Poroelastic stressing and pressure diffusion along faults induced by geological carbon dioxide storage

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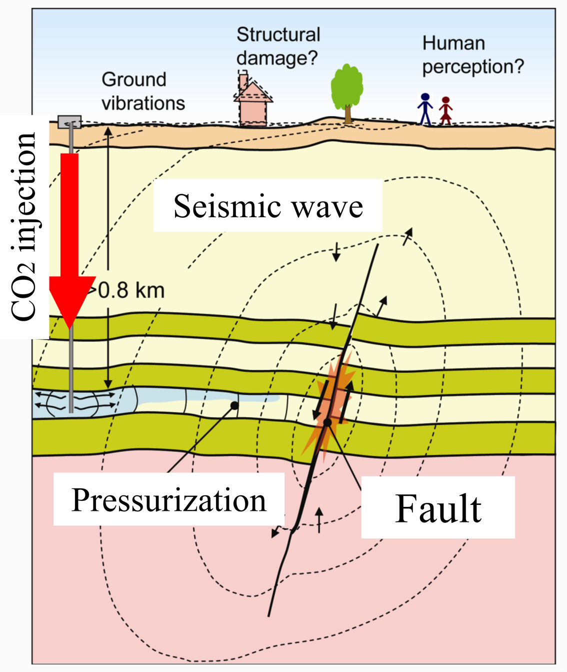
Motivations

- Injection of a large amount of fluids for subsurface energy activities can increase pore pressure and change the stress field, potentially inducing earthquakes.
- Geological CO_2 injection into brine aquifers generates the multiphase flow system.
- Few studies performed the coupled effect of multiphase flow and poroelastic deformation on induced seismicity.

