Inhomogeneous fault stability due to fluid injection

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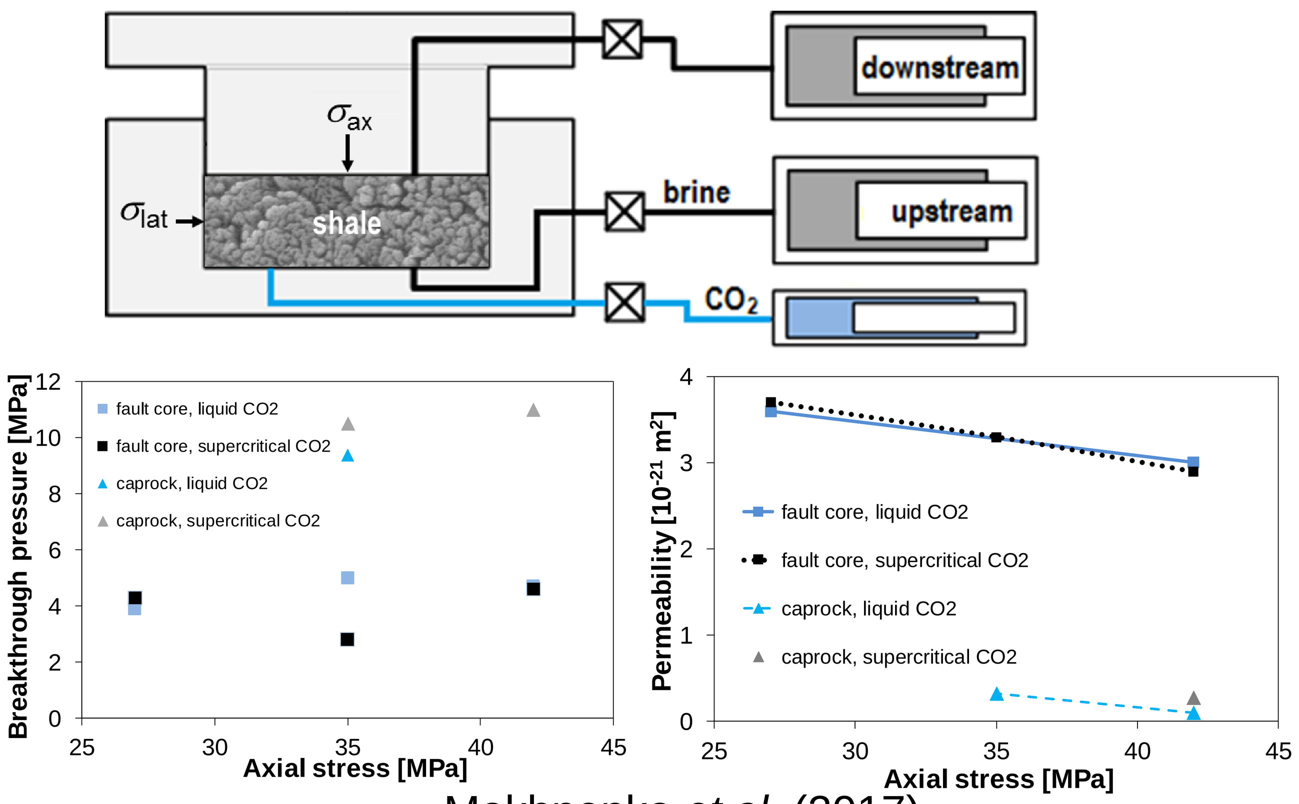
Summary

Forecasting and mitigating induced seismicity requires understanding of the underlying physical processes. Poromechanical and thermal effects on stresses and shear slip stress transfer play a non-negligible role that has challenged the classical interpretation in which induced seismicity is caused exclusively by pressure buildup (De Simone et al., 2017). In this contribution, we analyze how the stress changes induced as a result of fluid injection affect fault stability. We perform fully coupled hydro-mechanical simulations of **fluid injection into a saline aquifer** bounded above and below by low-permeable clay-rich rock and **intersected by a low-permeable steep fault**. Simulation results show that **maintaining a constant injection rate leads to a progressive reservoir pressurization** on the side of the fault where injection takes place (Fig. 1a). Given the low-permeability of the fault core, pressure buildup is negligible on the other side of the fault. These **pore pressure changes cause strong variations in the total stresses controlled by rock stiffness around the fault**. Deviatoric stress changes are controlled by stress balance from the two sides of the fault: the upper part of the reservoir, juxtaposed to the stiffer reservoir on the right, has a lower increase in the deviatoric stress than the lower part, which is juxtaposed to the more compliant caprock. This implies increased fault stability in the upper part and decreased fault stability in the lower part (Fig, 1d). As highlighted by our results, **fault stability is: i) non-homogeneous within the whole fault and ii) controlled by poromechanical stress changes as much as by pressure buildup**.

