# Matching 4D Porous Media Fluid Flow GeoPET Data with COMSOL Multiphysics Simulation Results

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## Abstract

Introduction: Our GeoEPT-method allows the 4D monitoring of transport processes in geological material on laboratory scale (Gründig et al., 2007; Kulenkampff et al., 2008; Richter et al., 2005). We apply COMSOL Multiphysics for reproducing our experiments and extracting parameter sets for our 4D problems. We learn that importing realistic structures from computer tomography (CT) as well as matching our experimental and simulated 4D data sets are complex tasks.

Use of COMSOL Multiphysics: A granite drill core (length = 198 mm, diameter = 50 mm) with a prominent fracture is scanned by means of a medical CT with a spatial resolution of about 1 mm³ (3·106 voxels, Figure 1, bottom). The data segmentation is conducted with Avizo® Fire under consideration of beam hardening effects. A voxel based fracture geometry is transferred to COMSOL Multiphysics in stl-file format (11 MB, Figure 1, top). After scaling the geometry object and converting it to solid, we allocate the material water to its volume of about 20 ml. First Laminar flow is assigned to the domain and solved stationary. By attributing No slip walls, initial (u = 0, p0 = 0), inflow (u0 = 2·10-5 m/s) and outflow conditions (p = 0) the experimental conditions are well represented by the model. A user-controlled mesh (free tetrahedral, normal element size) calibrated for Fluid dynamics consists of ~370,000 elements (Figure 2). The stationary flow and pressure field is solved by the GMRES solver in less than four minutes. We add Transport of a diluted species with a Gaussian concentration-input function (standard deviation ~14 min at t = 30 min) for simulating our time dependent experiment (Figure 3). This computing time amounts to additional 23 minutes.

Results: We obtain 4D simulation results covering 10 hours with 10 min resolution. The 4D data sets (Figure 3) as well as breakthrough curves (BTC) are matched with our 4D experimental results obtained in GeoPET experiments (Figure 4). Although effects caused by filter plates at the flange facings were not yet considered in the COMSOL, model the BTC matches fairly well.

Conclusion: The development of algorithms for flow pattern identification, parameterisation of pattern evolution and pattern tracking might allow for quantitative similarity studies of 4D flow and transport processes. In parallel, refining the geometry on the basis of higher resolution CT measurements will help approaching better matches between simulated and measured 4D data sets of flow and transport in heterogeneous geological media.

Outlook: Intermediate and long-term aim of such matching attempts of 4D simulation results with corresponding measurement results is (A) to quantify the effect a simplified geometry from high resolution CT measurements has on the quality of reproducing our real GeoPET flow and transport monitoring results, (B) to quantify the effect a simplified geometry has on the quality of reactive transport in geological material, when additional interactions have to be considered and (C) to evaluate appropriate algorithms for reducing high resolution, high dimension, complex physics models to continuum scale models capable of capturing the relevant processes ruling on the field scale.

## Reference

Gründig, M. et al., 2007. Tomographic radiotracer studies of the spatial distribution of heterogeneous geochemical transport processes. Appl. Geochem., 22: 2334-2343.
Kulenkampff, J. et al., 2008. Evaluation of positron emission tomography for visualisation of migration processes in geomaterials. Physics and Chemistry of the Earth, 33: 937-942.
Richter, M. et al., 2005. Positron Emission Tomography for modelling of geochmical transport processes in clay. Radiochim. Acta, 93: 643-651.

