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SMECTITE FREE SWELLING AND EROSION IN ARTIFICIAL FRACTURES

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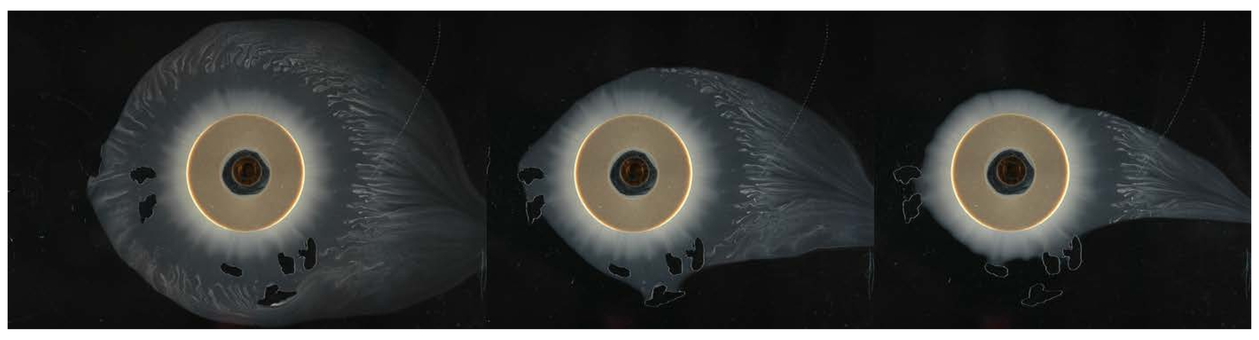
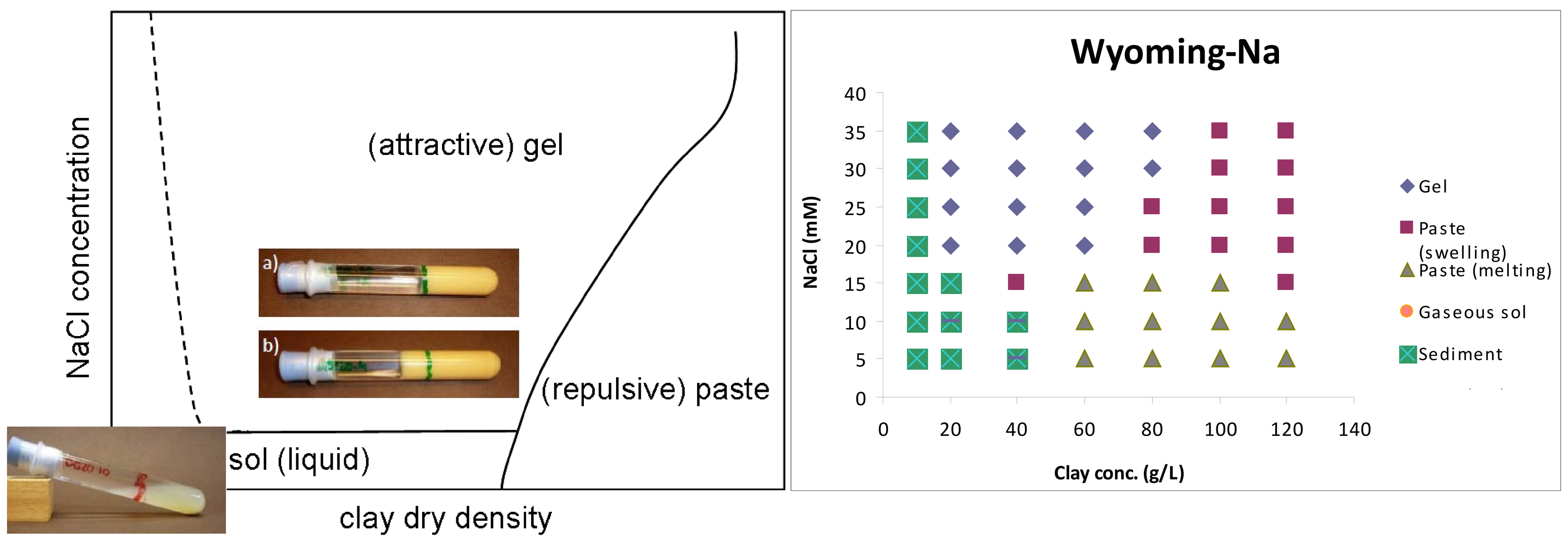
Introduction

One scenario of interest for the long-term safety assessment of a spent nuclear fuel repository involves the loss of bentonite buffer material through contact with dilute groundwater at a transmissive fracture interface (SKB 2011, Posiva 2012). In dilute water, sodium dominated montmorillonite is known to form a colloidal sol which would easily be transported away with flow.



