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Assessing the Mechanical Impact of CO2 Injection on Faults and Seals

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SUMMARY

Two options for geological storage of CO2 are currently considered: storage in depleted hydrocarbon fields, which have a hydrocarbon proven seal, and storage in deep (>800m) saline aquifers, which lack such a seal. Pore pressure changes resulting from fluid extraction and subsequent CO2 injection into the reservoir induce stress changes that may mechanically damage seals, or trigger existing faults, creating the leakage pathways for CO2 escape from the containment. It is therefore required to predict the impact of CO2 injection and long-term storage on seals and faults. This is commonly done as a part of feasibility study carried out to assess the storage capacity and containment characteristics of the selected candidate site.

In this paper we examine current practices for geomechanical evaluation of the mechanical impact resulting from pressure build-up on seals and faults. Discussion is supported by the results from recently accomplished studies of currently active and future potential storage sites, e.g. the Sleipner site located offshore in Norway (ongoing CO2 injection since 1996)and the De Lier depleted field located onshore in the Netherlands.

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In this paper we examine current practices for geomechanical evaluation of the mechanical impact resulting from pressure build-up on seals and faults. Discussion is supported by the results from recently accomplished studies of currently active and future potential storage sites, e.g. the Sleipner site located offshore in Norway (ongoing CO_2 injection since 1996 - Chadwick et al. 2006) and the De Lier depleted field located onshore in the Netherlands (in this case the hazards, associated with well integrity, were unacceptable and un-economic to mitigate; hence the operator decided to discontinue the project - Hofstee et al. 2008).

Common practice in assessing the impact of CO_2 injection on seals and faults is to first utilise simple analytical and semi-analytical tools for stress analysis (e.g. Mohr's circles) and then to embark on more complex numerical modelling (e.g. Orlic and Schroot 2005). Numerical models are preferred as they can correctly deal with: (i) the structurally complexity and irregularity of hydrocarbon fields and aquifers which are potential candidates for geological CO_2 storage; (ii) the spatial variability of material properties and non-linear constitutive material laws for different lithostratigraphic units; and (iii) the spatial variability of pressure build-up resulting from CO_2 injection. The availability and quality of the numerous input data required for geomechanical analyses is crucial for developing reliable geomechanical models.

CO_2 injection in depleted hydrocarbon reservoirs is preceded by pressure depletion during prior hydrocarbon production from the same reservoir. Because both stages induce stress changes in the reservoir and its surroundings, both have to be taken into account in geomechanical analyses. The reservoir rock may react fully elastically to compaction resulting from reservoir depletion. It may also exhibit non-linear deformational behaviour which will not be fully reversible during de-compaction, i.e. unloading, resulting from the subsequent CO_2 injection. Non-linear behaviour is typical for poorly consolidated sandstone reservoirs with high clay content, or high porosity chalk. While the reservoir rock may either be elastic or inelastic in geomechanical analyses, seals and faults will commonly only behave in elastic way unless there is a historical evidence for their non-elastic response – e.g. (micro)-seismicity which implies fault re-activation during depletion. Indeed, stress changes in seals and other rocks surrounding the reservoir are much smaller than in the reservoir - in many cases by one to two orders of magnitude. Apparently, the rock is more likely to respond elastically to a smaller stress change than to a larger one. During injection period, the reservoir stress path will be fully, or at least to some extent, reversed with regard to the stress path caused by depletion. Consequently, the reservoir rock will decompact fully, or to some extent. Seals elastically coupled to the reservoir rock will undergo (partial) release of stresses induced by depletion. Common wisdom suggests that in the case of a hydrocarbon proven seals re-pressurization of the depleted reservoir can be done safely up to the initial field pressure decreased by a safety margin.

