

Bentonite Erosion

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Buffer Erosion

- Severe erosion of the buffer could cause the buffer not to fulfil its safety functions
 - e.g., bulk hydraulic conductivity could increase above $1\text{E-}12$ m/s
- This could allow increased sulphide transport to the canister, which could cause more rapid canister corrosion, leading to canister failure
- Sustained mass-loss and lowering of buffer density may also cause canisters to sink to the bottom of their emplacement holes
- The key driving forces are water inflow rates and hydraulic pressure gradients (water and gas)

Objectives

- Contribute to an evaluation of SKB's reporting of experimental studies on the chemical erosion of the bentonite buffer
- This will include considering SKB's experimental conditions, the experimental set-up and the interpretation of the experimental results
- The consistency between the experimental results and the theoretical models should also be evaluated

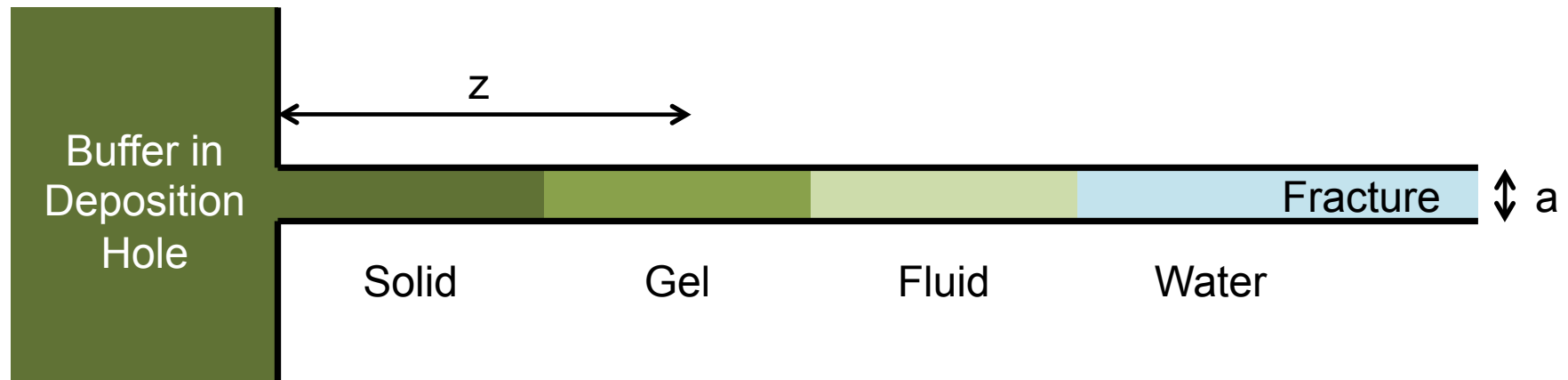
Main Documents Examined

- Jansson (2009) **Bentonite Erosion. Laboratory Studies**, KTH.
- Neretnieks (2009) **Some Scoping Erosion Experiments in Thin Slits Between Glass Plates**, KTH.
- Birgersson *et al.* (2009) **Bentonite Erosion. Final Report from Clay Technology**, Clay Technology.
- Neretnieks *et al.* (2009) **Mechanisms and Models for Bentonite Erosion**, KTH.

Other References Examined

- Liu *et al.* (2009) A Novel Approach to Determine the Critical Coagulation Concentration of a Colloidal Dispersion with Plate-Like Particles, *Langmuir* 25, 688-697.
- Pettersson *et al.* (2009) AFM Study of Montmorillonite, KTH.
- Jönsson *et al.* (2009) Structure and Forces in Bentonite MX-80, SKB TR-09-06.
- Liu *et al.* (2008) A Dynamic Force Balance Model for Colloidal Expansion and its DVLO-Based Application, *Langmuir* in press.
- Liu and Neretnieks (2008) Homo-interaction Between Parallel Plates at Constant Charge. *Colloids and Surfaces A: Physiochem. Eng. Aspects* 317, 636-642.
- Richards (2008) Particle Clogging in Porous Media Filtration of a Smectite Solution, Chalmers University of Technology.
- Liu *et al.* (2007) Interaction Between Colloidal Particles. Literature Review. RIT.

Clay Technology Conceptual Model



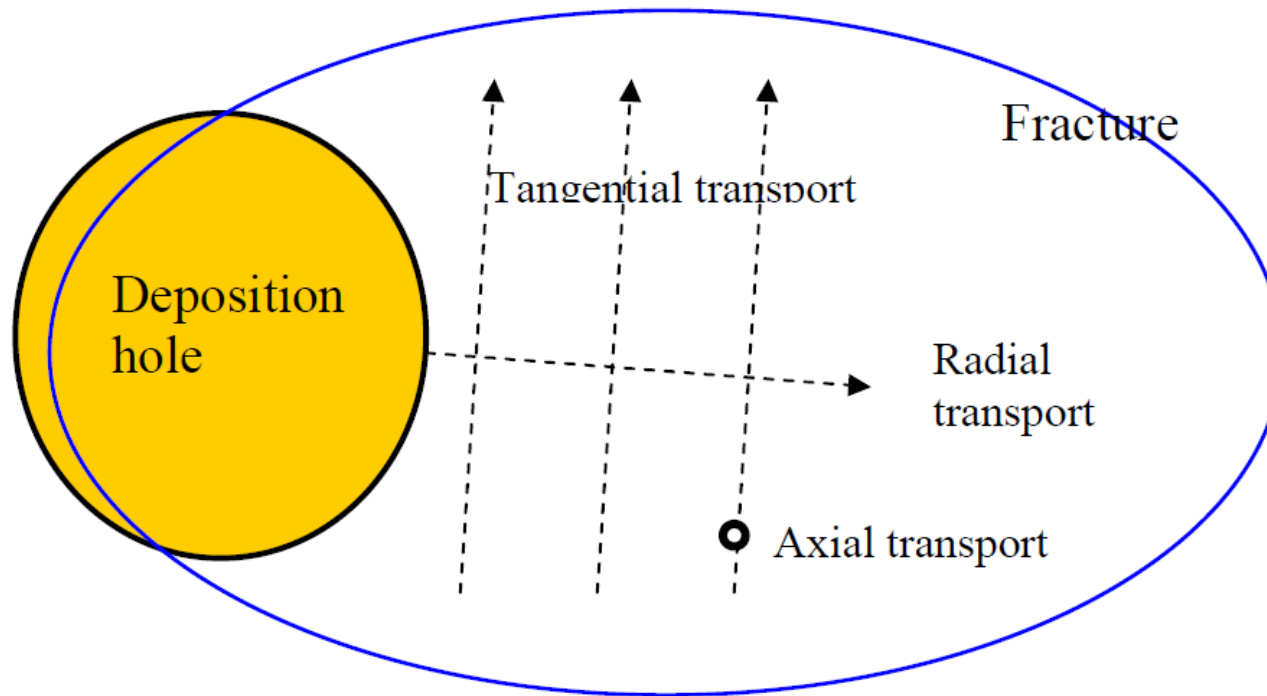
$$\sigma = \sigma_1 \cdot e^{-2 \tan \phi (z/a)}$$

