Project: CO_2 injection with fracturing in geomechanically protected caprock

Task 6 of LLNL's Research Activities to Support DOE's Carbon Storage Program (FWP-FEW0191)

Poroelastic Sustainability of Pressure-Driven Fracture in Carbon Storage Reservoir

Implications for Injectivity and Caprock Integrity

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LLNL-PRES-788277

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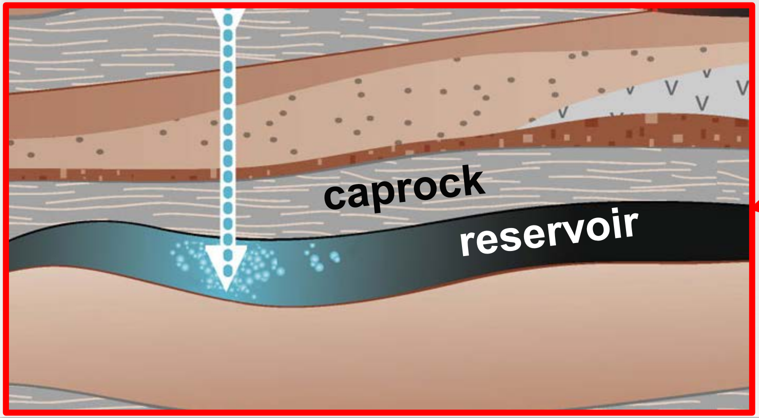
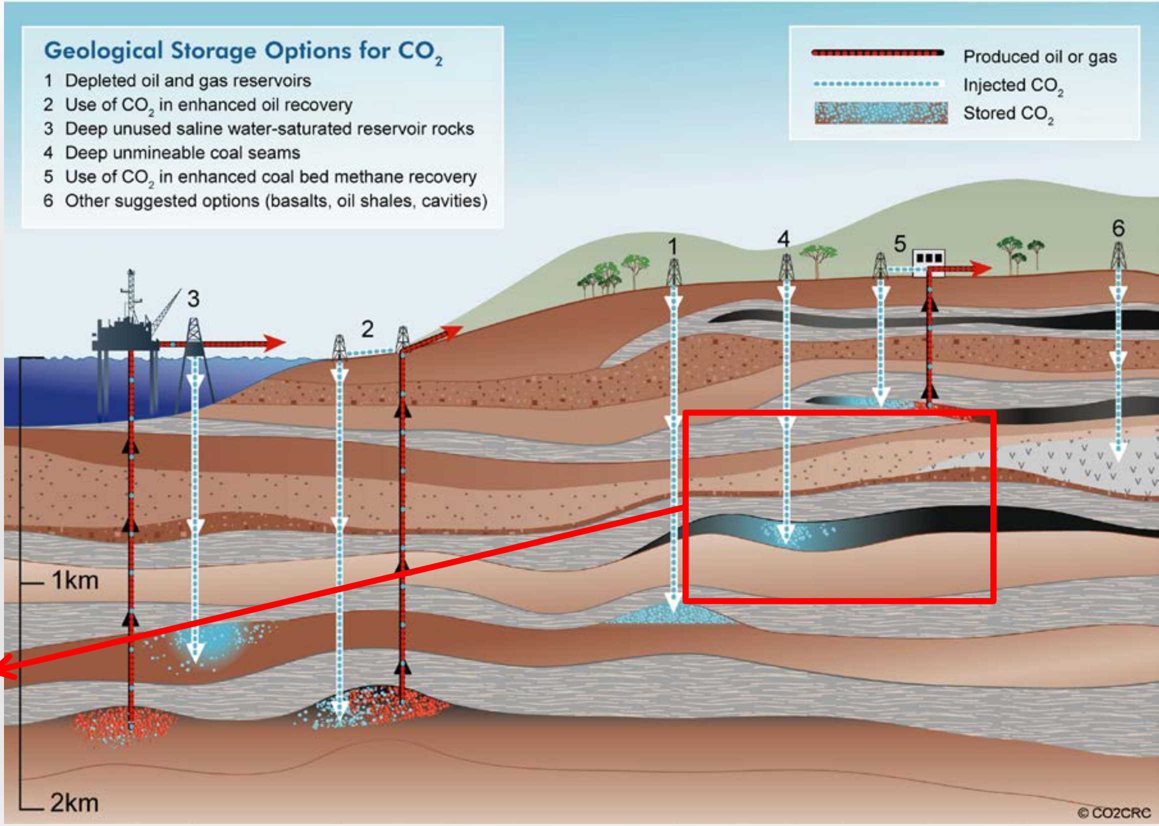
Background: geologic carbon storage (GCS)

- 70% energy in US is from fossil fuel.
- Demands immense storage volume
- Local accessibility is a key
- Caprock secures integrity





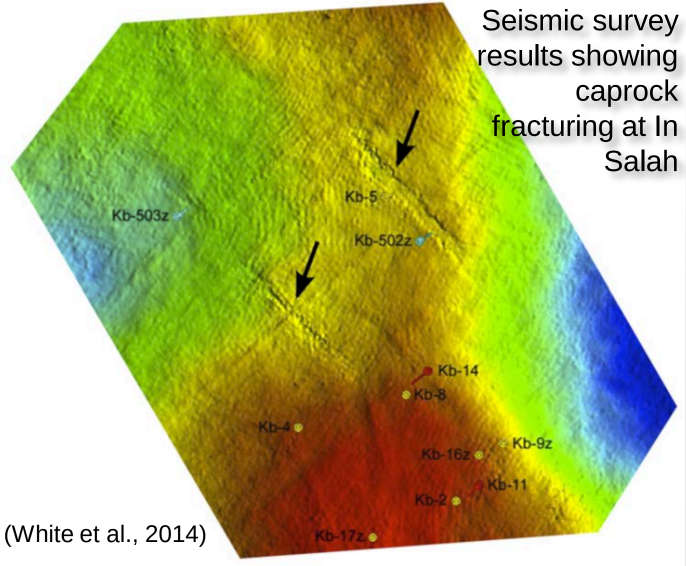
Why studying caprock fracturing

- Conventional strategy: Injecting below the fracturing pressure to prevent fracturing

- Hydraulic fracturing has been suspected.
  - Evidence showed the storage complex was not comprised.

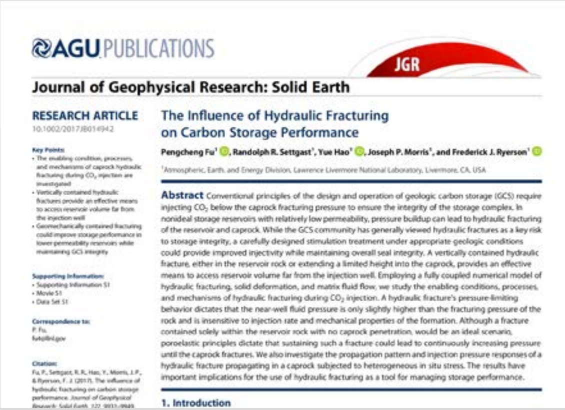
- Need to re-assess the role of hydraulic fracturing in GCS.