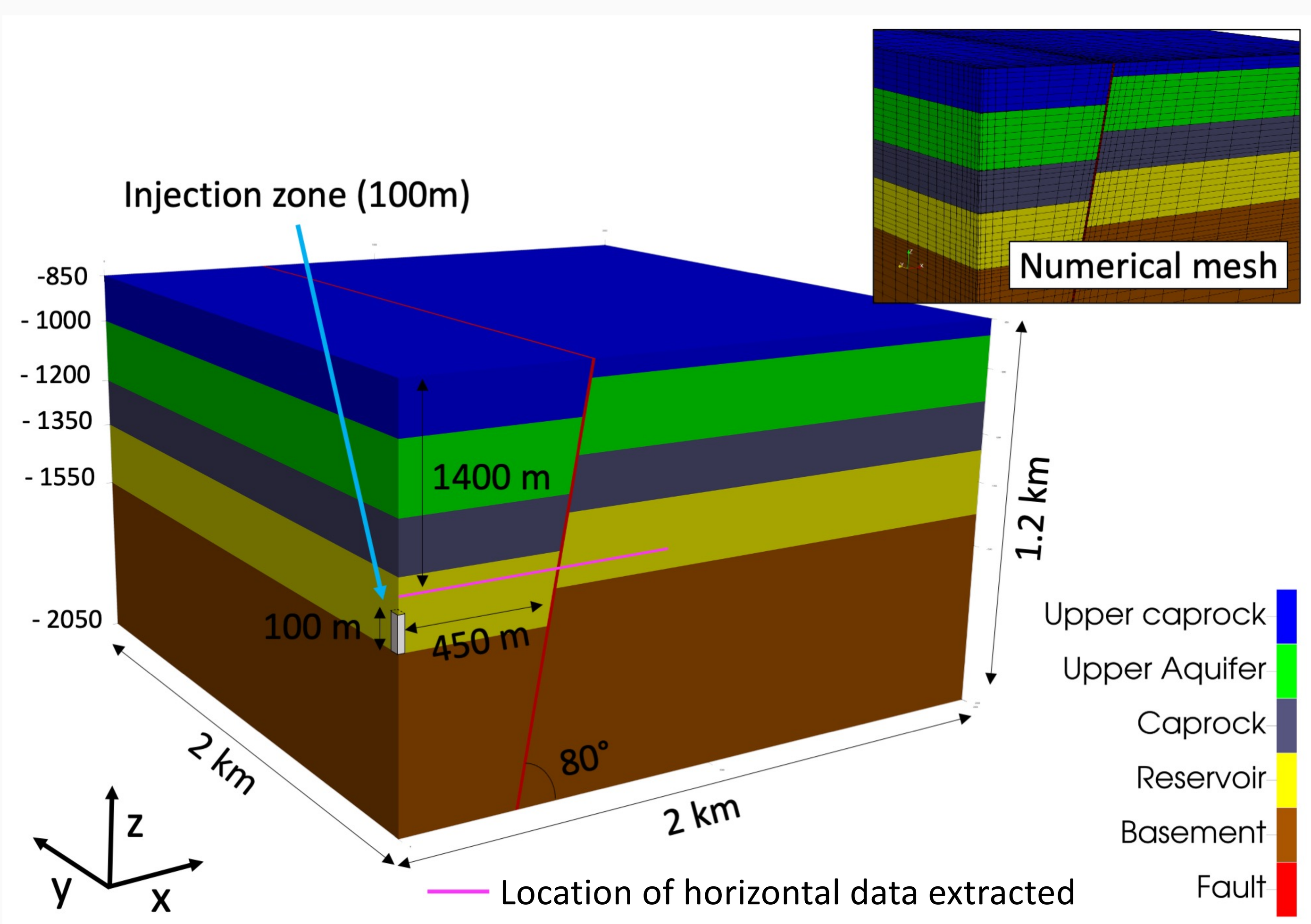


Rutqvist et al. (2014) IJGGC

Objectives

- To understand the physical mechanism of potential induced seismicity along the fault in a coupled multiphase flow and poroelasticity system.

Model Description



- Layered system juxtaposed by the fault, representing a quarter of the horst-graben system.
