Carbon Storage and Management

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Geomechanical Considerations for CO_2 Geological Storage Projects

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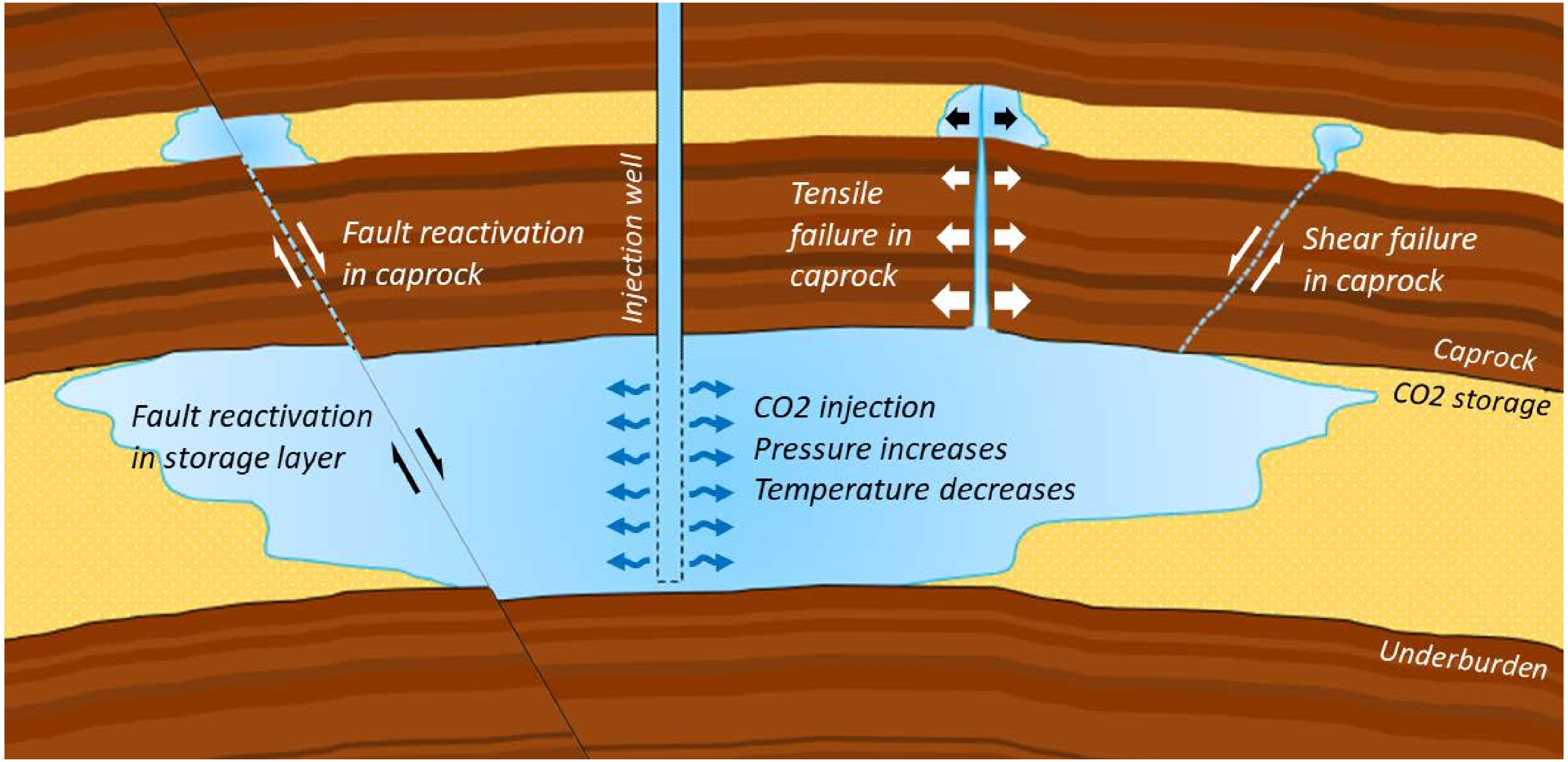
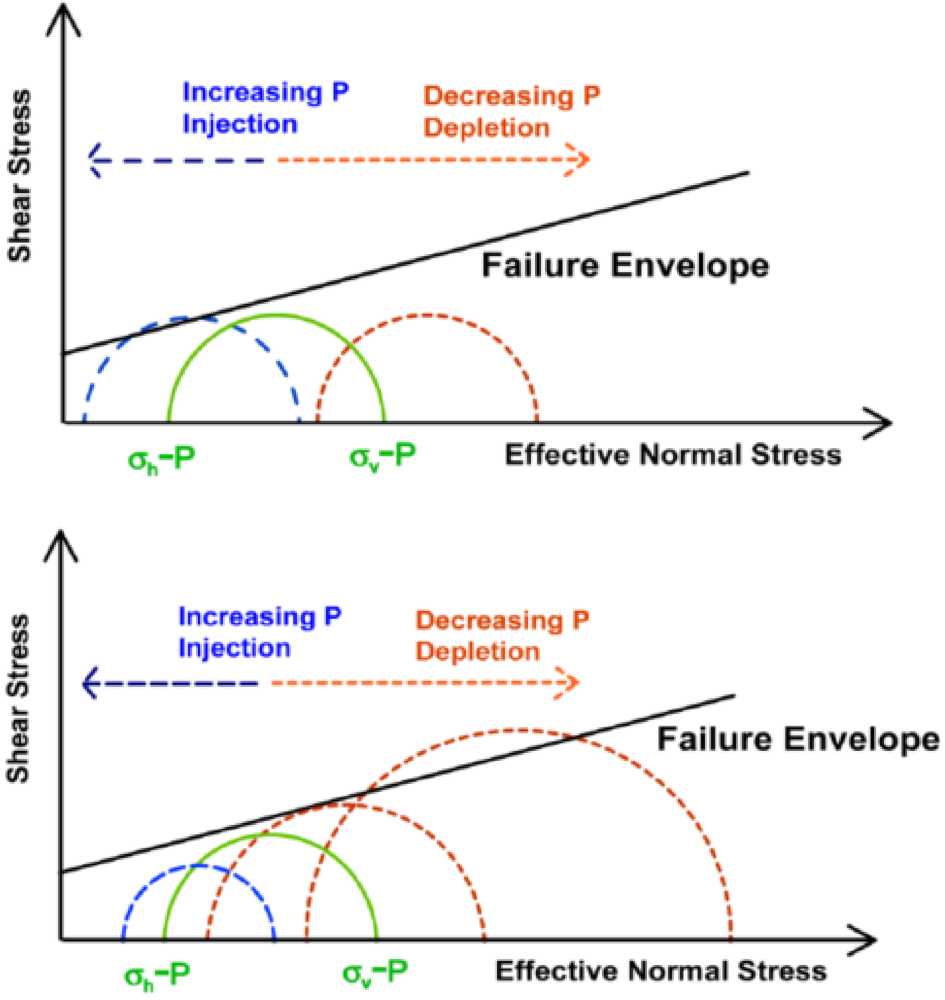
Possible Geomechanical Related Failures in CO_2 Storage



Reference: Younessi et al. (2024), Geomechanical Analysis of Caprock Integrity and Fault stability for Greensand CO_2 Storage Project Feasibility. ARMA 2024

- State of stress in the storage layer and caprock changes due to the pore pressure increase in the storage layer and the temperature cooling effect in the storage layer because of the CO_2 injection.
- These failures can be predicted for the entire zone of injection, i.e., the storage layer, the overburden and underburden layers, over the entire life of the CO_2 storage project using a 3D field-scale dynamic geomechanical model.
- For this purpose, a 3D dynamic finite element model is built and coupled with the reservoir flow dynamic simulation results.

