Stress Path Evolution Due to Fluid Injection into Geological Formations

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Kunnskap for en bedre verden

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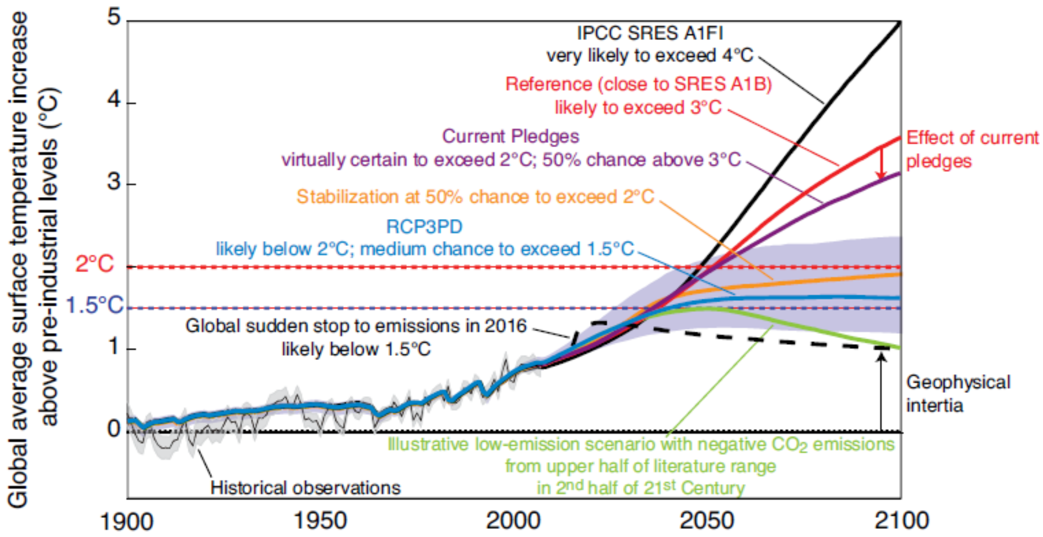
Outline

1. Introduction
2. Stress path in a no fault model
3. Stress path in a faulted model
4. Conclusion

1. Introduction

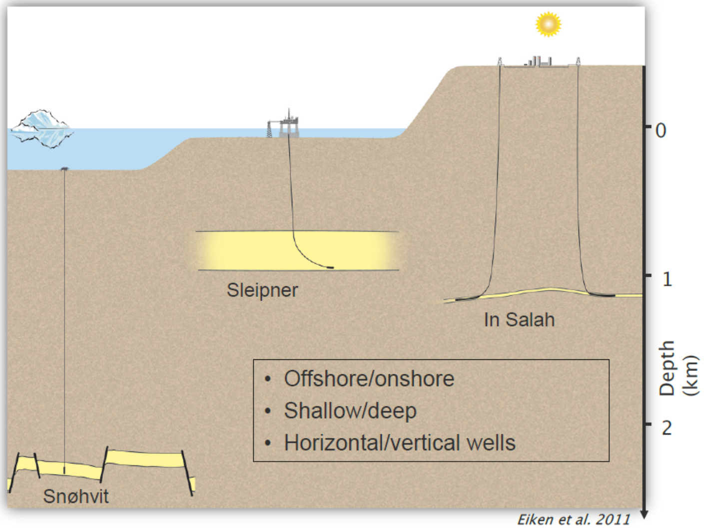
- Increase of the amount of CO_2 in the atmosphere has affected the raise of the planet's temperature



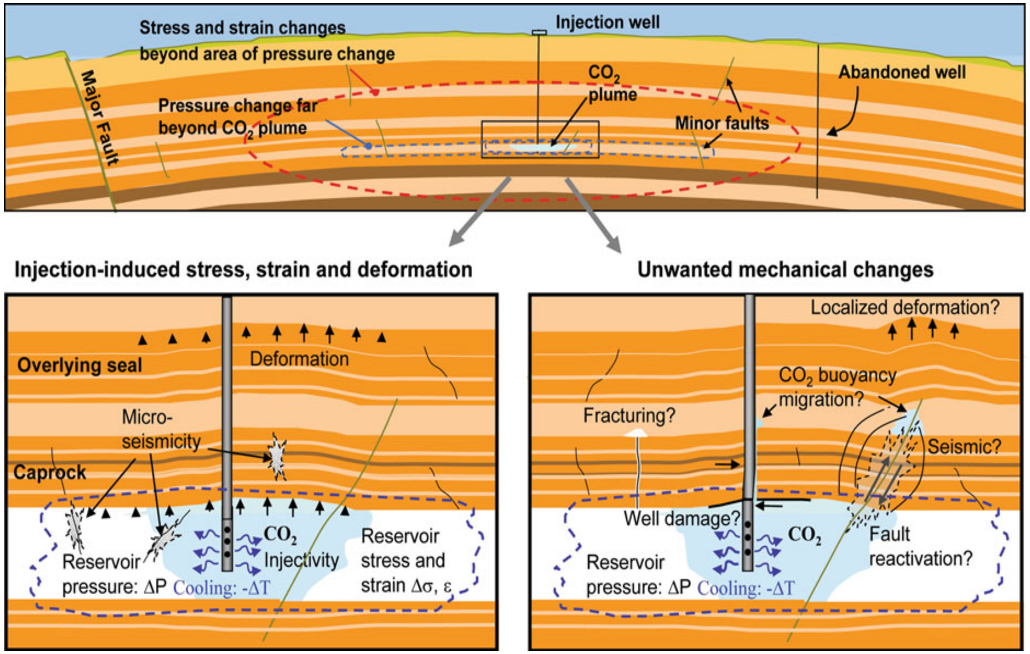
World bank 2012

- **Storage Options**

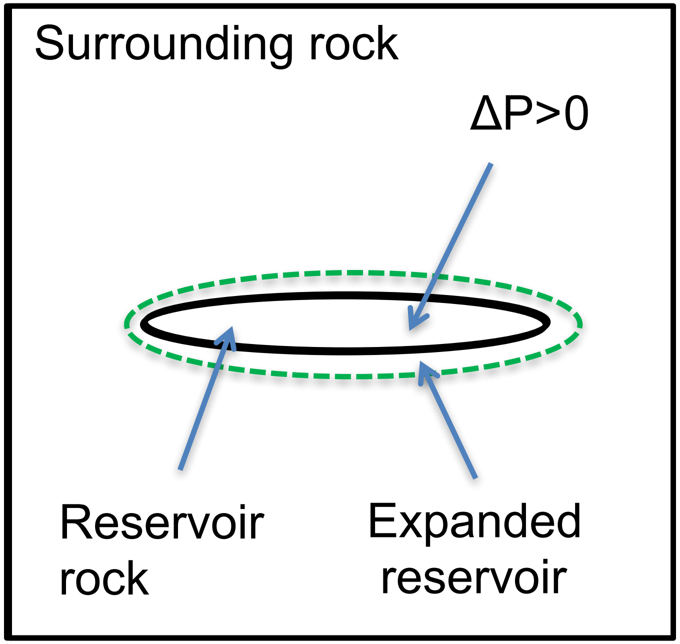
- Saline aquifer formations
- Depleted oil and gas reservoirs
- Storage in CO2-EOR projects
- Coal bed storage



