Development of tools for studying contaminant transport in fractured rock environment: laboratory migration experiments in physical models with artificial and natural fractures

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Objectives
Contaminant migration in crystalline rock environment is driven mainly by advective process in fracture network. The main goal of our project is to develop tools for evaluation of migration and retention of potential contaminants (radioisotopes, heavy metals, nanoparticles) in the crystalline single fracture physical models.

Migration experiments on physical model with artificial fracture (MS1, MS2)

Pressure field
- Model fracture transmissivity derived from the hydraulic aperture using cubic law: 
  \[ T = \frac{W_{\text{fracture}}}{D_{\text{fracture}}} \]
- Hydraulic aperture calibration based on minimalization of simulated and measured pressure field differences

![Transmissivity of the calibrated fracture with corresponding pressure field distribution](image1)

- Mean hydraulic aperture: MS1: 213 µm x MS2: 386 µm
- Calibrated hydraulic aperture is lower compared to the directly measured aperture

![Instrumented block MS1 during KI tracer experiment (with pressure sensors)](image2)

- Block model dimensions (MS1, MS2): 80 x 50 x 40 cm

Tracer transport
- Calibration of the transport aperture is based on conformity of simulated and measured breakthrough curves
- Conservative: NaCl, KCl, KI, HTO
- Reactive tracers: Pb(ClO4)2

![Simulated Pb²⁺ concentrations with various partition ratio parameter in timestamp 1000 s after tracer injection (MODFLOW+MT3D)](image3)

- Mean transport aperture: MS1: 325 µm x MS2: 580 µm
- Transport aperture is greater compared to hydraulic
- Calibrated dispersivity: cca 7.5 mm longitudinal / 5 mm transverse
- Intensive sorption of tracer Pb²⁺ on the granite fracture surface

Migration experiments on physical model with natural fracture

Sample preparation
- Core sample drilling (URL Bukov)
- Sample resized and embedded with resin
- One inlet / one outlet

![Core sample dimensions: 7.8 x 9 cm](image4)

3D fracture characterisation (HZDR, Leipzig)
- µCT density mapping of core samples
- Spatial resolution: 50 µm
- Fracture segmentation
- Aperture determination

![Segmented fracture grid for transport simulations](image5)

GeoPET experiments (HZDR, Leipzig)
- Tracer: [18F]KF (100 MBq)
- Spatial resolution: 1 mm
- Flow rate: 1 ml/h
- Activity and flow velocity field
- Heterogenous migration pathways

![Heterogenous activity map](image6)

Conclusion
- Systematically higher transport aperture compared to hydraulic; advective transport affected by friction.
- Approximately the same ratio of transport to hydraulic aperture regardless of the sample.
- First results indicate possibility of using PET-µCT techniques for reactive transport analysis.

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