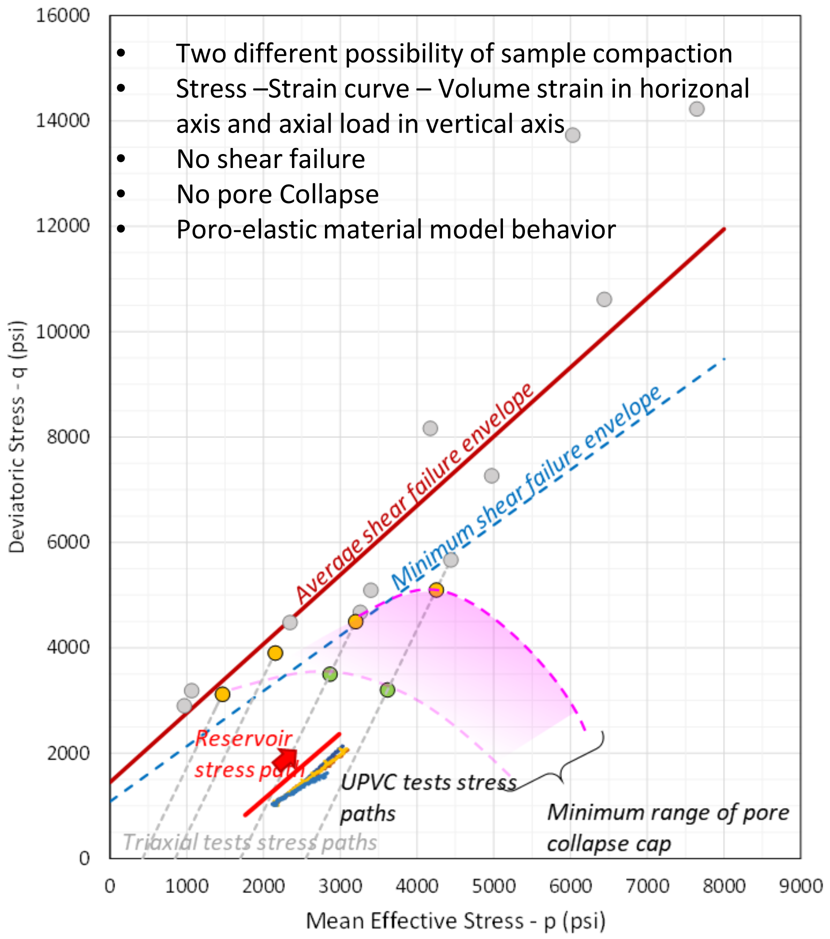
Pore Pressure – Stress

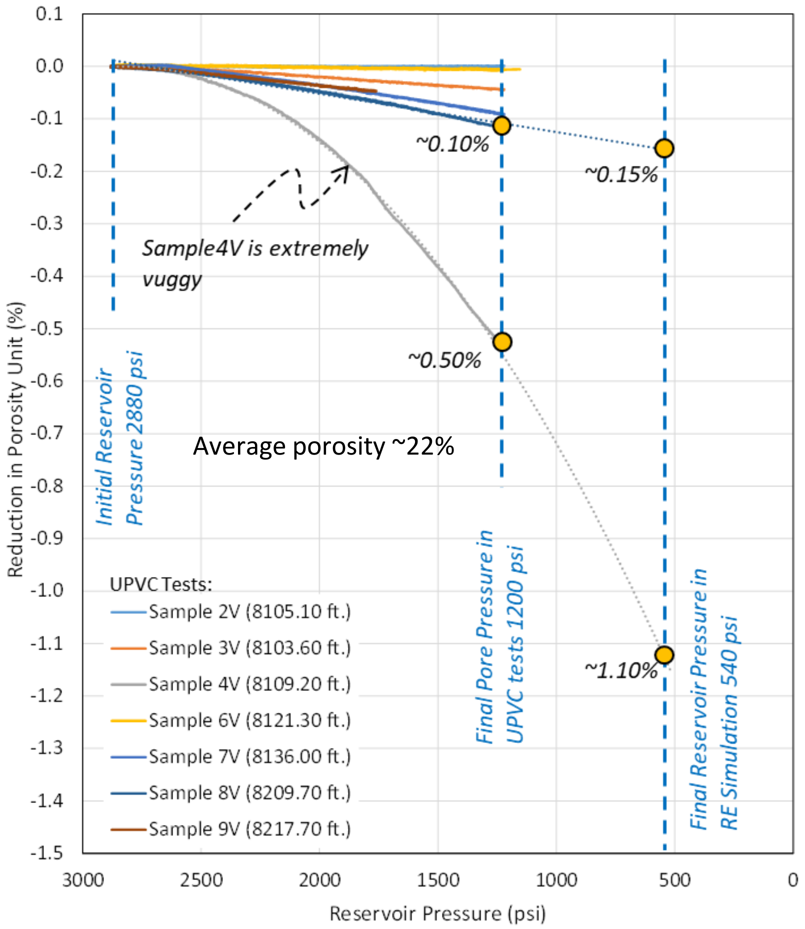


Reference: Muller et al. (2008), Modelling Pore Pressure/Stress Coupling

- For pressure-independent stresses, increase in pore pressure such as injection ($\Delta P > 0$) leads to a reduction of effective stresses. This results the Mohr circles shift to the left approaching the failure envelope which would destabilize the faults in the reservoirs.
- Conversely , a decrease in pore pressure, such as depletion ($\Delta P < 0$) would stabilize faults.
- Pore pressure/stress coupling generates for decreasing pore pressure (depletion) a reduction of the total minimum horizontal stress and therefore the effective horizontal stress increases less than the effective vertical stress which leads to an increase of the Mohr circle and higher risk to reach the failure envelope.
- In the case of injection, the size of the Mohr circle is reduced, since the effective horizontal stress is reduced less than the effective vertical stress