Geomechanical issues related to CO2 storage reservoir:



Rutqvist (2012)



- Surface uplift
- Caprock sealing
- Well integrity
- Fault reactivation

In all of the above mentioned problems the stress changes play a significant role

Stress path

- Fluid extraction or injection leads to stress changes
- Stress path determines the change of stresses inside and outside the reservoir

$$\gamma_v = \frac{\Delta\sigma_v}{\Delta P} \qquad \gamma_h = \frac{\Delta\sigma_h}{\Delta P}$$

$$\gamma_{dev} = \frac{\Delta\sigma_{\mathrm{dev}}}{\Delta P} \qquad \gamma_{mean} = \frac{\Delta\sigma'_{mean}}{\Delta P}$$

The stress path is controlled by

- Reservoir geometry (shape; inclination)
- Elastic contrast between reservoir and surroundings
- Non-elastic / Failure processes

Numerical model of the reservoir

Reservoir thickness: 40 m
Reservoir length: 600 m

E= 15 GPa
v=0.3

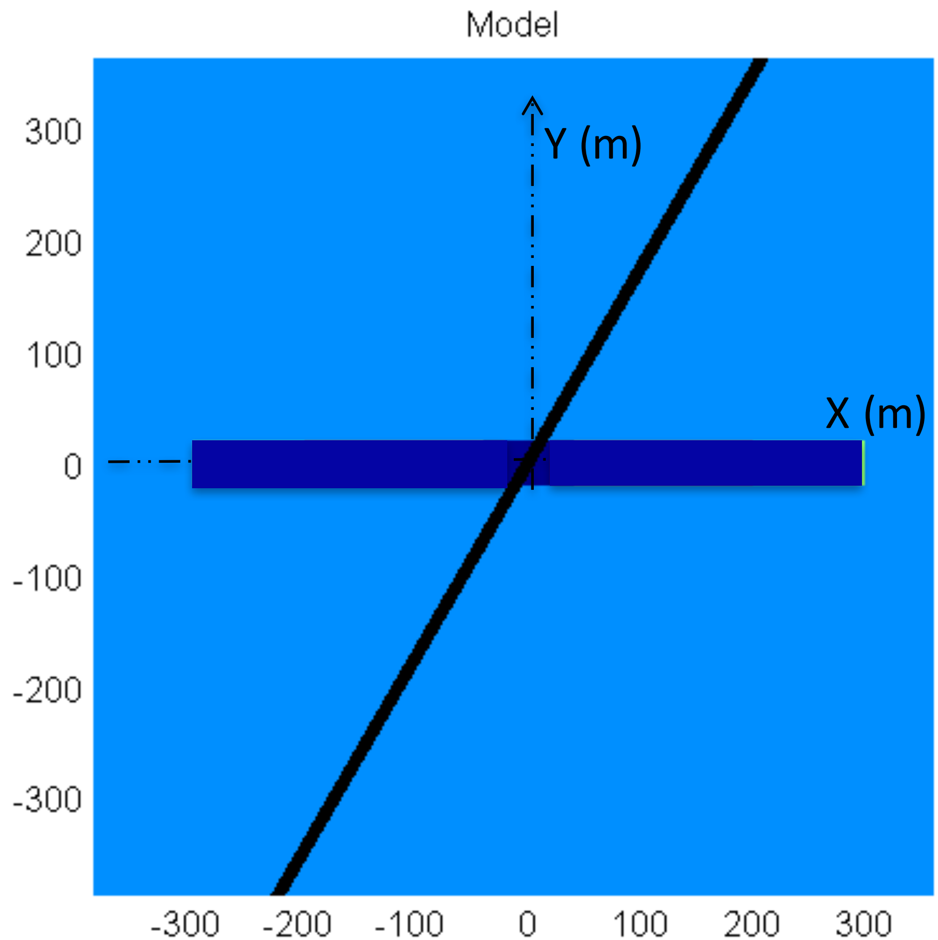
σ'1=30 MPa
σ'3=15 Mpa

Compressional and
Extensional stress regimes

ΔP=10 MPa
2D plane-strain

FEM-DEM code (MDEM)

