BELBaR Project

Results from erosion experiments

Summary for WP2

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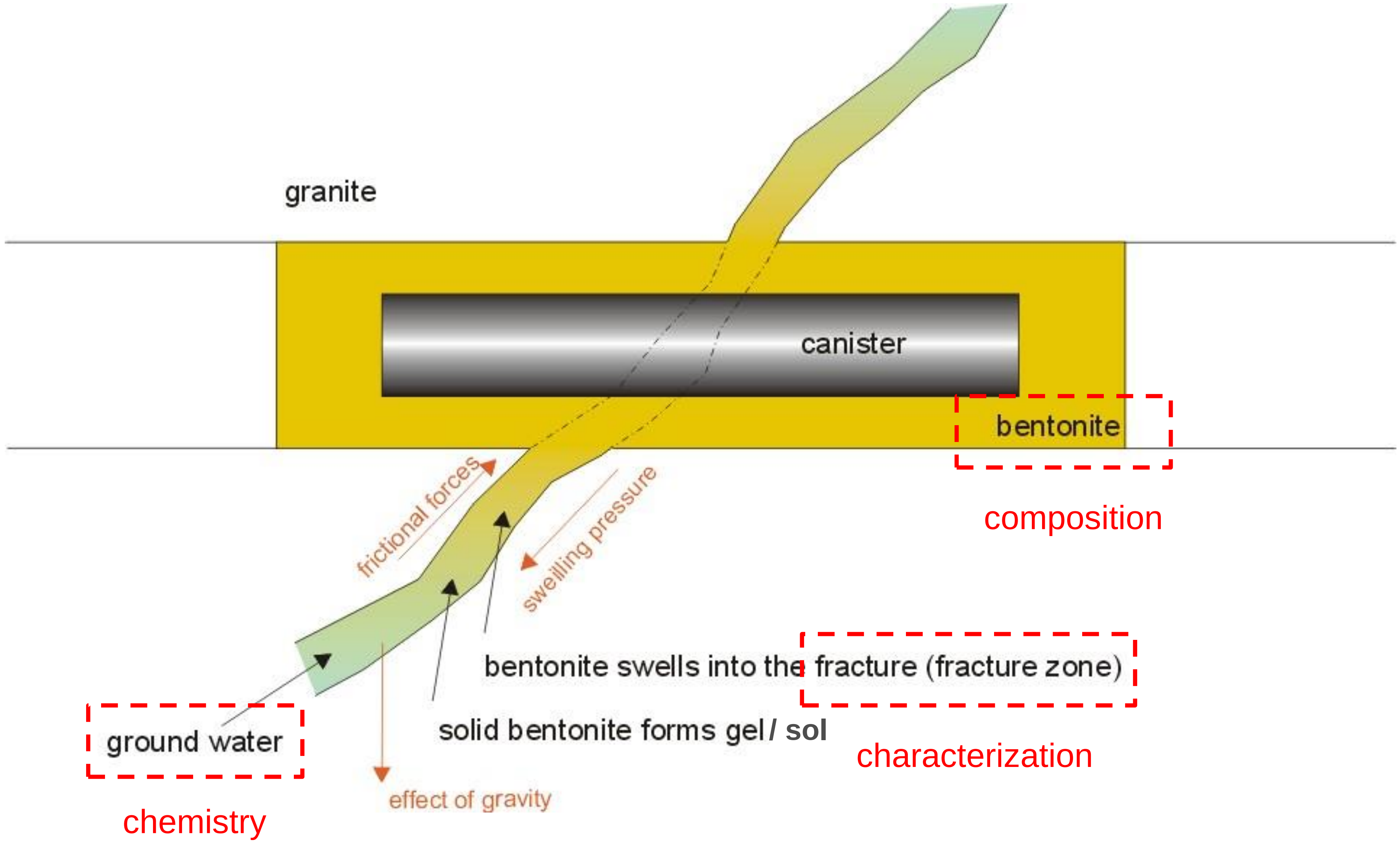
ÚJV Řež, a. s., 2015

CP BELBAR WP4 MEETING

Karlsruhe - 12-13 October, 2015

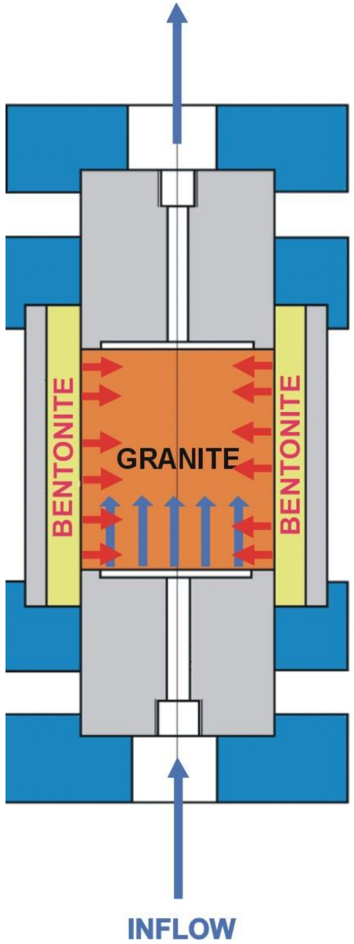
Introduction: Conceptual scheme of bentonite erosion in horizontal deposition hole