Material Model and Property Mapping

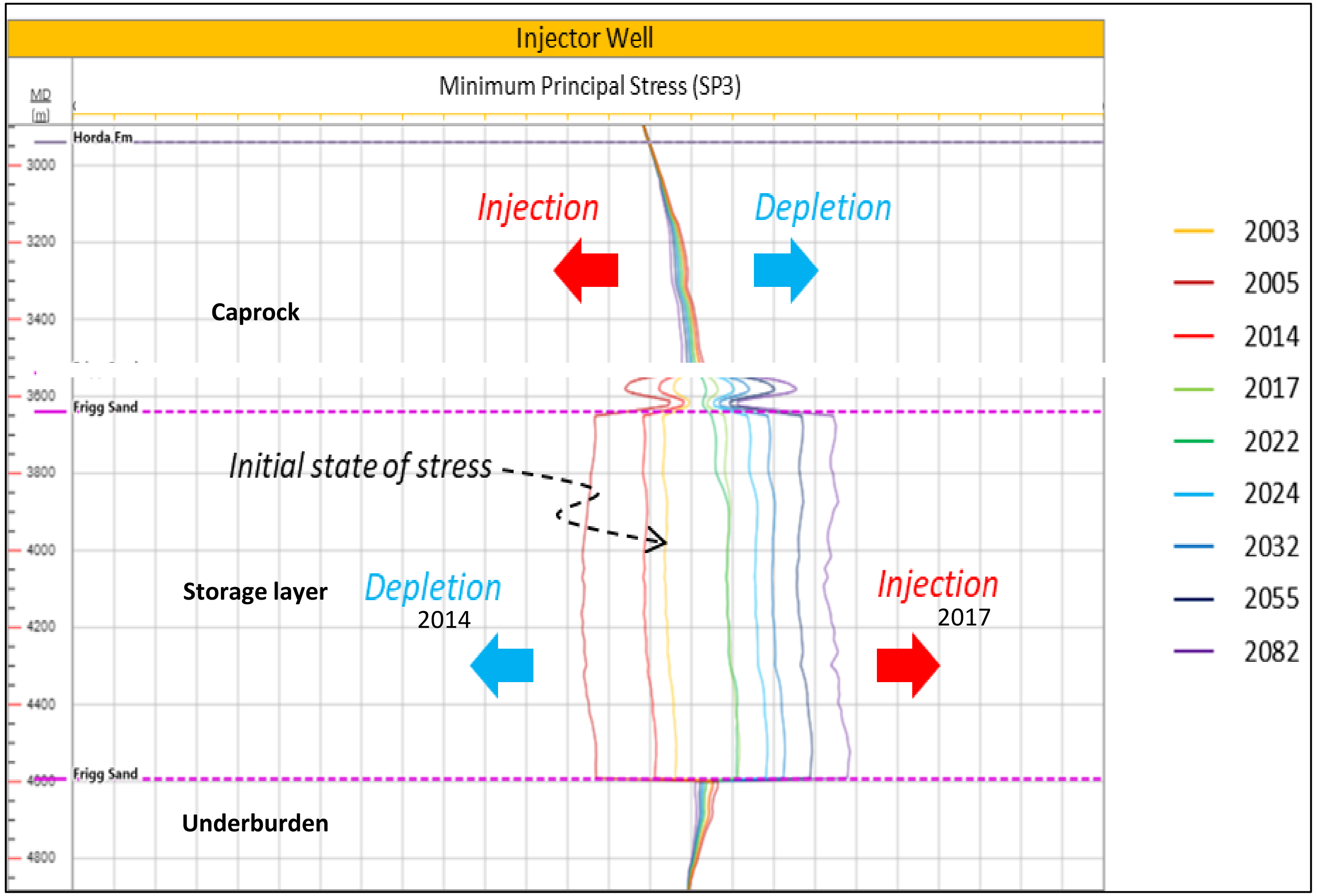


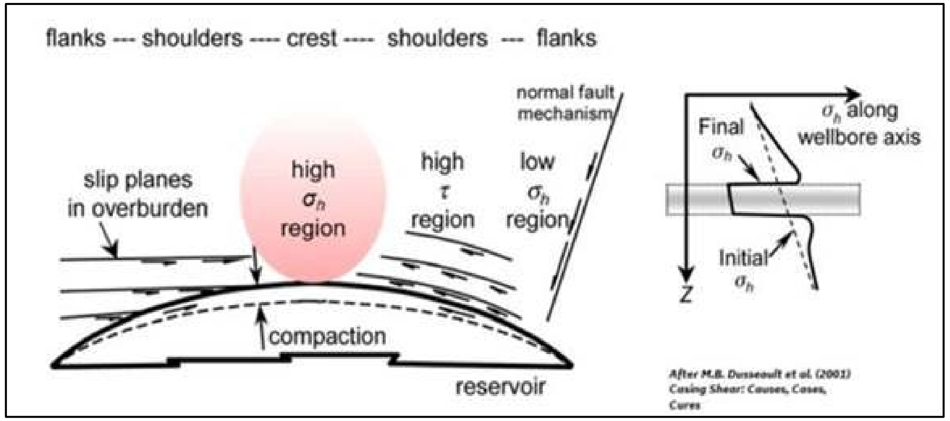


- The material model is defined using the available rock mechanical laboratory tests and the 1D and 3D geomechanical model results.
- The stress path calculated for the reservoir due to depletion is compared against the average and minimum shear failure envelope and minimum possible cap model.
- The required properties and parameters to run the simulation under the specified material model are propagated in the 3D FE mesh.
- Compaction (porosity change due to depletion) within the reservoir for the depletion phase of the storage can be investigated by UPVC test.
- Change in porosity due to compaction is not significant in this case.

Reference: Younessi et al. (2023), Assessment of Filed-Scale Geomechanical Risks Associated to Carbonate Reservoir Production in South Senoro Field. APOGCE 2023