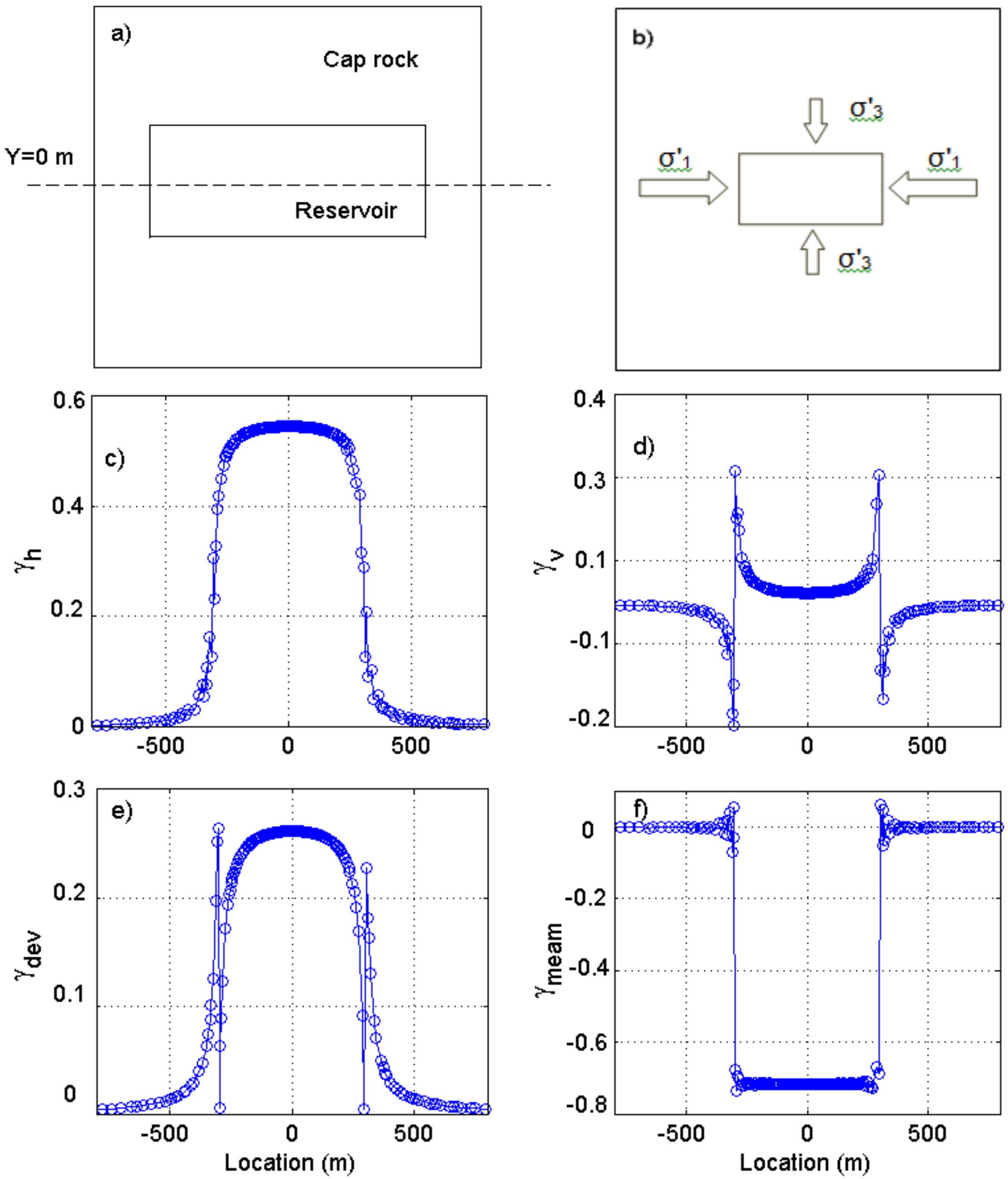
Fault case (60 deg.)



2. Stress path in the no fault model

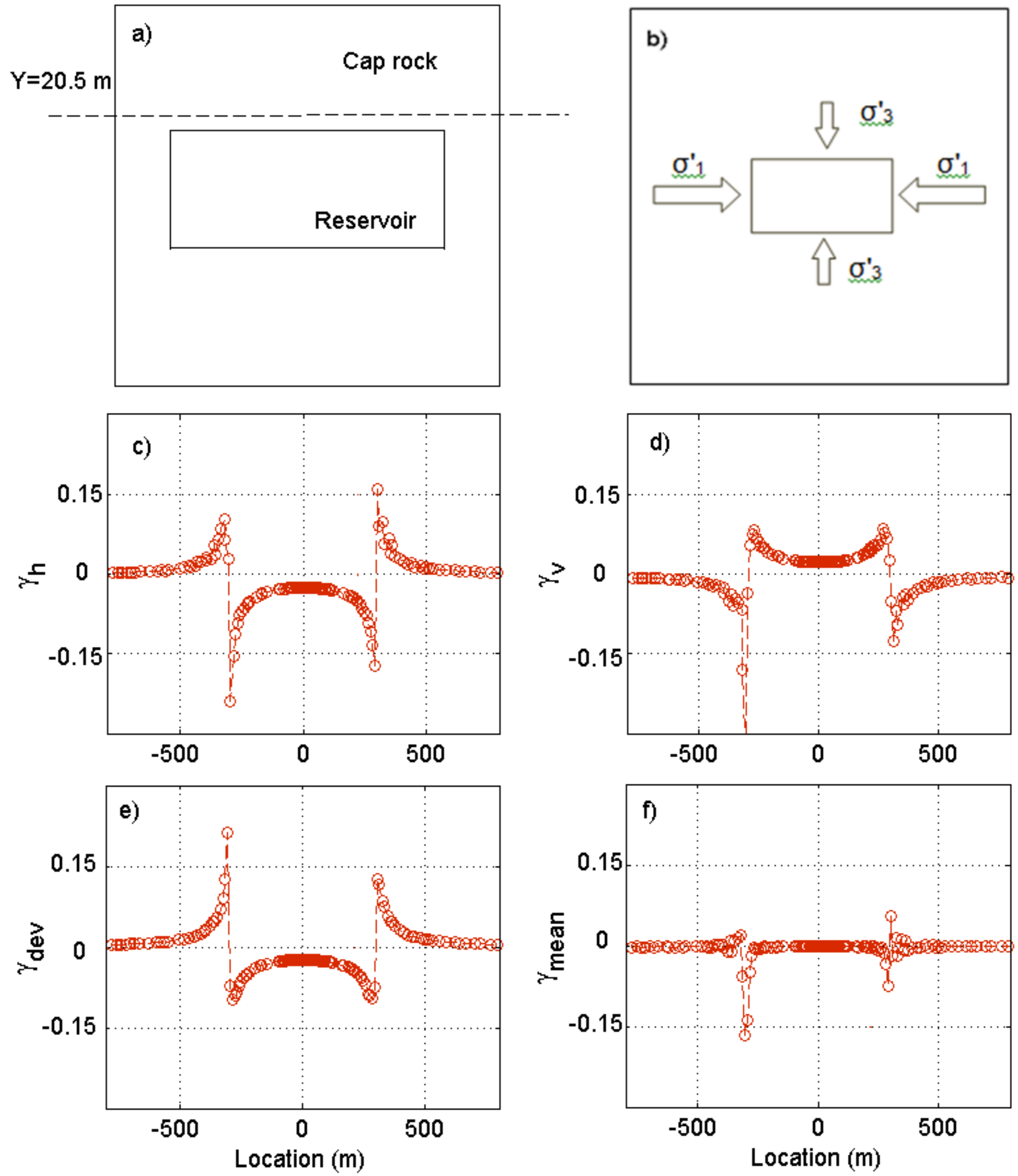
Stress path profiles in the reservoir and the flanks

