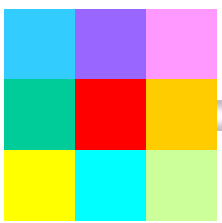


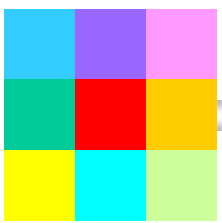
Karlsruhe, October, 2015

WP2: EROSION

WRAP-UP



	<b>position at start of BELBaR</b>	<b>final State-of-art report</b>
<b>Mechanisms of erosion of clay particles from the Bentonite surface</b>	<p>Erosion will cause a loss of bentonite buffer performance under some conditions.</p> <p>This may lead to corrosion failures of the canisters.</p> <p>Corrosion failure leads to the largest impact on risk, a less pessimistic approach may have significant impacts on the calculated risk.</p>	<p>Mechanisms of clay colloid release (WP2 output).</p> <p>Improved quantitative models with new data (WP5 output).</p>
<b>Characteristics of Bentonite clay</b>	<p>Divalent cations have not been studied that systematically.</p> <p>Should the existence and quantitative effect of divalent cations be argued, the importance of this outstanding uncertainty would reduce.</p>	<p>The role of divalent cations (WP2 and WP4).</p> <p>The stability of different bentonites (WP4)</p>



## Mechanisms of erosion of clay particles from the bentonite surface

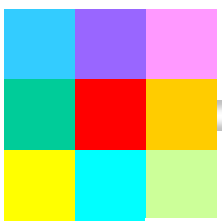
- Clay must be hydrated enough for the gel (source of colloid) to be formed;
- Swelling pressure driving force causing the gel intruding the fracture/pores of the rock; (but it must have a place to go)
- The presence of colloids in solution will be limited to the surface available for colloid transport from the clay surface to the liquid phase (fractures/pores) and not to the surface available for clay hydration;
- **Water flow can shear off particles (physical forces);**
- **Repulsive electrostatic (double layer) forces separate particles, from the gel. Double layer depends on water (chemical forces); Conditions for particle stability necessary.**
- Erosion process (dispersion) is not continuous. Colloid concentration at the equilibrium depends on various factors (ionic strength and/or Ca content and on the bentonite/water chemical interactions. Chemical conditions are of major importance in all the cases).

## Characteristics of the bentonite clay

- **Pure Ca-clays** do not suffer erosion but a quantity of Na around 20-30 % in the exchange complex is enough to make the clay erodible (similarly to Na-clays) in spite of the presence of divalent ions in the exchange complex;
- Even the colloidal behavior (**stability**) is similar in all the bentonites, their erosion behavior presents clear differences; Max. FEBEX clay and the lowest for the B75 clay under similar experimental conditions.
- Smectite content plays a role;
- Exchange complex, mineral composition, total charge, tetrahedral/octahedral charge, trace elements being analyzed (relative importance);
- Difference are also seen in Na-clays obtained from these different bentonites (similar stability, exchange complex no critical, if enough Na present);

## Characteristics of the bentonite clay

- **Eroding material is predominantly smectite:** clay mineral is the primary eroding phase.
- Existence of **minerals that may cause hetero-aggregation** (kaolinite, oxides); a small percentage of kaolinite (less than about 15 %), produced an evident destabilization of the colloidal system, promoting fast aggregation. Not for example with illite (proportion of smectite).
- **Presence of accessory minerals** (larger than the smectite particles) that can slow down smectite particle limiting the rate of mass transfer and stop erosion. behind and form a filter bed or cake. Ultimately, depending on their extent, properties, and durability, such processes may provide the bentonite buffer system with an inherent, self-filtration mechanism which serves to limit the effects of colloidal erosion.
- It is clear that accessory phases **remain behind and form bed layers**. No apparent attenuation of montmorillonite erosion observed with added accessory materials. The accessory mineral layer may (or not) be subject to erosion (not clear); in sloped fracture both smectite and minerals are removed.

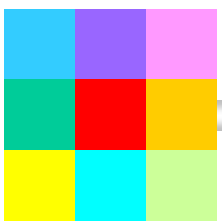


Issue	Safety case position at start of BELBaR	Outcomes sort for final State-of-art report
Groundwater Chemistry	<p>The key factor for colloid stability is the ionic strength and the content of divalent cations.</p> <p>pH should have an effect, but the pH-range considered in the safety case is rather limited.</p>	<p>The effect of mixed monovalent/divalent systems (WP2, WP4 and WP5)</p>
Clay – Groundwater interactions	<p>Changes in bentonite porewater solute concentrations can be modelled.</p> <p>The related rates assumed to be limited by the availability of different porewater solutes.</p> <p>Mass loss rate assumed to have hydrodynamic contribution.</p> <p>The buffer and the groundwater never reach a true equilibrium.</p>	<p>A validated argumentation for (the conditions for) maximum clay mass loss rate to be used in safety case (cross-WP effort).</p> <p>Summary of how these processes should be integrated in the safety case.</p>