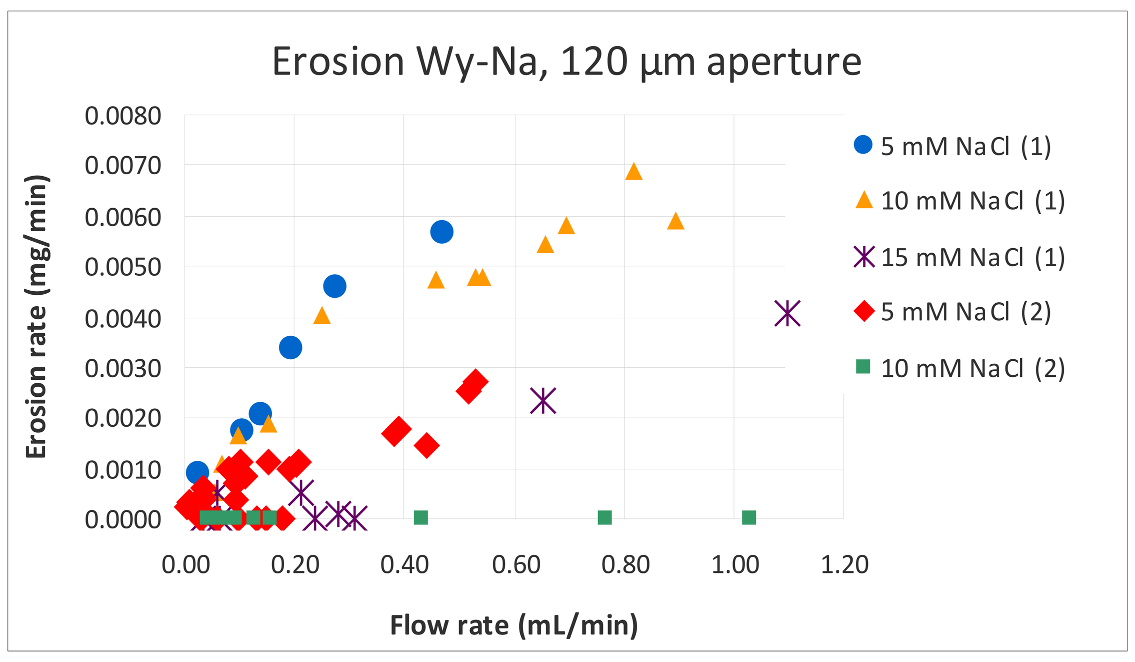
Top view of Na-montmorillonite in 0.12 mm artificial fracture, clearly showing erosion of the sol phase after 30 days of swelling in stagnant DI water. The sol is liquid, while the repulsive paste has solid character and a yield strength that can withstand the mechanical forces from the flowing solution (Eriksson & Schatz 2015). The flow does not mechanically erode the repulsive paste, rather it is mass transfer from paste to sol that determines erosion.

Montmorillonite phase diagram



Schematic (left) and actual (right) state/phase diagrams of Na-montmorillonite.
Rotating vane rheometry shows that the gels have yield strength that will withstand the shear forces from the flowing solution (Nilsson & Hedström 2016). Erosion stops in artificial fracture tests (Wy-Na) when the NaCl concentration is increased to 20 mM.

