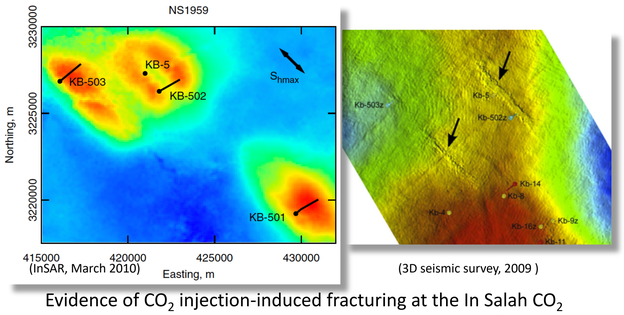
The Influence of Hydraulic Fracturing on Carbon Storage Performance

Pengcheng Fu, Randolph R. Settgast, Yue Hao, Joseph P. Morris, and Frederick J. Ryerson

Atmospheric, Earth, and Energy Division, Lawrence Livermore National Laboratory

Hydraulic fracturing in GCS

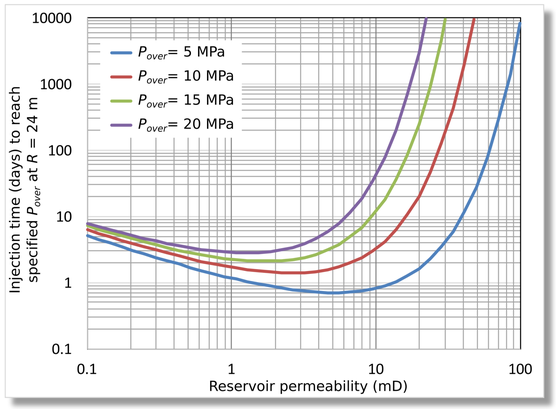
Conventional principles of geologic carbon storage (GCS) require injecting CO_2 below the caprock fracturing pressure to ensure the integrity of the storage complex. Previous works have simplified caprock fractures as a high-permeability "wing" of the reservoir, ignoring the intrinsic mechanical behaviors of hydraulic fractures. We study how a vertically contained hydraulic fracture interacts with a GCS reservoir and thereby shapes the reservoir's responses to CO_2 injection.



Evidence of CO_2 injection-induced fracturing at the In Salah CO_2 storage project. There are no indications that the overall storage complex has been compromised. It is therefore possible to have vertically contained fracturing in a geomechanically protected caprock complex. Both images from White et al. (2014).

Processes leading to caprock fracturing

When injecting fluid at a constant rate into a reservoir, the overpressure continues to increase. If the reservoir permeability is relatively low, the injection pressure could eventually overcome the confining stress in the caprock and create a hydraulic fracture.

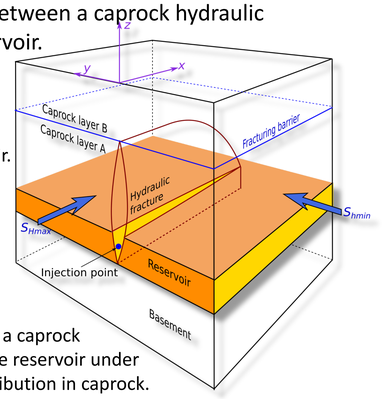


Assuming a 24 m thick reservoir with 0.15 porosity, under an injection rate of 24 liters per second or 530,000 tonnes per year, the required injection time to attain various levels of overpressure at R = 24 m from the injection line source as a function of reservoir rock permeability.

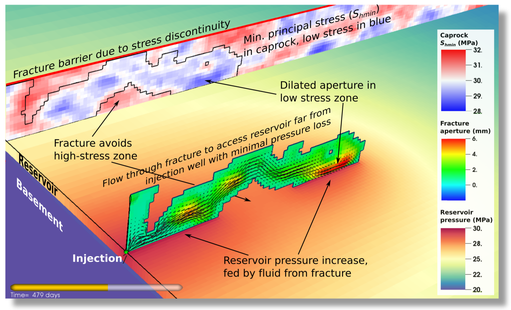
Findings from numerical modeling

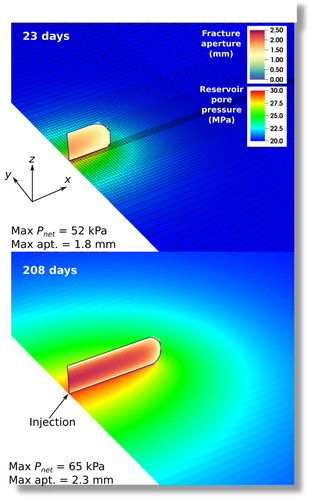
We built a fully coupled numerical model in LLNL's GEOS code to simulate the interactions between a caprock hydraulic fracture and the storage reservoir.