## Groundwater chemistry

- Condition favoring colloid stability: **necessary condition but not sufficient** for erosion;
- An electrolyte concentration exist above which erosion does not occur (this being related with also with the solid);
- CCC determined in *batch* experiments, often overestimates the limit for erosion. It is a concept **not directly applicable** especially in systems where more than one type of ion is present; ill-defined if ion exchange processes occur;
- Maximum erosion always observed with deionized water (**DW**).
- Ca in solution ( $I \sim 1 \text{ mM}$ ) inhibits erosion. The increase of ionic strength attenuates erosion;
- Amongst crystalline waters, Grimsel groundwater is one the most favorable for colloid stability for its low salinity (1 mM). However, average mass loss is significantly lower than that of the limiting DW (30 %). The existence of more than ion influences erosion;

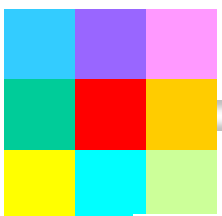






## Clay-groundwater interactions

- Important is the history of the clay. Hysteresis is observed in the erosion behavior, passing from high ionic strengths to diluted ones. That means that smectite eroding at 10 mM NaCl, might be completely stable against erosion, if it has previously had a higher salinity present. Also seen in stability tests.
- Water/clay interactions are very important for the evaluation of erosion and stability of colloids in a repository at a long-term.
- Ionic exchange;
- Chemical evolution;
- Kinetic and geochemical modelling to be included in stability models ?

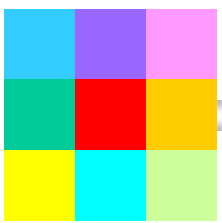




Issue	Safety case position at start of BELBaR	Outcomes sort for final State-of-art report
 <p>Groundwater velocity</p>	<p>Groundwater velocity has been considered as a variable. The loss of bentonite will be affected by the groundwater velocity and it is important to verify this dependence for erosion rates.</p>	<p>Verification of the dependence between the groundwater velocity and the erosion rate.</p>
 <p>Clay extrusion paths</p>	<p>Fractures have been assumed to be planar with a constant aperture. Extrusion of clay into a fracture is an integral part of the current model and will have a strong impact on the mass loss.  Piping may occur before full saturation of the buffer under certain circumstances.</p>	<p>The effect of fracture geometry on clay mass loss (WP2).</p>

## Groundwater velocity

- **Not perfectly clear**, but the erosion dependence on the groundwater velocity is also related with the chemistry. Shear forces depends on the size of the particles;
- The average mass loss rates for the tests with the highest levels of observed erosion (well below CCC), appear to be equivalently correlated to flow velocity.
- In other cases, the water flow velocity did not seem a relevant parameter (no clear trend between water velocity and erosion);
- Ej: Increased flow velocities lead to decreased peak effluent solids concentrations. This correlation of effluent solids concentration to flow velocity (in Na-montmorillonite). Related to the mean residence time of water within the fracture: suggests a rate-limited erosion mechanism at least within the range of tested flow velocities (hydrodynamic shear forces maybe not significant).
- Loss of smectite governed by diffusion; flow just “transports” generated particles ?. Chemical effects prevails.



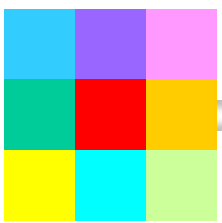
## Clay extrusion paths

### FRACTURE APERTURE

- The erosion rate seems to be proportional to the area of the fracture (double areas double concentration of colloid in solution);
- Artificial fracture experiments conducted at 0.1 mm aperture showed nearly order of magnitude reduction in average erosion rates, with respect to results from 1 mm artificial fractures.

### GEOMETRY: SLOPE ANGLE (& Gravity)

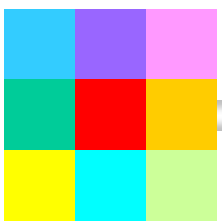
- Artificial fracture tests 45° / 90: purely sedimentary mass loss mechanism compared to horizontal fractures, where the mass is released by dispersion. Average mass loss rates in the sloped fractures were always larger than those of the corresponding horizontal cases with larger slope angles generally resulting in increased mass loss rates. Such sedimentary-type mass loss was observed in sloped fractures under stagnant (no flow) as well as flow-through conditions.



## Clay extrusion paths

### SURFACE ROUGHNESS

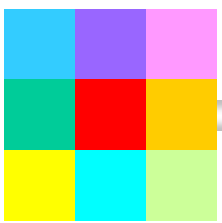
- The average mass loss rate is lower in the rough system; Natural fractures are characterized by rough surfaces and complex fluid flows and, as the limited data described here indicates, buffer mass loss in rough-walled fractures may be significantly attenuated relative to that in smooth-walled systems.



## Clay extrusion paths

### SCALING EFFECTS

- In order to try to assess the effect of scale through the experimental data, erosion tests with cells of different dimensions were carried out. The observed normalized average mass loss rates are in reasonable agreement.



# Thanks for your attention