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Microscale simulations of NMR relaxation behaviour in the presence of fluid flow in porous media

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Structure and state of soils have considerable influence on their flow and transport properties in particular for the vadose zone. In petrophysical applications of nuclear magnetic resonance (NMR), the measured relaxation signals originate from the fluid filled pore space. Hence, in (partially) saturated rocks or sediments the water content directly corresponds to the initial amplitude of the recorded NMR relaxation signals. The rate of relaxation (longitudinal / transversal relaxation time T1/T2) is sensitive to the pore size and physiochemical properties of the rock-fluid interface (surface relaxivity), as well as the concentration of paramagnetic ions in the fluid phases (bulk relaxivity).

Joint numerical simulations of the NMR relaxation behaviour (Bloch equations) and fluid flow (Navier-Stokes) on a pore scale dimension have been implemented in a finite element model using Comsol Multiphysics. Solving the differential equations for general cases allows to simulate NMR responses for arbitrary pore geometries and heterogeneous distributions of surface properties. The simulations can cover every possible NMR relaxation regime, e.g. diffusion or surface limited as well as intermediates, depending on the model's properties. The implementation of the KST approach for NMR surface properties allows to link the (magnetization) sink terms in the differential equations with spatially distributed concentrations of paramagnetic ions in the fluid phase and at the fluid-rock interfaces. A strong inter-pore coupling due to connectivity of pores with different NMR properties (size, surface properties) can significantly shift the relaxation time distribution that is not accounted for in the determination of pore size distribution from NMR decay times.

These simulations are verified by corresponding NMR and SIP laboratory experiments on fully and partially saturated reference samples with accurately defined pore spaces determined by computer tomography (see Wiens et al, MPRG7). Based on these investigations and pore scale simulations of frequency dependent behaviour of the complex resistivity (Spectral Induced Polarization, SIP; see also Volkmann et al, MPRG7) we aim at an interpretation scheme combining NMR and SIP to assess structure, state and thus flow properties of partially saturated soils.