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N2 and CO_2 capillary breakthrough experiments on Opalinus Clay

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The aim of this project was to identify the critical capillary pressures on the drainage and the imbibition path for clay-rich rocks, at a burial depth of 1500 m (30 MPa confining pressure, 45°C). The experiments were performed on fully water-saturated sample plugs of 38 mm diameter and 5 to 20 mm length. The capillary breakthrough pressure was determined by step-wise increase of the differential pressure (drainage), the capillary snap-off pressure was determined from the final pressure difference at the end of a spontaneous imbibition phase. The confining pressure was kept constant throughout the experiment, which resulted in a continuous change of effective stress. The measurements were performed in a closed system and the pressure response was interpreted in terms of different flow mechanisms (diffusion-controlled vs. viscous flow).

In total, four breakthrough experiments with N2 and five experiments with CO_2 were conducted. Because of very low flow rates and high critical capillary pressures the experiments took rather long. In some cases the experiments were allowed to run for half a year (drainage experiments).

Substantial differences were observed between gas breakthrough (drainage) and snap-off (imbibition) pressures. As expected, breakthrough pressures were always higher than the snap-off pressures. For three samples a pbreakthrough/psnap-off ratio of 1.6 to 1.9 was observed, for one sample a ratio of 4. A clear permeability-capillary pressure relationship could not be identified.

Based on (omnidirectional) Hg-injection porosimetry results, and assuming perfectly water wet mineral surfaces, gas breakthrough pressures were predicted to occur at approximately 16 MPa for N2 and 5.7 MPa for CO_2. The gas breakthrough experiments, however, produced different results. Even though a relatively homogeneous sample set was chosen, with permeability coefficients ranging between 1E-21 and 6E-21 m^2, the critical capillary breakthrough pressures for nitrogen ranged between 3.4 and 12.3 MPa and snap-off pressures from 0.5 to 6.4 MPa. The CO_2 experiments yielded breakthrough pressures of 14.0 to 17.5 MPa and snap-off pressures of 3.5 to 10 MPa.

No significant changes in single-phase water permeability coefficients before and after the gas breakthrough experiments were observed.

In our contribution we will discuss the following points:

1. Gas fluxes occurring during gas breakthrough experiments may be extremely low. Therefore an unambigous identification of gas breakthrough is not always possible. Besides viscous or diffusive transport, dissolution of CO_2 in the pore water may affect the observed pressure changes in the upstream and downstream compartments. All of these processes occur simultaneously and can only be partly discriminated. Gas fluxes detected during the diffusion-controlled flow regimes result in nominal effective gas permeability coefficients as low as 6E-25 m^2 to 7E-24m^2.

2. The application of purely capillary-controlled flow models may not be justified.
o Gas breakthrough is controlled by effective stress, i.e. the opening of pores or small fissures.
o Assumptions about wettability (completely water-wet mineral surfaces) may be incorrect.