- The *x*- stress increases in the reservoir and the flanks
- The *y*-stress decreases in the outer flanks and increases in the reservoir
- The dev. stress increase in the reservoir and the outer flanks
- The mean effective stress decreases in the reservoir and constant in the outer flanks



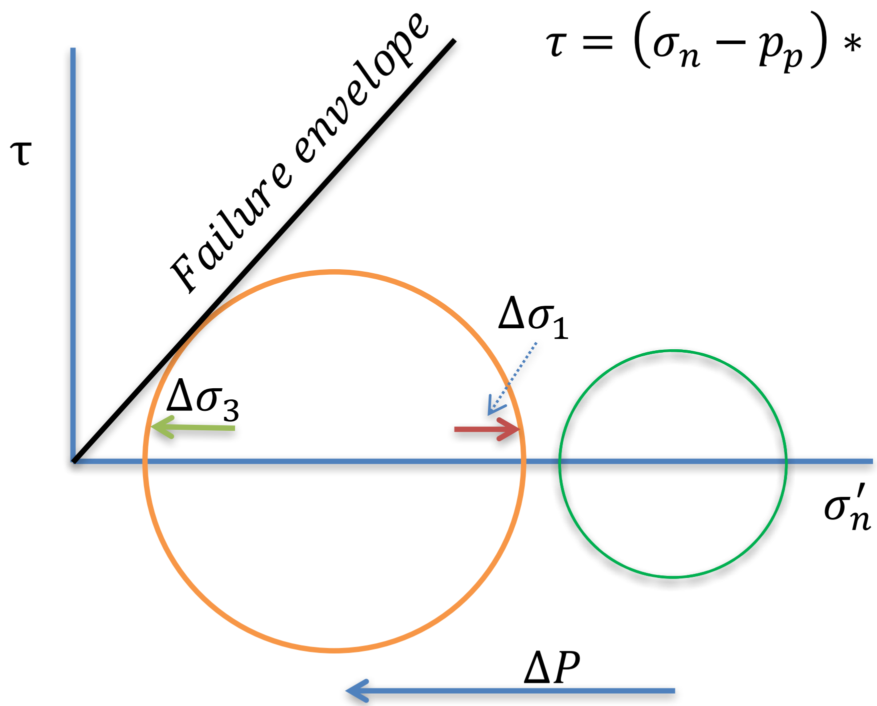
Stress path profiles in the cap rock

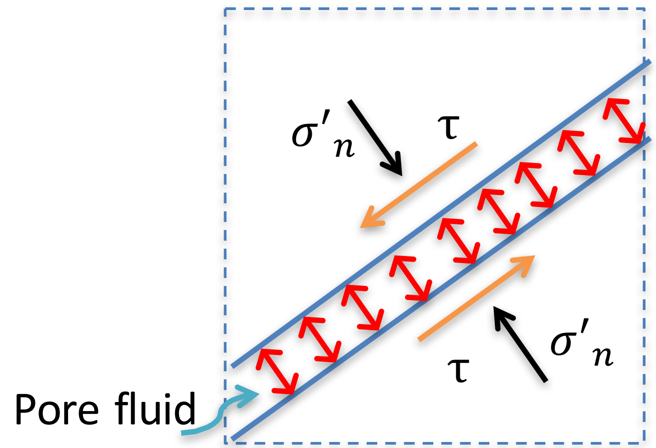
- The *x*- stress decreases in the cap rock
- The *y*-stress increases in the cap rock
- The dev. stress decreases in the cap rock
- The mean effective stress is constant in the cap rock



The rock stability check

$$\tau = (\sigma_n - p_p) * \mu$$





$\Delta\sigma_3, \Delta\sigma_1$: Total stress change

σ_n': Effective normal stress on the plane

τ : Shear stress acting on the plane

μ: Friction coefficient

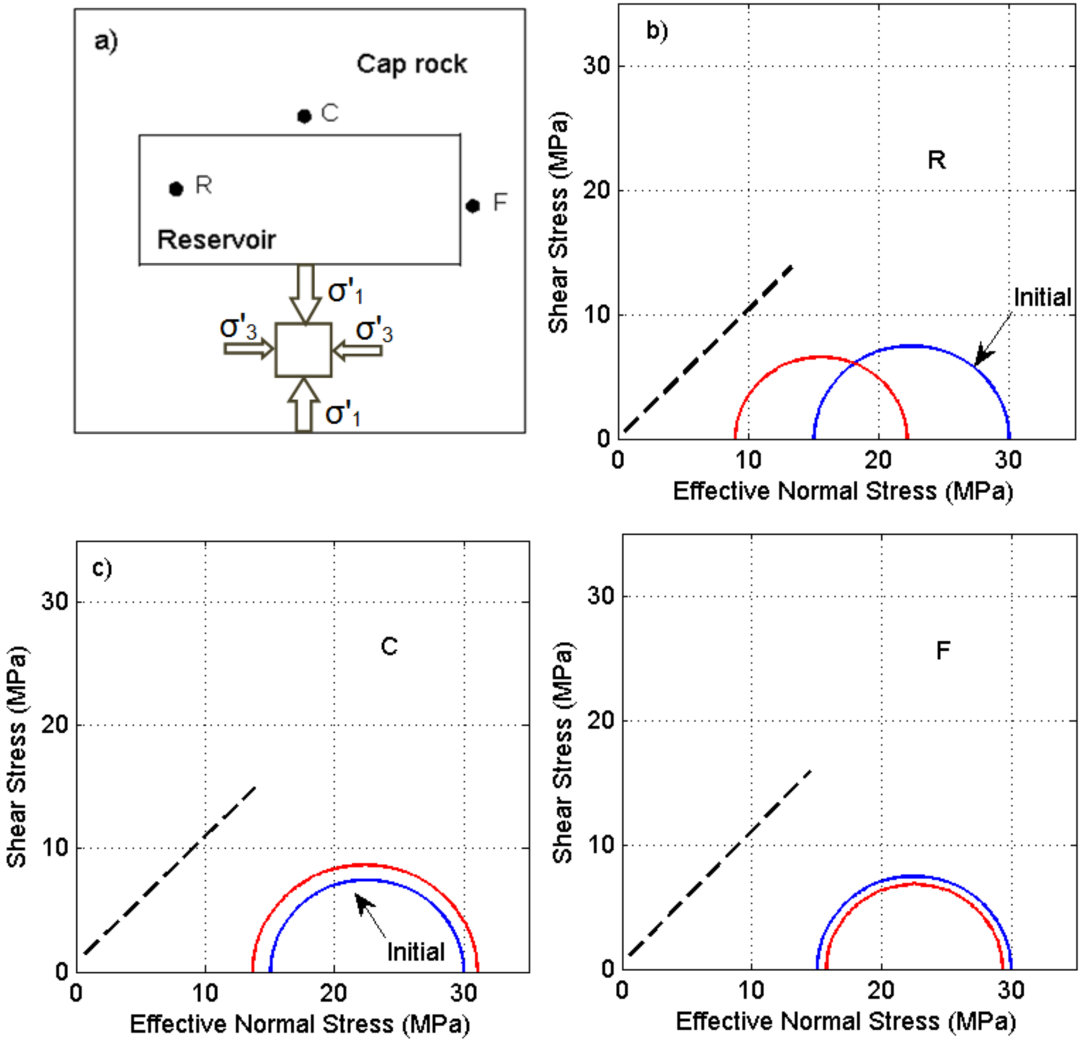
- Increase of the pore pressure decreases the effective normal stress and decreasing the frictional resistance