- If CO_2 can be injected through a vertically contained fracture, reservoirs of marginal permeability will be economically viable.



Seismic survey results showing caprock fracturing at In Salah

(White et al., 2014)



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RESEARCH ARTICLE

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Key Points:
- The enabling condition, processes, and mechanisms of caprock hydraulic fracturing during CO_2 injection are investigated
- Vertically contained hydraulic fractures provide an effective means to access reservoir volume far from the injection well
- Geomechanically contained fracturing could improve storage performance in lower permeability reservoirs while maintaining GCS integrity

Supporting Information:
- Supporting Information S1
- Movie S1
- Data Set S1

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The Influence of Hydraulic Fracturing on Carbon Storage Performance

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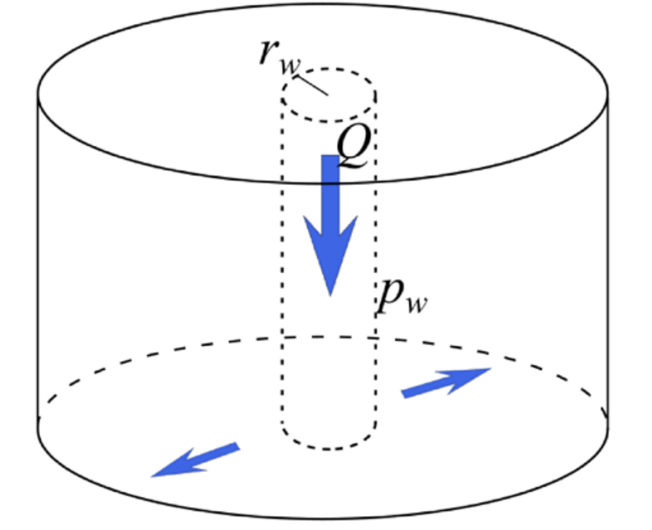
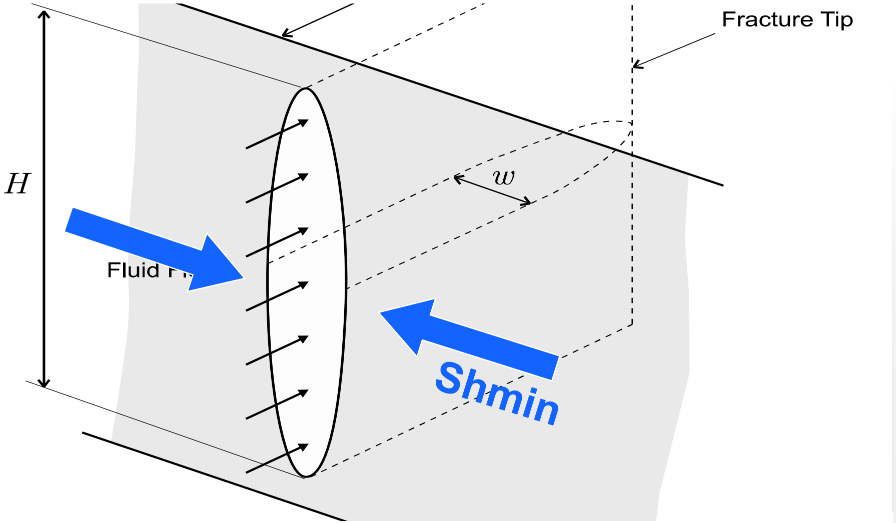
Abstract Conventional principles of the design and operation of geologic carbon storage (GCS) require injecting CO_2 below the caprock fracturing pressure to ensure the integrity of the storage complex. In nonideal storage reservoirs with relatively low permeability, pressure buildup can lead to hydraulic fracturing of the reservoir and caprock. While the GCS community has generally viewed hydraulic fractures as a key risk to storage integrity, a carefully designed stimulation treatment under appropriate geologic conditions could provide improved injectivity while maintaining overall seal integrity. A vertically contained hydraulic fracture, either in the reservoir rock or extending a limited height into the caprock, provides an effective means to access reservoir volume far from the injection well. Employing a fully coupled numerical model of hydraulic fracturing, solid deformation, and matrix fluid flow, we study the enabling conditions, processes, and mechanisms of hydraulic fracturing during CO_2 injection. A hydraulic fracture's pressure-limiting behavior dictates that the near-well fluid pressure is only slightly higher than the fracturing pressure of the rock and is insensitive to injection rate and mechanical properties of the formation. Although a fracture contained solely within the reservoir rock with no caprock penetration, would be an ideal scenario, poroelastic principles dictate that sustaining such a fracture could lead to continuously increasing pressure until the caprock fractures. We also investigate the propagation pattern and injection pressure responses of a hydraulic fracture propagating in a caprock subjected to heterogeneous in situ stress. The results have important implications for the use of hydraulic fracturing as a tool for managing storage performance.

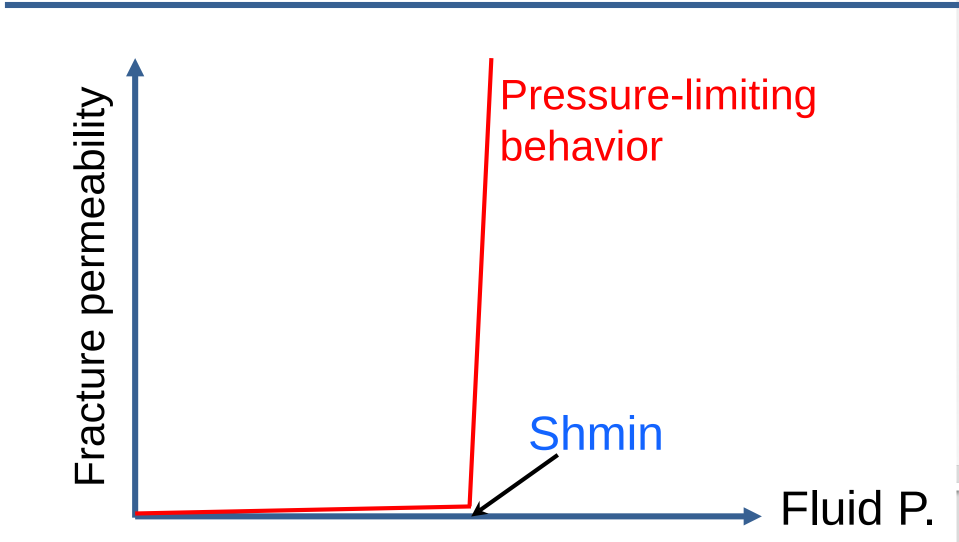
1. Introduction

The essence of hydraulic fracturing

- The generation of a hydraulic fracture is simply a flow regime change.
- Fracturing occurs if porous medium flow cannot accommodate the injection rate below the fracturing pressure.