Minimum Horizontal Stress Changes Along the Wells

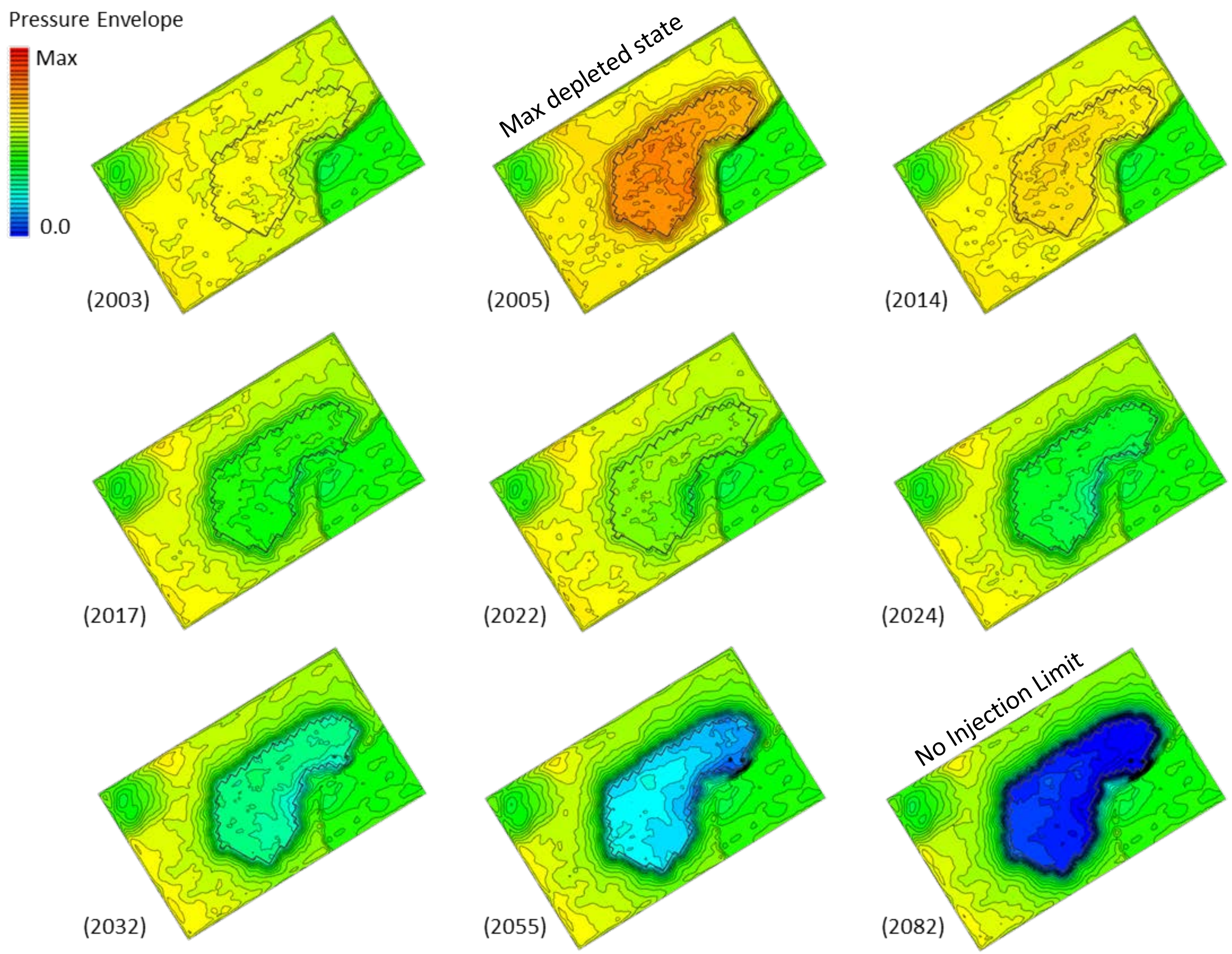




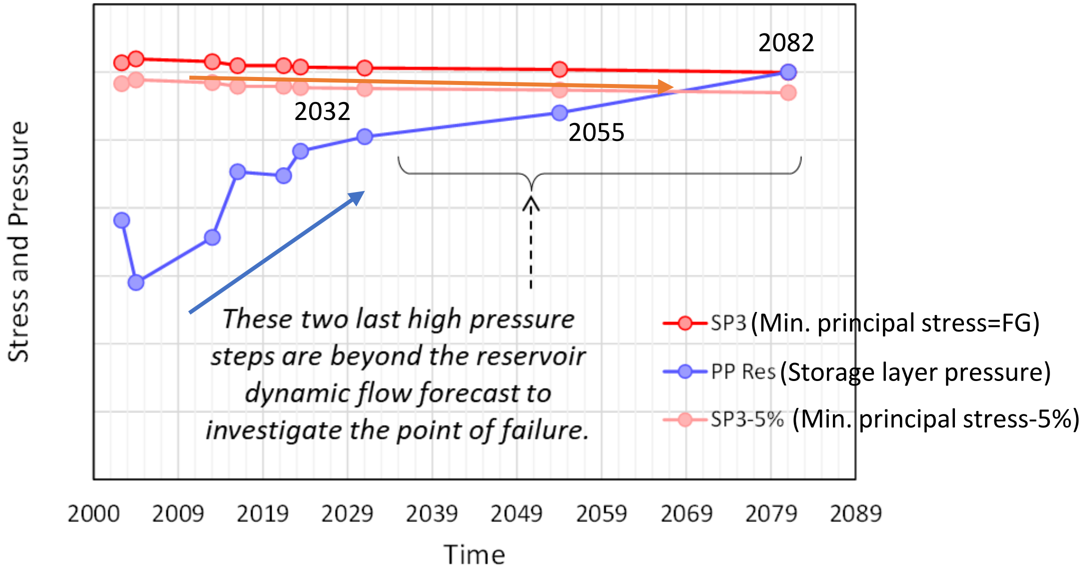
Reference: M.B. Dusseault et al. (2001) Casing Shear: Causes, Cases, Cures

- The stress changes in the overburden is mainly due to the reservoir compaction (anticline the overburden layers in the two sides of the crest tend to move toward each other, hence you will have stress concentration in above the crest and relaxation in the flanks.
- Upon injection, the fracture gradient in the caprock decreases and it's important to quantify the amount of stress changes in the caprock.

