Geophysical Research Abstracts
Vol. 13, EGU2011-10669, 2011
EGU General Assembly 2011

Combined 3D high-resolution PET and CT measurements with lattice Boltzmann simulations of fluid flow in heterogeneous material

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The joint research project "Dynamics of drowned and flooded salt mines and their overlaying rocks" aimed at exemplarily and comprehensively clarifying causes, processes and effects of damages caused by abandoned historical potassium mining in Staßfurt, Germany [1]. Funded by the BMBF (Bundesministerium für Bildung und Forschung) ten universities, research facilities and companies were coordinated by the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe). The IRC - Research Site Leipzig contributed small scale laboratory experiments of flow and transport process observations in drilling cores from hydrologic relevant regional lithologies and the matching of fluid flow patterns with high resolution CT imaging data and structure-controlled model simulations obtained and conducted by colleagues from JGUM [2]. This close collaboration aimed at enhancing the comprehension of small scale fluid flow in heterogeneous natural porous media.

Visualization of fluid flow in homogeneous porous as well as in fractured heterogeneous media was conducted with a preclinical PET scanner with a spatial resolution of 1 mm and a temporal resolution of 1 minute [3]. Drill cores from anhydrite, sandstone and rock salt formations of the Staßfurt salt dome were examined with continuous flow-through experiments. Pulses of radiotracer solutions ([^{18}F]KF and [^{124}I]KI) were injected and in situ PET-observations of the tracer propagation were conducted throughout the course of several hours and weeks, depending on the sample permeability. The flow behavior can be described with heterogeneous and process-dependent parameter distributions, like effective volume, permeability and dispersion rates. Based on μXCT measurements with a spatial resolution of 65.3 μm the percolating pore space, including all connected pores and fractures and the maximal inner surface, was quantified [2].

This "GeoPET" method is an excellent tool for direct quantitative spatiotemporal visualization of tracer transport in heterogeneous rocks on core scale [3, 4]. Combined interpretation of μXCT and PET data enables deepened understanding on causes and effects of the structural constraints (pore space, cleavages etc.) on fluid flow patterns, enables to stereotype combined structural characteristics and flow path topologies and to determine the ratio between total and effective pore volume. The latter is for instance revealed by observable fingering phenomena in extended fractures. The fraction of the internal surface of a rock sample in contact with the mobile fluid – the effective reactive surface area – decreases with increasing localization of actual transport paths. Therefore, combined PET-CT data interpretation enables to realistically describe the considerably narrowed potential of dissolution and sorption reactions in heterogeneous and fractured media. In combination with simulated data the flow velocity patterns were quantified along the pathways, and they appeared highly variable within the fractures. In saline rocks we observed that localized high flow velocities may locally stimulate the salt dissolution and cause the widening of fracture cross sections. Such self energizing mechanisms may lead to increasing permeabilities, flow velocities and flow rates.

The complex flow patterns and the different resolutions of the data sets require scale independent comparison methods. We thus applied variography [4], which also could be applicable as simple method for upscaling to the field scale.

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[3] Kulenkampff, J. et al. (2008) *Phys. Chem. Earth*, 33, p. 937-942.
[4] Wolf, M. et al. (2010) *EDGG*, 244, p. 200-212.