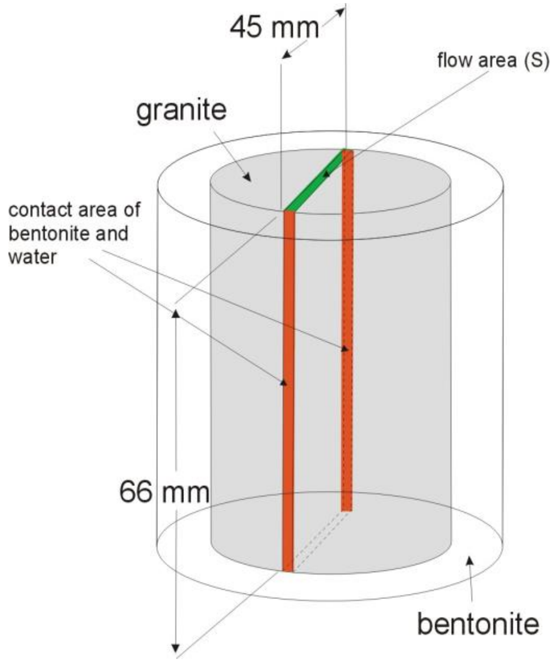


Experimental set-up: Bentonite erosion in the granite fracture

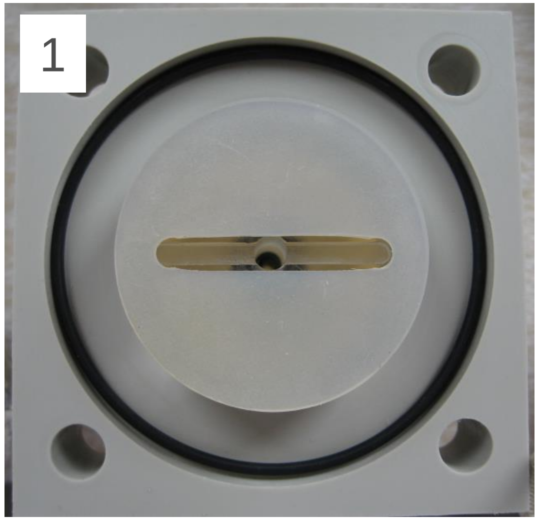
Size up the amount of bentonite particles eroded from the swelling bentonite by the flowing water in the granite fracture during the **bentonite saturation** (characterization of released clay particles).

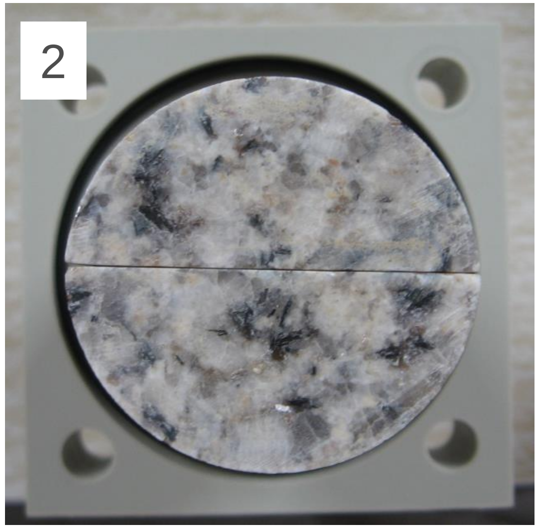
- **Conditions:**
  - Na/Mg-bentonite Rokle (bentonite ring with initial moisture, compacted dry density ~ 1600 kg/m^3)
  - Granite cylinder with artificial fracture
  - Distilled water
  - At the beginning, the fracture was washed out with enough amount of water
  - Time - till full saturation of bentonite (~ 30 wt.% of water)
- **Variables**
  - water flow velocity in fracture (5.37×10^{-6} – 2.48×10^{-4} m/s)
  - aperture of granitic fracture (0.15 – 2 mm)
- **Analyses**
  - colloids concentration indirectly (conc. Al using ICP-MS)
  - colloids concentration using PCCS
  - pH, conductivity, flow rate
  - total amount of eroded bentonite gravimetrically
  - optical stereomicroscopy

