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Two-way hydro-mechanical coupling is required not to underestimate fault fluid flow in numerical simulations

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Pressure elevation in saturated porous media induced by any kind of fluid injection into a reservoir generally triggers pore volume changes in the host rocks and/or adjacent fault zones due to volumetric strain increments. Consequently, the hydraulic conductivity of faults can increase by several orders of magnitude, and thus allows for unwanted upward migration of fluids accompanied by environmental impacts in shallower aquifers. Interaction between hydraulic and mechanical processes is significant in this context. Hence, coupled hydro-mechanical simulations were applied in the present study to assess the impact of saline aquifer utilization on the recent stress state and fluid flow at a prospective German onshore carbon dioxide storage site, in particular with regard to present fault zones.

The location of interest is a Mesozoic anticline structure, approximately 80 km southeast of the German capital Berlin [1, 2]. A Lower Triassic saline sandstone aquifer, the Detfurth Formation located at a depth of about 1,080 m, was chosen as storage horizon for 34 Mt CO_2, injected within 20 years. Four major regional fault zones consisting of individual faults with different dip angles and directions are located at a distance of minimum 5 km and maximum 45 km from the injection location at the anticline top. The storage formation is overlain by several cap rocks from the Triassic to Tertiary with thicknesses varying between 50 m and 520 m. The Upper Tertiary Rupelian clay forms the main regional barrier separating salt water bearing aquifers from Tertiary and Quaternary freshwater reservoirs. However, glacial erosion resulted in thinning or a complete absence of the Rupelian clay in some areas that meet parts of the fault zones.

The structural geological model applied for coupled hydro-mechanical simulations has an extent of 70 km x 100 km and extends from 5,000 m depth up to the ground surface. Multi-phase flow simulations were carried out using the scientific code TOUGH2-MP and coupled to the hydro-mechanical simulator FLAC3D through hydraulic property changes as a function of volumetric strain increments.

Numerical simulations are based on one-way and two-way coupling procedures. The one-way coupling considers pore pressure calculated by the multiphase flow as input to the hydro-mechanical simulator without any feedback. The two-way coupling procedure includes a feedback from the hydro-mechanical simulator to the multiphase flow simulator using the parameters porosity and permeability accompanied by a capillary pressure correction.

Results of the comparison of both coupling procedures outlines that a two-way coupling is required when fault fluid flow is assessed by numerical simulations, since hydraulic flow properties may change by several orders of magnitudes inducing significant migration pathways at faults under given conditions. Hence, in such cases one-way coupling tends to underestimate fault fluid flow.

[1] Tillner E, Kempka T, Nakaten B, Kühn M. Brine migration through fault zones: 3D numerical simulations for a prospective CO_2 storage site in Northeast Germany. Int J Greenh Gas Con 2013; 19: 689–703. doi: 10.1016/j.ijggc.2013.03.012.

[2] Röhmann L, Tillner E, Magri F, Kühn M, Kempka T. Fault Reactivation and Ground Surface Uplift Assessment at a Prospective German CO_2 Storage Site. Energy Procedia 2013; 40: 437–446. doi: 10.1016/j.egypro.2013.08.050.