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Analogue modelling of caprock failure and sediment mobilisation due to pore fluid overpressure in shallow reservoirs

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Injection of CO_2 in geological formations may cause excess pore fluid pressure by enhancing the fluid volume in the reservoir rock and by buoyancy-driven flow. If sediments in the reservoir and the caprock are undercompacted, pore fluid overpressure can lead to hydro-fractures in the caprock and fluidisation of sediments. Eventually, these processes trigger the formation of pipe structures, gas chimneys, gas domes or sand injections. Generally, such structures serve as high permeable pathways for fluid migration through a low-permeable seal layer and have to be considered in risk assessment or modelling of caprock integrity of CO_2 storage sites.
We applied scaled analogue experiments to characterise and quantify mechanisms determining the onset and migration of hydro-fractures in a low-permeable, cohesive caprock and fluidisation of unconsolidated sediments of the reservoir layer. The caprock is simulated by different types of cohesive powder. The reservoir layer consists of granulates with small particle density. Air injected through the base of the experiment and additionally through a single needle valve reaching into the analogue material is applied to generate fluid pressure within the materials. With this procedure, regional fluid pressure increase or a point-like local fluid pressure increase (e.g. injection well), respectively, can be simulated. The deformation in the analogue materials is analysed with a particle tracking imaging velocimetry technique. Pressure sensors at the base of the experiment and in the needle valve record the air pressure during an experimental run.
The structural evolution observed in the experiments reveal that the cohesive cap rock first forms a dome-like anticline. Extensional fractures occur at the hinges of the anticline. A further increase of fluid pressure causes a migration of this fractures towards the surface, which is followed by intrusion of reservoir material into the fractures and the collapse of the anticline. The breakthrough of the fractures at the surface is accompanied by a significant drop of air pressure at the base of the analogue materials. The width of the dome shaped uplift is narrower and the initiating fluid pressure in the needle valve is lower, if the fluid pressure at the base of the experiment is larger. The experimental outcomes help to evaluate if the injection of CO_2 into a reservoir potentially provokes initiation or reactivation of fractures and sediment mobilisation structures.