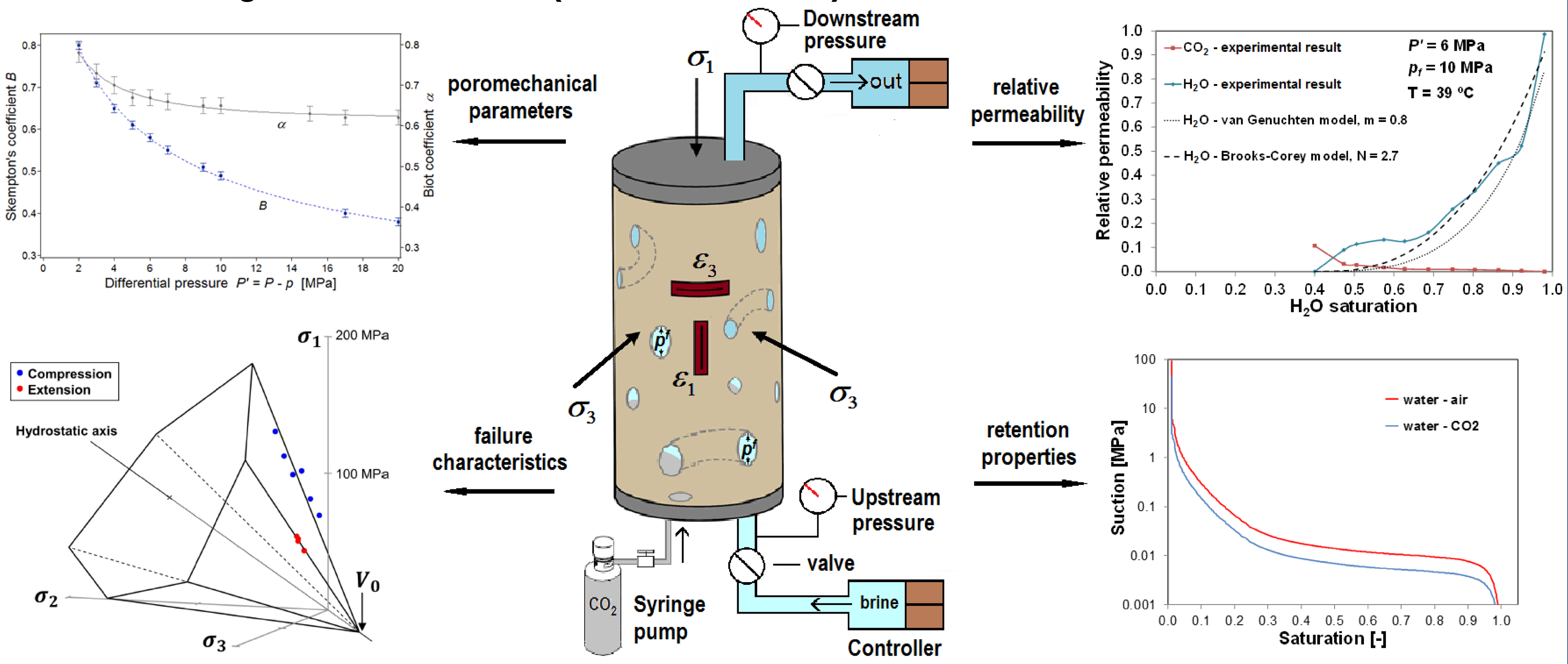
Material properties

Oedometric testing on caprock and fault core (Opalinus clay)



Makhnenko *et al.* (2017)

Triaxial testing on reservoir rock (Berea sandstone)



Makhnenko and Labuz (2016)

We use, as representative of shale, the properties of **Opalinus clay**, a Jurassic shale from Mont Terri underground rock laboratory, which we have **measured in the laboratory at conditions corresponding to 1 km depth**. Poromechanical parameters are measured for both intact rock and remolded specimens. **Remolded shale** is **representative of sheared material** that may be found in faults. We find that the permeability of remolded shale is only one order of magnitude higher than that of the intact rock and that its entry pressure is reduced by a factor of two to 4 MPa, remaining high enough to hinder CO_2 leakage in geologic carbon storage (Vilarrasa and Carrera, 2015).

Results

Including faults in numerical models leads to **non-intuitive stress changes** that affect fault stability (Vilarrasa et al., 2016). Since horizontal stress does not increase in the lower half of the reservoir (Fig. 1b), the deviatoric stress is maintained, becoming the most critical zone (Fig. 1d).