Swelling pressure in fracture at distance z

Swelling pressure in deposition hole

Friction angle at fracture surface

Clay Technology Conceptual Model

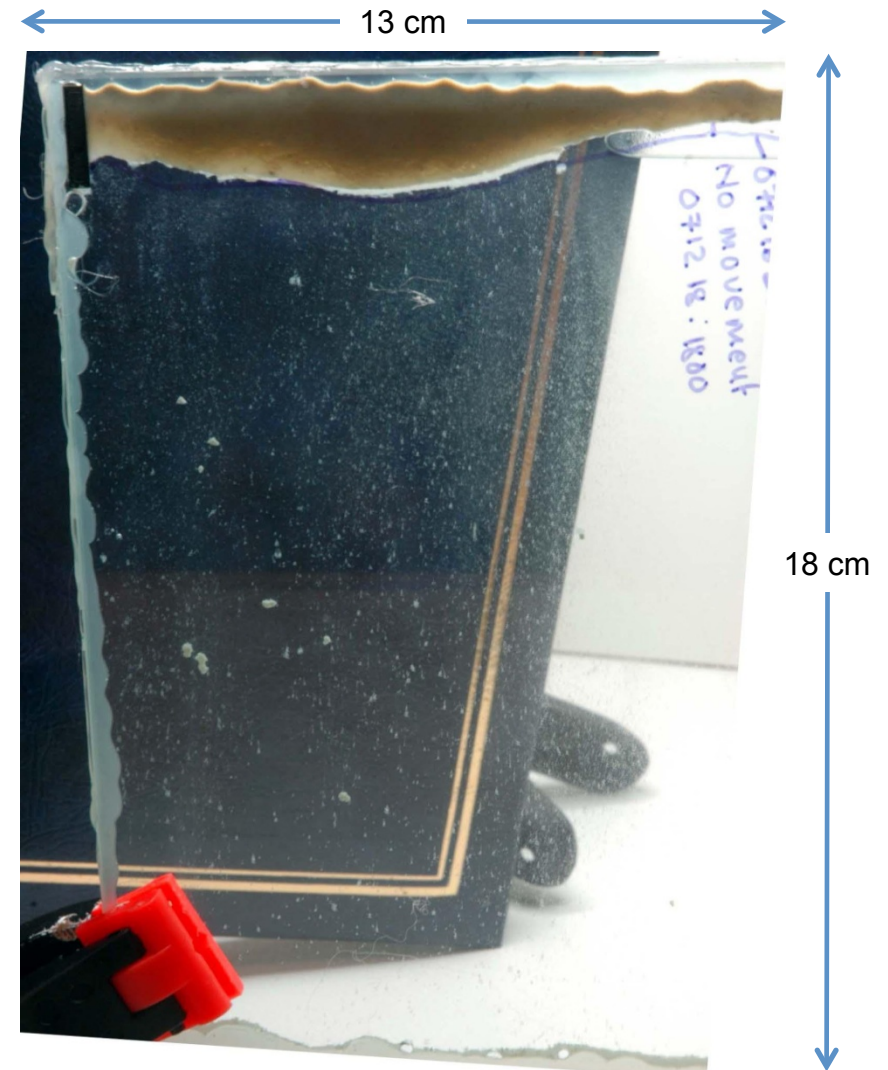


Summary & Evaluation of Relevant Experiments

- The key area of interest is if and how bentonite from the buffer moves into and subsequently behaves in fractures
- Key experiments:
 - Neretnieks (2009) Glass Slit Tests
 - Jansson (2009) Artificial Fracture Tests
 - Birgersson et al (2009) Erosion Tests

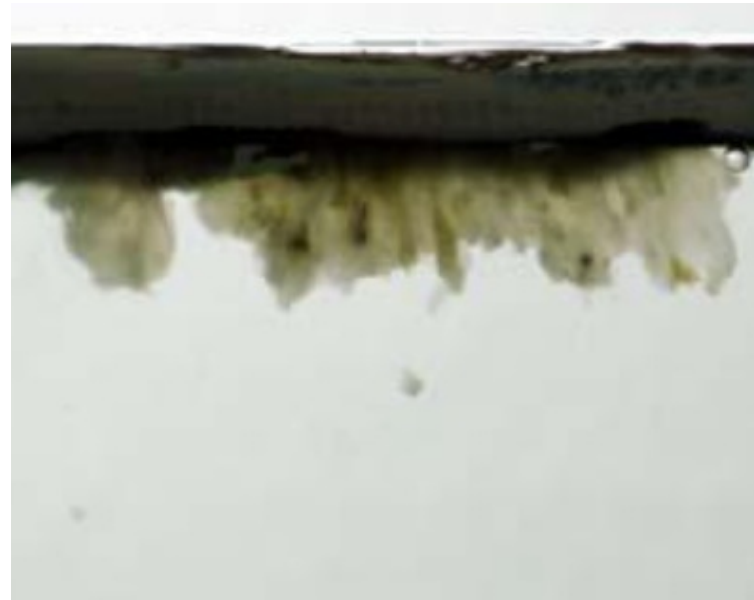
Neretnieks (2009) Glass Slits

- Bentonite in vertical glass slits
 - 1.3 mm aperture
 - Bentonite initially added as a layer at the bottom of the fracture, allowed to settle and swell, and then inverted
- Four clay materials used:
 - Untreated MX-80
 - MX-80 no gypsum
 - Na-MX-80 no accessory minerals
 - Ca-MX-80 no accessory minerals