Stability in an extensional stress regime

- Reservoir =>
Becomes more unstable

- Cap rock =>
Becomes more unstable

- Outer flank =>
Becomes more Stable

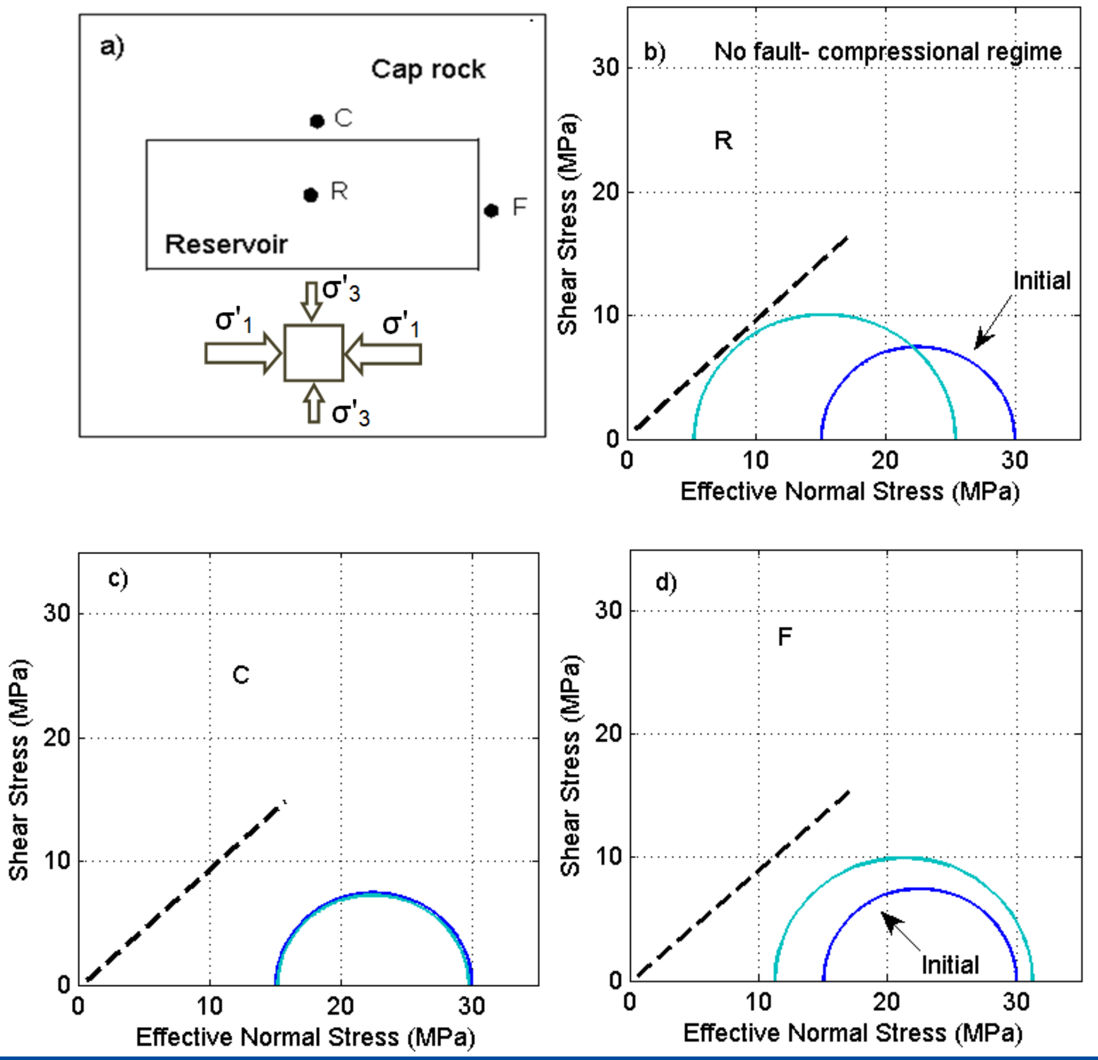


Stability in a compressional stress regime

- Reservoir =>
Becomes more unstable

- Cap rock =>
Becomes more Stable

- Outer flank =>
Becomes more unstable