- Injection of CO_2 for 15 years, and the simulation runs for 30 years to see the post shut-in behaviors of the formation.
- Fault strikes N-S (y-direction), and dips 80° to the east (positive x-direction).

Coulomb Stress Change

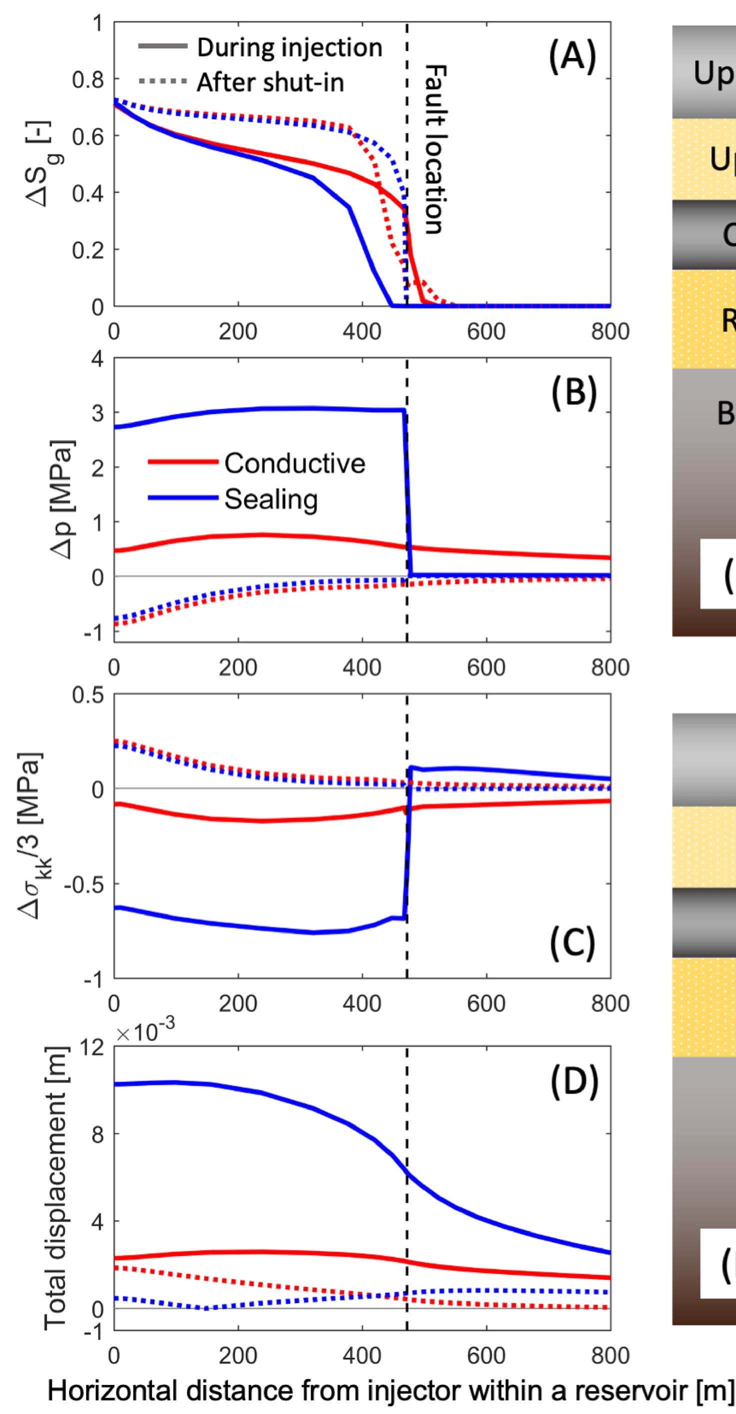
$$\Delta\tau = \underbrace{(\Delta\tau_s + f\Delta\sigma_n)}_{\text{Poroelastic stress}} + \underbrace{f\Delta p}_{\text{Pore pressure}}$$