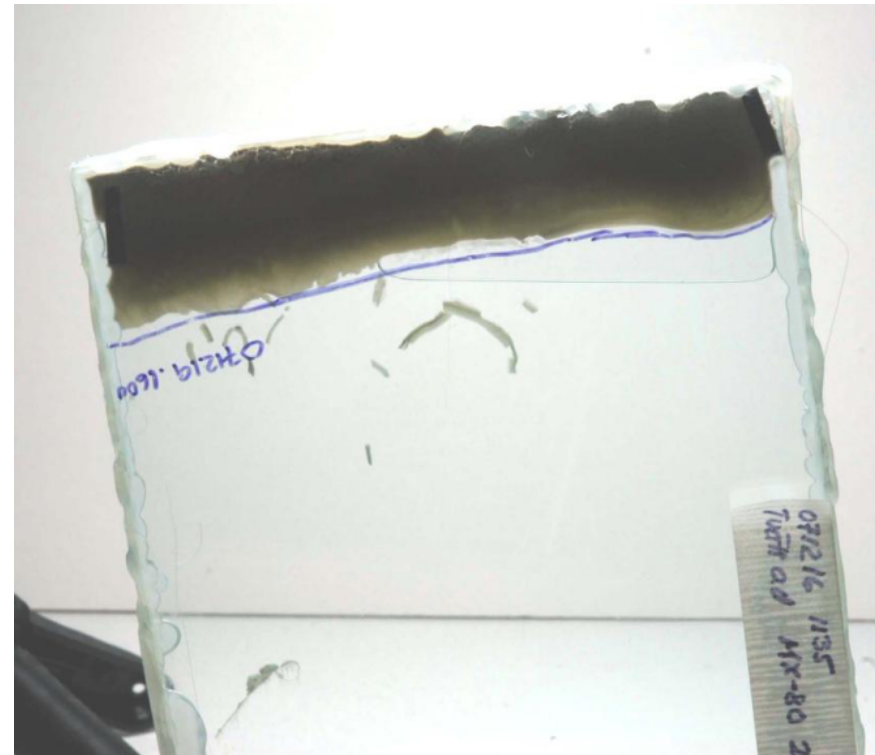
Neretnieks (2009) Glass Slits

- Untreated MX-80
 - Below the CCC, bentonite gel can be pulled apart by gravity to form blobs with enclosed accessory minerals - these sediment downward in the narrow slit
 - Large blobs, which span the aperture of the slit, are retarded by friction on the walls; small blobs sediment rapidly
 - The dimensions of the slit influence the formation of the gel blobs and their sedimentation rate



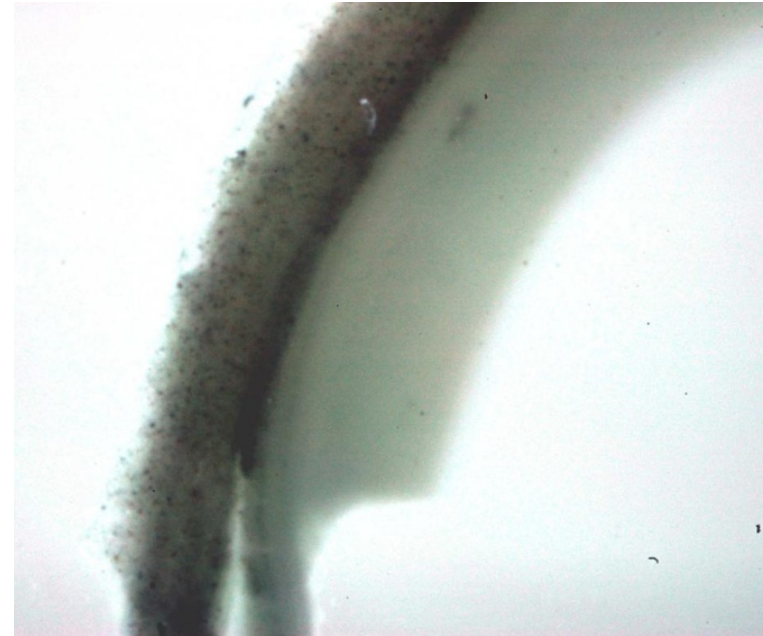
Neretnieks (2009) Glass Slits

- MX-80 washed to remove gypsum
 - Washing removes gypsum and clay, and yields a material with a relatively high concentration of accessory minerals
 - The washed material does not rapidly disintegrate into a stable sol, even if the porewater concentration is below the CCC
 - But blobs and ‘worms’ of gel can be pulled apart by gravity and sediment downwards



Neretnieks (2009) Glass Slits

- MX-80 washed to remove gypsum (cont.)
 - *“The outer rim of the swollen gel can separate into a clear, thin gel and a more concentrated gel containing the detritus material Neretnieks (2009)”*



- *“A tentative interpretation is that as the gel expanded upwards the detritus material expands with it, but near the edge where the gel density had decreased the smectite particles could move independently of the detritus leaving it behind. In this case, half a mm thick region of more concentrated detritus remained forming a potential filter cake. (Neretnieks et al. 2009)”*