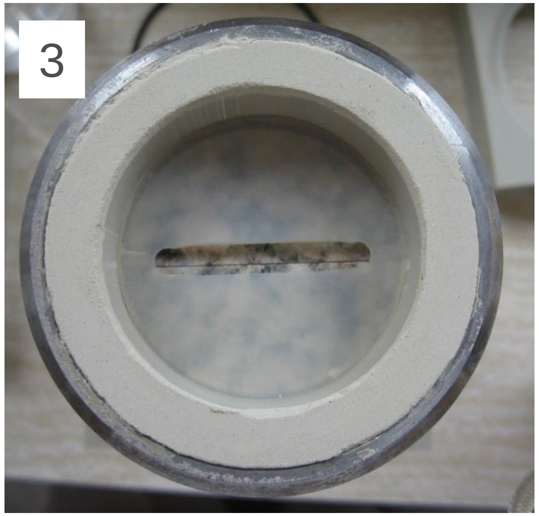


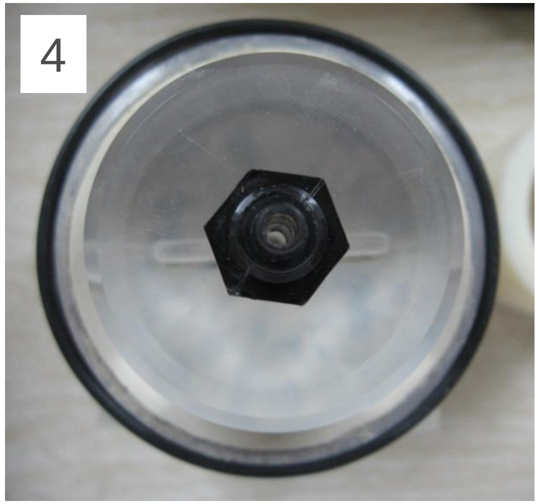


Experimental set-up: Bentonite erosion in the granite fracture



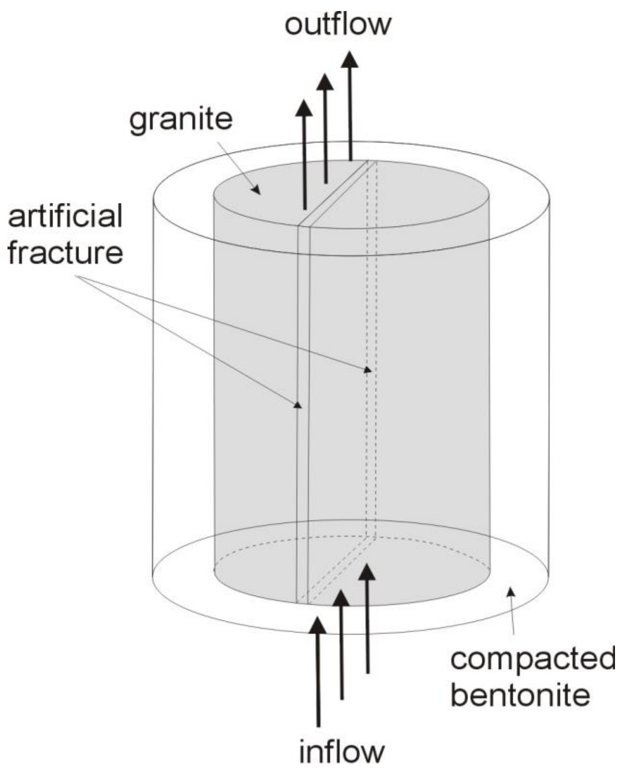




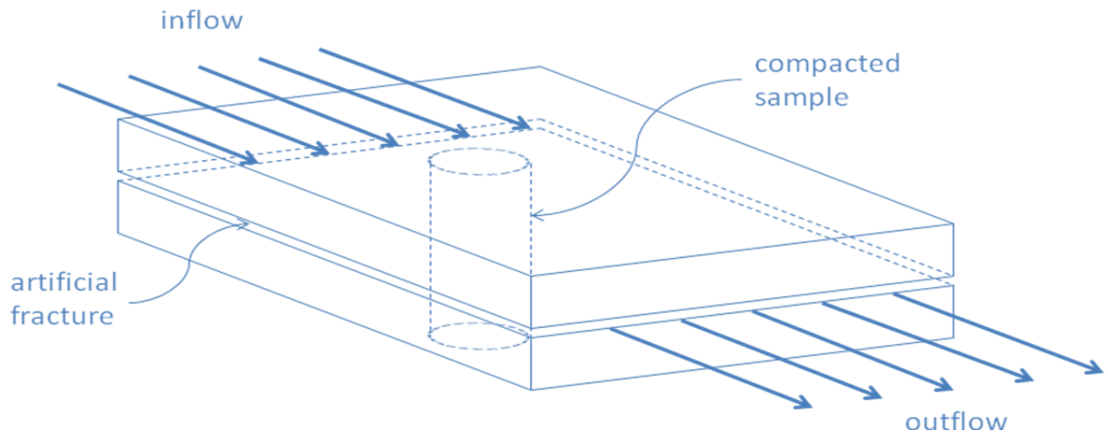


Experimental set-up: Comparison of arrangement

- Simple cylindrical arrangement with artificial granite fracture surrounded by compacted bentonite.
- The flow direction (from bottom to top) was selected mainly for avoiding of air bubbles capture within the apparatus and for homogenous saturation.



ÚJV Řež



Schatz et al. POSIVA 2012-44.