CO_2 injection into an aquifer generally requires more demanding geomechanical analyses based on even more sparse data than in the case of depleted hydrocarbon reservoirs. Aquifers are not overcapped by a hydrocarbon proven seal and injecting the CO_2 will generate overpressure that will propagate throughout the aquifer far away from the CO_2 accumulation. The main question to be answered once a suitable structural trap has been detected, and its storage capacity has been estimated, is what is the maximal admissible overpressure which must not be exceeded. Different criteria can be put forward: (i) risk of capillary leakage through the primary seal, whereby the admissible overpressure is determined by the capillary entry pressure to supercritical and gaseous CO_2; (ii) risk of fracturing reservoir rock (tensile failure) and subsequent fracture propagation into seals and faults, whereby the admissible overpressure is limited by the magnitude of the minimum horizontal *in situ* stress (assuming a normal-faulting stress regime); (iii) risk of shearing of pre-existing fractures and faults, whereby the admissible overpressure is determined by the mobilized shearing capacity of fractures and faults. The effects of overpressurizing a synthetic aquifer resulting from pressure increase due to CO_2 injection are illustrated in Figs. 1 and 2. Geomechanical analyses carried out as a part of feasibility study investigating the viability of CO_2 storage in an aquifer in the Northern Netherlands suggest that the criterion for fracture shearing will be reached first. This can cause (micro-)seismicity in the reservoir

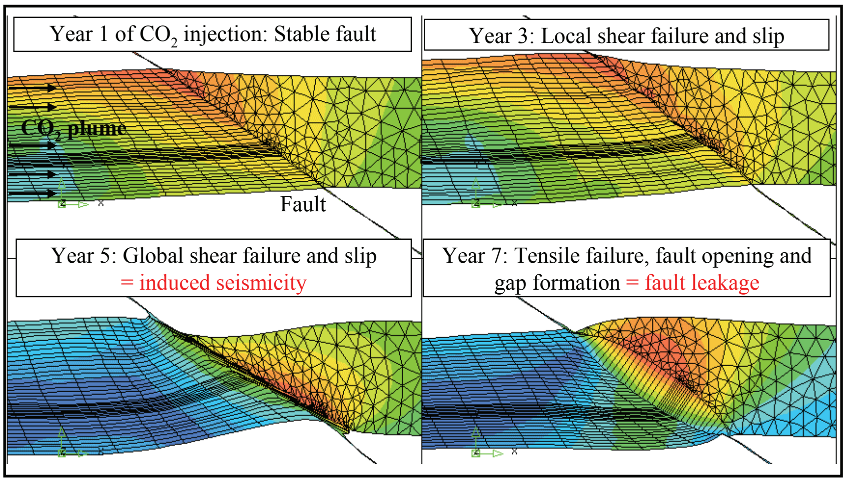

Figure 1 *Different stages of fault destabilization resulting from CO_2 injection into a synthetic aquifer.*

while opening and shearing of fractures in the top seal could jeopardize its sealing integrity leading to a leak from the CO_2 storage site. Besides the poroelastic stresses discussed so far, the effects of additional thermoelastic stresses must be assessed if colder CO_2 is injected into a hot reservoir.

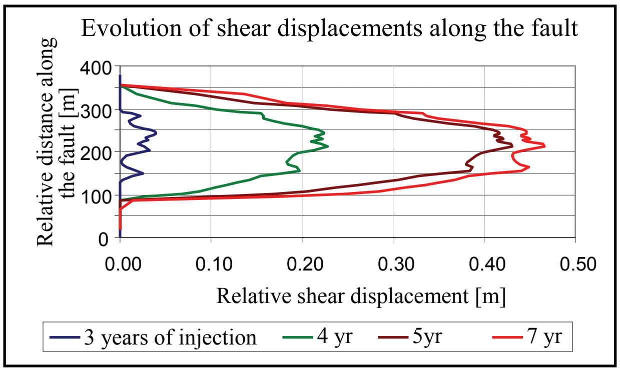

Figure 2 *Evolution of relative shear displacement along the fault through different stages of fault destabilization.*

References

Chadwick, A., Noy, D., Lindeberg, E., Arts, R., Eiken, O. and Williams, G. [2006] Calibrating reservoir performance with time-lapse seismic monitoring and flow simulations of the Sleipner CO_2 plume - Proceedings of the 8th International Conference on Greenhouse Gas Control Technology (GHGT-8), Trondheim, Norway (Abstract).

Hofstee, C., Seeberger, F., Orlic, B., Mulders, F., van Bergen, F. and Bisschop, R. [2008] The feasibility of effective and safe carbon dioxide storage in the De Lier gas field. *First Break*, **26**, 53-57.

Orlic, B. and Schroot, B. [2005] The mechanical impact of CO_2 injection. *67^{th} EAGE Conference & Exhibition*, Extended Abstracts, A14.