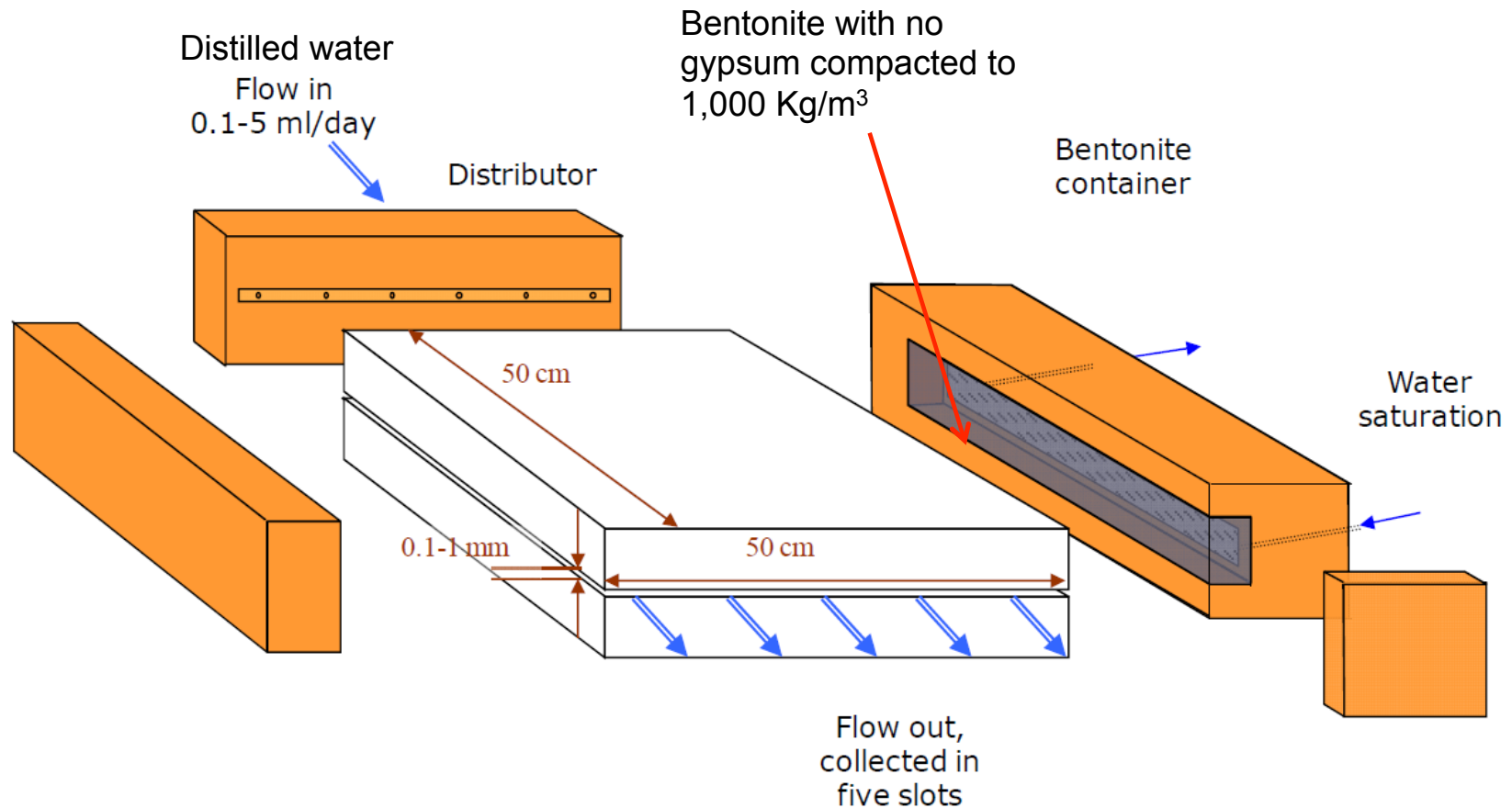
Neretnieks (2009) Glass Slits

- Na-MX-80 no accessory minerals
 - Experiments failed because of leaks and air bubbles
 - Also anomalous Ca concentrations
- Ca-MX-80 no accessory minerals
 - Water concentrations close to CCC (~1 mM Ca)
 - Aggregation seen
 - Settling of clay aggregates

Evaluation of Neretnieks (2009) Glass Slits

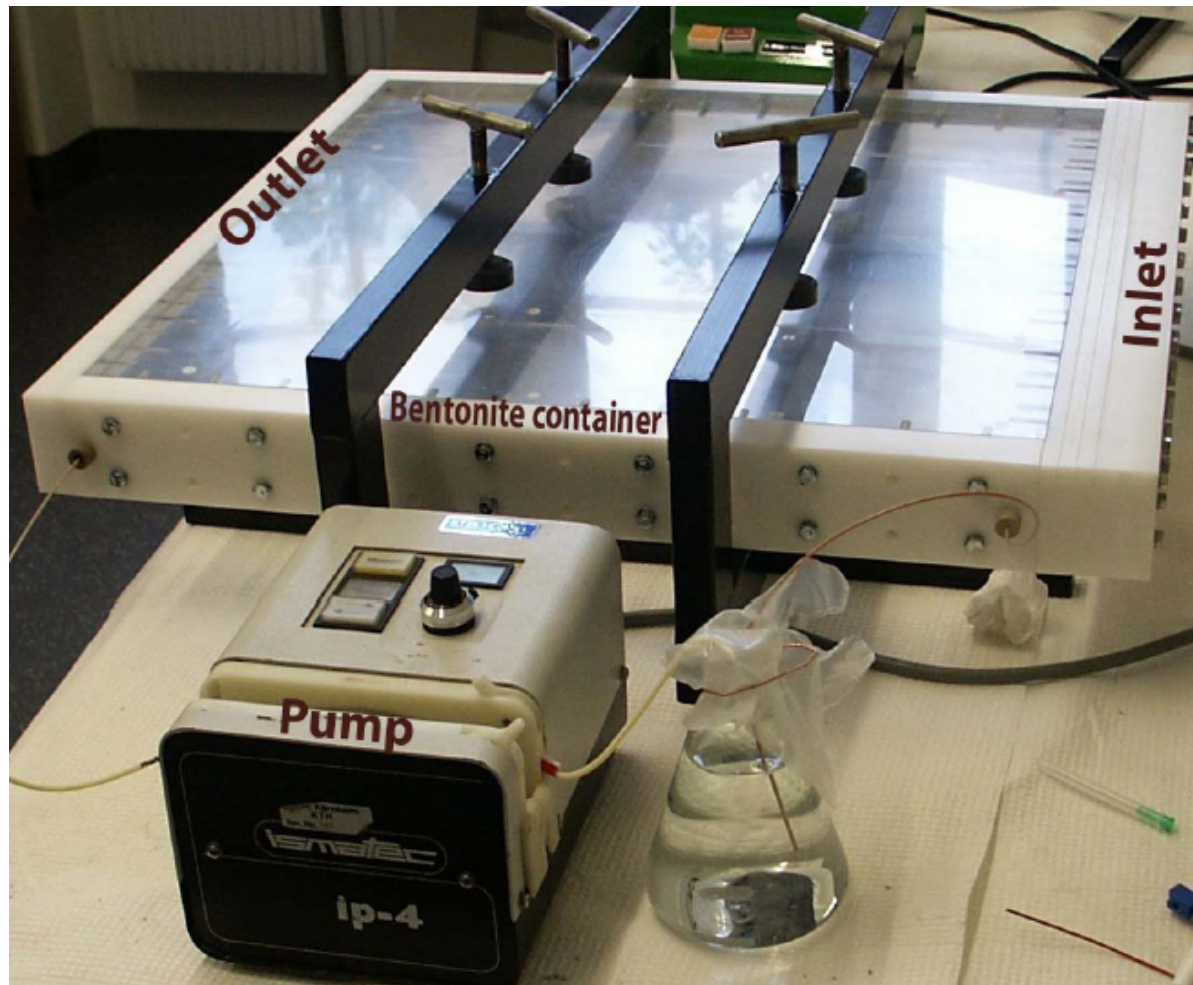
- These are acknowledged to be simple scoping experiments
 - Not very tightly controlled conditions
 - The glass slit is a poor representation of a real fracture
 - The results are affected by the experimental set-up and the clay pre-treatment steps
- The experiments do show the effects of gravity on clay gels and demonstrate settling
- The authors claim that the accessory minerals could slow the expansion of smectite towards the gel/water interface
 - The evidence presented for this is really not clear or convincing