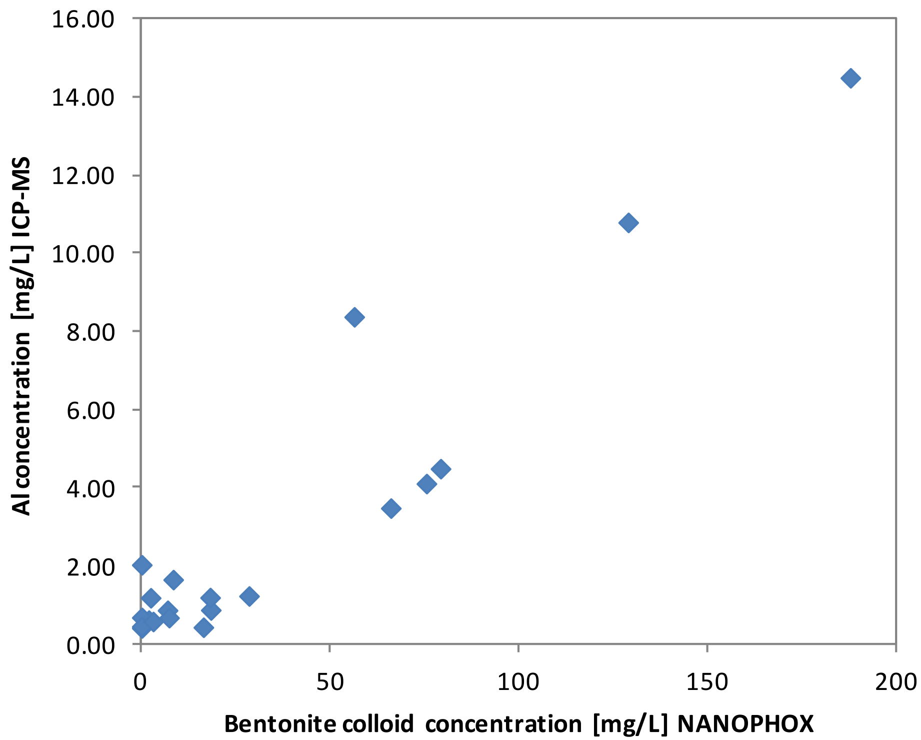
Experimental set-up: Colloids measurement

- Colloids concentration measurement indirectly, Al as a tracer (ICP-MS) and colloids concentration measurement with photon cross-correlation spectroscopy (PCCS)

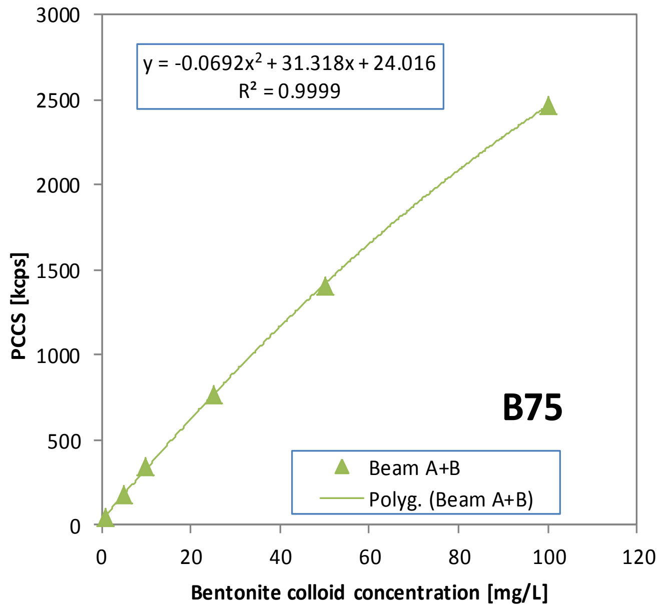
Aluminium in the bentonite B75

Bentonite B75	[hm. %]	Al [hm. %]
Smectite (Montmorillonite) $Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot 4H_2O$	60	6.7
Kaolinite $Al_2Si_2O_5(OH)_4$	4.4	0.9
K-mica (Illite) $(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$	2.4	0.5
Total	66.8	8.1

Al conc. (ICP-MS) vs. PCCS measurement



PCCS calibration curve



Response of the photomultiplier (kcps) vs. the known concentration of bentonite colloids (linear or polynomial calibration curve). The detection limit for bentonite colloid with PCCS is around 1 mg/L.

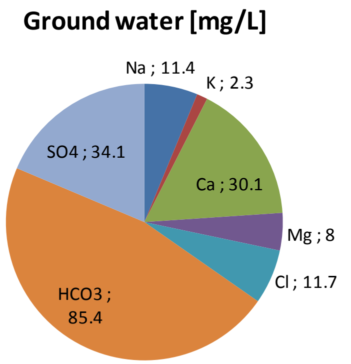
Synthesis of issues: Groundwater Chemistry (1)

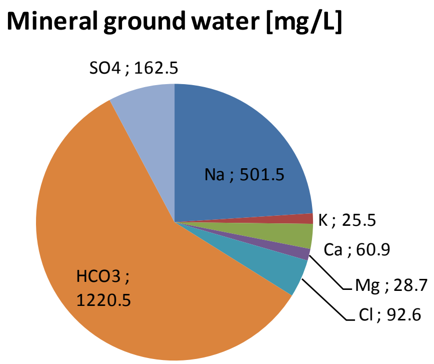
Groundwater Chemistry	The key factor for colloid stability is the ionic strength and the content of divalent cations. pH should have an effect, but the pH-range considered in the safety case is rather limited.	The effect of mixed monovalent/divalent systems (WP2, WP4 and WP5)