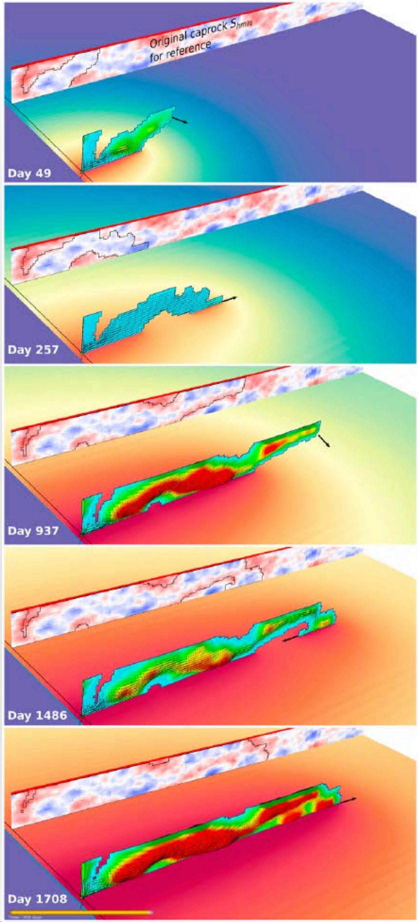




Project Overview

- To assess short and long term behavior of hydraulic fractures in geomechanically protected caprock.
  - Goal is to increase injectivity in low-permeability reservoirs and ensure storage security.
  - Develop mechanically rigorous tools to evaluate various fracturing scenarios.
  - In essence, we bring rigorous fracture mechanics and geomechanics to the evaluation of caprock fracturing.

- Tasks:
  - Develop and validate a CO_2-saline two phase hydraulic fracture model in GEOS. (75%)
  - Study the sustainability of hydraulic fracture within the reservoir rock and the implication for injectivity improvement. (85%).
  - Study mechanisms and processes contributing to fracture-related phenomena unique to CO_2 injection and containment of and fractures in the caprock.



Is hydraulic fracture in reservoir rock poromechanically sustainable?

- A hydraulic fracture tends to close under constant fluid pressure
  - (Detournay and Cheng, 1991; …)

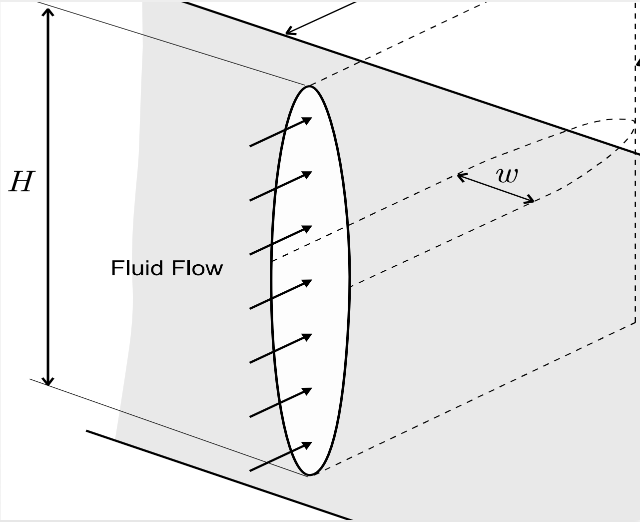
- Can we sustain a reservoir hydraulic fracture with a pressure safe for caprock?

Unconventional oil and gas:

- Very low reservoir *k*
- Can use high viscosity fluid
- Relatively short injection

Carbon storage:

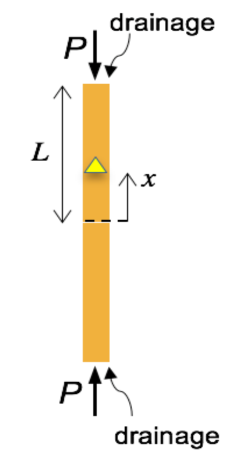
- Much higher reservoir *k*
- Has to inject CO_2
- Long injection

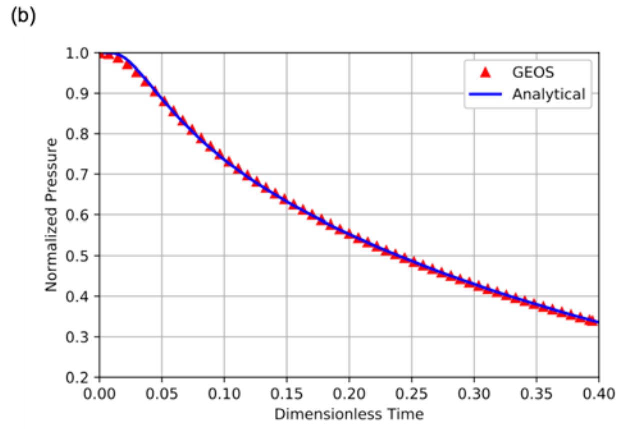


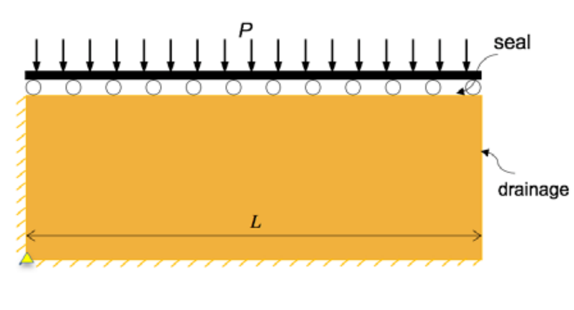
Model reservoir-caprock fracturing requires:

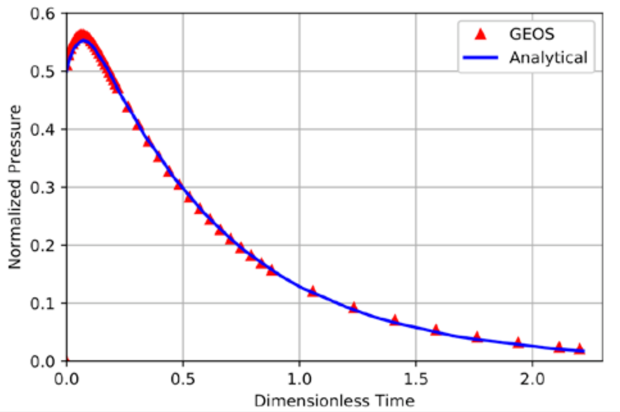
- Multiphase multi-component porous mediums flow.
  - Supercritical CO_2 and brine
  - Heat transport
- Fully coupled poroelasticity
- Thermal contraction
- Implemented in LLNL's GEOS
- Fixed-stress coupling