Jansson (2009) Artificial Fracture



Two experiments, one with a horizontal fracture, one inclined by 2 to 3 degrees towards the inlet

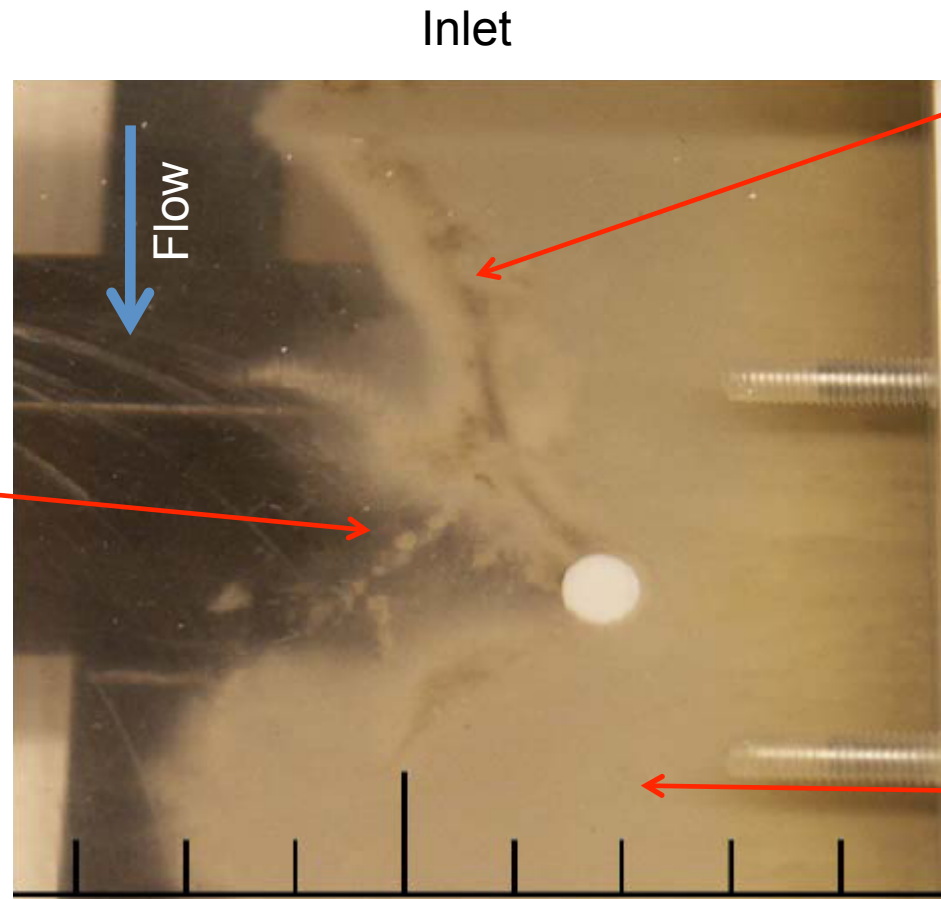
Jansson (2009) Artificial Fracture



Jansson (2009) Artificial Fracture

Experiment 1
Horizontal
Fracture

Bentonite
eroding and
dispersing into
fracture



Discontinuous
dark feldspar-
rich rim at gel/sol
boundary

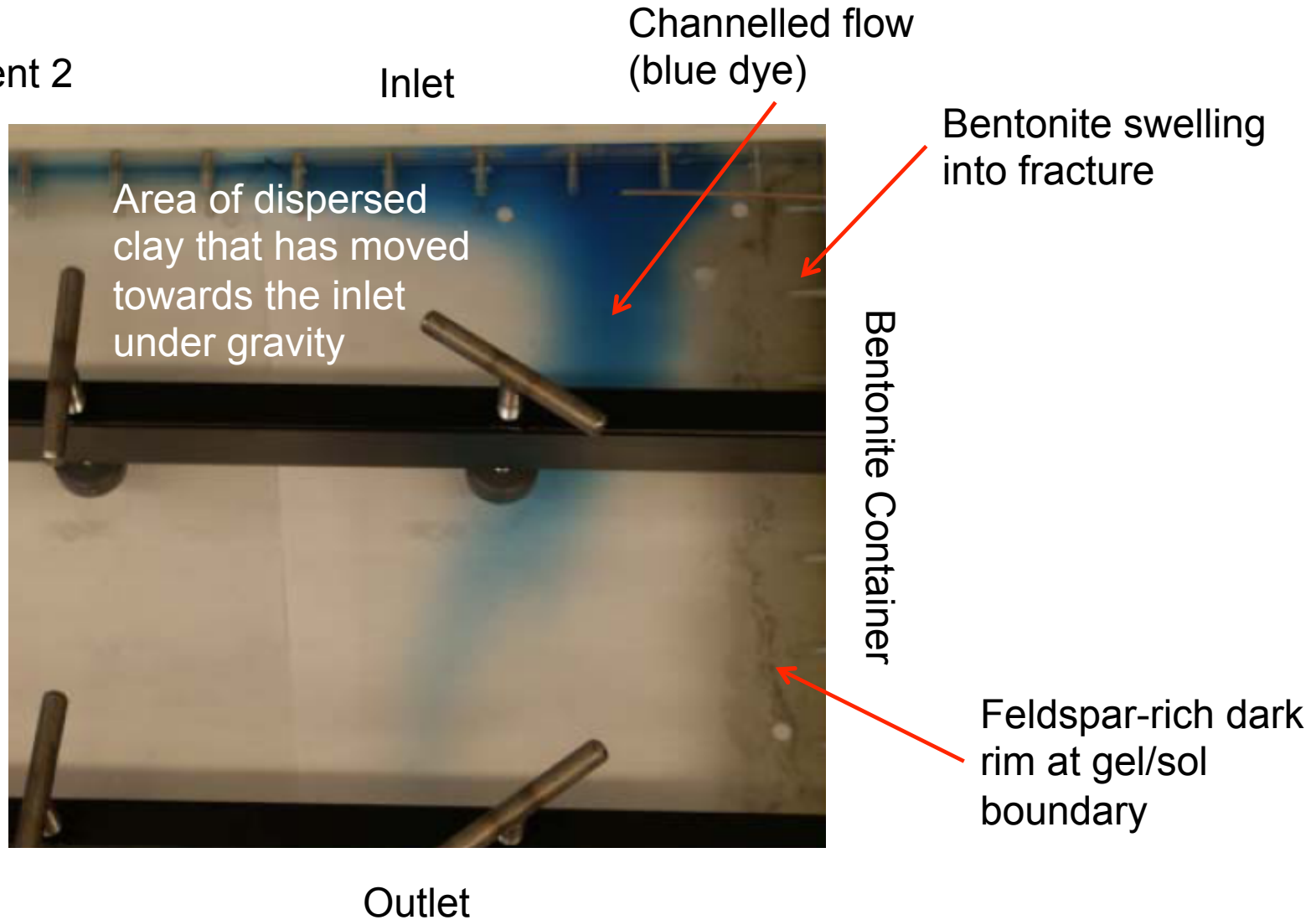
Bentonite Container

Bentonite
swelling into
fracture

Outlet

Jansson (2009) Artificial Fracture

Experiment 2
Inclined
Fracture



Evaluation of Jansson (2009) Artificial Fracture

- At first sight, the experimental set-up appears to correspond well with the conceptual model and has produced some interesting observations:
 - Colloids reaching the outlet are <200 nm and mostly < 100 nm in size
 - Colloid concentrations at the outlet are <0.18 g/l
 - Flow patterns through gel filled areas may be complex and time varying
 - Channelling, fingering effects?
 - These effects are not in the conceptual model
- However...

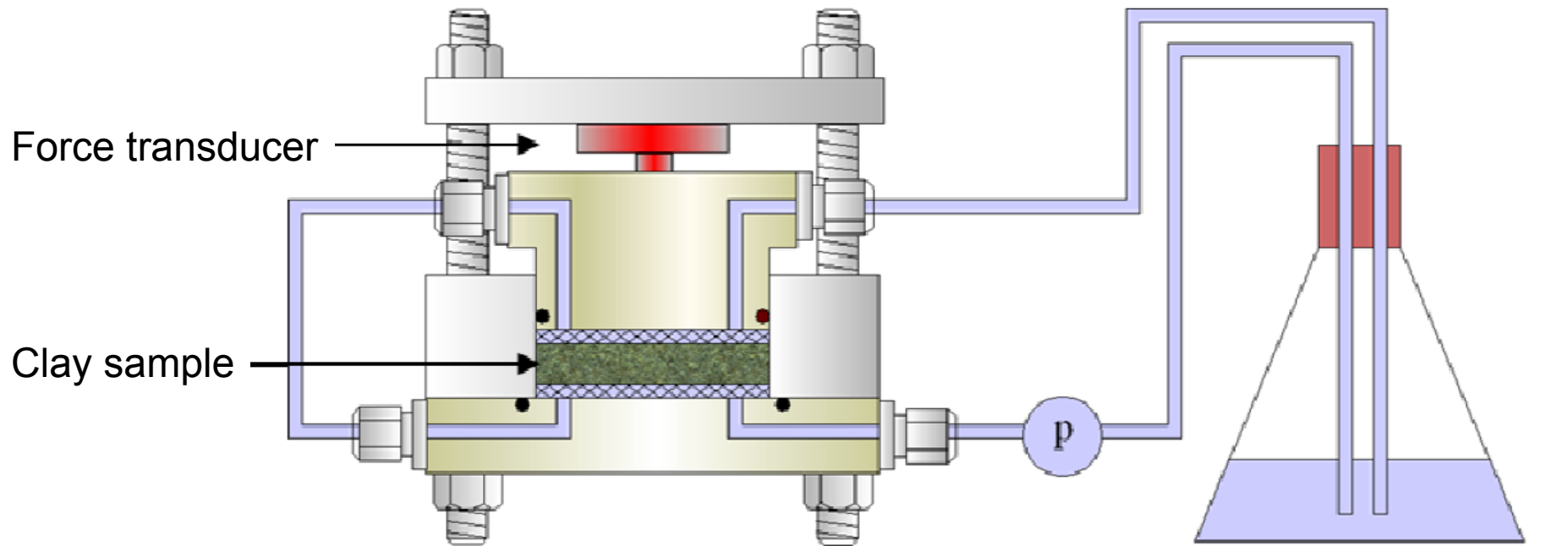
Evaluation of Jansson (2009) Artificial Fracture

- ...in more detail:
 - The bentonite density in the experiments was lower than expected in deposition hole – do the experiments underestimate the swelling?
 - The experiments were conducted with distilled water and the solution chemistry was not well constrained – is erosion over-estimated?
 - The experiments were conducted at atmospheric CO₂ levels – this affects calcite solubility, Ca⁺² concentrations and the stability of the clay colloids
 - One of the two experiments suffered from air bubbles
 - The number of experiments was very low (reproducibility?)
 - The outlet colloid concentrations are of questionable relevance

Birgersson *et al* (2009) Erosion Tests

- In these tests, various ionic solutions were circulated past clay samples and the swelling pressure exerted and the turbidity of the circulating solution were measured
- Changes were made to the composition and salinity of the solutions during the experiments
- Bentonite erosion was evidenced by a drop in pressure and an increase in turbidity

Birgersson *et al* (2009) Erosion Tests



- i) Pure Na-montmorillonite
- ii) MX-80 no gypsum

Circulating solutions

- i) CaCl_2
- ii) $\text{CaCl}_2 + \text{NaCl}$
- iii) CaSO_4
- iv) CaCO_3
- v) Pure water