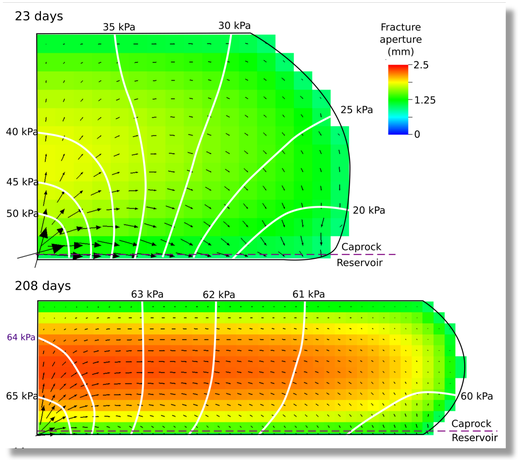
Right: Modeling the interaction between a caprock hydraulic fracture and CO_2 storage reservoir. Near the wellbore, most of the injected fluid first flows into the fracture and gradually feeds, by porous media flow, into the reservoir along the fracture-reservoir interface.



Below: The relationship between a caprock hydraulic fracture and CO_2 storage reservoir under heterogeneous *in situ* stress distribution in caprock.







- A caprock hydraulic fracture could shape how injection interacts with the reservoir.
  - Controlled by hydraulic fracture's pressure-limiting behavior.
  - It provides an effective means to communicate with the reservoir through an adaptively growing interface.
  - It caps the injection pressure at S_{hmin} right above the reservoir (+ near-well loss).
    - Beyond this pressure, fracture conductivity becomes very sensitive to pressure change.
- The propagation rate of the fracture is insensitive to caprock properties.
  - Dominated by leak-off interface between fracture and reservoir.

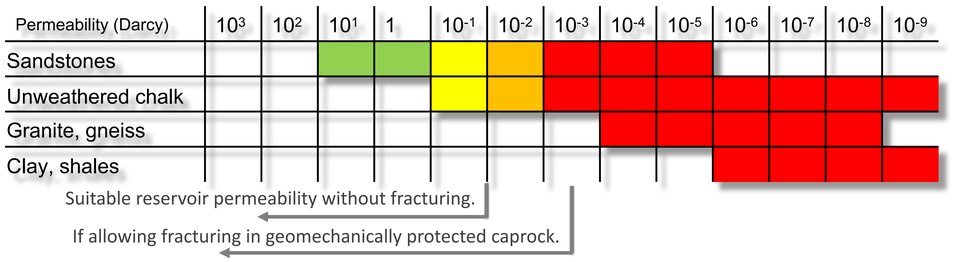
Moving forward

We have started a new project to study mechanisms and processes related to the containment of pressure-driven caprock fractures unique to CO_2 injection.

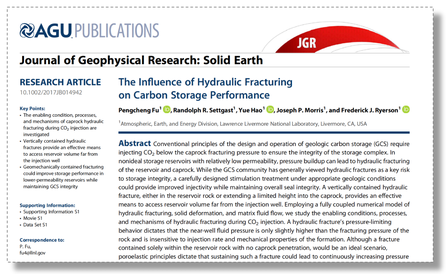
The results could have important implications for the design of geological carbon storage projects:

- Expand the number of suitable storage reservoirs by providing scientific support to injection in low-permeability reservoirs.
- Reduce the uncertainty around caprock failure by better understanding of long-term caprock seal mechanisms with the presence of caprock fractures.

Layers of sedimentary rock in Makhtesh Ramon, from Wikipedia. Such a layered structure is known to hinder vertical growth of hydraulic fractures through the so-called composite layering effect.



Proof-of-concept study has been published in Journal of Geophysical Research-Solid Earth, 122: 9931–9949. Recorded presentation at the USGS Earthquake Science Center, Menlo Park, CA, Nov. 1, 2017 is available at https://earthquake.usgs.gov/contactus/menlo/seminars/1110



Acknowledgments:
Inputs from Dr. Joshua A. White and Dr. Susan A. Carroll of LLNL are appreciated. This work was partly supported by LLNL LDRD project "High-Fidelity Fracture Model for Hydraulically Fractured Shale Reservoirs" (16-ERD-014). This manuscript has been authored by Lawrence Livermore National Security, LLC under Contract No. DE-AC52-07NA2 734-I with the US. Department of Energy (LLNL-POST-756240).

Lawrence Livermore National Laboratory