Terzaghi's 1D consolidation



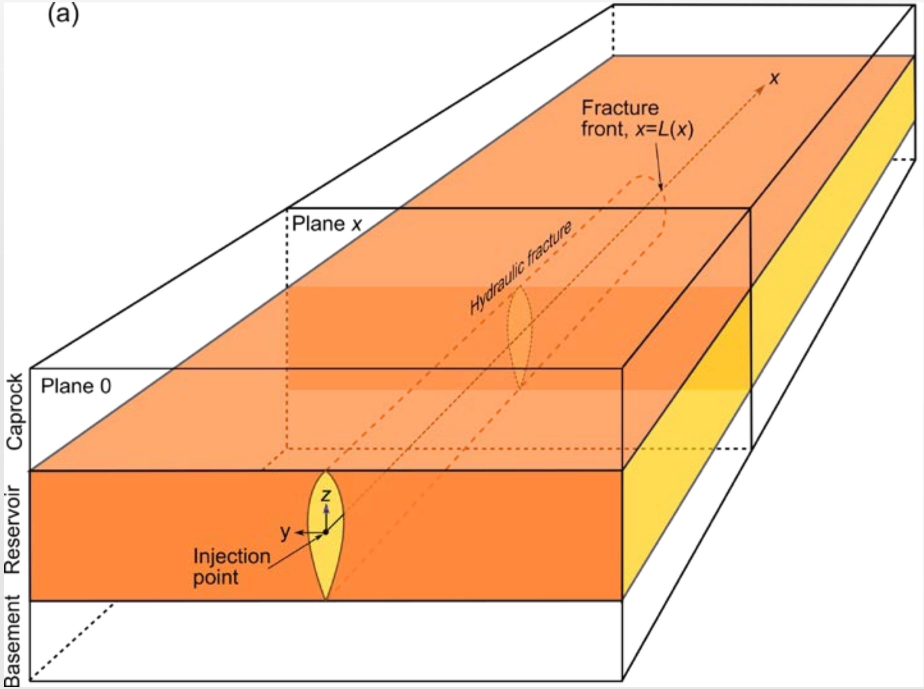




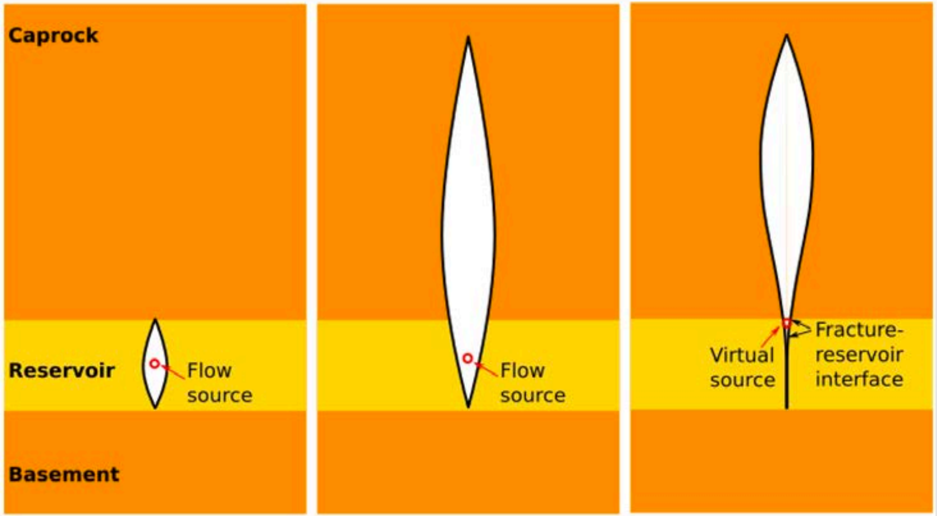


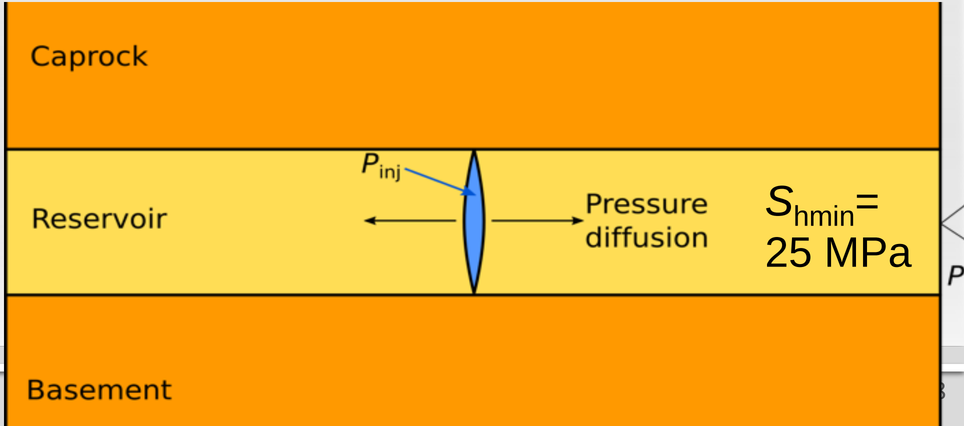
Mandel's problem

Fracture's poroelastic sustainability: model setup



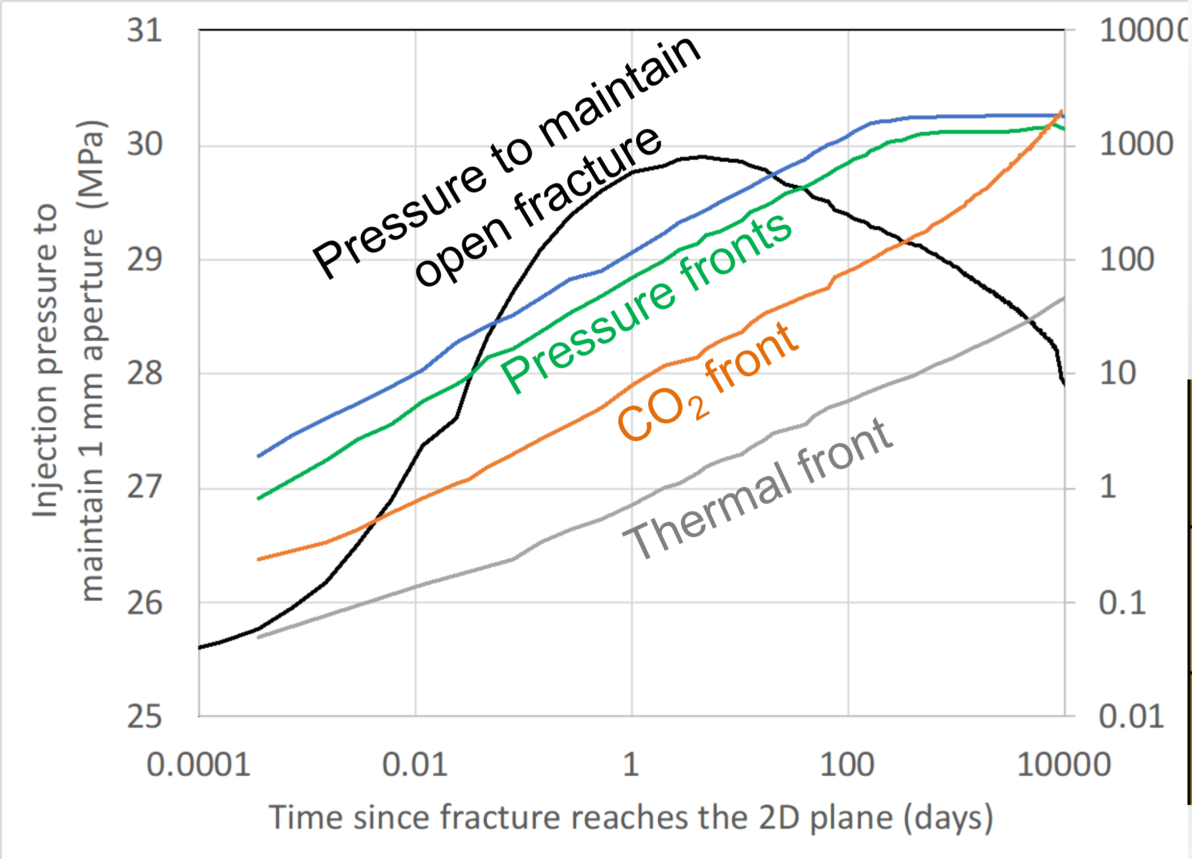
Contained in resv. Extending into caprock Closed in resv.