Tensile Failure in Caprock – Upper Pressure Limit

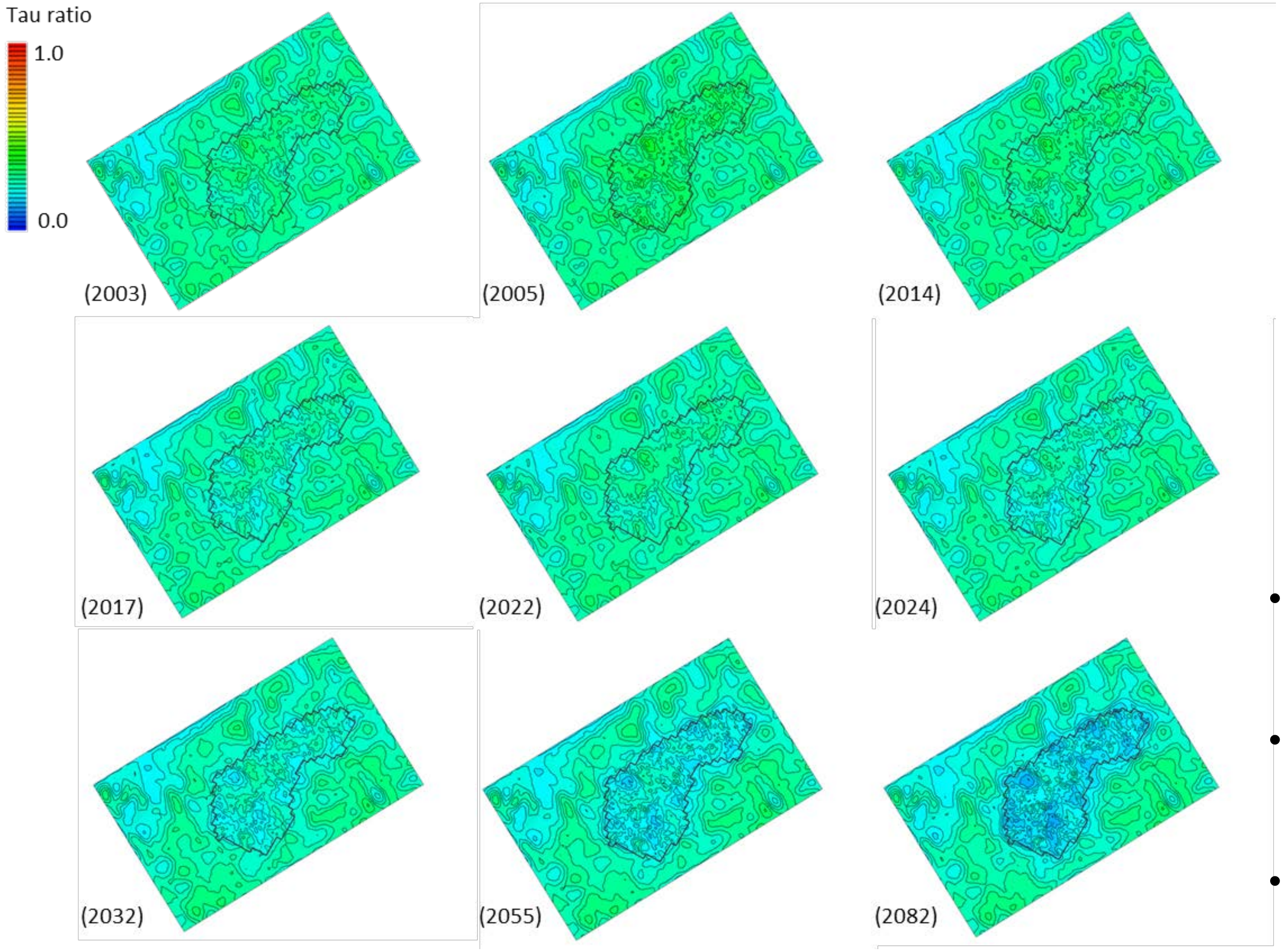


Map showing Fracture pressure (caprock) and Reservoir pressure (storage) window

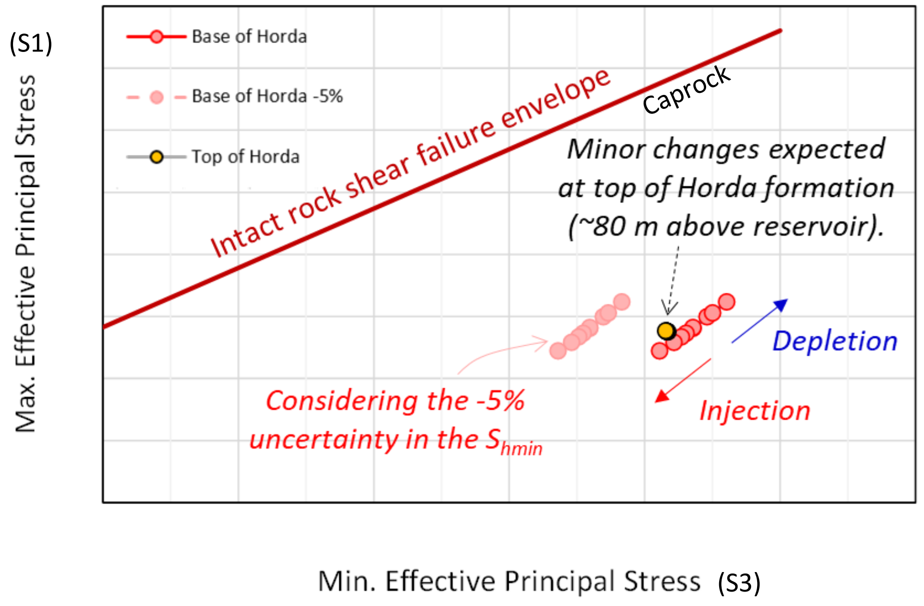


- Failure in the caprock is expected when the effective minimum principal stress overcomes the tensile strength of the caprock, in which a tensile fracture could be induced.
- No tensile failure is expected in the caprock till 2055 because the in-situ stresses of the caprock are higher than the reservoir pore pressure for the entire numerical simulation.
- Storage layer pressure must not exceed the fracture pressure of the caprock. Estimate the maximum pressure injection within the storage layer.

Shear Failure in Caprock

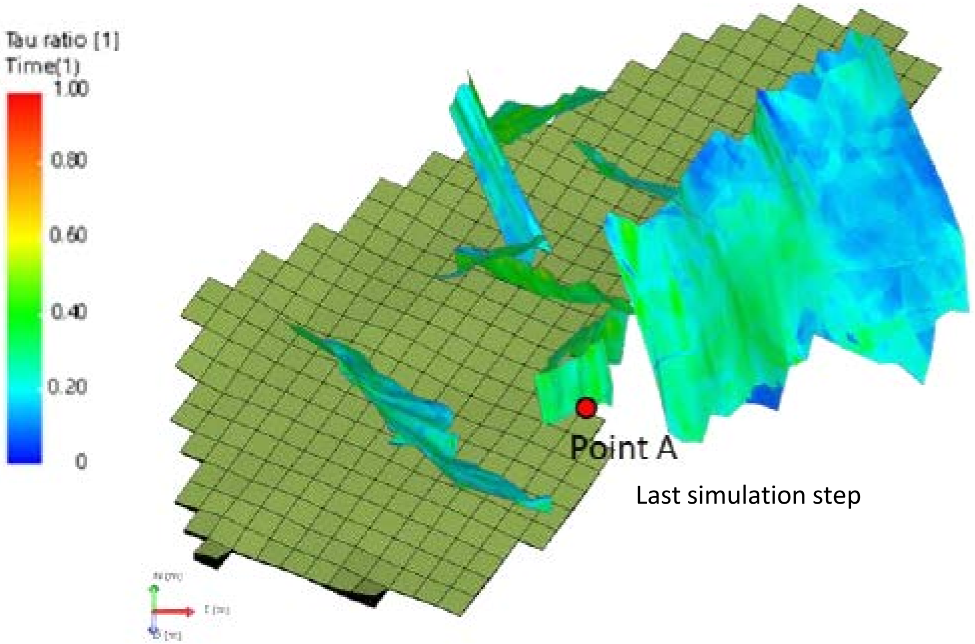


Map of Tau ratio (Maximum shear stress/shear strength) showing the risk of shear failure