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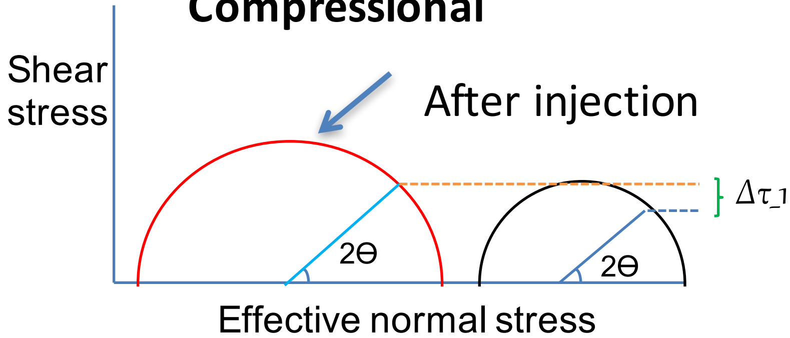
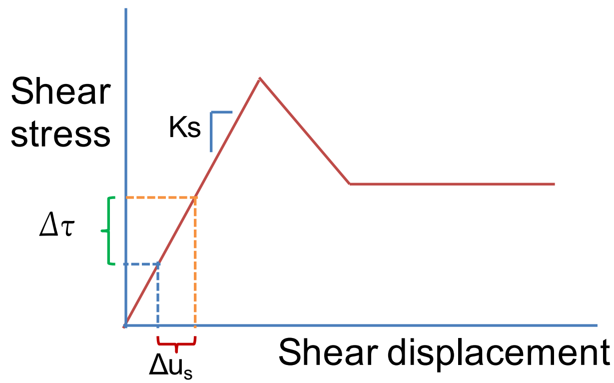
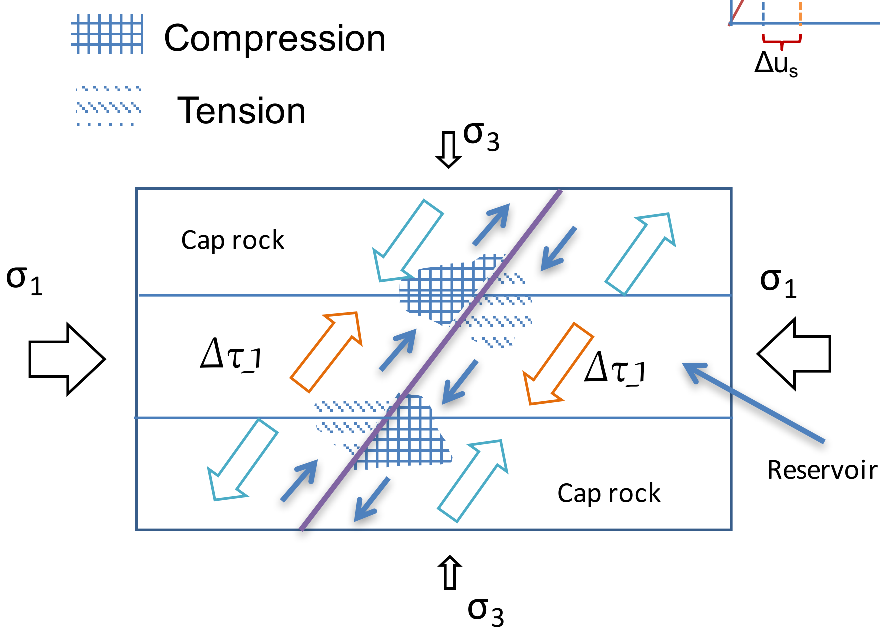
3. Stress path in the faulted model

Compressional







The stress path profiles in the reservoir in the presence of a 60° fault

- In the hanging wall:

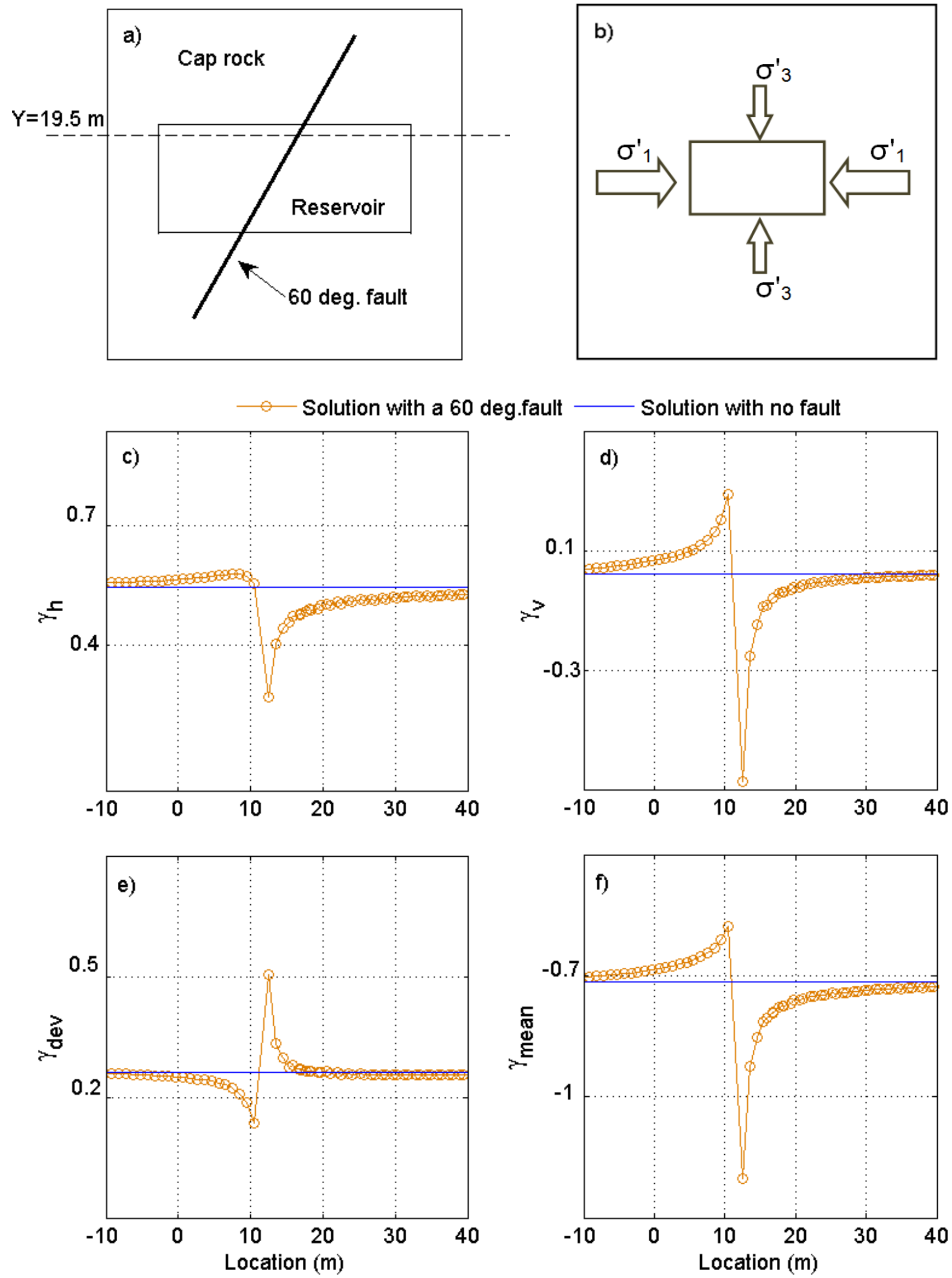
γ_h ↑ γ_v ↑

γ_{dev} ↓ γ_{mean} ↑

- In the footwall:

