
# BELBaR Project

## Update of ÚJV laboratory results

WP2 and WP4

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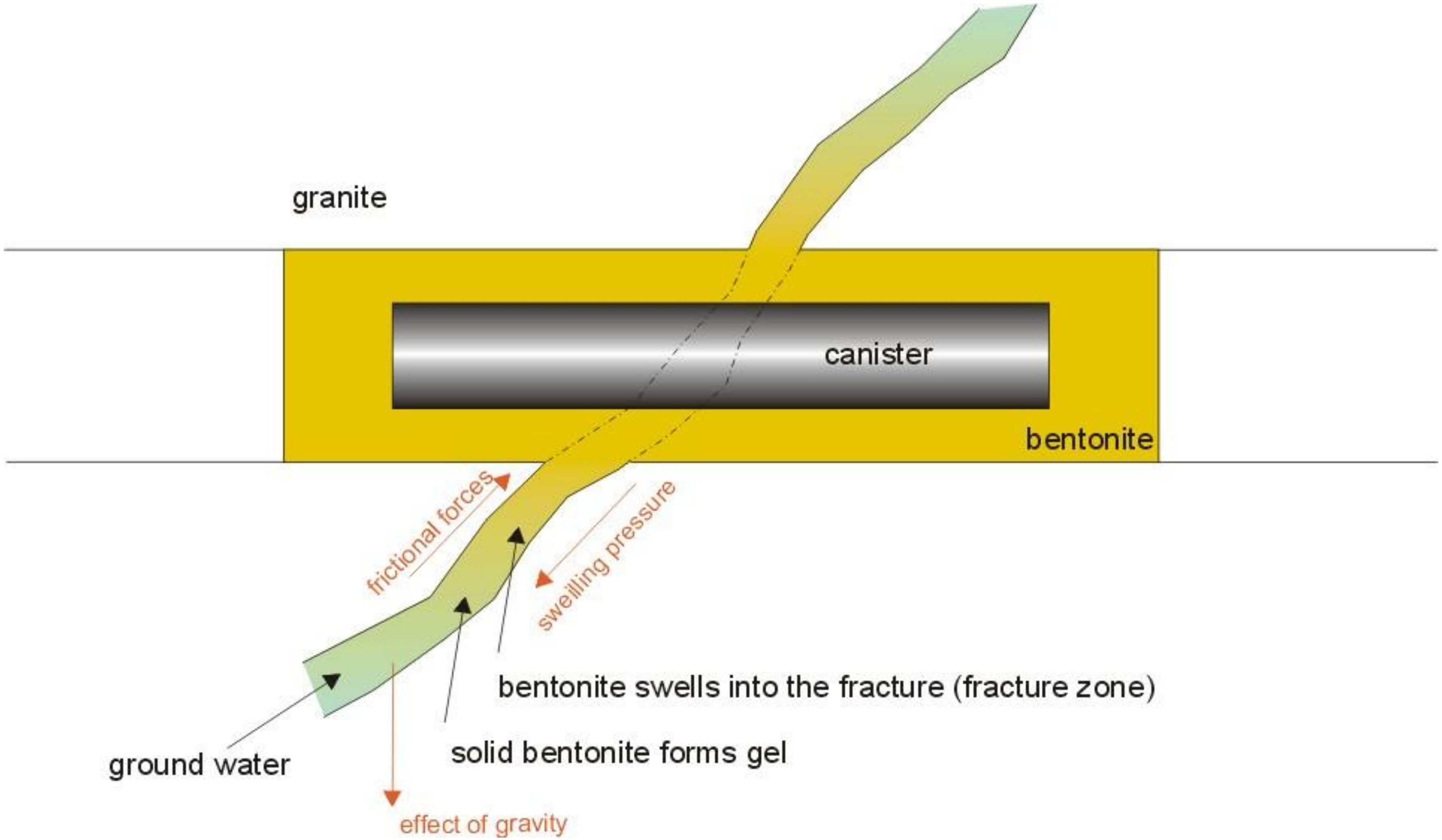
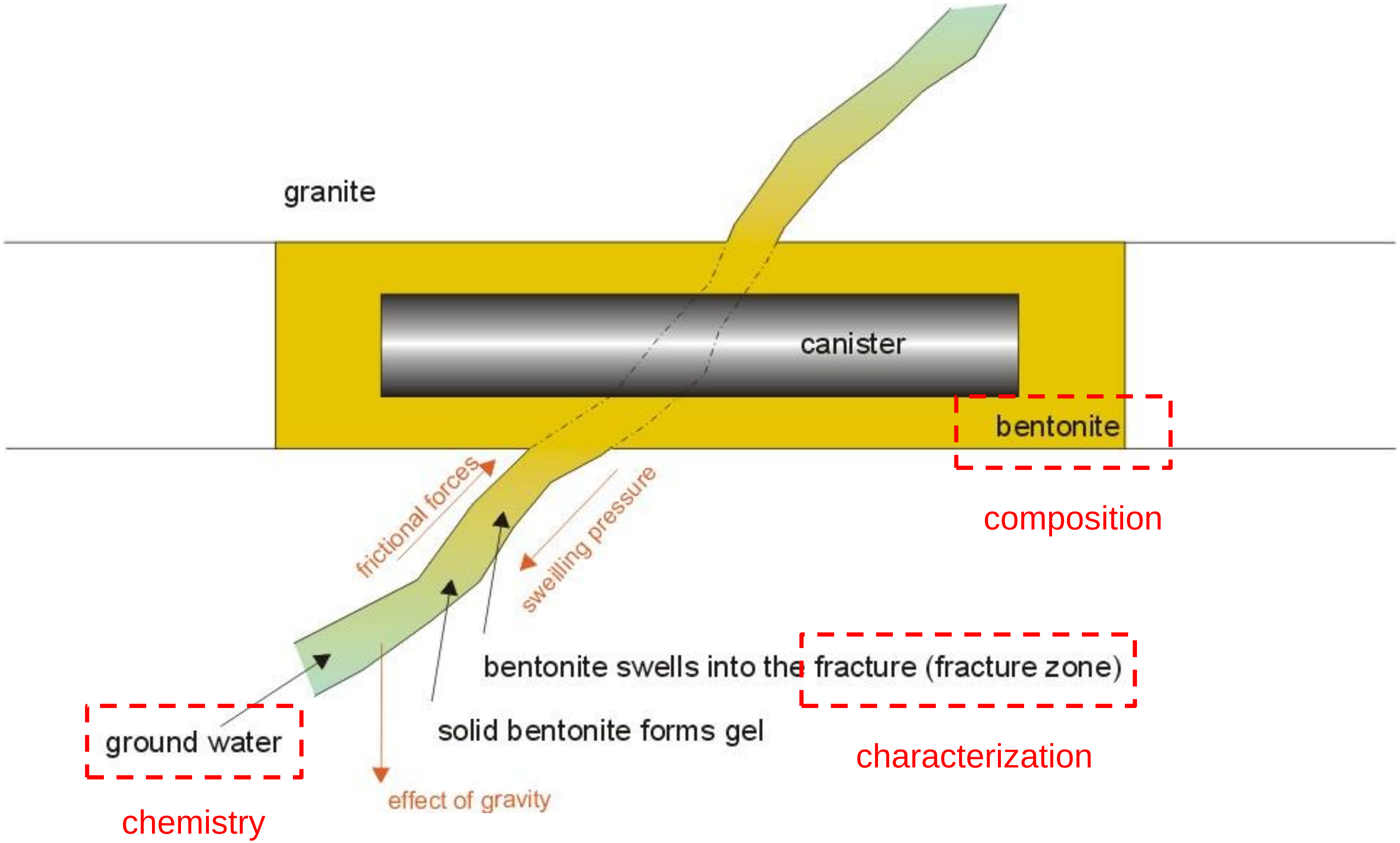
ÚJV Řež, a. s., 2014