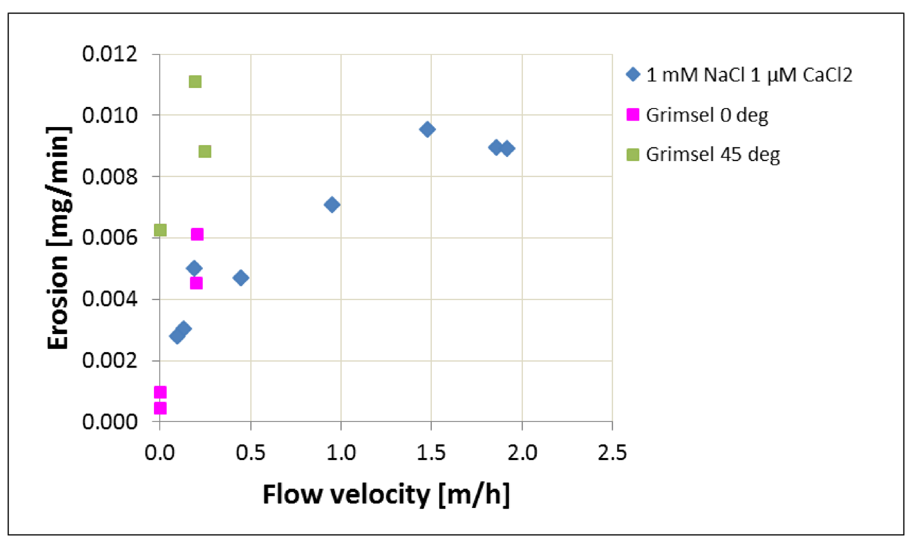
Hysteresis



Erosion rates vs. flow rate.
(1) Increasing [NaCl]
(2) After reaching 20 mM NaCl concentration was decreased

Evidently there is a strong hysteresis related to the ionic strength changes. Note that at 10 mM (2) no erosion is detected as opposed to 10 mM (1).

Erosion in 45° sloped fractures



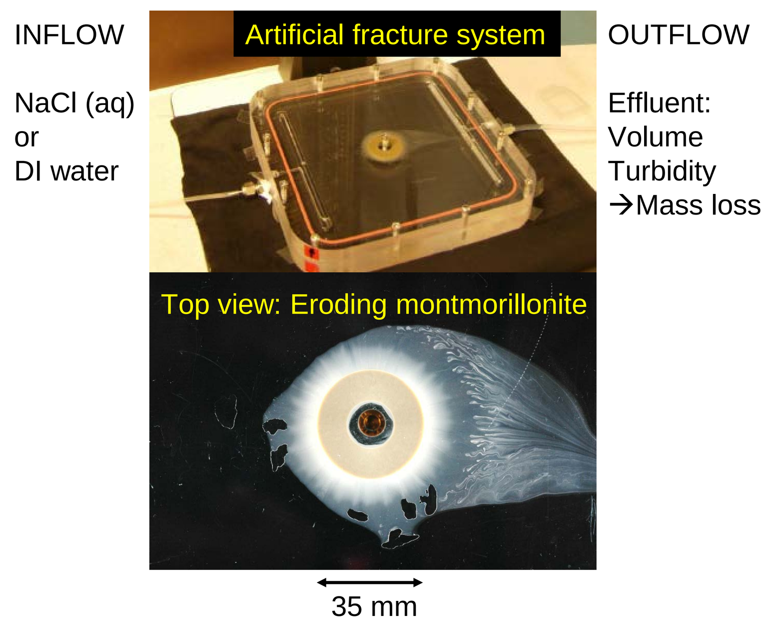
Grimsel: 0.7 mM NaCl, 0.14 mM $CaCl_2$
At no flow the erosion rate in a sloped fracture corresponds to a unit erosion rate of 170 kg/(m²·year).

Experimental details: Artificial fracture system

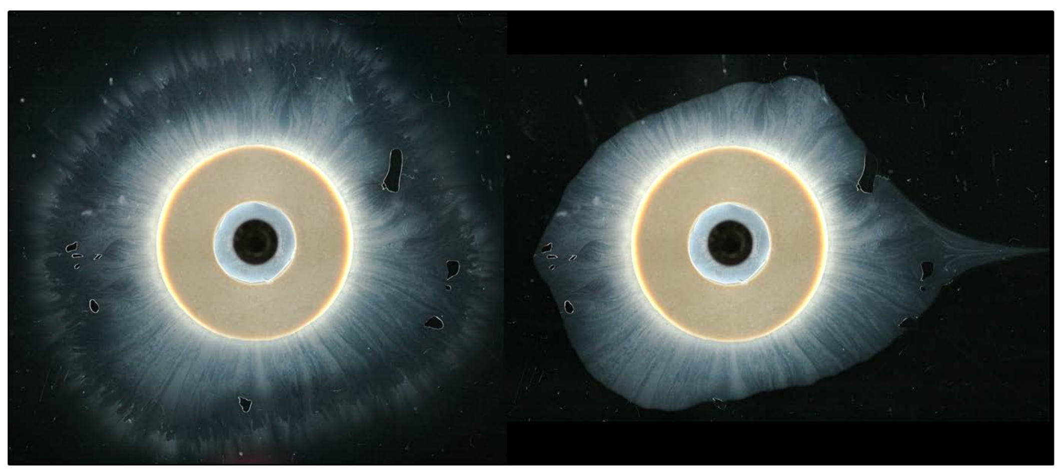
Extrusion/erosion behaviour of montmorillonite under dilute water conditions was studied using small-scale flow-through artificial fractures. The lateral dimensions of the fracture are 20 cm × 20 cm and the aperture is 0.12 or 0.24 mm. The compacted sample dimensions were 1 cm (height) × 3.5 cm (diameter) The montmorillonite dry density in the compacted sample was initially ~1260kg/m³.