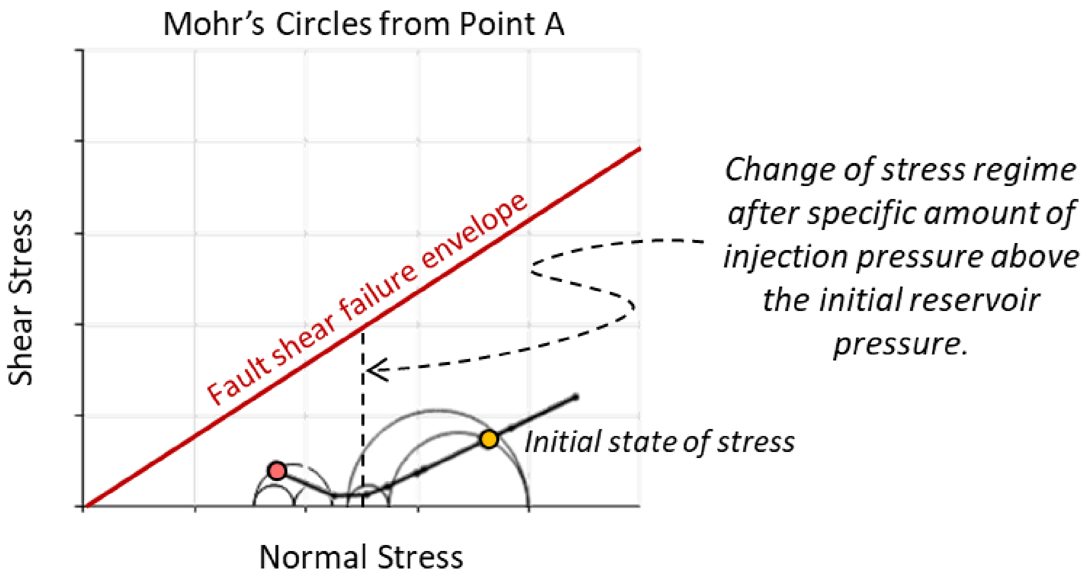


- Failure in the caprock is expected when the resulting stresses exceed the compressive strengths of caprocks, in which shear failure could occur.
- Cross plot shows how stress path (stress changes) with depletion and injection and comparison with intact rock shear failure envelope.
- The stress changes at the top of the caprock layer are relatively minor compared to the base of the caprock layer. Nevertheless, the stress path for the entire caprock layer appears to be far below the intact rock shear failure.

Tendency of Fault Reactivation (Tau Ratio)



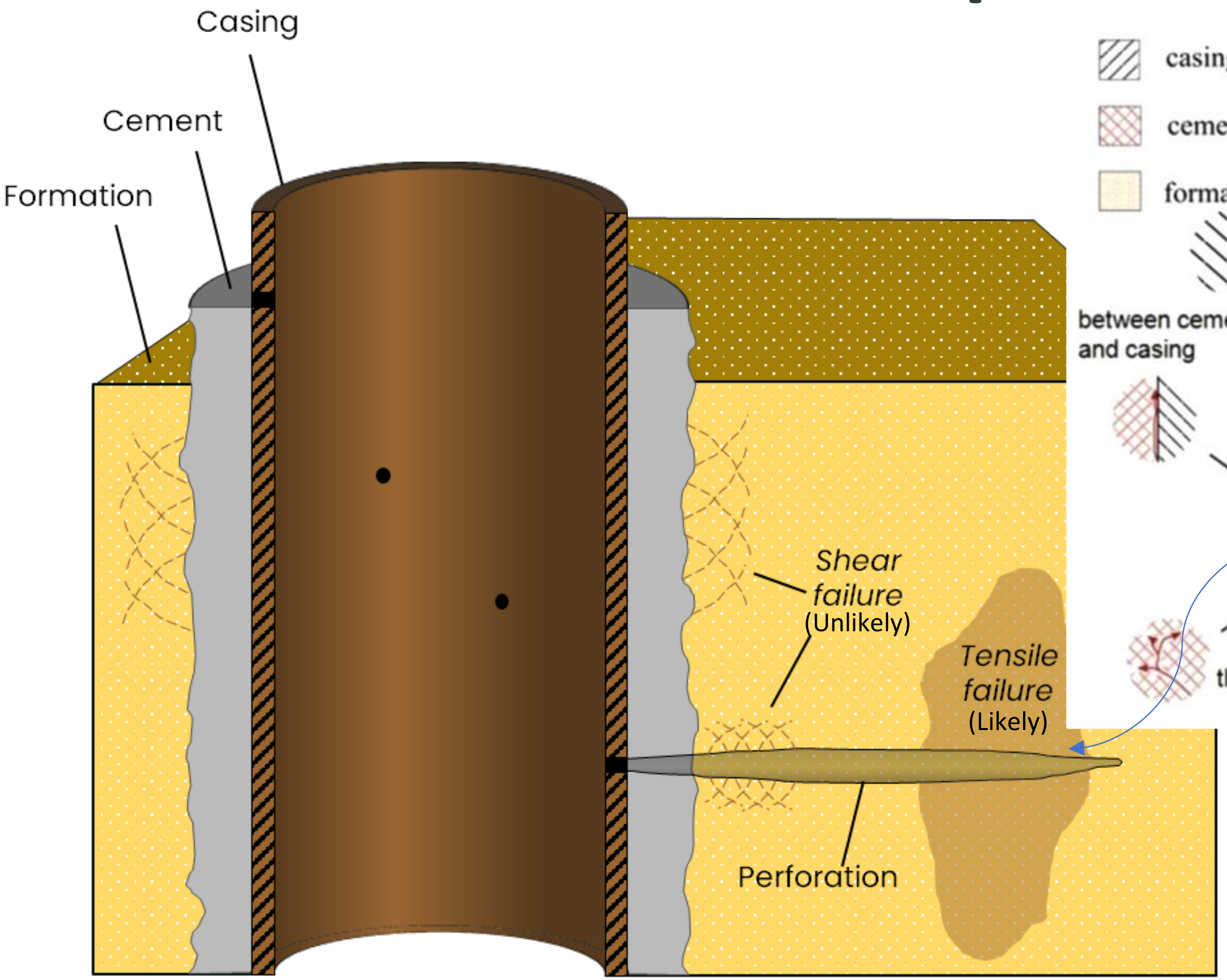
3D view of the calculated Tau ratio on the surface of the fault planes for the last simulation step

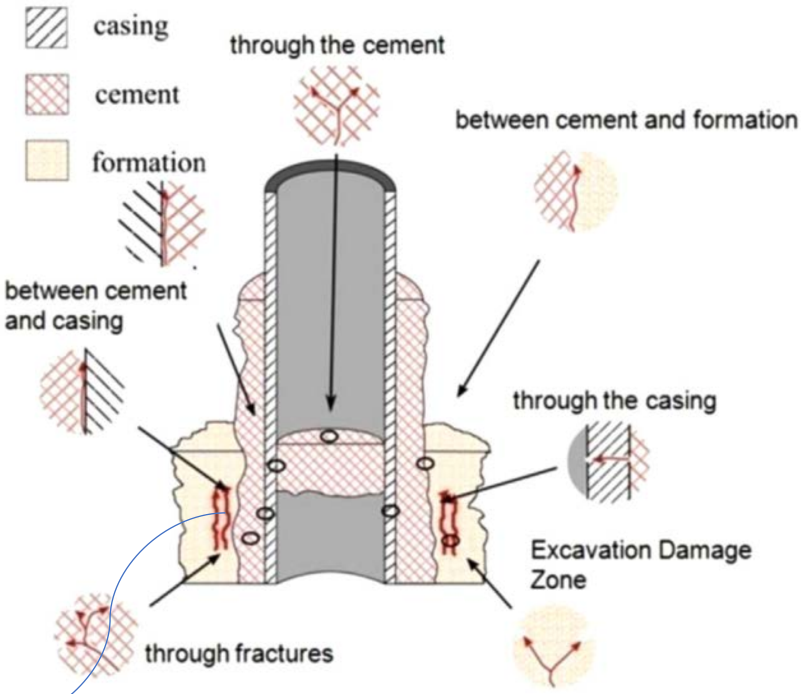


Mohr diagram from a representative point on the CO2 storage section of a nominated fault

- Cross plot shows the points in storage layers for the maximum stress changes condition (during depletion and injection) is below the failure envelope.