BELBaR WP2 and WP4 Meeting, CTU in Prague, Faculty of Civil Engineering, October 30-31 2014

# Introduction: Conceptual scheme of bentonite erosion process in horizontal deposition hole

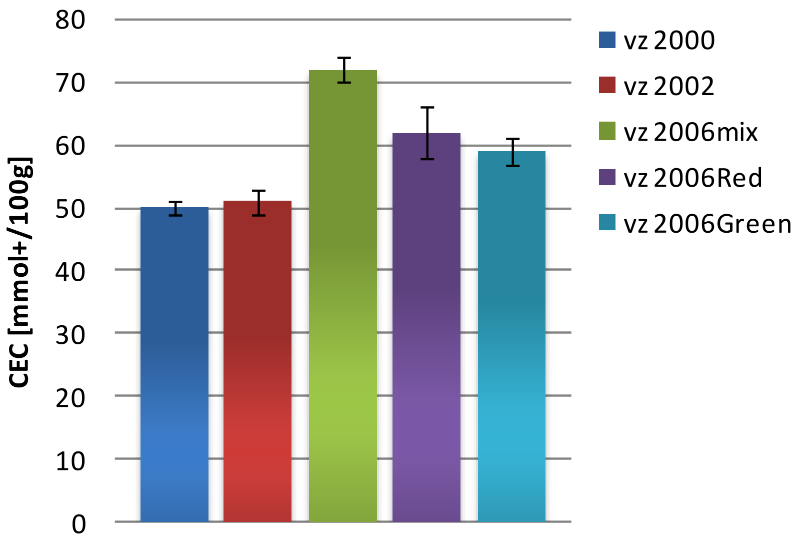


# Introduction: Conceptual scheme of bentonite erosion process in horizontal deposition hole

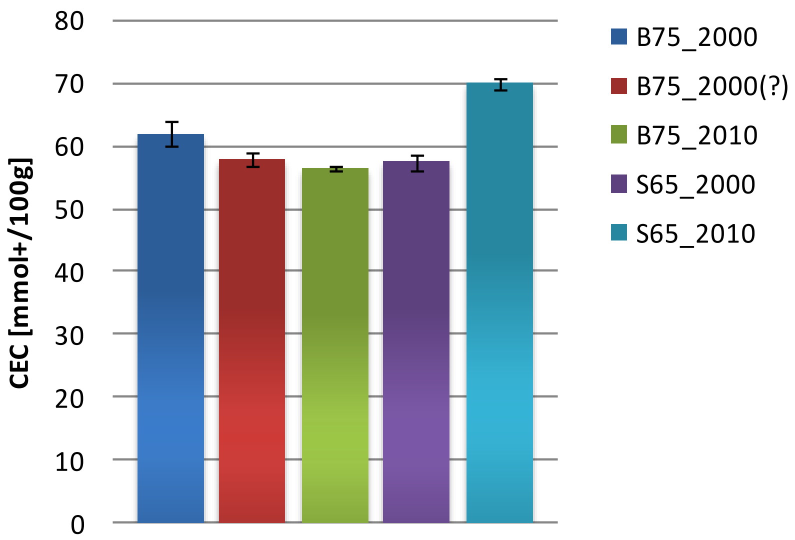


# Introduction: Czech bentonites (Rokle)

- The amount of swelling minerals (mainly montmorillonite) varies from ~ 50 to ~ 75 wt. %, similarly as a cation exchange capacity (CEC) ~ 50 to ~ 75 meq/100g for both natural and commercial bentonites.



