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Microseismic monitoring of reservoir rock and cap rock integrity at North Sea geological CO_2 storage sites: insights from acoustic emission testing

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Carbon capture and storage (CCS) has the potential to drastically decrease CO_2 emission into the atmosphere. At geological CO_2 storage sites—comprised of a high porosity and high permeability reservoir rock below a sealing caprock—geophysical monitoring and regular risk assessment are necessary to maximise CO_2 injection, while preventing caprock failure and leakage. Pressure changes due to CO_2 injection may cause slip on faults within and around the reservoir, resulting in detectable microseismic activity. Microseismic monitoring therefore provides a window through which to observe reservoir deformation, and can help constrain geomechanical models by improving understanding of the location and geometry of faults, and the stress conditions local to them. Currently, shallow (1000-2500 m) North Sea sandstones (saline aquifers) are under consideration for large-scale CO_2 storage. To assess the effectiveness of microseismics as a monitoring tool, we must first characterise the potential for microseismicity within these lithologies.

We carried out triaxial tests on samples of potential North Sea reservoir rocks (sandstones of Sognefjord and Utsira formations) and cap rock (shale of Draupne formation). In each test, the sample was coupled with an array of 16 piezo-transducers to measure ultrasonic wave velocities and monitor acoustic emissions (AE)—sample-scale microseismic activity generated by extending microcracks. Each sample was first consolidated by axial and radial loading to relevant effective horizontal and vertical stresses, before a through-going shear failure was created by axial loading. Following failure, the fracture planes were then reactivated multiple times by axial loading at different effective radial stresses, i.e. at different simulated depths. We calculated the AE rate, analogue seismic b-values and AE source parameters (including magnitude and frequency content), localised AE events, and inferred AE focal mechanisms and moment tensors from P-wave first motion polarities and amplitudes.

We detected several thousand AE events while testing the sandstones, but the deformation of the shale was aseismic within the observable frequency range. We quantified the stress conditions required for fracture propagation and fracture reactivation within these materials, and developed stress-strain constitutive models relevant for geomechanical modelling of North Sea reservoirs. For the sandstones, we analysed the AE event characteristics in space and time, to better understand the deformation mechanisms during the different stages of testing. Our laboratory results on representative lithologies at relevant stresses suggest that as a result of CO_2 injection, we expect little microseismic activity to originate from the caprock, although microseismics may provide insight into deformation and stress changes within the reservoir itself.