Failures Around Completed Wells



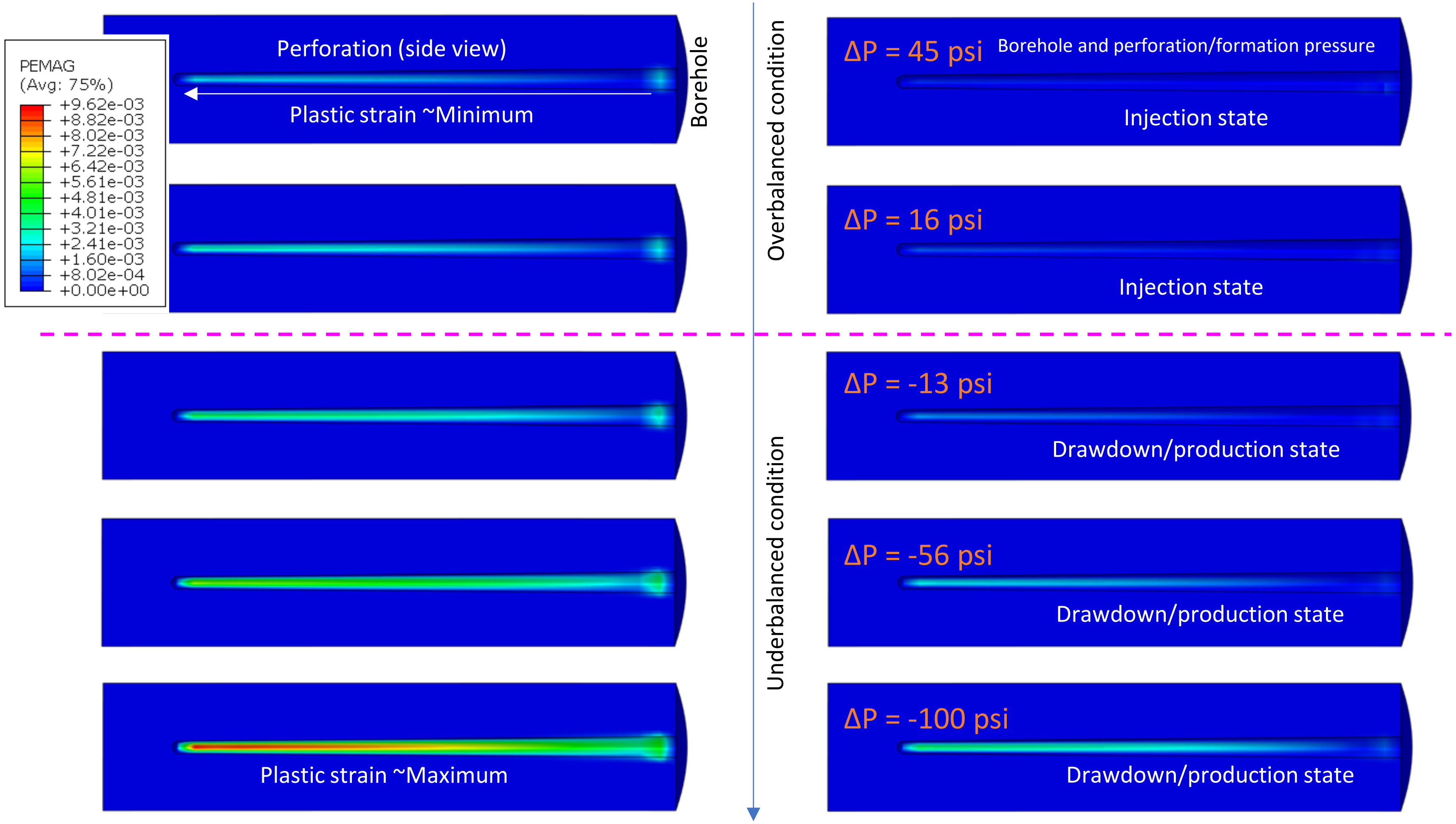


Reference: M. Bai et al, A review on well integrity issues for CO2 geological storage and enhanced gas recovery, Renewal and Sustainable Energy Reviews 59 (2016)

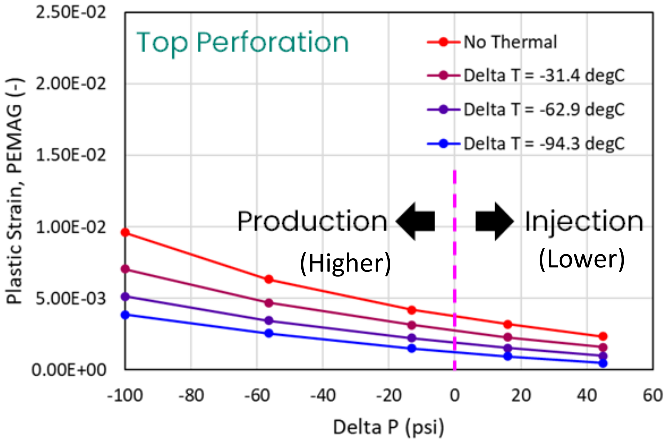
- The construction of CO_2 injection wells has additional regulations to avoid any well integrity risks associated to CO_2 injection (shear failure and tensile failure)
- Potential leakage pathways for CO_2 in a well may happen through interfaces of casing-cement-formation and through fractures in the cement.
- Apart from these integrity issues, the stability of the wellbore and perforation must be assessed during the CO_2 injections.
- This can be done using advanced geomechanical applications discussed in the following slides.