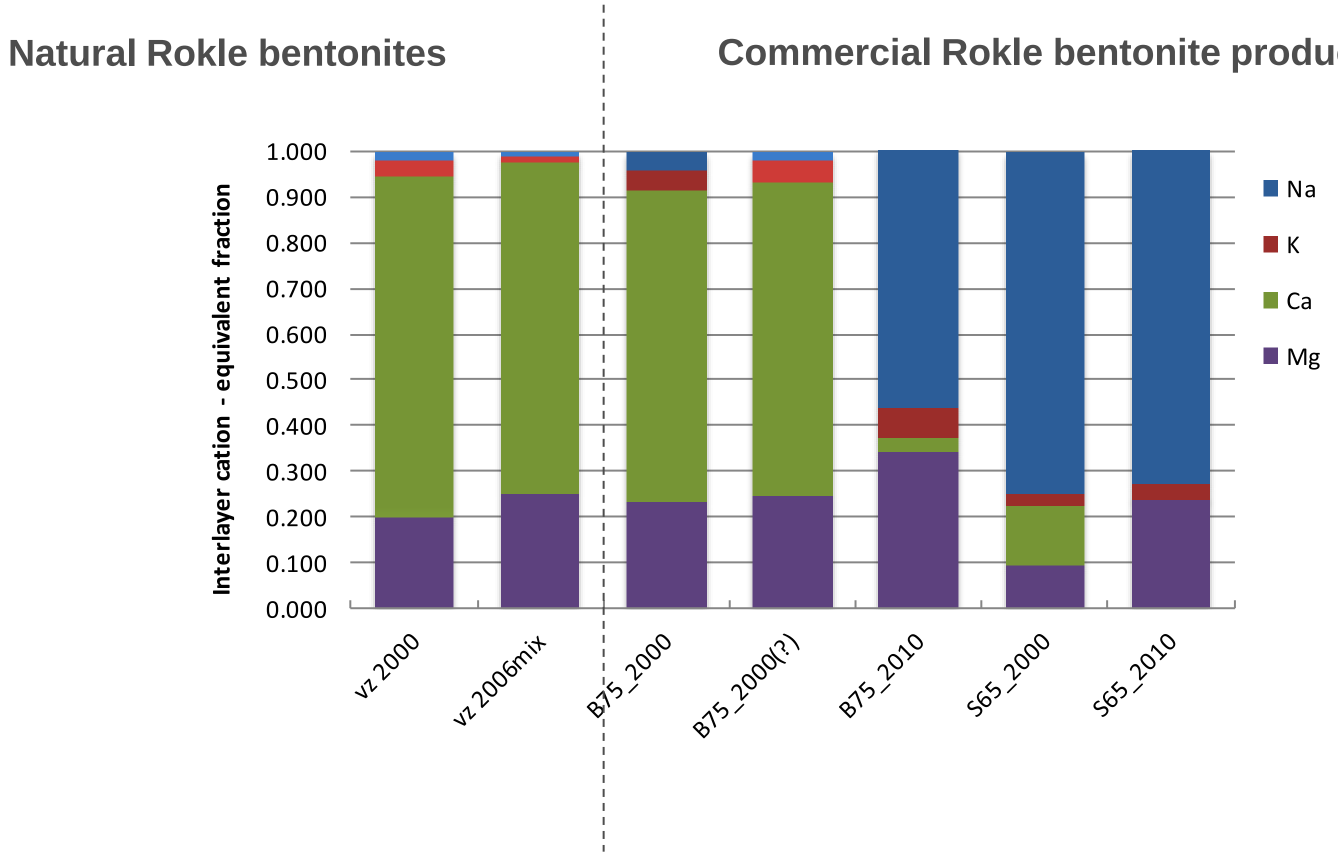

**Natural Rokle bentonites**




**Commercial Rokle bentonite products**

# Introduction: Czech bentonites (Rokle)

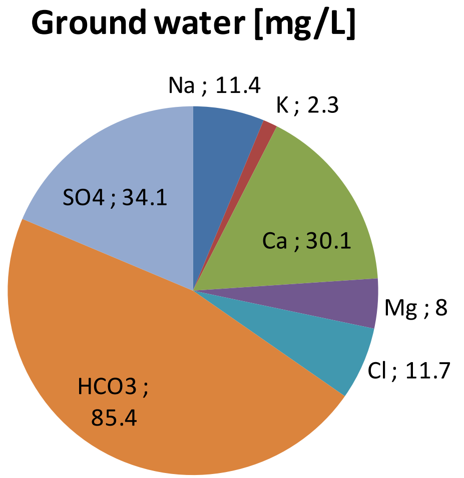
- Interlayer cation occupation for Czech bentonites from Rokle deposit. B75_2010 – commercial product (partly Na-activated), S65_2000 and S65_2010 – commercial product (fully Na-activated).

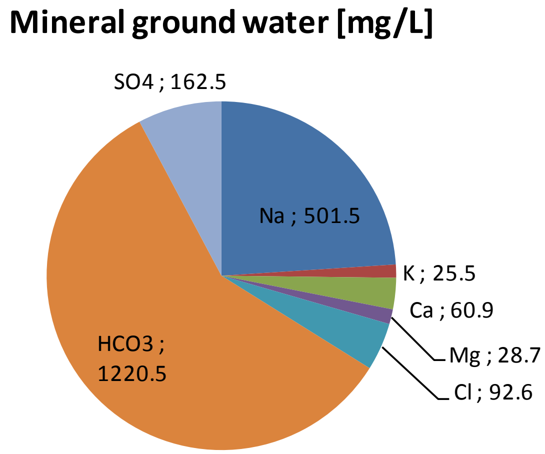


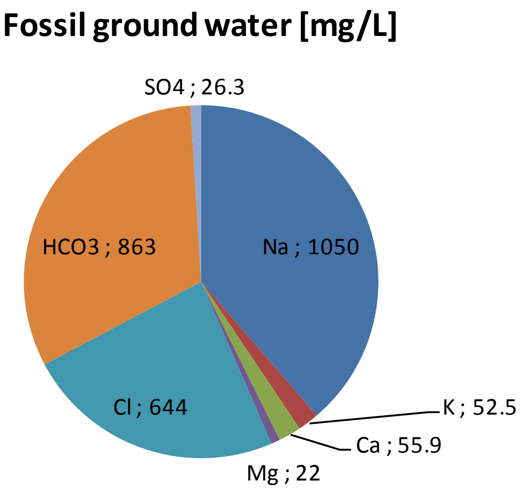
# Introduction: Expected chemistry of ground water in granitic Bohemian Massif

- 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.

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

Groundwaters from granitic Bohemian Massif

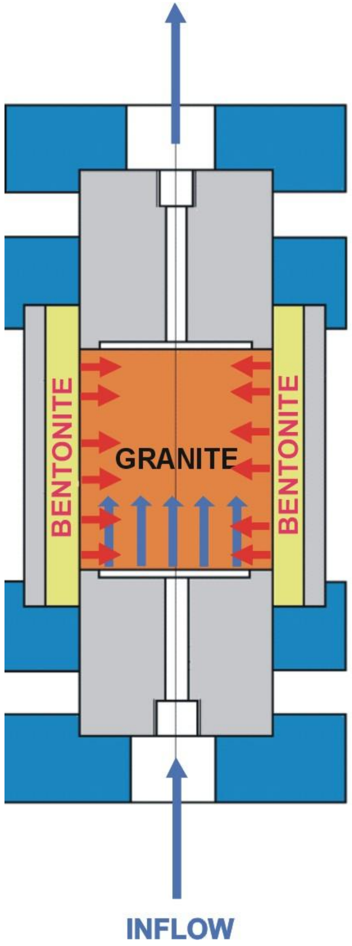
| Component | | Na | K | Ca | Mg | F | Cl | $SO_4$ | $HCO_3$ | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **SGW** | **mg/l** | 10.6 | 1.8 | 27.0 | 6.4 | 0.2 | 42.4 | 27.7 | 30.4 | 6.3 |
| | **mmol/l** | 0.5 | 0.0 | 0.7 | 0.3 | 0.0 | 1.2 | 0.3 | 0.5 | 0.1 |
| **Groundwater** | **mg/l** | 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 | - | - | - | - | - |