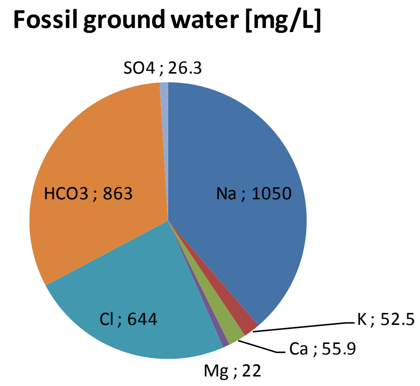
Expected chemistry of ground water in granitic Bohemian Massif (CZ)

- Analyses of ground water in granitic Bohemian Massif, depth > 30 m
  (need for more deep analyses from 300 – 1000 m)
- Three types of ground water
  - ground water – meteoric water in contact with granite (n > 351)
  - mineral ground water - meteoric water in contact with granite and deep CO_2 (n = 16)
  - fossil ground water – old saline waters (n = 15)
- The expected chemistry of ground water in DGR is combination of ground waters above

Median







Rukavičková et al., 2009. DZZ 3.3. Výzkum procesů pole vzdálených interakcí HÚ VJP a VAO. Czech report.

Synthesis of issues: Groundwater Chemistry (2)

Coagulation of clay dispersions (B75 in Na^+ form) by inorganic cations (Na^+, K^+, Ca^{2+}, Mg^{2+})

Groundwaters from granitic Bohemian Massif

Component		Na	K	Ca	Mg	F	Cl	SO_4	HCO_3	NO_3
SGW	**mg/l**	10.6	1.8	27.0	6.4	0.2	42.4	27.7	30.4	6.3
	mmol/l	0.5	0.0	0.7	0.3	0.0	1.2	0.3	0.5	0.1
Groundwater	**mg/l**	11.4	2.3	30.1	8.0	-	11.7	34.1	85.4	-
(median, n > 351)	**mmol/l**	0.5	0.1	0.8	0.3	-	0.3	0.4	1.4	-
Mineral groundwater	**mg/l**	501.5	25.5	60.9	28.7	-	92.6	162.5	1220.5	-
(median, n = 16)	**mmol/l**	21.8	0.7	1.5	1.2	-	2.6	1.7	20.0	-
Fossil groundwater	**mg/l**	1050.0	52.5	55.9	22.0	-	644.0	26.3	863.0	-
(median, n = 15)	**mmol/l**	45.7	1.3	1.4	0.9	-	18.2	0.3	14.1	-
CCC for selected cations		**Na**	**K**	**Ca**	**Mg**					
0.5 % w/w	**mg/l**	138-161	157-196	40-100	24-61	-	-	-	-	-
	mmol/l	6-7	4-5	1-2.5	1-2.5	-	-	-	-	-
0.05 % w/w	**mg/l**	138-161	117-157	4-20	12-24	-	-	-	-	-
	mmol/l	6-7	3-4	0.1-0.5	0.5-1	-	-	-	-	-
0.005 % w/w	**mg/l**	115-138	78-117	4-20	2-12	-	-	-	-	-
	mmol/l	5-6	2-3	0.1-0.5	0.1-0.5	-	-	-	-	-

- **From estimated CCC we can conclude, that bentonite colloids are not stable in the potential ground waters. Mainly due to divalent cations. Confirmed also by simple coagulation experiments in SGW.**

Synthesis of issues: Clay – Groundwater interactions (1)

Clay – Groundwater interactions	Changes in bentonite porewater solute concentrations can be modelled. The related rates assumed to be limited by the availability of different porewater solutes. Mass loss rate assumed to have hydrodynamic contribution. The buffer and the groundwater never reach a true equilibrium.	A validated argumentation for (the conditions for) maximum clay mass loss rate to be used in safety case (cross-WP effort). Summary of how these processes should be integrated in the safety case.

- **All erosion experiments were carried out with distilled water which simulated ground water with very low ionic strength and therefore the extreme conditions with the highest rate of erosion. Max erosion rate was 55 $kg/m^2/year$ for flow velocity 2.41×10^{-4} m/s.**

