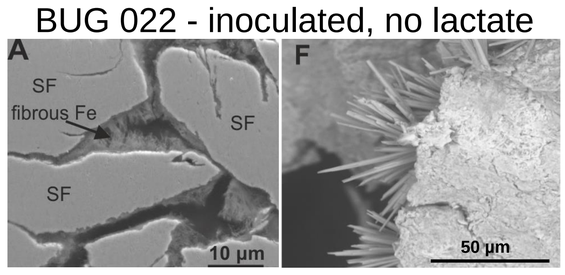
Preliminary results

BUG 021 - uninoculated, no lactate



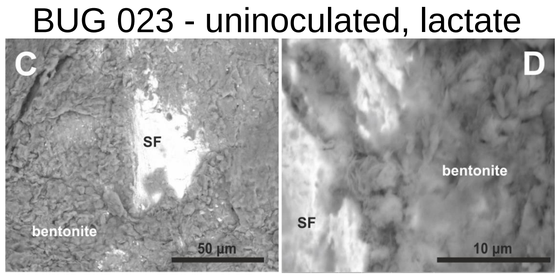
Iron enrichment, no aragonite

BUG 022 - inoculated, no lactate



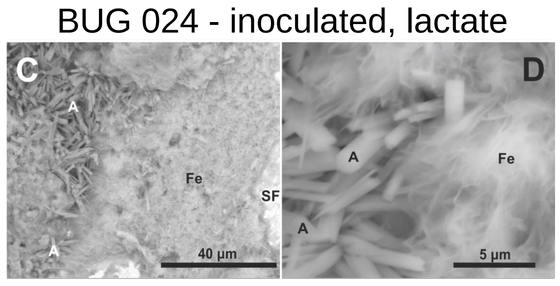
Iron coating around steel filings and aragonite

BUG 023 - uninoculated, lactate



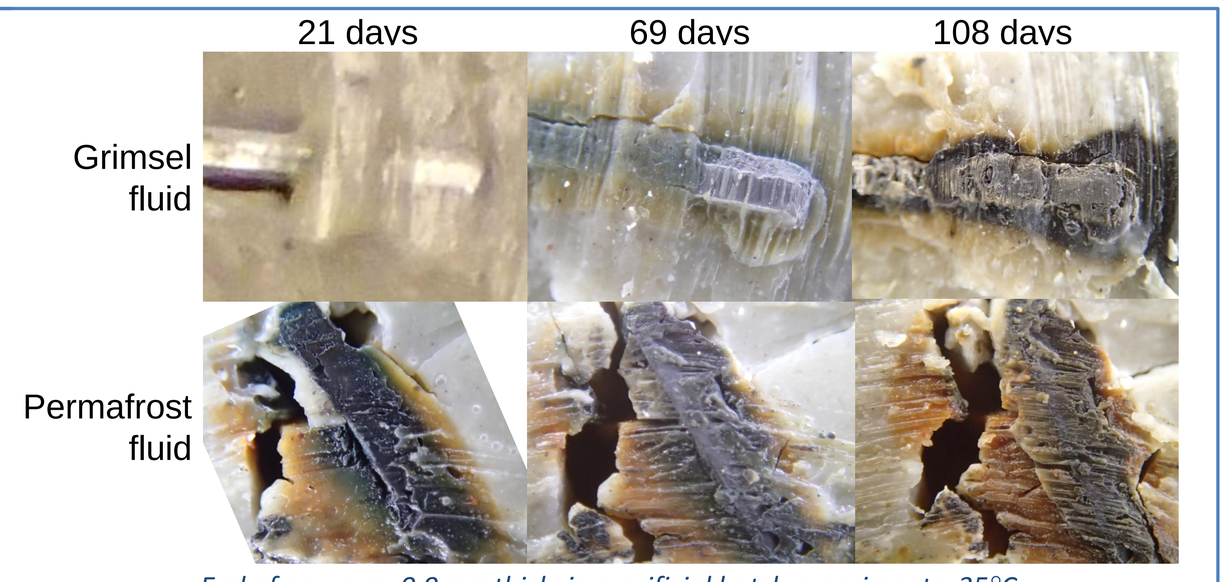
No visible iron alteration, no aragonite

BUG 024 - inoculated, lactate



Iron-rich coating over acicular aragonite

A – aragonite, bt – bentonite, SF – steel filings



End of coupons, 0.9mm thick, in sacrificial batch experiments, 35°C.

MIND. SEM analysis shows differences in iron alteration products and the presence of acicular calcium carbonate growth in inoculated experiment.

X-ray diffraction data suggest a change from monovalent to divalent interlayer cations around steel. A small increase in spacing were seen in uninoculated over inoculated experiments (no lactate pair).

Batch. Visible discolouration of bentonite from black close to steel, transitioning to green then to red. Discolouration was seen earlier in permafrost fluid. Visible striations are due to untwisting of lid.

Future

MIND. A pair of lower density experiments (completed not analysed), repeat of lactate amended 1400 kg m^{-3} experiment with steel placed nearer the radial load cells.

Test for microbial abundance and diversity on DNA extracts.

Batch. Disassemble experiments test steel for corrosion products and bentonite for pore fluid composition (iron and nitrogen speciation), microbial diversity, surface area and swelling capacity.

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