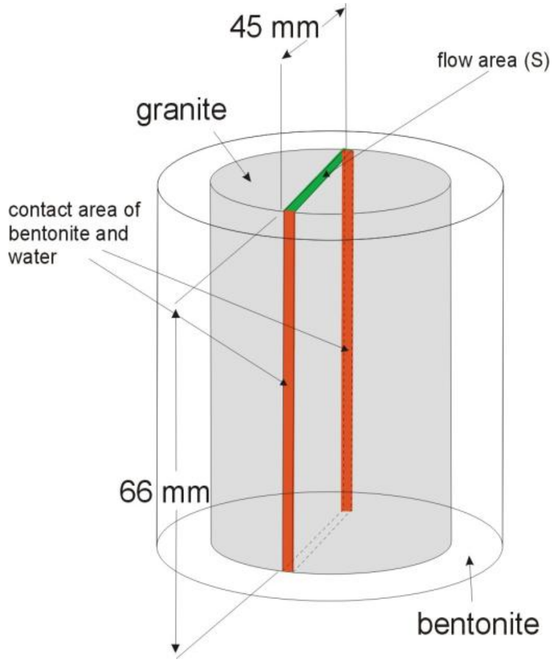
- From estimated CCC we can conclude, that bentonite colloids are not stable in the potential ground waters. Confirmed also by simple coagulation experiments in SGW.

# Experimental set-up: Bentonite erosion in the granite fracture

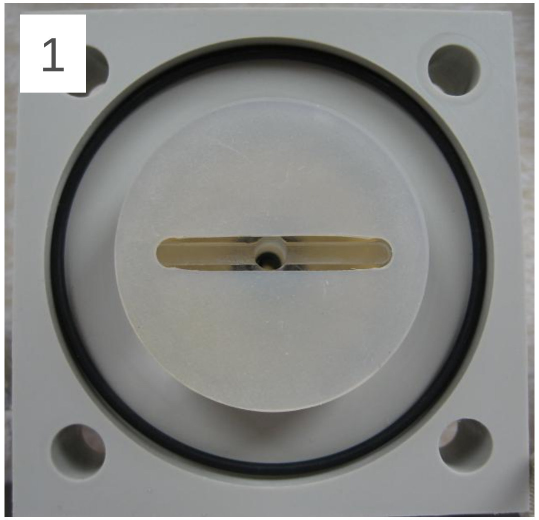
Size up the amount of bentonite particles eroded from the swelling bentonite by the flowing water in the granite fracture during the **bentonite saturation** (characterization of released clay particles).

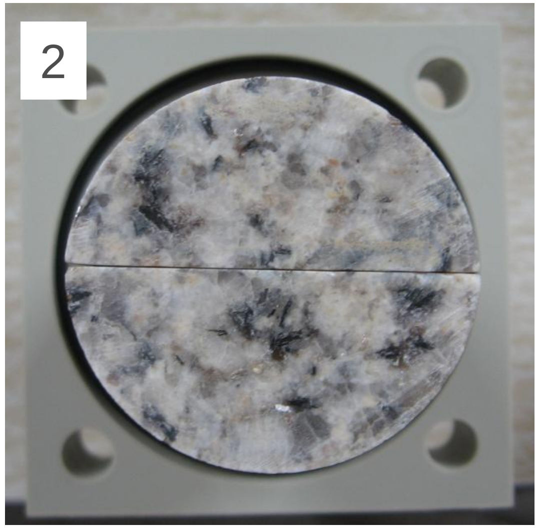
- **Conditions:**
  - Na/Mg-bentonite Rokle (bentonite ring with initial moisture, compacted dry density ~ 1600 kg/m$^3$)
  - Granite cylinder with artificial fracture
  - Distilled water
  - At the beginning, the fracture was washed out with enough amount of water
  - Time - till full saturation of bentonite (~ 30 wt.% of water)
- **Variables**
  - water flow velocity in fracture ($1.12\times10^{-5}$ – $2.48\times10^{-4}$ 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