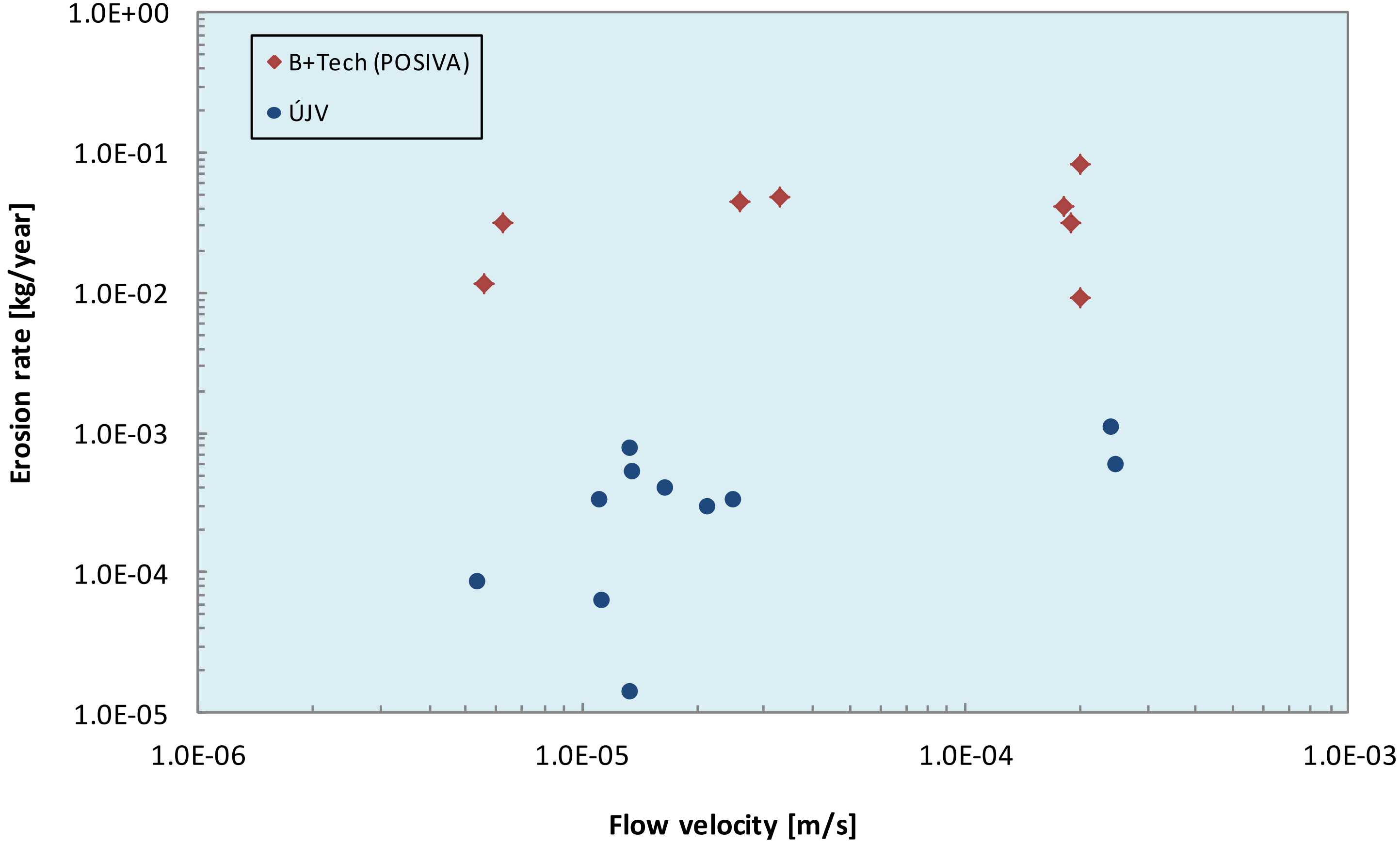
Synthesis of issues: Clay – Groundwater interactions (3)

Comparison of B+Tech and ÚJV Řež results

Both sets of experiments are similar/differ in:

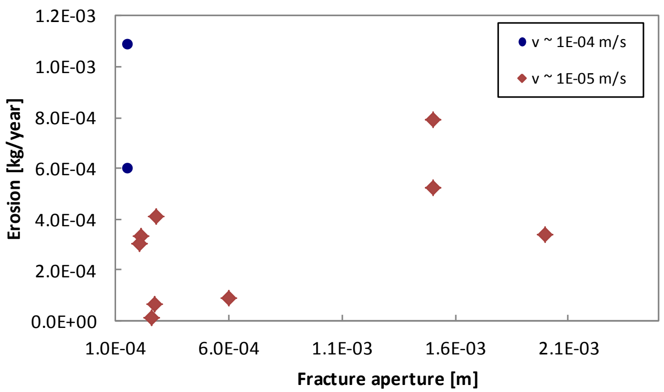
- fracture aperture (ÚJV range 1.5 × 10^{-4} to 2.0 × 10^{-3} m and B+Tech 1.0 × 10^{-3} m)
- solid phase (ÚJV; NaBent, Na/MgBent and B+Tech; NaMt, 50/50 Ca/NaMt)
- liquid phase (ÚJV; DI and B+Tech; DI, GW, NaCl electrolyte)
- flow direction

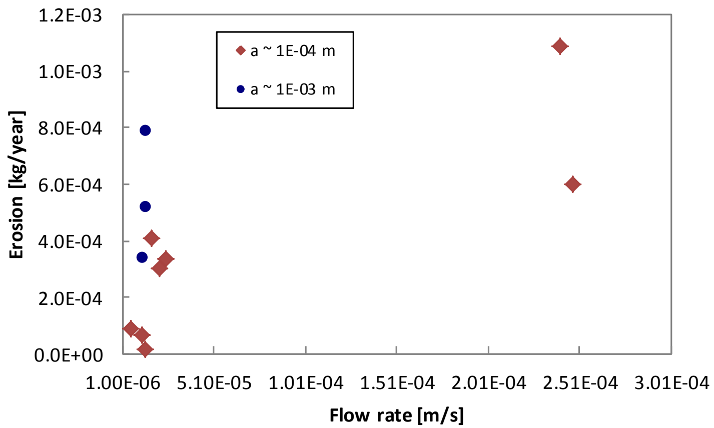
Schatz et al. POSIVA 2012-44.