Birgersson *et al* (2009) Erosion Tests

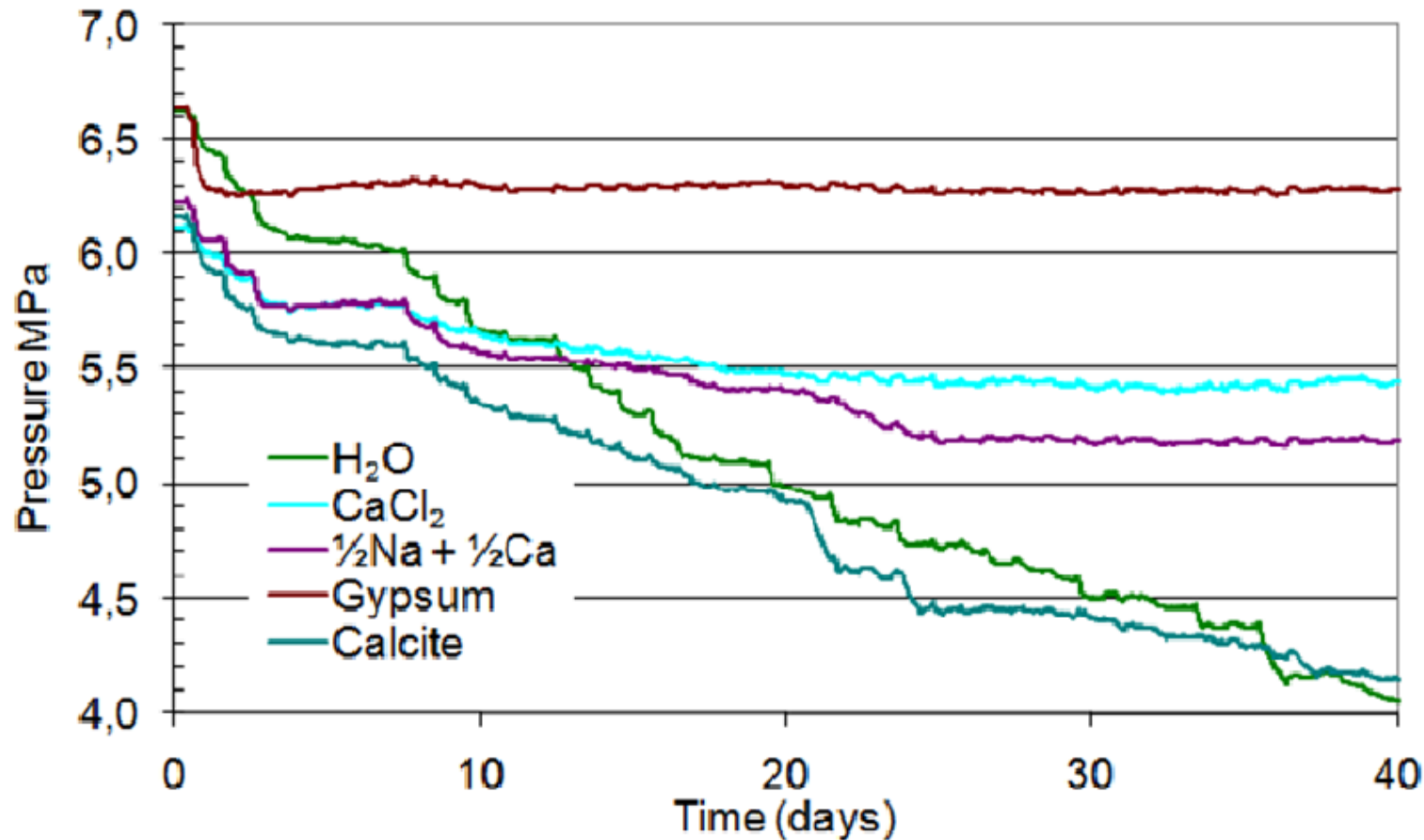
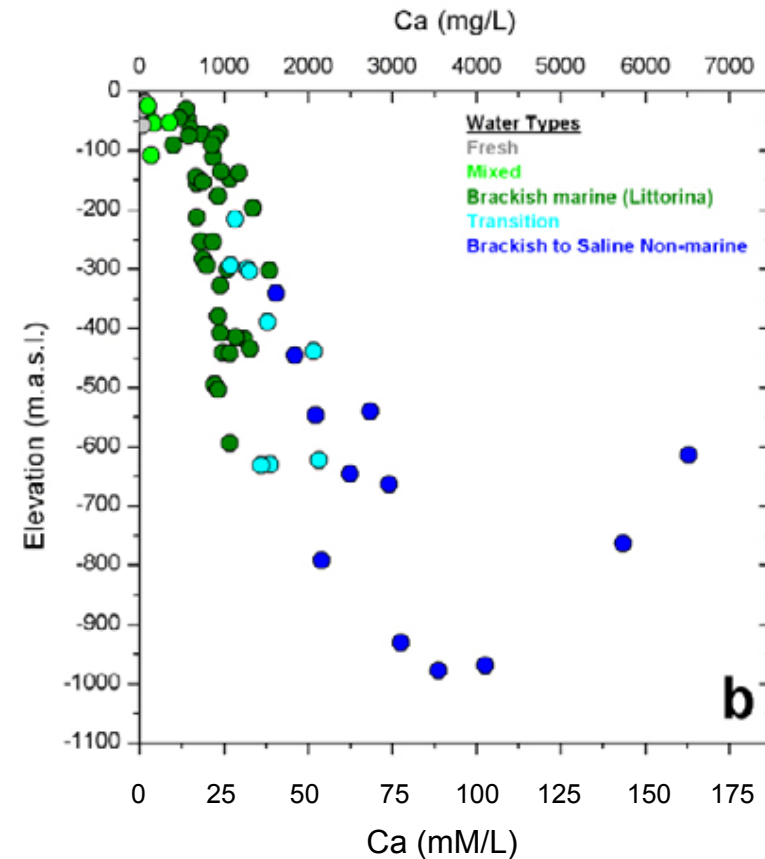
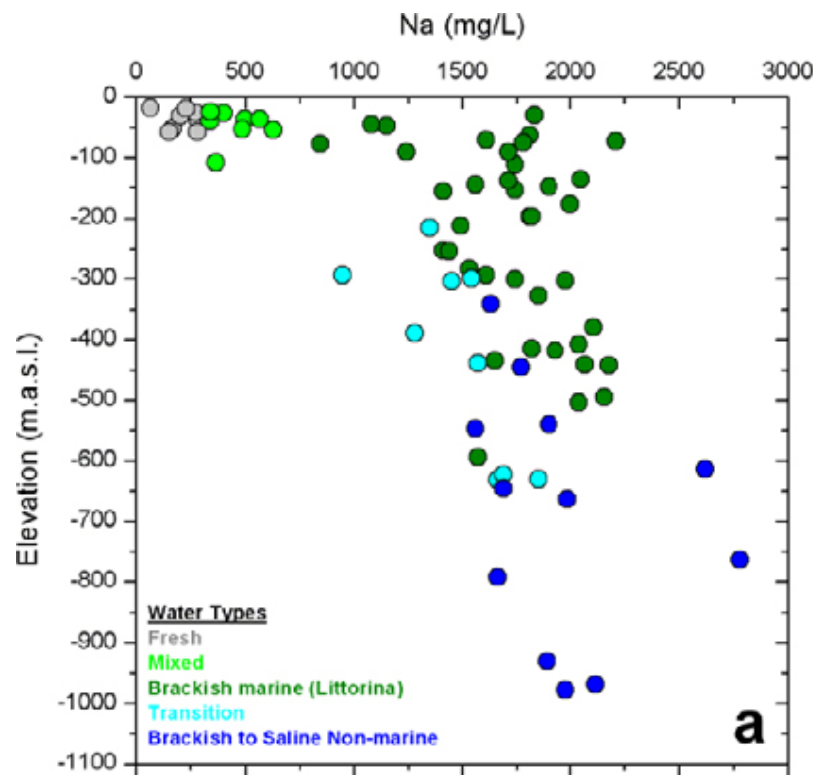


Figure 7-29: Swelling pressure response for the four tested systems with different circulation Ca or Ca/Na solutions over an initially pure sample of Na-montmorillonite. Also shown is a sample with deionized water for comparison (labelled H₂O).