Simulation results show that the ductile clay-rich **fault is reactivated in the lower half of the reservoir** if no pressure management is performed (only for low-permeable faults with k<10^{-17} m^2).

Thus, potential ruptures are likely to be arrested in sedimentary formations with alternating reservoirs and clay-rich formations.

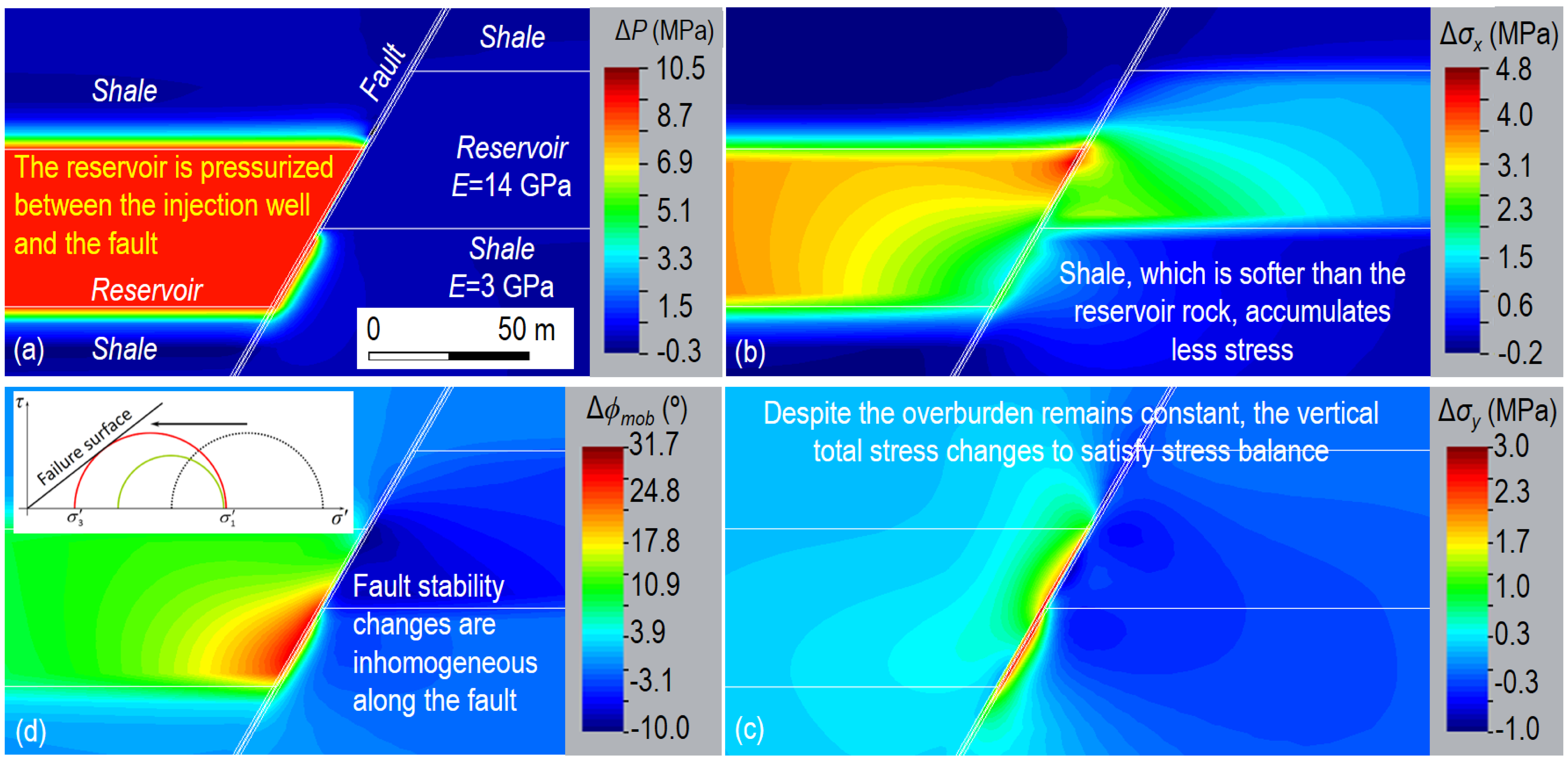


Figure 1: Distribution of changes in (a) fluid pressure, (b) horizontal total stress, (c) vertical total stress and (d) mobilized friction angle after 1 year of fluid injection on the left-hand side of the low-permeable fault

Conclusions

We model fluid injection in a semi-closed reservoir bounded by a low-permeable fault, which causes reservoir pressurization between the well and the fault. Despite this pressurization, **shale stability is maintained**. However, **fault stability undergoes inhomogeneous changes, which are controlled by both poromechanical stress changes and pore pressure changes**.

References

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