## Figures used in the abstract

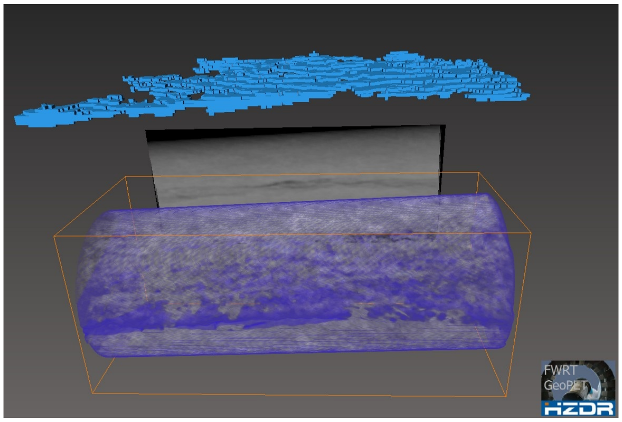


**Figure 1**: CT-scan (bottom) of a 19.8 cm long granite core with a diameter of 5 cm. Bluish are open voids, grey the solid matrix (Visualization and segmentation is conducted by means of AVIZO®). The projection behind the core scan illustrates the axial position of a prominent fracture. Topmost displayed is the voxel based binary stl-file roughly representing the fracture geometry in 3D (~370.000 elements).

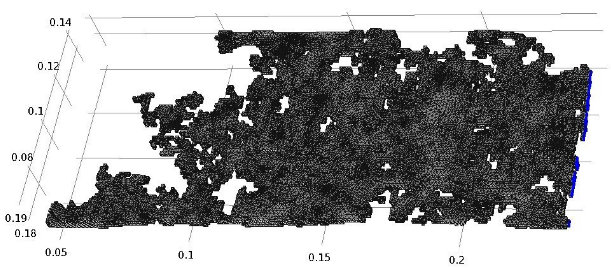


**Figure 2**: User-controlled mesh (free tetrahedral, normal element size) calibrated for Fluid dynamics consists of ~370,000 elements. At the right hand side individual boundaries are defined as inflow boundaries with a constant normal velocity. At the left hand side a much smaller area is defined as outflow boundary. All other boundaries are walls with no slip conditions.

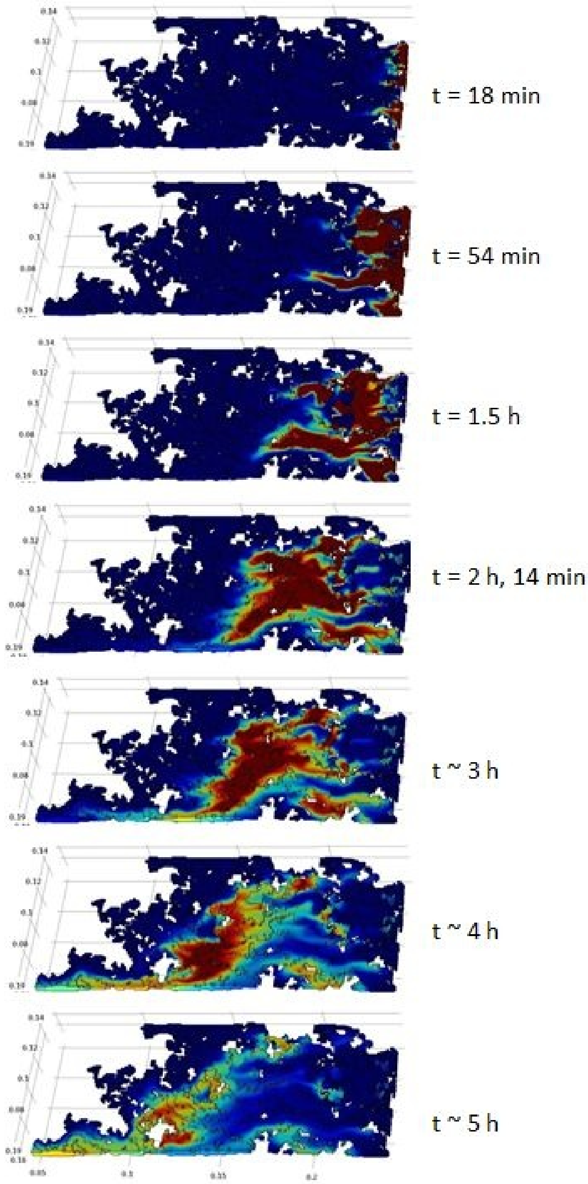


**Figure 3**: Seven selected images reflecting the transport (from right to left, flow rate = 0.1 mL/min) of a concentration pulse (3.4 mL, arbitrary units) through a fracture (fracture volume = 20,4 mL) of a granitic drill core (length = 19.8 cm, diameter = 5 cm). Underlying physics are Laminar flow (Navier-Stokes, Compressible flow, Ma