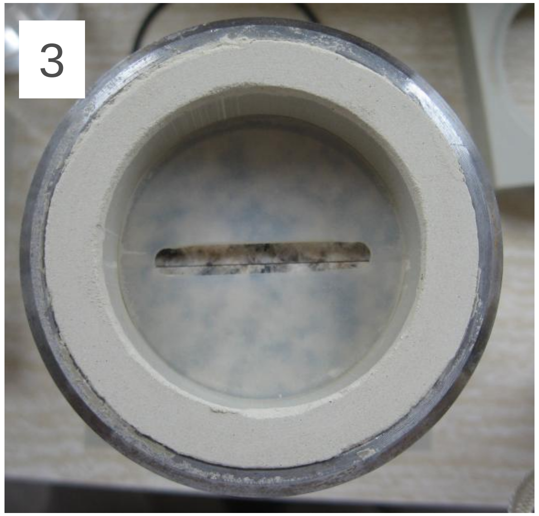


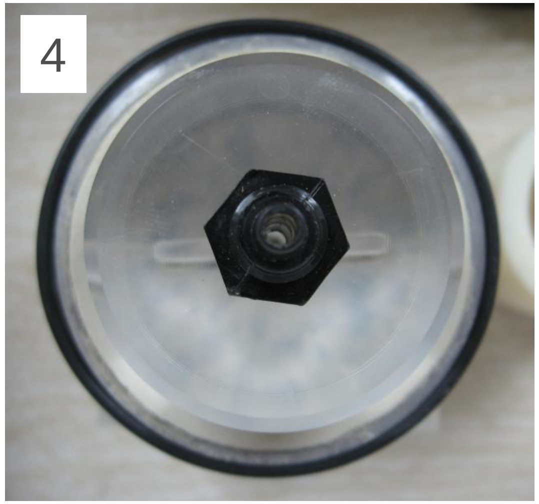



# Experimental set-up: Bentonite erosion in the granite fracture



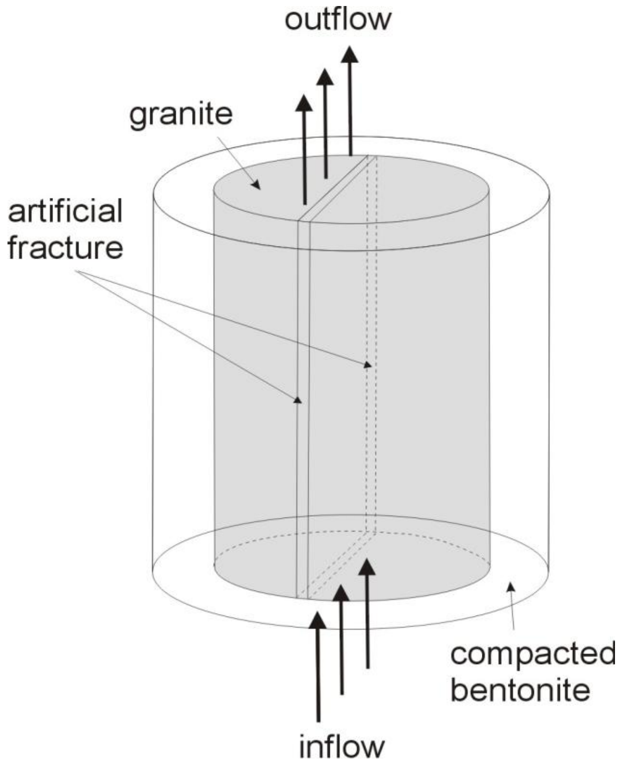



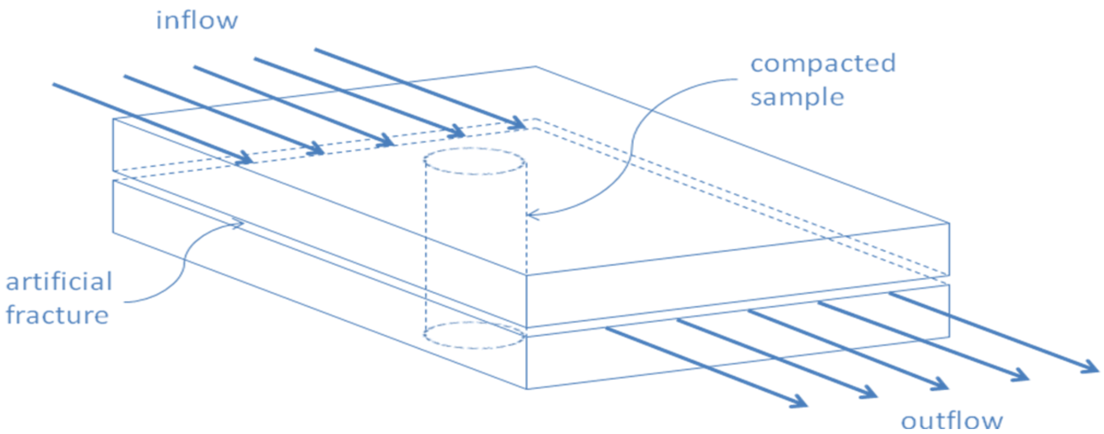



# Experimental set-up: Comparison of arrangement

- 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.

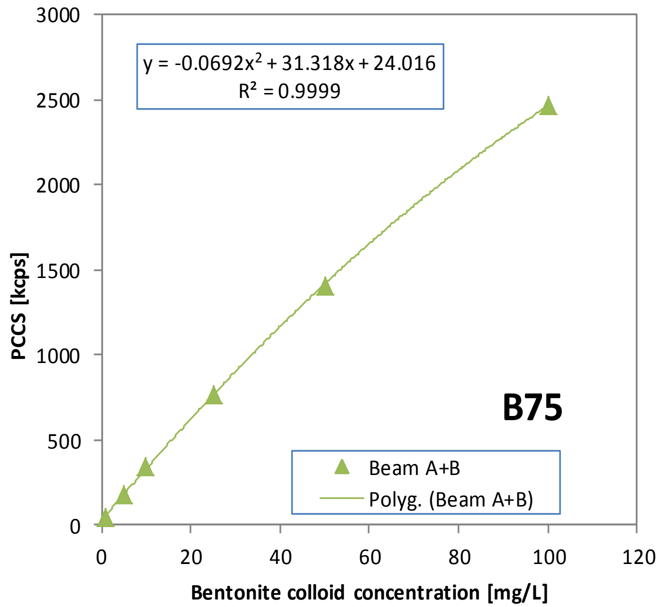
# Experimental set-up: Colloids measurement