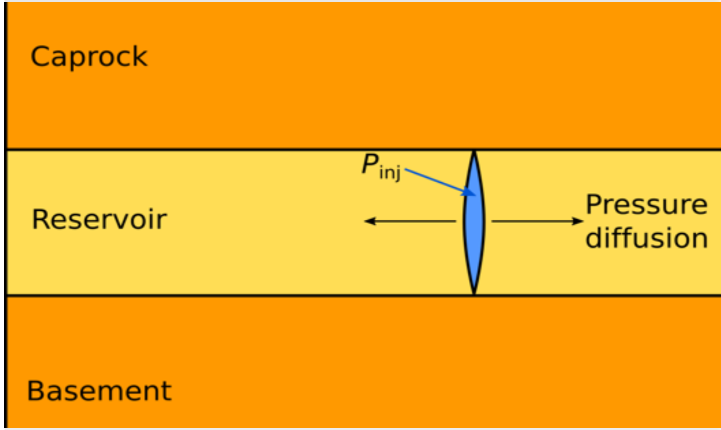




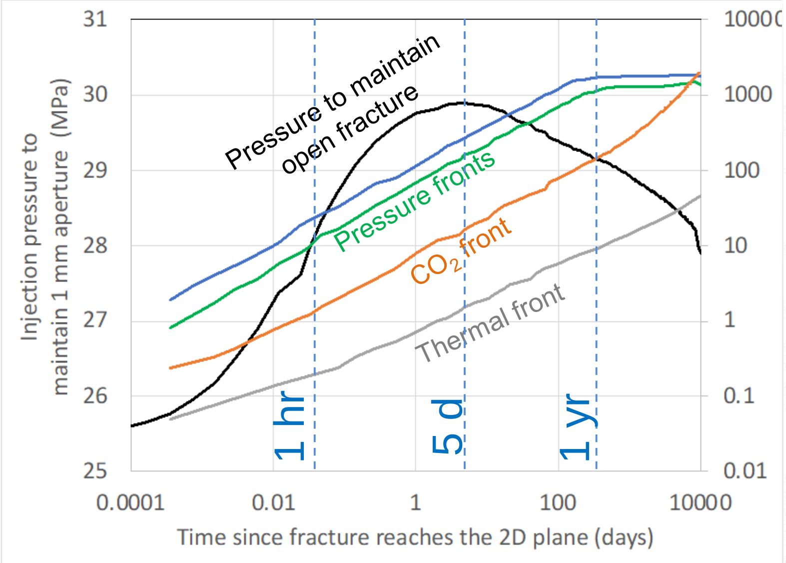
S_{hmin}= 25 MPa

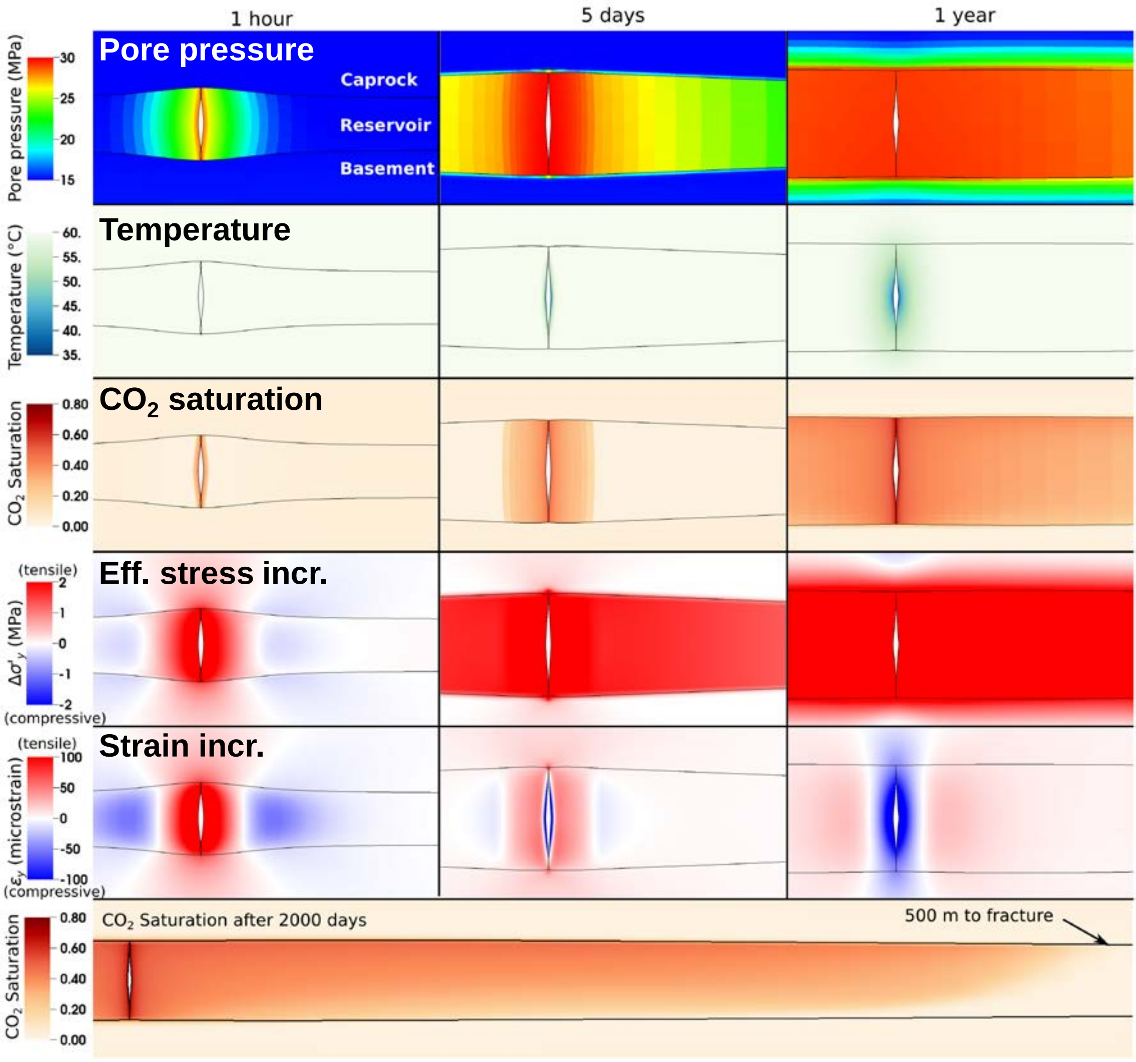
Fracture's poroelastic sustainability: baseline results