γ_h ↓ γ_v ↓

γ_{dev} ↑ γ_{mean} ↓



The stress path profiles in the cap rock in the presence of a 60° fault

- In the hanging wall:

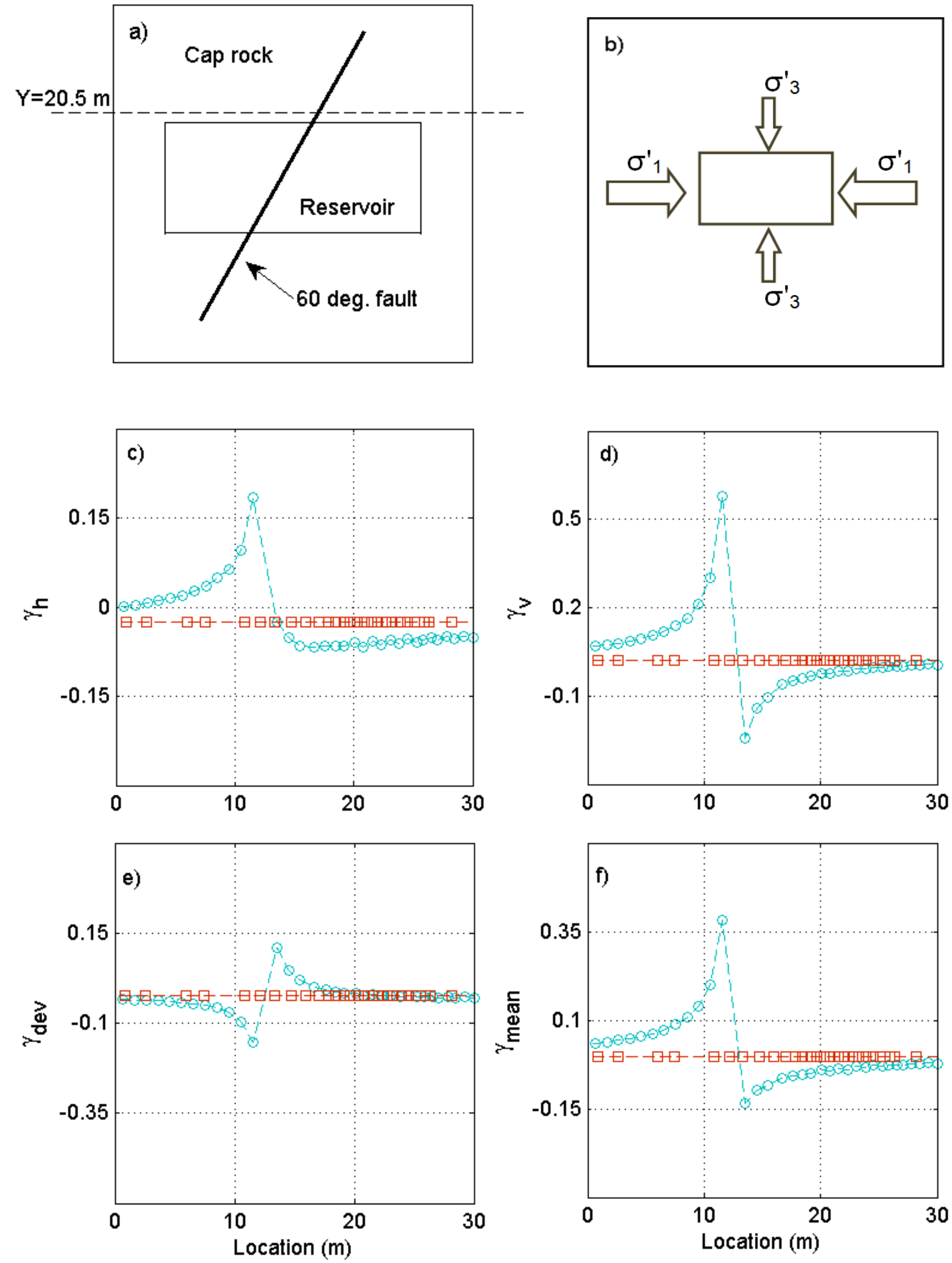
γ_h ↑ γ_v ↑

γ_{dev} ↓ γ_{mean} ↑

- In the footwall:

