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Soils, Pores, and NMR

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Within Cluster A, Partial Project A1, the pore space exploration by means of Nuclear Magnetic Resonance (NMR) plays a central role. NMR is especially convenient since it probes directly the state and dynamics of the substance of interest: water. First, NMR is applied as relaxometry, where the degree of saturation but also the pore geometry controls the NMR signature of natural porous systems. Examples are presented where soil samples from the Selhausen, Merzenhausen (silt loams), and Kaldenkirchen (sandy loam) test sites are investigated by means of Fast Field Cycling Relaxometry at different degrees of saturation. From the change of the relaxation time distributions with decreasing water content and by comparison with conventional water retention curves we conclude that the fraction of immobile water is characterized by $T1 < 5$ ms. Moreover, the dependence of the relaxation rate on magnetic field strength allows the identification of 2D diffusion at the interfaces as the mechanism which governs the relaxation process (Pohlmeier et al. 2009). T2 relaxation curves are frequently measured for the rapid characterization of soils by means of the CPMG echo train. Basically, they contain the same information about the pore systems like T1 curves, since mostly the overall relaxation is dominated by surface relaxivity and the surface/volume ratio of the pores. However, one must be aware that T2 relaxation is additionally affected by diffusion in internal gradients, and this can be overcome by using sufficiently short echo times and low magnetic fields (Stingaciu et al. 2009).

Second, the logic continuation of conventional relaxation measurements is the 2-dimensional experiment, where prior to the final detection of the CPMG echo train an encoding period is applied. This can be T1-encoding by an inversion pulse, or T2 encoding by a sequence of 90 and 180° pulses. During the following evolution time the separately encoded signals can mix and this reveals information about the connectivity of the pore system. Examples are given for T1-T2 correlation of some soil samples (Haber-Pohlmeier et al. 2010).

Third, relaxometric information forms the basis of understanding magnetic resonance imaging (MRI) results. The general difficulty of imaging in soils are the inherent fast T2 relaxation times due to i) the small pore sizes, ii) presence of paramagnetic ions in the solid matrix, and iii) diffusion in internal gradients. The last point is important, since echo times can not set shorter than about 1ms for imaging purposes. The way out is either the usage of low fields for imaging in soils or special ultra-short pulse sequences, which do not create echoes. In this presentation we will give examples on conventional imaging of macropore fluxes in soil cores (Haber-Pohlmeier et al. 2010), and the combination with relaxometric imaging, as well as the advantages and drawbacks of low-field and ultra-fast pulse imaging. Also first results on the imaging of soil columns measured by SIP in Project A3 are given.

Haber-Pohlmeier, S., S. Stapf, et al. (2010). "Waterflow Monitored by Tracer Transport in Natural Porous Media Using MRI." Vadose Zone J.: submitted.

Haber-Pohlmeier, S., S. Stapf, et al. (2010). "Relaxation in a Natural soil: Comparison of Relaxometric Imaging, T1 – T2 Correlation and Fast-Field Cycling NMR." The Open Magnetic Resonance Journal: in print.

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Stingaciu, L. R., A. Pohlmeier, et al. (2009). "Characterization of unsaturated porous media by high-field and low-field NMR relaxometry." Water Resources Research 45: W08412