Fracture's poroelastic sustainability: baseline results

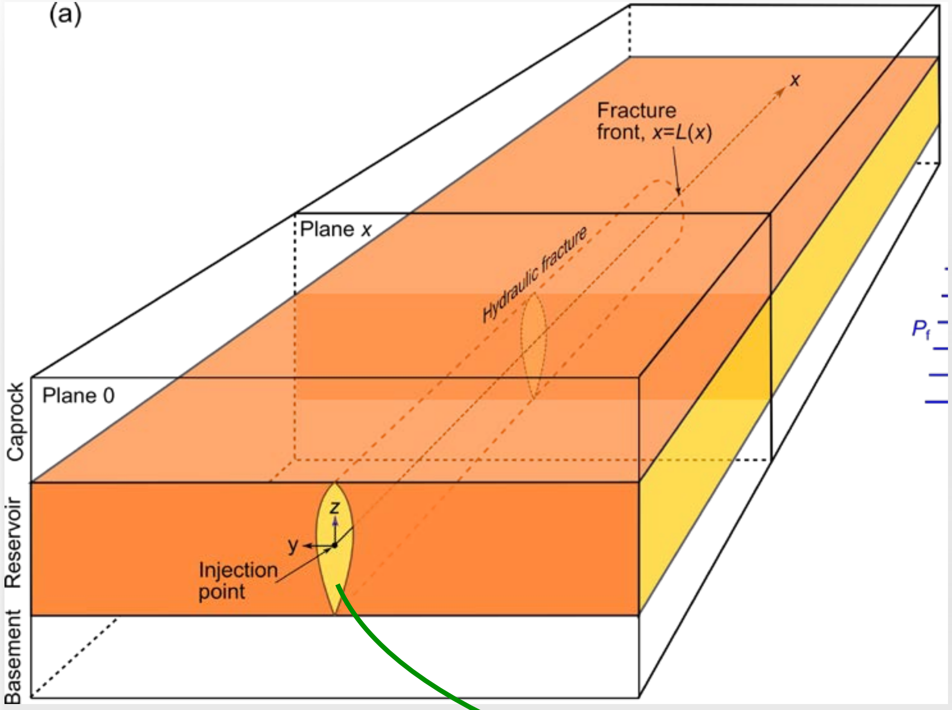


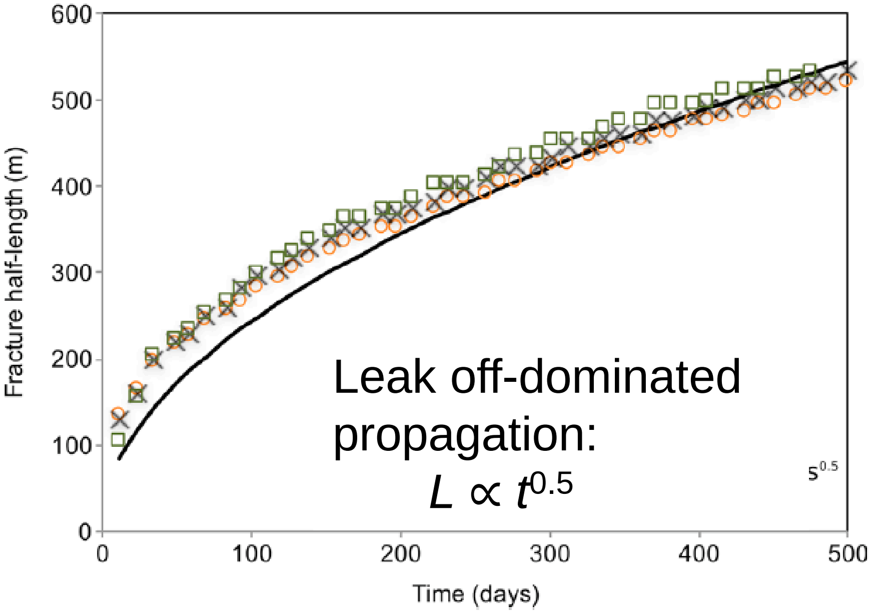


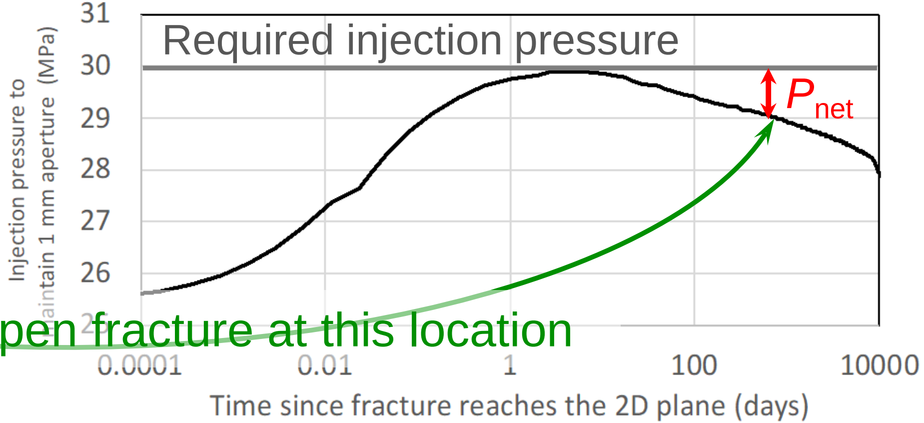
Poroelastic effect causes expansion of reservoir (closing fracture).

Fracture opened by fracture loading + Poisson's effect + thermal contraction.