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

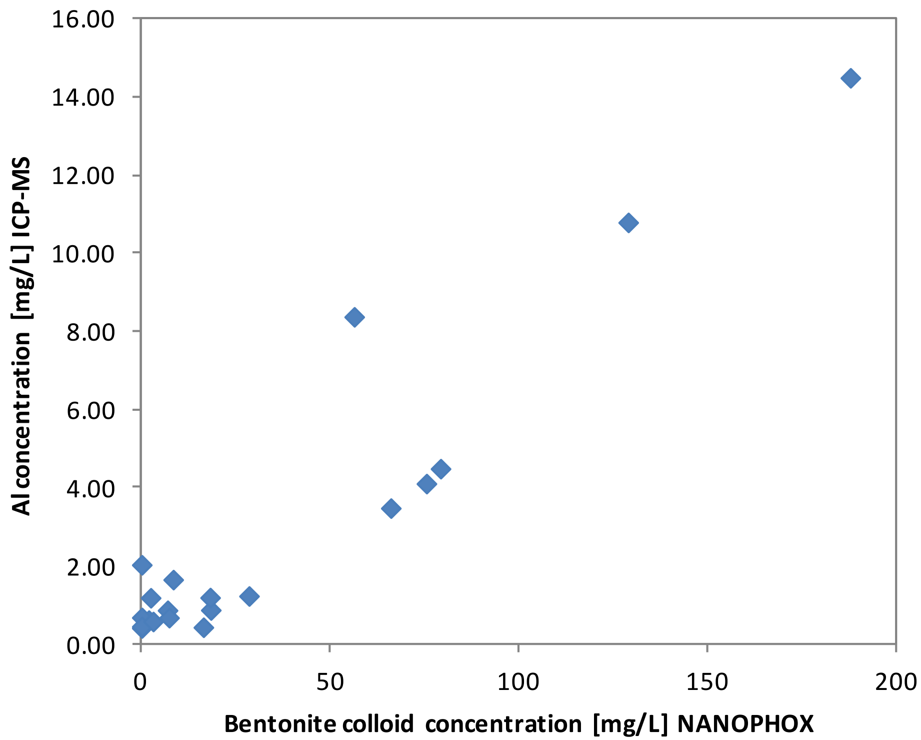
Aluminium in the bentonite B75

| 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 |

PCCS calibration curve



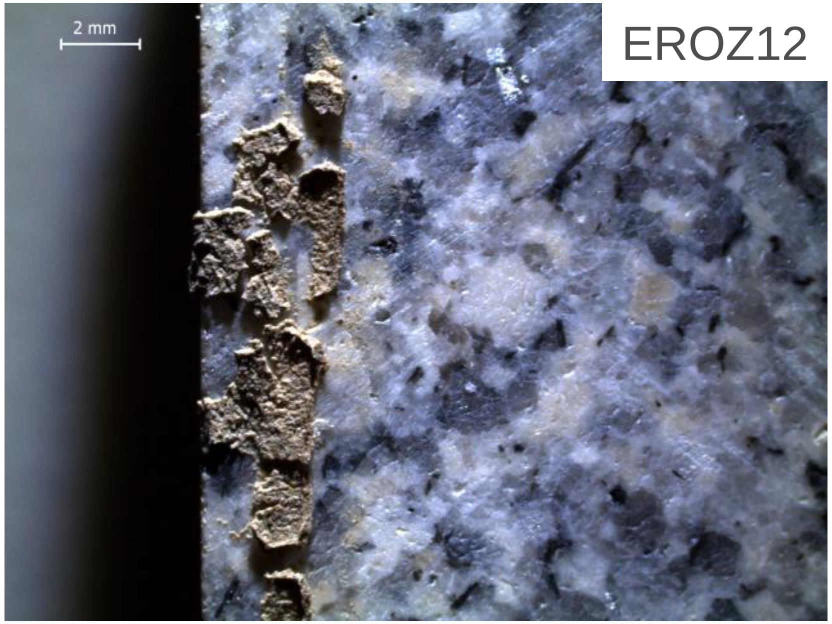

Al conc. (ICP-MS) vs. PCCS measurement




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.

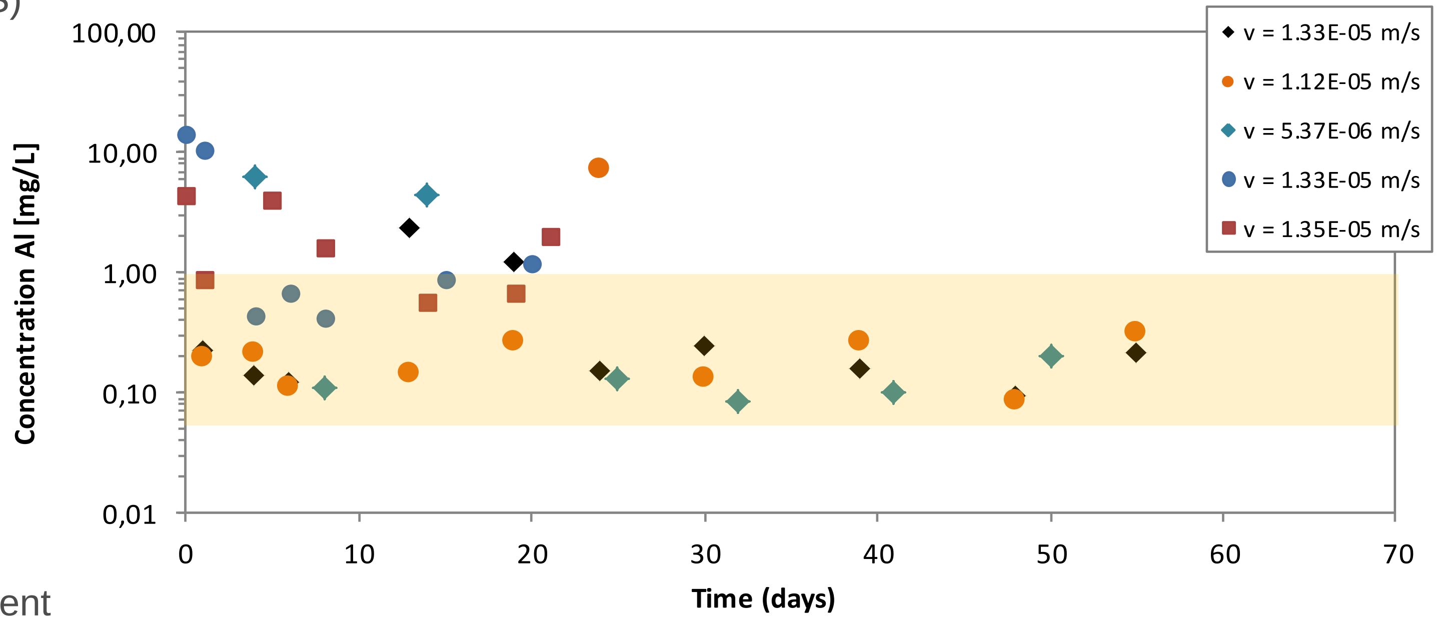
# Results: Optical stereomicroscopy

- 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.