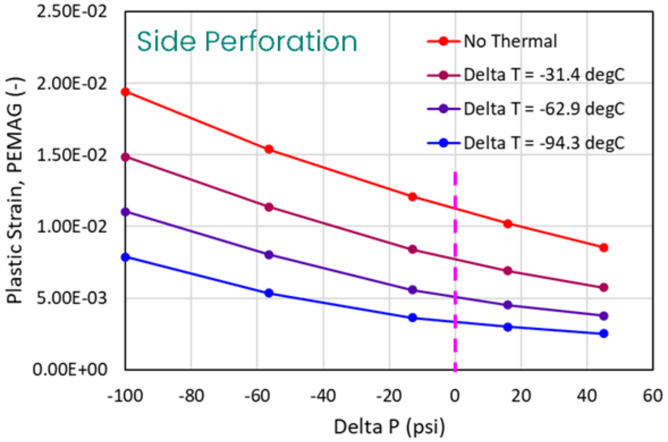
Shear Failure in Perforation

No Thermal Effect (ΔT = 0 °C) — With Max. Thermal Effect (ΔT = -94.3 °C)



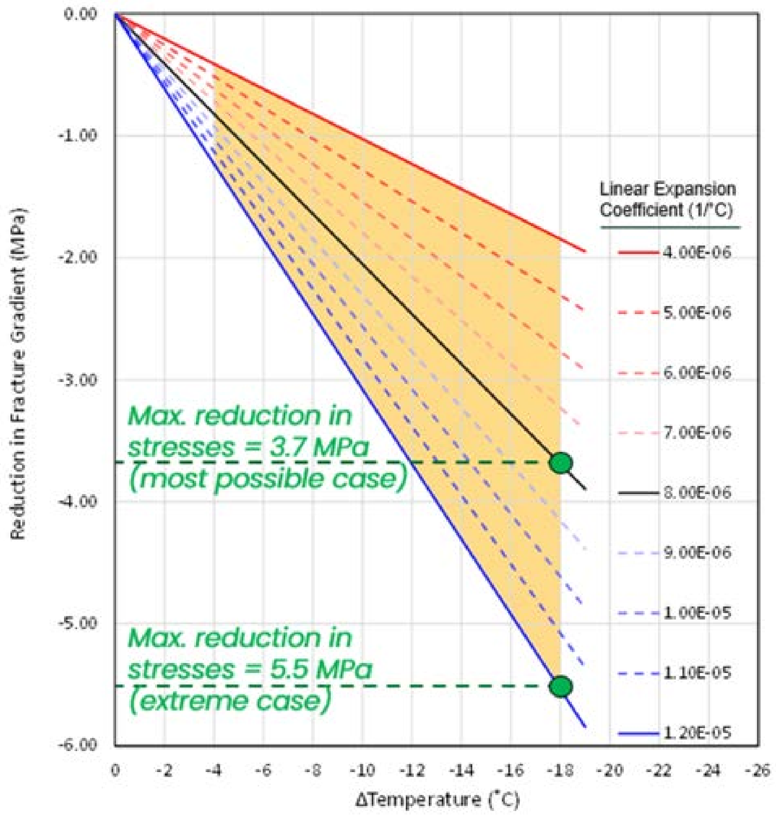
Five different simulation cases to investigate the impact of cooling on the shear failure in perforation

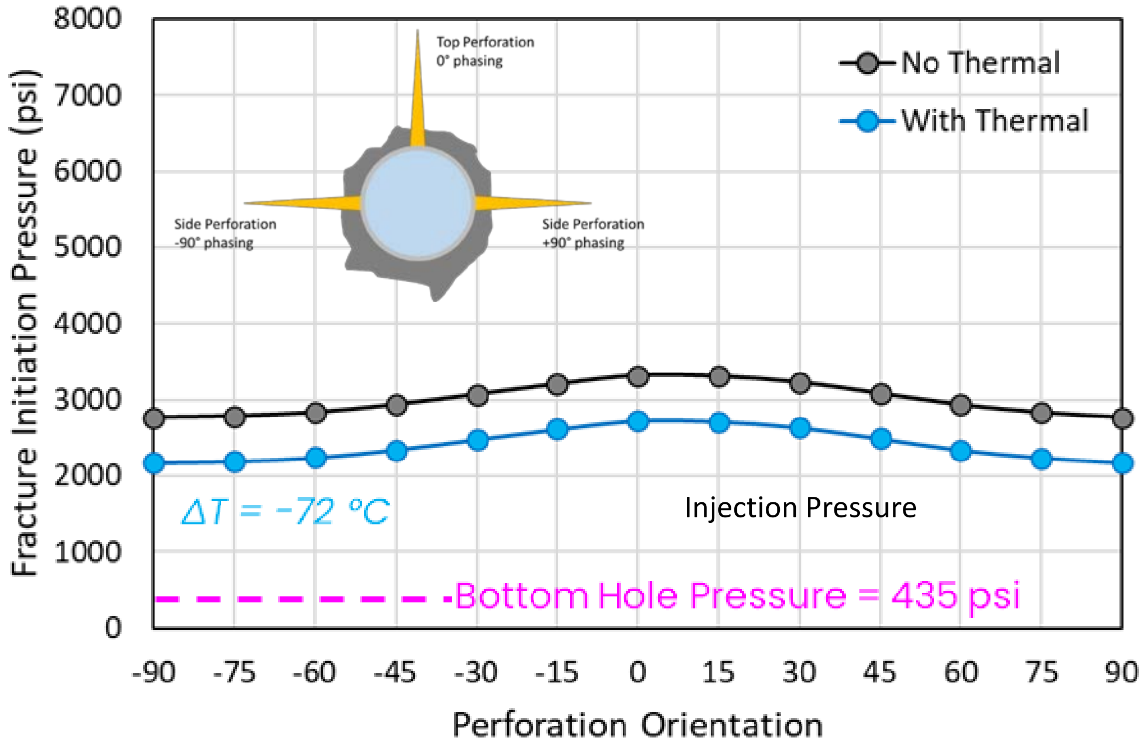




Thermal effect on the plastic strain for different perforation orientation during injection (Higher cooling effect reduces plastic strain as compared to no thermal effect)

Tensile Failure in Perforation





- The fracture initiation pressures in the perforations within the storage layer zones of the CO_2 injector wells can be calculated using an analytical approach. For this purpose, the reservoir pressure and in situ stresses can be extracted from the 3D geomechanical model along the injector wells. The bottom hole pressure and temperatures during CO_2 injection are usually obtained from the flow assurance study. Note that the most extreme cases are from the start and end of injection scenarios.
- The stress changes induced by the thermal expansion/contraction of the rocks are calculated from the thermoelastic equations for both the reservoir and caprock using the following equation, $\Delta Stress = \frac{E\alpha_T \Delta T}{1-\nu}$, where E is the Young's modulus, αT is the linear expansion coefficient, ΔT is temperature difference and ν is Poisson's ratio. The calculation is done for different perforation orientations covering the top half of the wellbore section (the results of the bottom half are repeating the top results).

Summary

- It is essential to investigate the geomechanical risks associated to CO_2 injection for geological storage.
- These are the shear and tensile failures in the caprock, reactivation of the faults and natural fractures connected to the storage layer, and failure around the completed wells.
- Monitoring and measurement technologies are used in injection and monitoring wells to verify and assure the integrity of the wellbores and seals. This is achieved through the Monitoring, Measurement and Verification (MMV) plan.