Extending the analysis to the whole length

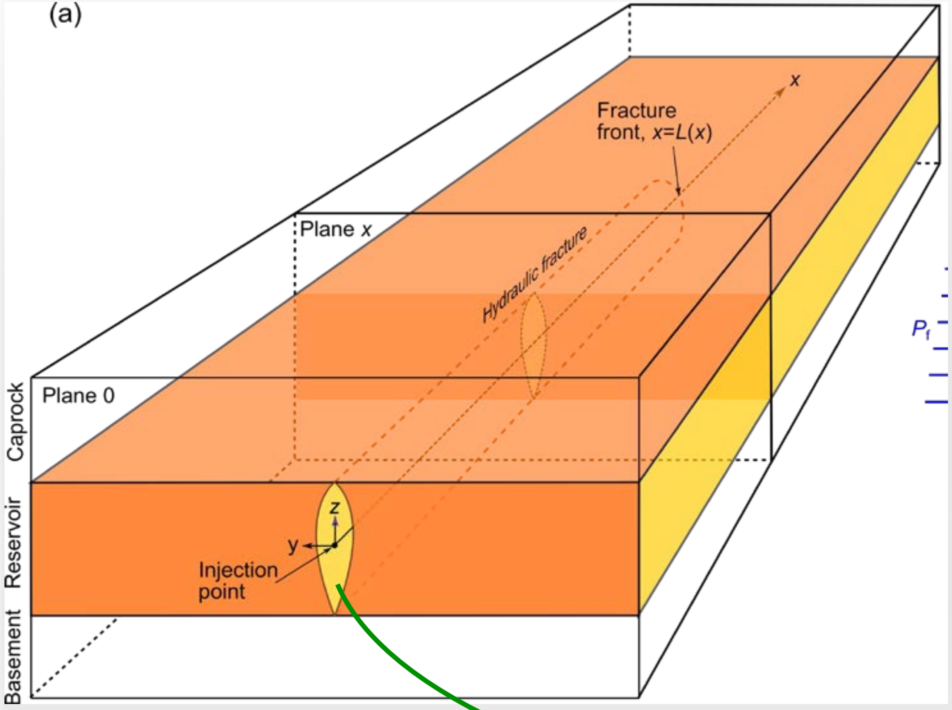


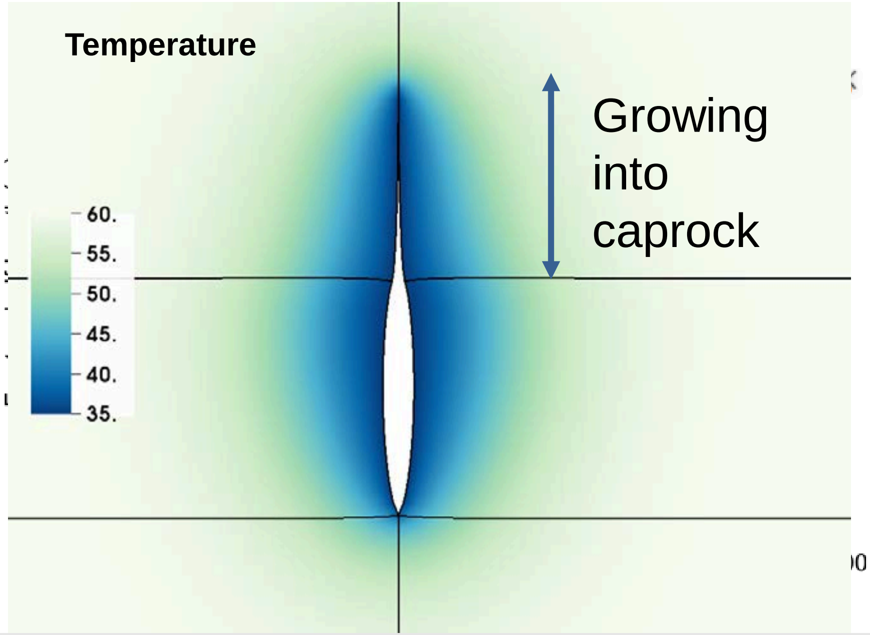


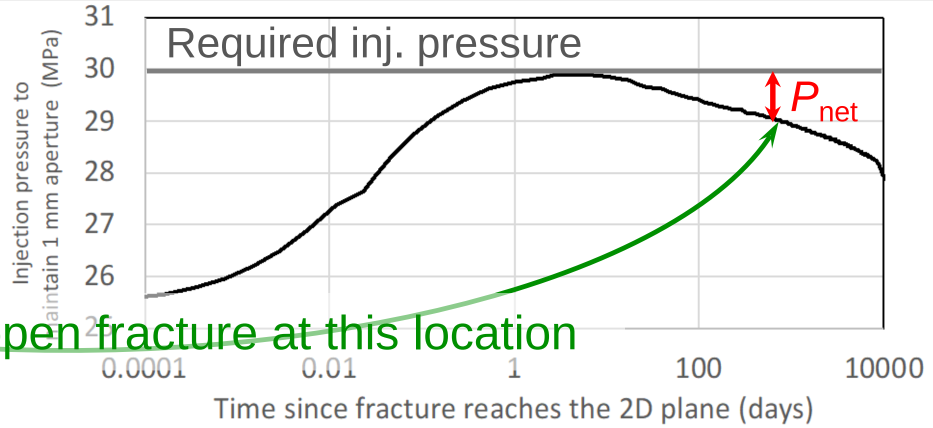


P required to open fracture at this location

Extending the analysis to the whole length



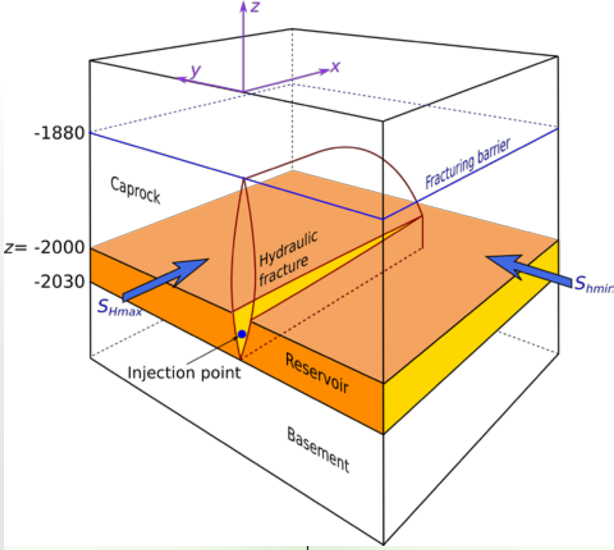


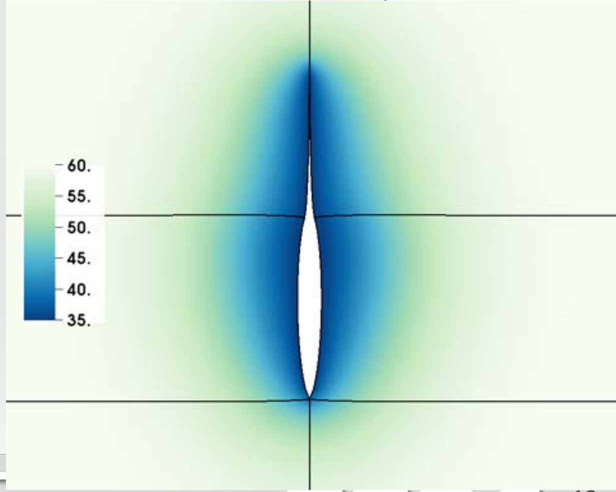


P required to open fracture at this location

Technical Conclusions from tasks 1 and 2:

- Sustainability of reservoir fracture and its containment involves complex processes
  - Poroelasticity
  - Poisson's effect
  - Thermal contraction
  - Fracturing through stress barrier
- Highest pressure is required to keep the fracture open near the fracture front
  - Could be several MPa higher than initial opening pressure
  - Wide aperture and likely penetration into caprock near the injection
    - Mostly caused by thermal contraction