Evaluation of Birgersson *et al* (2009) Erosion Tests

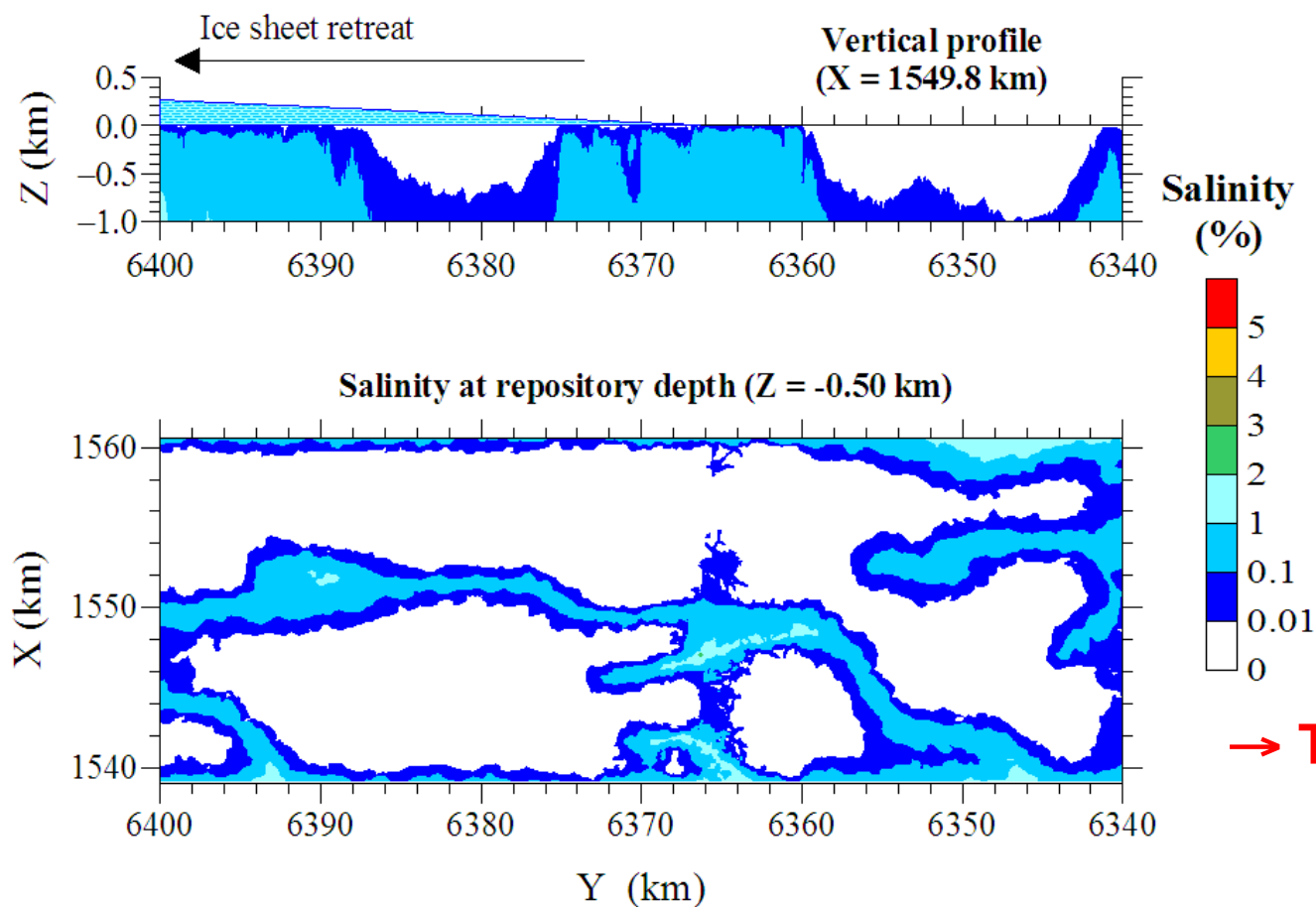
- Useful experiments
 - Would have been better if the final ion contents of the clay and the waters had been measured instead of being inferred from ion-exchange calculations
- Some key results:
 - Erosion prevented while gypsum present
 - Ca = 16 mM
 - But gypsum is not likely to persist for long in a repository situation
 - Erosion of Na-rich montmorillonite stopped by
 - 5mM NaCl with < 2.5 mM CaCl₂
 - Erosion of MX-80 with no gypsum stopped by
 - 0.7 mM NaCl with 0.2 mM CaCl₂

SKB (2008) Bedrock Hydrogeochemistry Forsmark, Site Descriptive Modelling, R-08-47



SKB (2006) Sr-Can Geochemistry

Salinity under Retreating Inland Ice



Glaciation and ice retreat:
very diluted groundwaters
at repository depth

→ TDS = 100 mg/L
Ca ≈ 0.5 mM

Conclusions

- Based on the information available at this stage, bentonite erosion by dilute groundwaters cannot be ruled out
- The Neretnieks *et al.* (2009) conceptual model seems reasonable in most respects, but not all aspects are sufficiently supported by experimental evidence
- The reports examined do not present convincing evidence that the accessory minerals in commercial bentonite will form effective filters, as postulated by Neretnieks *et al.* (2009)
- The conceptual model is a significant simplification of the repository situation

Conclusions

- The calculated rates of bentonite erosion presented by Neretnieks *et al.* are highly uncertain
- There remain some apparently significant gaps in data and knowledge
- Neretnieks *et al.* (2009) suggest that it might be appropriate to add specially chosen particles to the buffer material that would increase confidence that smectite eroding from the bentonite would be filtered
- It is not clear that this would be practicable or effective
- Neretnieks *et al.* (2009) make no comment about other risk management possibilities (e.g., a supercontainer envelope or deposition hole liner)