Magnetic resonance imaging to assess transport properties of porous media due to dissolution and precipitation processes

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Introduction: Precipitation/dissolution processes often occur in engineered systems in the subsurface such as mineral mining, at interfaces in concrete structures and rocks, or due to carbon dioxide sequestration. Thus, pore space is modified and flow and transport processes are strongly affected leading to dynamic changes in porosity-permeability. 3D non-invasive imaging is mandatory for the understanding and theoretical description of these processes. In this work we conducted flow-through column experiments – according to the experimental concept of Poonoosamy et al. [1, 2]- to investigate the effect of barite precipitation following dissolution of celestine and consequential permeability changes: $SrSO_4(s) + BaCl_2(aq) \rightarrow SrCl_2(aq) + BaSO_4(s)$.

Methods: The relaxation properties of the original and reacted materials were determined by CPMG and IR relaxometric imaging at high field, as well as by 2-dimensional T_2-T_2 correlation experiments at low field using a Magritek tomograph at B_0 = 0.6 T to gain information about the pore connectivity. For monitoring the pore space changes due to barite precipitation, a flow-through column of 1.5 cm diameter was placed in the Bruker scanner with a WB insert at B_0 = 4.7T and scanned under continuous flow from bottom to top, with simultaneous monitoring of the pressure increase. We determined T_2 as well as T_1 maps by multi-echo multi-slice and an IR-single echo multi-slice sequence with normalization on a reference image, respectively [3].

Results and Discussion: The longitudinal relaxation time in both, barite and celestine compartments of (2.6 ± 0.1) s was identical to that of bulk water, meaning that the pore walls have no influence on T_1 despite of the relative small pore size of 10 to 100 µm. In contrast, T_2 decreased unambiguously from 13 to 10 ms during the precipitation and additionally showed a distinct dependence on the echo time. This indicates that the relaxation is controlled by diffusion in internal gradients, not by surface relaxivity changes. The T_2 map showed a homogeneously progressing front of barite in the celestine packing over a period of 5 weeks, characterized by short T_2, and constant T_1.

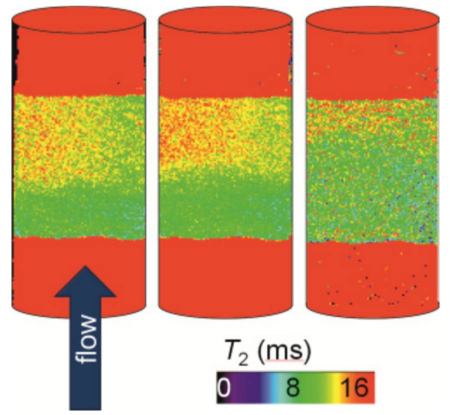

Figure 1: Moving barite front (green) in the celestine packing (yellow-orange).

Conclusion:

NMR relaxometry and MRI allows the detailed characterization of the distribution of precipitates forming in porous media and associated changes in pore geometry. In combination with pressure monitoring the image series allows the derivation of realistic porosity-permeability relations, which can be used in reactive transport simulations.

References: [1] Poonoosamy J., et al. J. Contam. Hydrol. (2015), [2] Poonoosamy et al. Geochim. Cosmochim. Acta (2016),[3] Haber-Pohlmeier et al. Wat. Res. Res. (2017)