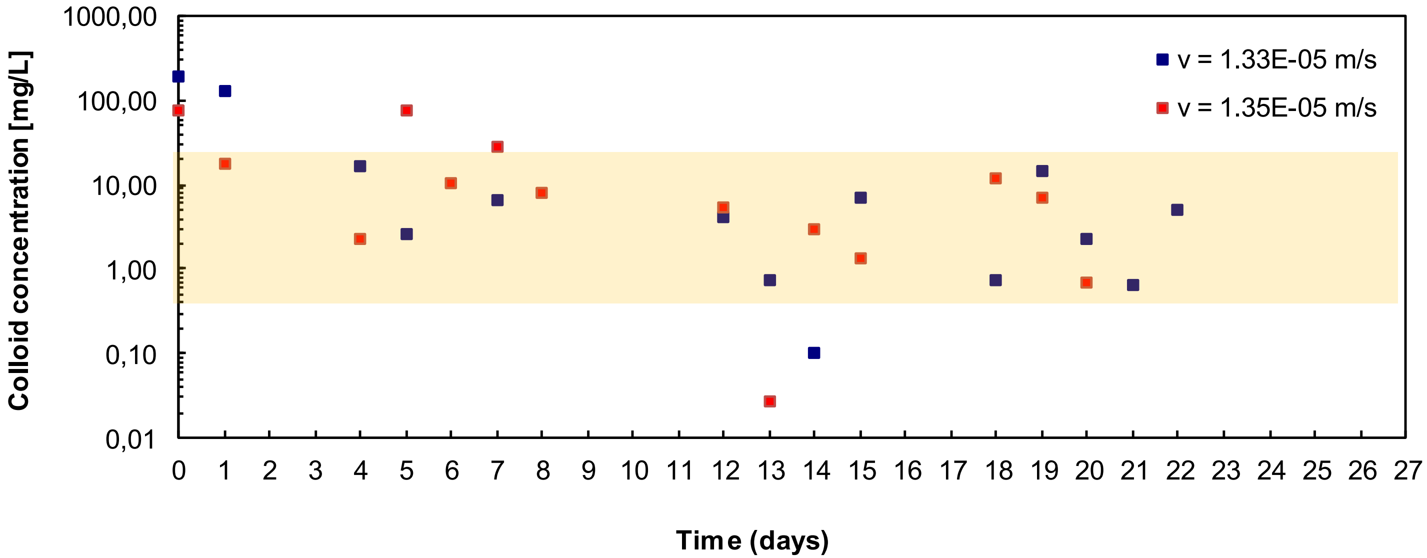



# Results: Clay colloids concentration

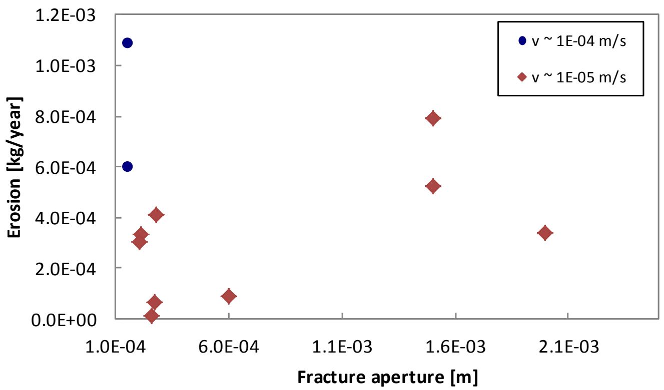
Al conc. (ICP-MS)