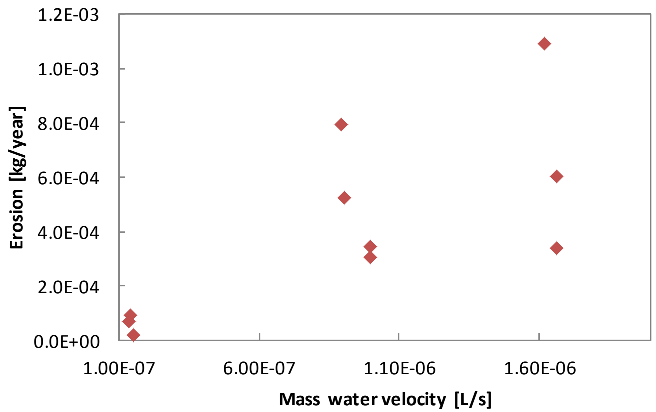


Synthesis of issues: Groundwater velocity (1)

Groundwater velocity	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.	Verification of the dependence between the groundwater velocity and the erosion rate.

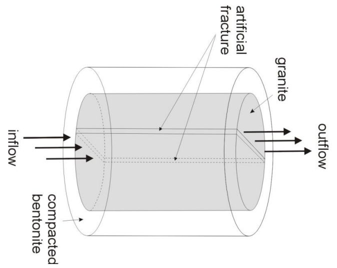






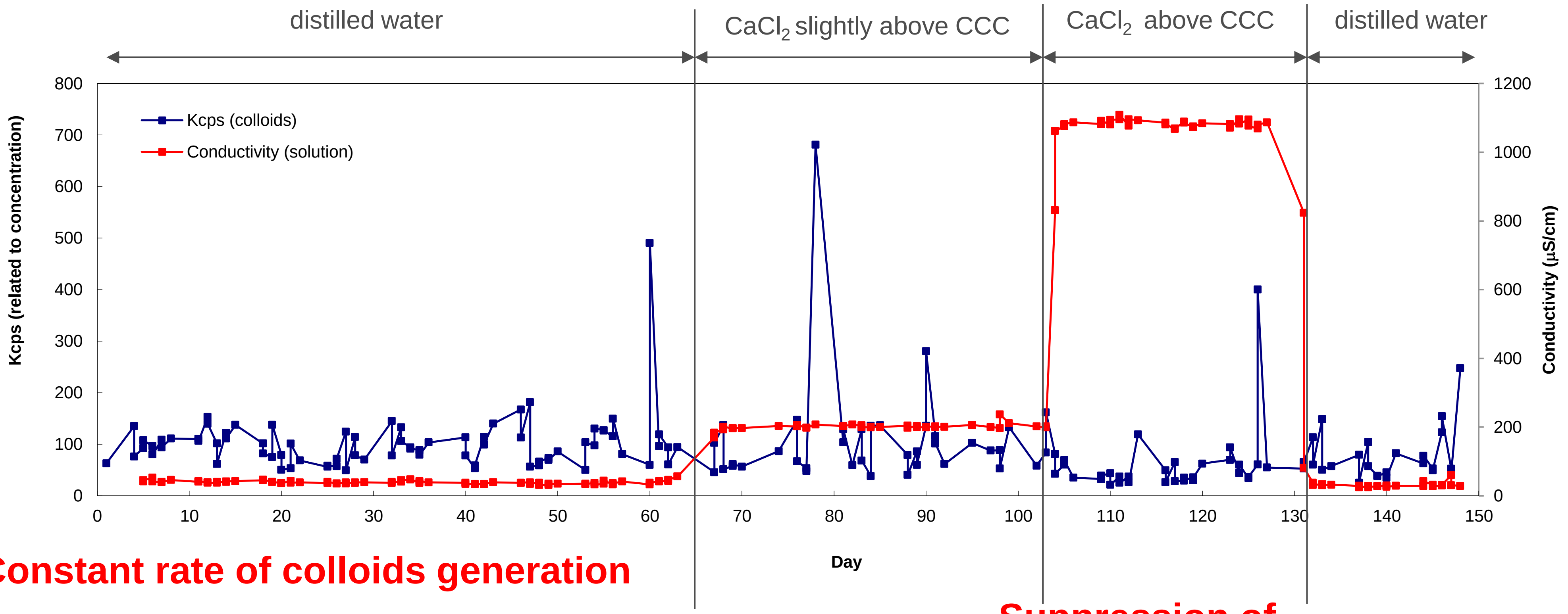
Generally, results do not show a clear trend between fracture aperture or flow velocity and the amount of eroded bentonite in a given experimental range. But, as expected, mostly results indicate, that with increasing fracture aperture and flow velocity increases also the eroded mass. The linear trend occur between the water mass flow and the amount of eroded bentonite.