γ_h ↓ γ_v ↓

γ_{dev} ↑ γ_{mean} ↓

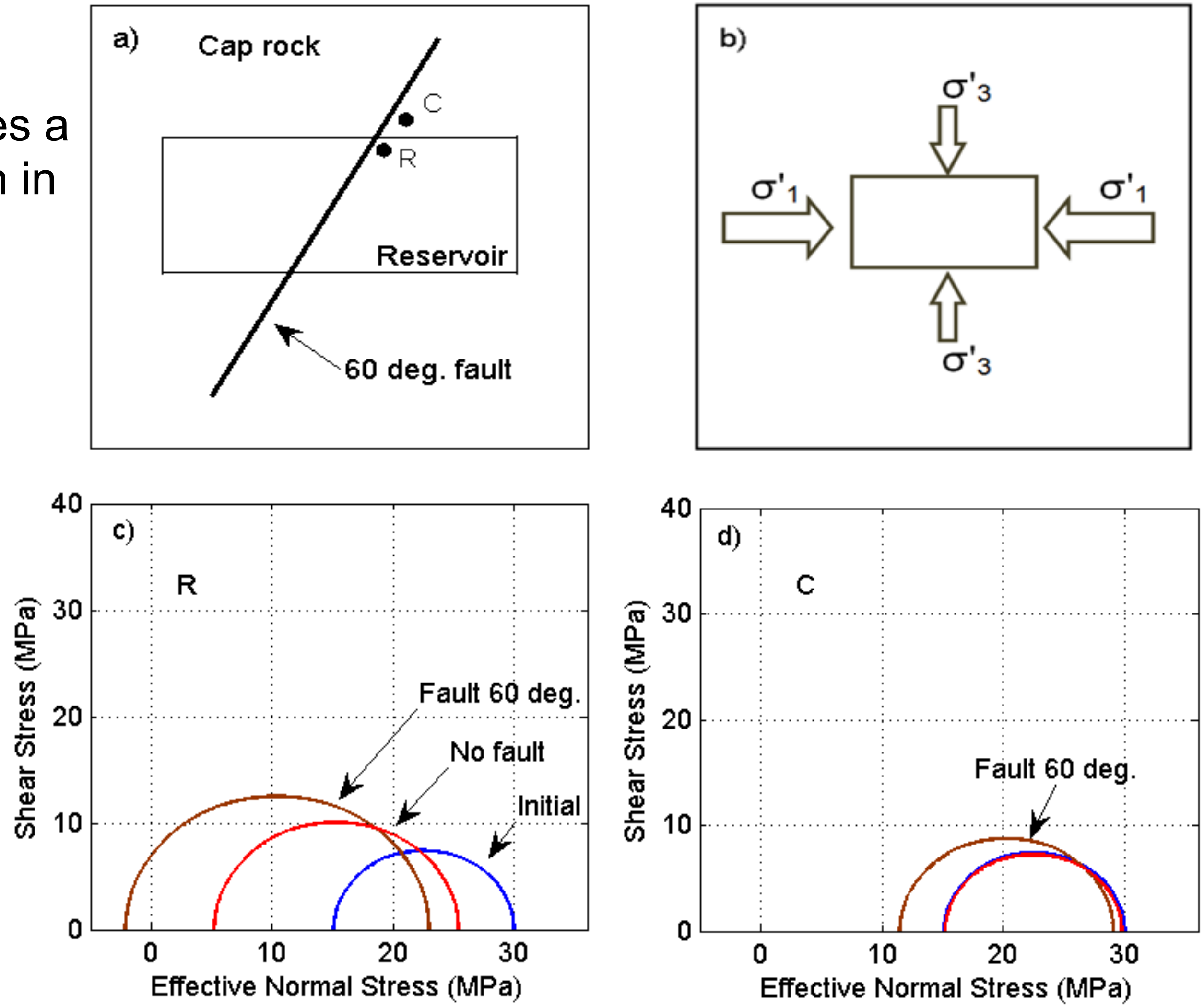


The stress state in the faulted vs. the no faulted model

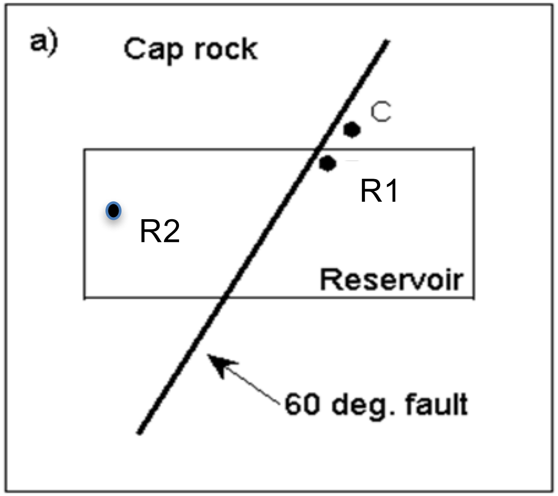
- The stress state imposes a more unstable condition in the reservoir and in the cap rock

- The minimum principal Effective stress becomes negative ➡ horizontal tensile fracturing when the fault is strong enough.

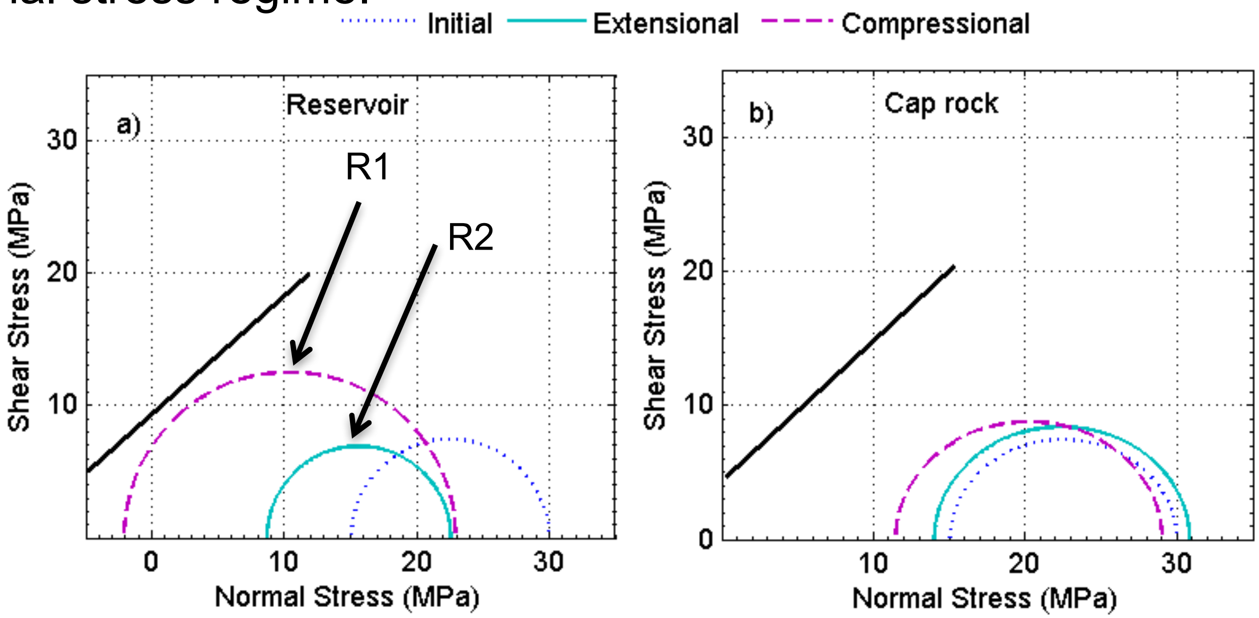
- The tensile fracture may or may not effect the cap rock performance.



Stress state in the presence of a 60° fault in a comp. *vs.* an ext. stress regime.



- The fault increases the instability of the stress state in a compressional stress regime.
- The fault doesn't affect the stability level of the stress state in an extensional stress regime.
- The cap rock becomes more unstable in a comp. regime than in an ext. regime which was opposite in the no fault model.



4. Conclusion

- The reservoir and the flanks can be unstable in a compressional regime
- The reservoir and the cap rock can be unstable in an extensional regime
- Faults/fractures can affect the stress path evolution in the reservoir-cap rock interface
- Faults show a higher impact on the stress state's stability in a compressional regime compared to an extensional regime.
- The reservoir and cap rock in footwall of the fault is more unstable than the hanging wall
- Tensile fractures can occur in the reservoir in the footwall due to the stress changes caused by the fault effect
- The interaction of the tensile fractures with pre-existing fractures crossing the cap rock needs further investigation

Thanks for you attention

Acknowledgment

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