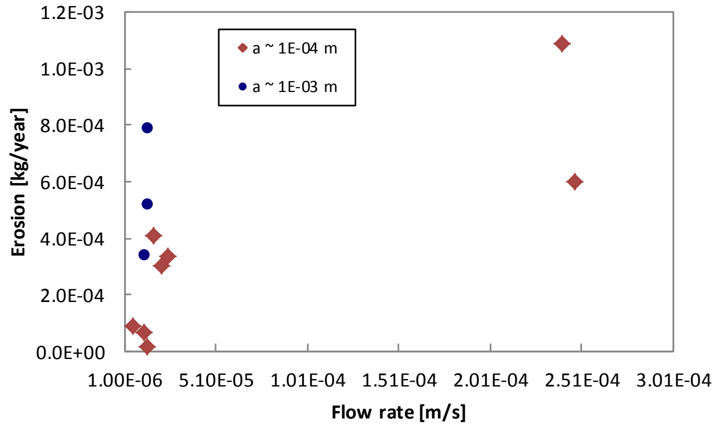


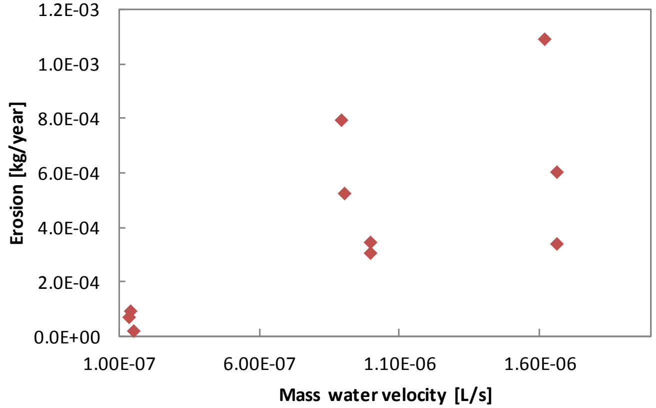

PCCS measurement



# Results: Complete results from erosion experiments



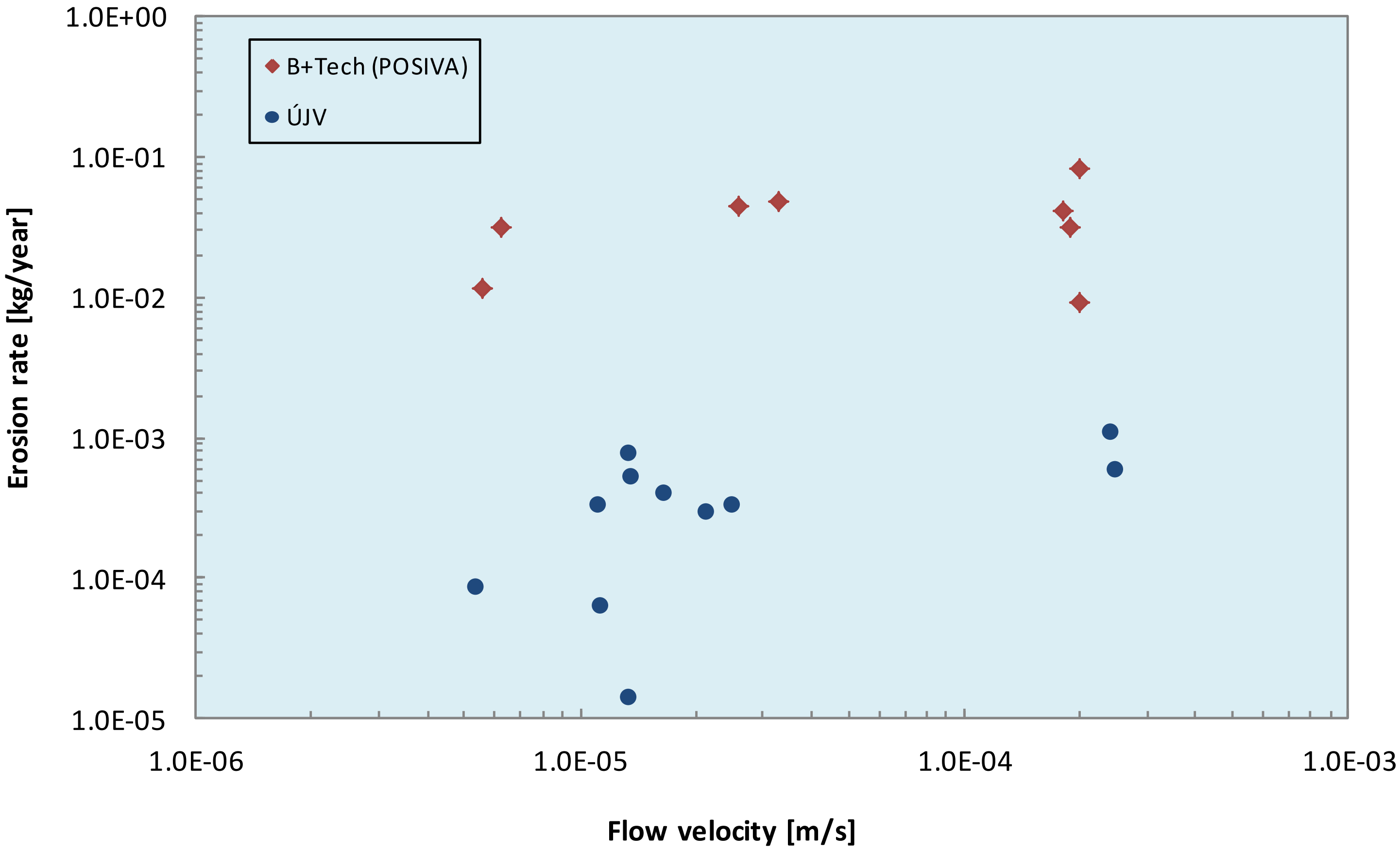

| Experiment no. | Fracture aperture [m] | Time [days] | Mass water velocity $v_m$ [L/s] | Flow rate Q [m³/s] | Area S [m²] | Flow velocity v [m/s] | Erosion per experiment [kg] | Erosion per year [kg/rok] | Water contact area with bentonite [m²] | Erosion per area [kg/m²/rok] |
|---|---|---|---|---|---|---|---|---|---|---|
| EROZ3 | 1.5E-04 | 32 | 1.67E-06 | 1.67E-09 | 6.75E-06 | 2.48E-04 | 5.24E-05 | 5.98E-04 | 1.98E-05 | 3.02E+01 |
| EROZ7 | 6.5E-04 | 32 | 3.33E-06 | 3.34E-09 | 2.93E-05 | 1.14E-04 | - | - | 8.58E-05 | - |
| EROZ8 | 2.0E-03 | 31 | 1.00E-06 | 1.00E-09 | 9.00E-05 | 1.11E-05 | 2.89E-05 | 3.40E-04 | 2.64E-04 | 1.29E+00 |
| EROZ10(1) | 2.6E-04 | 61 | 1.56E-07 | 1.56E-10 | 1.17E-05 | 1.33E-05 | 2.40E-06 | 1.44E-05 | 3.43E-05 | 4.18E-01 |
| EROZ10(3) | 2.7E-04 | 61 | 1.36E-07 | 1.37E-10 | 1.22E-05 | 1.12E-05 | 1.08E-05 | 6.46E-05 | 3.56E-05 | 1.81E+00 |
| EROZ12(3) | 6.0E-04 | 58 | 1.44E-07 | 1.45E-10 | 2.70E-05 | 5.37E-06 | 1.38E-05 | 8.72E-05 | 7.92E-05 | 1.10E+00 |
| EROZ13(1) | 1.5E-03 | 27 | 8.97E-07 | 9.00E-10 | 6.75E-05 | 1.33E-05 | 5.87E-05 | 7.93E-04 | 1.98E-04 | 4.01E+00 |
| EROZ13(2) | 1.5E-03 | 27 | 9.06E-07 | 9.08E-10 | 6.75E-05 | 1.35E-05 | 3.87E-05 | 5.23E-04 | 1.98E-04 | 2.64E+00 |
| EROZ13(3) | 1.5E-04 | 21 | 1.62E-06 | 1.62E-09 | 6.75E-06 | 2.41E-04 | 6.26E-05 | 1.09E-03 | 1.98E-05 | 5.50E+01 |
| EROZ14 (1) | 2.1E-04 | 40 | 2.36E-07 | 2.37E-10 | 9.54E-06 | 2.48E-05 | 3.66E-05 | 3.34E-04 | 2.80E-05 | 1.19E+01 |
| EROZ14 (2) | 2.8E-04 | 40 | 2.06E-07 | 2.06E-10 | 1.26E-05 | 1.64E-05 | 4.48E-05 | 4.09E-04 | 3.68E-05 | 1.11E+01 |
| EROZ14 (3) | 2.1E-04 | 40 | 1.94E-07 | 1.95E-10 | 9.23E-06 | 2.11E-05 | 3.31E-05 | 3.02E-04 | 2.71E-05 | 1.12E+01 |

# Results: Comparison of B+Tech and ÚJV Řež

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; NaMt, Na/MgMt 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.



# Conclusions

- **Generally, results achieved so far do not show a clear trend between fracture aperture or flow velocity and the amount of eroded bentonite in a given experimental range (aperture size of granitic fracture: 0.15 – 2 mm; flow velocity of water in granitic fracture: $1.12\times10^{-5}$ – $2.48\times10^{-4}$ m/s).**

- **The experiments carried out show this erosion rate between 0.4 to 30.2 kg/m$^2$/year considering the values of water velocity and fracture aperture mentioned above (in saturation phase and low IS = distilled water)**

- **Used flow velocities are still higher than the predicted flow velocities in DGR. Expected real values of flow velocity in permeable zones in czech granitic host rocks (about $1\times10^{-6}$ m/s at 600 m depth).**


- 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.