Homoionic Wy-Na or mixed 50/50 Ca/Na-montmorillonite extracted from MX-80 was investigated.

Clay mass loss was determined from turbidity of effluent.



Concentration of erodible clay phase (Wy-Ca/Na 50/50)



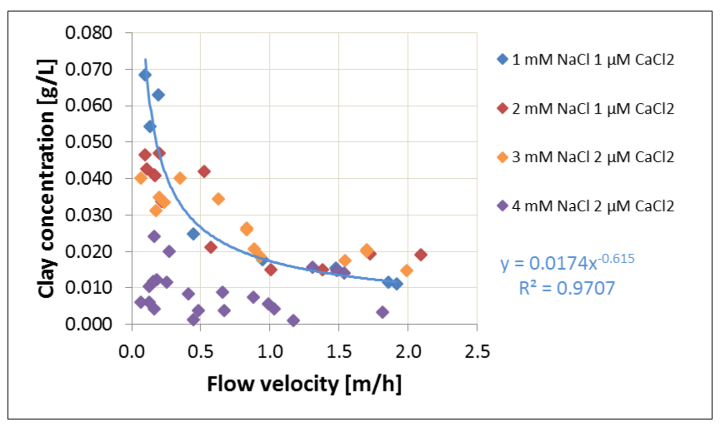
Free swelling 6.75 days After flushing DI water during 14 min

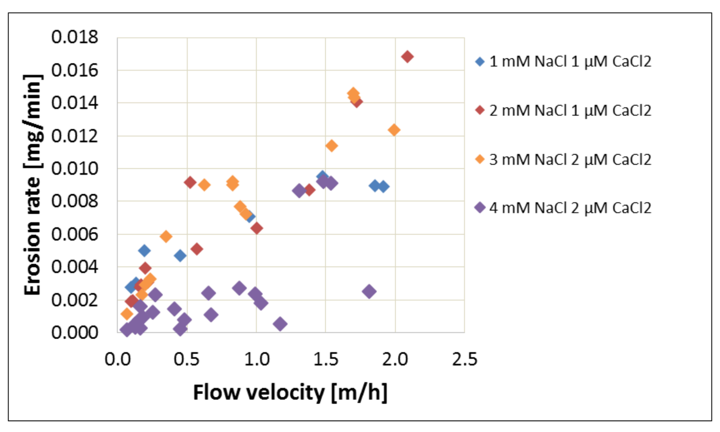
Area difference *aperture
→volume change
Turbidity of effluent → clay mass

Concentration of erodible phase ~30g/l (31, 32 and 34 g/l)

28g/l: yield stress 14 mPa (Eriksson & Schatz 2015)

Erosion of Wy-Ca/Na 50/50 at ionic strengths 1 to 4 mM





Erosion rates at 4 mM are substantially lower than the rates at 1 mM in agreement with earlier findings in Birgersson et al. 2009 and Schatz et al. 2013. Unit erosion rate for 1 mM case at lowest flow velocity is 65 kg/(m²·year) while at 4 mM the erosion rate is almost an order of magnitude smaller.

The clay concentration in the effluent is several order of magnitude lower than the estimated concentration of the erodible phase (30g/l). This is a dilution effect: most of the flow is not in contact with the clay.

Summary

Erosion does not occur when salinity is high enough to cause gel formation.
Erosion rates at salinity below 4 mM may cause large loss of bentonite buffer.
In a sloped fracture the unit erosion rate of 170 kg/(m²·year) translates to 500 kg over a 10 000 year period assuming an aperture of 50 μm and a 2 m deposition hole diameter.

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