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Modelling of long-term along-fault flow of CO_2 from a natural reservoir

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Abstract

Geological sequestration of CO_2 requires the presence of a competent seal above the storage reservoir to ensure containment of the stored CO_2. Most of the considered storage sites are overlain by low-permeability evaporite or shale-rich caprocks that form competent seals in the absence of defects. Potential defects are formed by man-made well penetrations (necessary for exploration and appraisal, and injection) as well as natural or injection-induced fracture systems through the caprock. These defects need to be de-risked during site selection and characterization.

From operational experience in the oil and gas industry, it is known that fault zones in caprocks in some cases may be conductive to fluid flow, depending on the internal geometry and subsequent connectivity of the fault/fracture damage zone and the local stress conditions. The controls on the leakage potential are only partially understood. Therefore, one approach during site selection is to avoid faulted areas altogether. Especially for CO_2 storage in saline aquifers, where the absence of defects has not been demonstrated by the presence of oil or gas accumulations, operators currently tend to take this approach. However, this approach severely limits large-scale storage capacity in many storage basins even though many fault/fracture systems are not conductive to flow, as demonstrated by the existence of oil and gas reservoirs in faulted areas that have contained these fluids for millions of years. Another practical concern is how to de-risk potential leakage rates along unidentified (seismically invisible) fault/fracture zones that may be present.

Therefore, to enable large-scale deployment of CO_2 storage, there is a need to understand and manage the risk of fault-related leakage rather than attempting to avoid faulted areas altogether. This requires the ability to predict potential leakage rates within an acceptable confidence band, based on adequate subsurface characterization, thus allowing selection of storage sites with extremely low leakage rates (well below accepted criteria), and develop appropriate monitoring and mitigation plans to allow timely reaction in the unlikely but possible case that higher than expected leakage rates would occur during injection operations. The development of such capabilities is the objective of the European ACT-sponsored DETECT project (Figure 1).

In this paper we describe the DETECT experimental-modelling workflow which aims to be predictive for fault-related leakage quantification, and its application to a field case example for validation. The workflow combines laboratory experiments to obtain single-fracture stress-sensitive permeabilities; single-fracture modelling for stress-sensitive relative permeabilities and capillary pressures; fracture network characterization and modelling for the primary and secondary caprocks; upscaling of properties and constitutive functions in fracture networks; and full compositional flow modelling at field scale.

We focus the paper on the application of the workflow to the Green River Site in Utah. This is a rare case of leakage from a natural CO_2 reservoir, where CO_2 (dissolved or gaseous) migrates along two fault zones to the surface. This site provides a unique

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opportunity to understand CO_2 leakage mechanisms and volumes along faults, because of its extensive characterization including a large dataset of present-day CO_2 surface flux measurements as well as historical records of CO_2 leakage in the form of travertine mounds. When applied to this site, our methodology predicts leakage locations accurately and, within an order of magnitude, leakage rates correctly without extensive history matching. Subsequent history matching achieves accurate leak rate matches within a-priori uncertainty ranges for model input parameters.

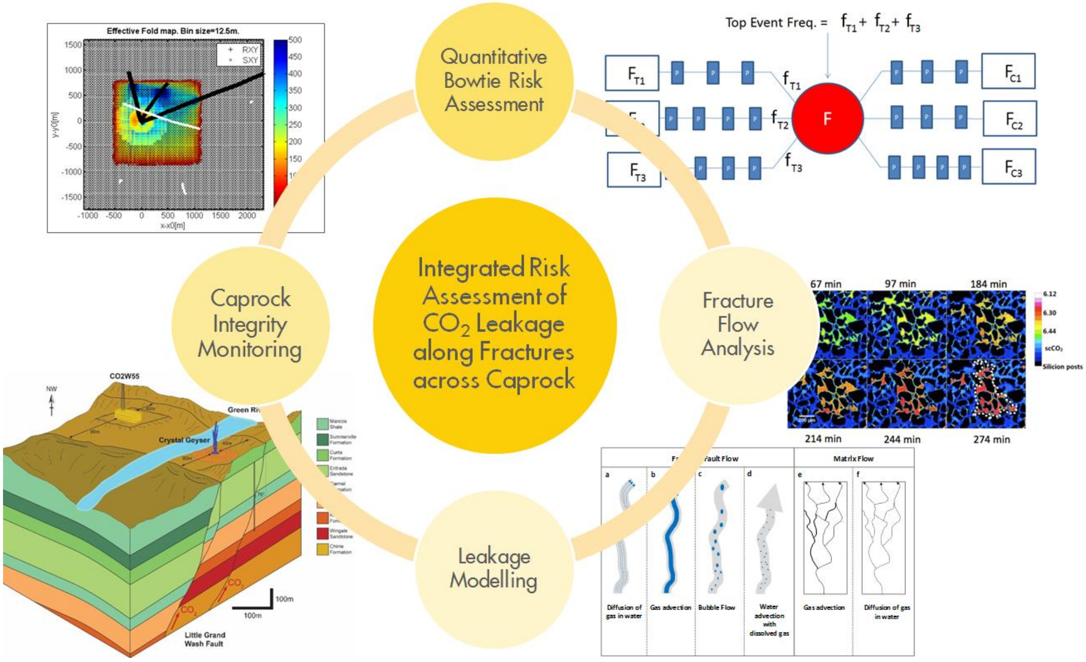

Figure 1. Integrated risk assessment of leakage along fractures across the caprock for CO_2 storage.

Keywords: CO2 storage; fault; fracture; leakage; model; stress; mineralisation; Green River