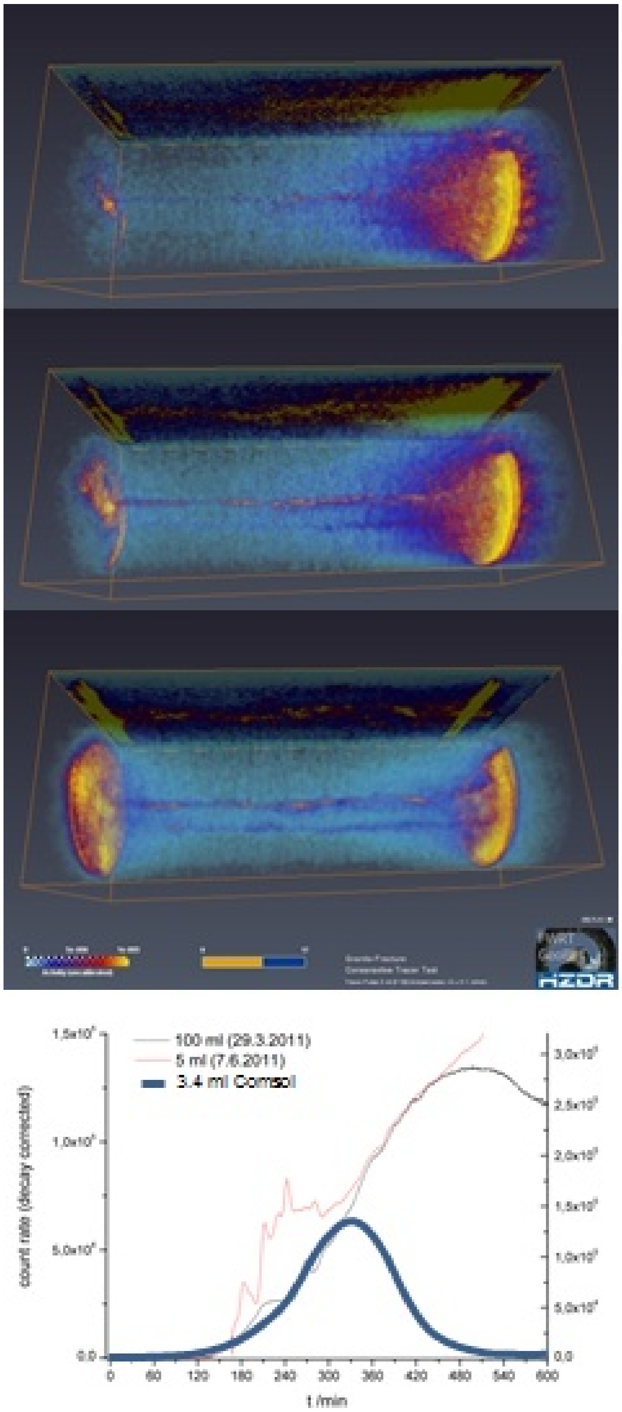


**Figure 4**: Displayed are three selected images out of a set of 16 covering the 10 h long fracture flow and transport monitoring experiment in a granitic core (length = 19.8 cm, diameter = 5 cm, flow rate = 0.1 mL/min). The PET camera is sensitive to gamma rays emitted during positron decay of the 18F-PET tracer. Consequently, at locations with high radiotracer concentrations (in both filter plates at the flange facings) the images are interfered by scatter effects (scatter correction improvement is underway). But besides the localized scatter effects, characteristic features the fracture flow is clearly resolved. A first comparison of the experimental (thin lines) and simulated BTC (thick line) returns a reasonable match.