Synthesis of issues: Groundwater velocity (2)



Long-term erosion experiment with horizontal plane of granite aperture

(results are not evaluated yet completely)



Constant rate of colloids generation

/ constant erosion rate

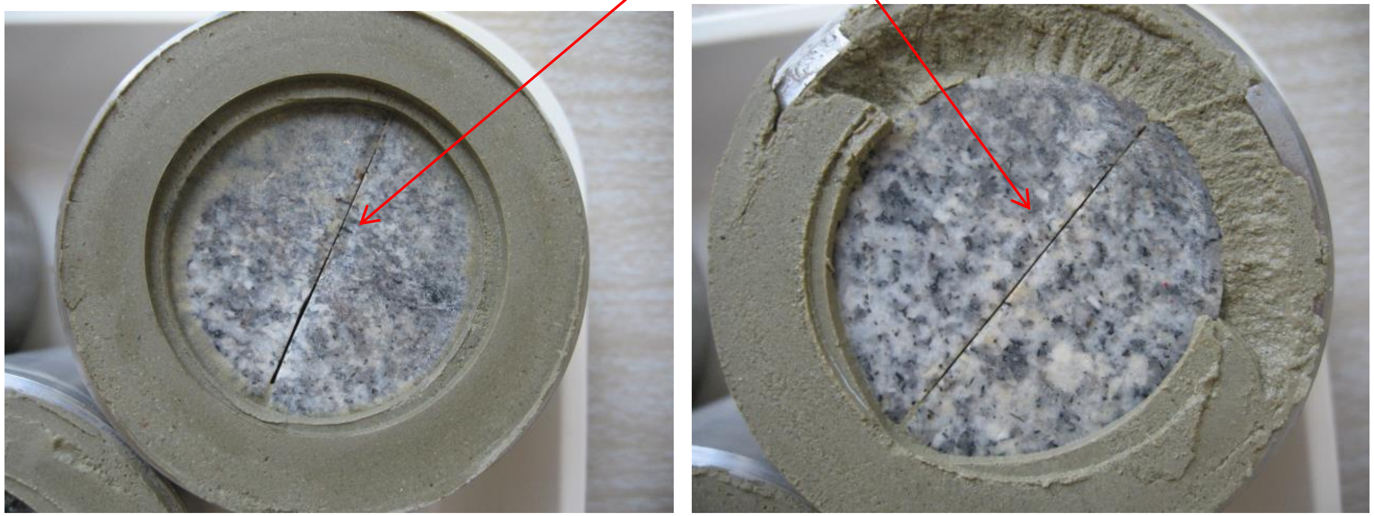
Suppression of

colloids generation

Synthesis of issues: Clay extrusion paths (1)

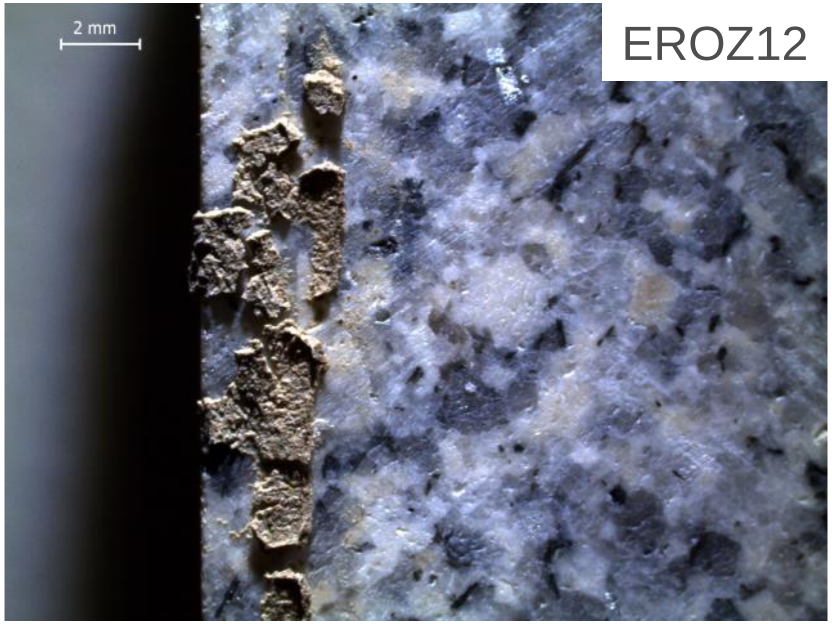
Clay extrusion paths	Fractures have been assumed to be planar with a constant aperture. Extrusion of clay into a fracture is an integral part of the current model and will have a strong impact on the mass loss. Piping may occur before full saturation of the buffer under certain circumstances.	The effect of fracture geometry on clay mass loss (WP2).

- **Two phenomena were occurred which are changing the aperture size:**
  - **Aperture clogging in case of pressure saturation (2MPa)**
  - **Mineral phase separation in fracture**



Synthesis of issues: Clay extrusion paths (2)

- The fracture aperture and entrance of swelling bentonite inside the fracture was studied by optical stereomicroscope.
- **Mineral phase separation** occurred during the transport of eroded bentonite, mainly in settings of aperture size about 0.1-0.2 mm. The size of grains (biotite and quartz) captured in fracture plain was about 0.07 mm.



Acknowledgement

- The research leading to these results has received funding from the European Atomic Energy Community's Seventh Framework Programme (FP7/2007-2011) under grant agreement 295487.