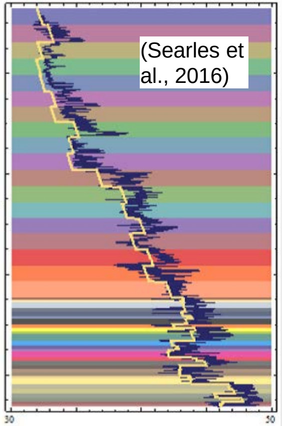




Technical status and impact

- Overall 50% completed in this two-year effort.
  - Model development 75% completed and reservoir fracture sustainability 85% completed.
  - Remainder of the project focuses on model validation and investigating robust containment conditions.
- The results could motivate a fundamental shift in exploration/design focuses:
  - Looking for systems with caprock protected by certain inherent geomechanical features.
  - Particularly when only marginal k reservoir is available.
- Addresses several priority research directions
  - *PRD S-6 (fault and fracture systems), S-3 (control of near-well environment) , S-2 (dynamic pressure limit), S-1 (Multiphysics and multiscale fluid flow)*

Layering structure of typical sedimentary rocks



Rock stress

Lesson learned and synergy opportunities

- Fracturing and fracture flow in GCS context is still poorly understood.
- When we incorporate more physics, new understanding emerges.
  - The process should make sense in hindsight, but would be hard to think of without the aid of high-fidelity models.
- Synergistic with
  - Ongoing studies of stress measurement, fault activation
  - Fracturing research in geothermal and oil-gas applications.
- Addresses several priority research directions
  - PRD S-6: Improving Characterization of Fault and Fracture Systems
  - PRD S-3: Optimizing Injection of CO2 by Control of the Near-Well Environment
  - PRD S-2: Understanding Dynamic Pressure Limits for Gigatonne-scale CO2 Injection
  - PRD S-1: Advancing Multiphysics and Multiscale Fluid Flow to Achieve Gigatonne/year Capacity

LLNL-PRES-123456

This work was partly supported LLNL FWP0191, task 6, *CO_2 injection with fracturing in geomechanically protected caprock*.

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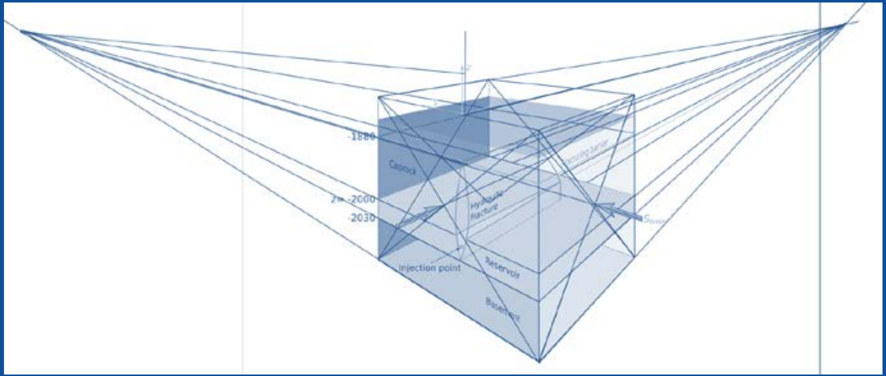
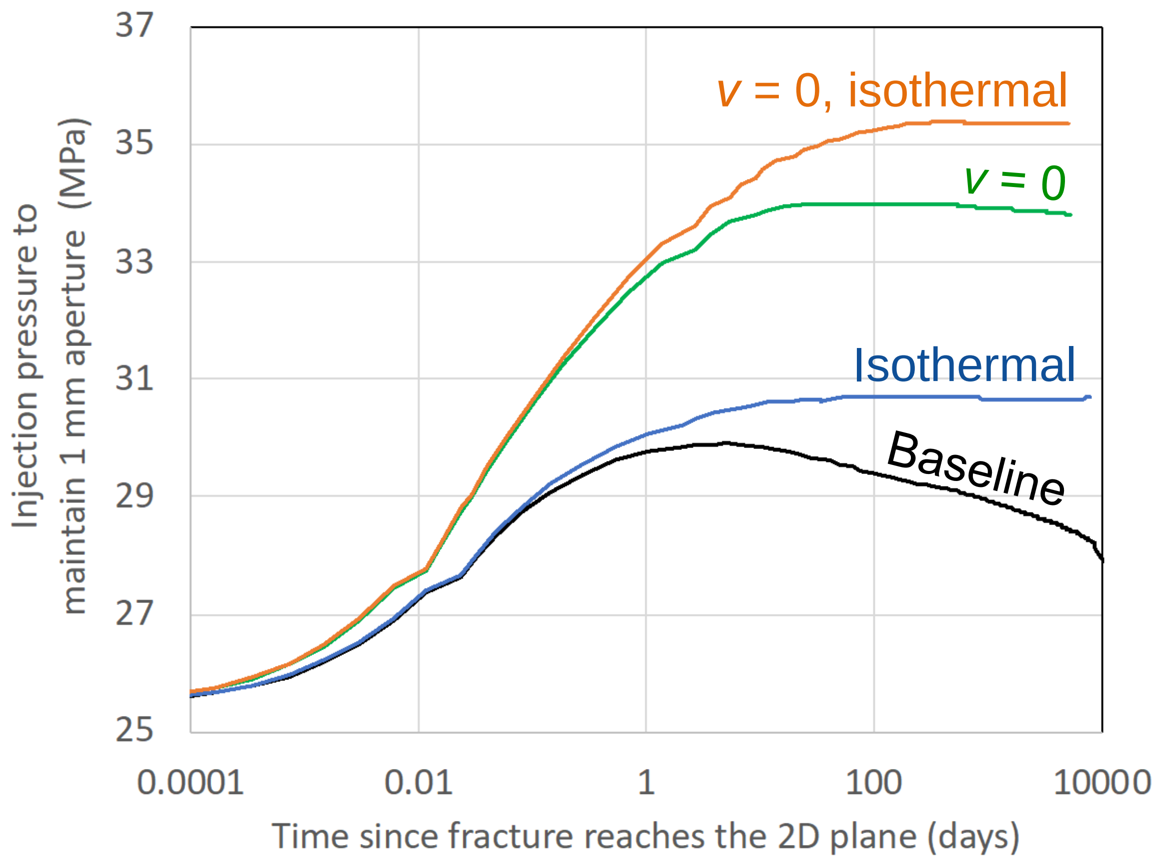


Fracture's poroelastic sustainability: bounding scenario



Upper bound of fracture opening pressure considering poroelasticity, a rough estimate:

$$P_\mathrm{f} > \underbrace{S_\mathrm{hmin} - bP_\mathrm{i}}_{\text{In situ eff. stress}} + bP_\mathrm{f}$$

$$P_\mathrm{f} > \frac{S_\mathrm{hmin} - bP_\mathrm{i}}{1-b}$$