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Coupled dynamic flow and geomechanical simulations for an integrated assessment of CO_2 storage impacts in a saline aquifer

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Potential changes in the recent tectonic stress field as a result of increasing pore pressure due to injection of CO_2 may induce mechanical failure of the storage formation and its caprock, reactivation of existing faults or ground uplift if disadvantageous geological conditions are encountered. Coupled hydro-mechanical simulations can be applied to analyse and predict to which extent stress field and mechanical material property changes resulting from pore pressure elevation pose a serious impact on the mechanical stability of faults, reservoir and caprock.

Within the frame of the on-going EU-funded SiteChar project, an assessment of CO_2 storage performance and associated geomechanical impacts was investigated at a prospective deep saline onshore CO_2 storage formation, the Gassum formation at Vedsted, situated in Northern Denmark. Simulations consider the constant injection of 3.15 Mt CO_2/year over a time span of 40 years into the marine and fluvial sandstone aquifer of Upper Triassic to Lower Jurassic age, located at a depth between 1,700 m and 2,000 m. For this purpose, coupling of two reservoir and two geomechanical simulators was undertaken by different partners. The widely used commercial Eclipse software and the scientific code TOUGH2-MP were used for the multi-phase flow simulations, whereas the geomechanical modelling was carried out with the commercial codes FLAC3D (coupled to TOUGH2-MP) and VISAGE TM (coupled to ECLIPSE). Pore pressure distribution at selected time steps of the flow simulations conducted was used as input to the geomechanical codes to compute displacement and stress changes. A 3D reservoir-scale model with a lateral extent of 12 km x 16 km was initially applied for the flow simulations and extended to 50 km x 50 km for the geomechanical simulations to minimise the influence of boundary effects. The extended 3D geological model of the Vedsted site also comprises ten different stratigraphic units from the Lower Triassic up to the ground surface to include the overburden. Five northwest-southeast trending major faults implemented into both models were treated as either hydraulically open or closed for cross-flow.

Simulation results indicate that changes in the recent stress field after 40 years of CO_2 injection are mainly confined to the vicinity of the injection well due to the fact that the greatest pressure build-up occurs in the near-well area of the injector. The magnitudes of stress changes near the faults closest to the injector were insignificant and as such there is as negligible risk for their reactivation. Although shear strength is slightly reduced close to the injection well, the mechanical stability of the reservoir and its caprock is not decreased below critical values at any time during the injection period of 40 years and after. The simulation results further suggest that CO_2 injection over a time span of 40 years may induce a vertical displacement of 9.4 cm at the top of the storage formation and a ground uplift of up to 10 cm.

The results of the present study show that coupled hydro-geomechanical modelling can be well applied to improve our understanding of the coupled processes during CO_2 storage and evaluate associated potential impacts such as ground deformation, fault reactivation and caprock failure.