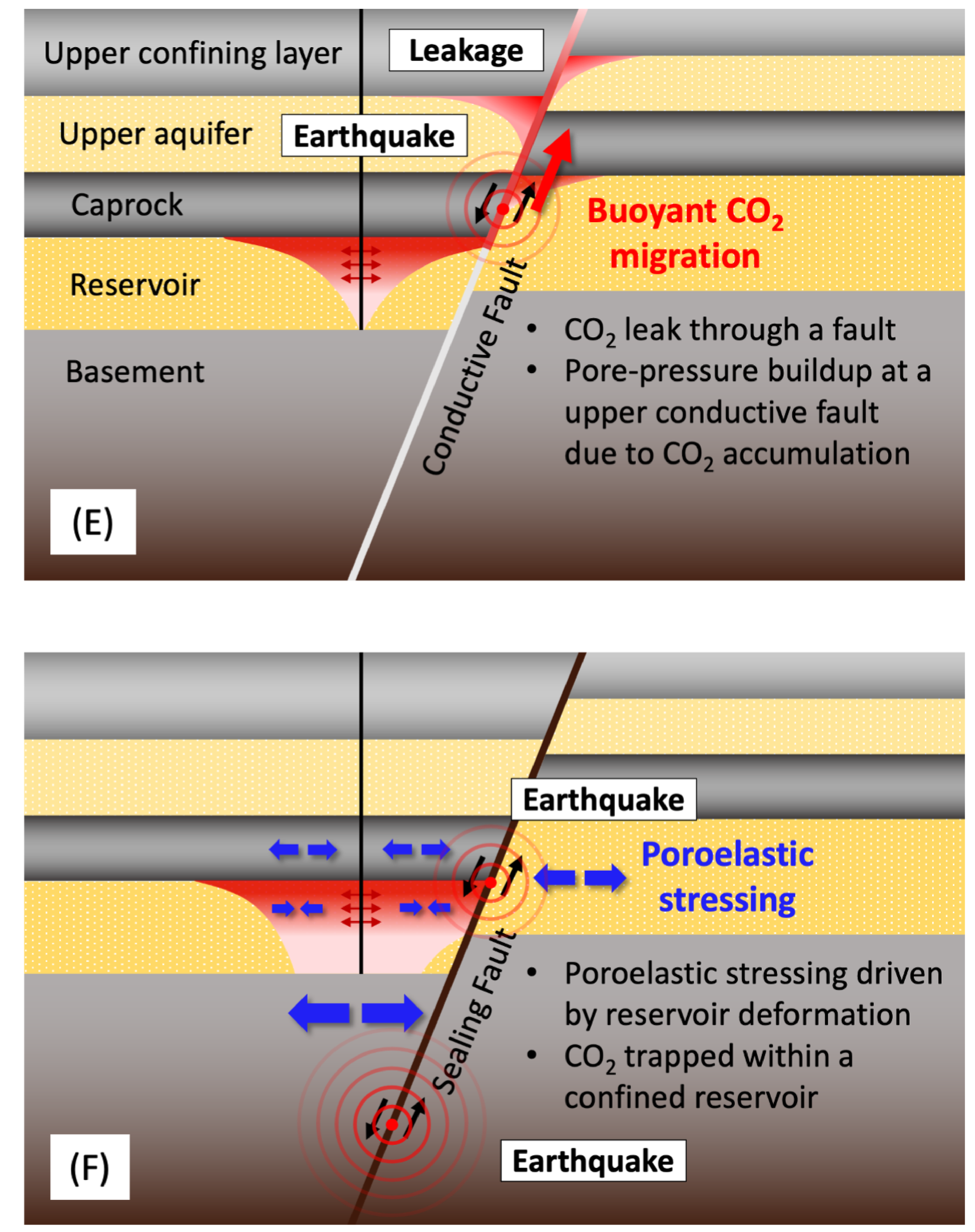
$\Delta\tau_s$ = shear stress change

$\Delta\sigma_n$ = normal stress change

Δp = pore pressure change

- (+) values of each quantity imply that the fault plane is moved closer to failure



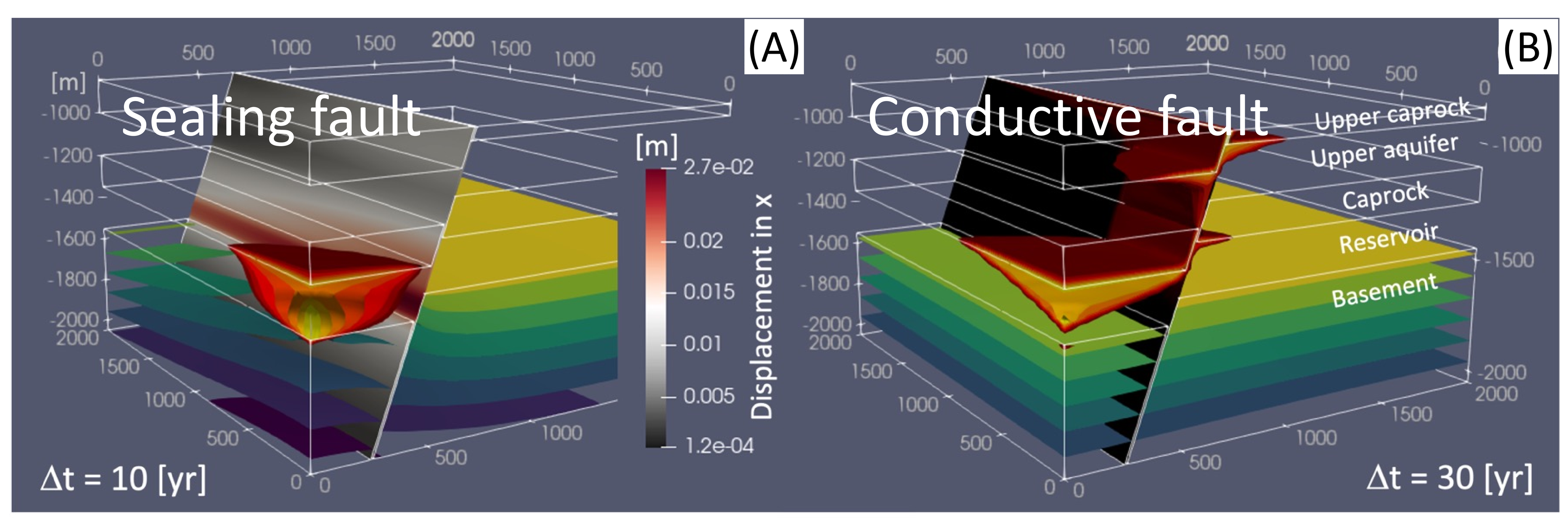


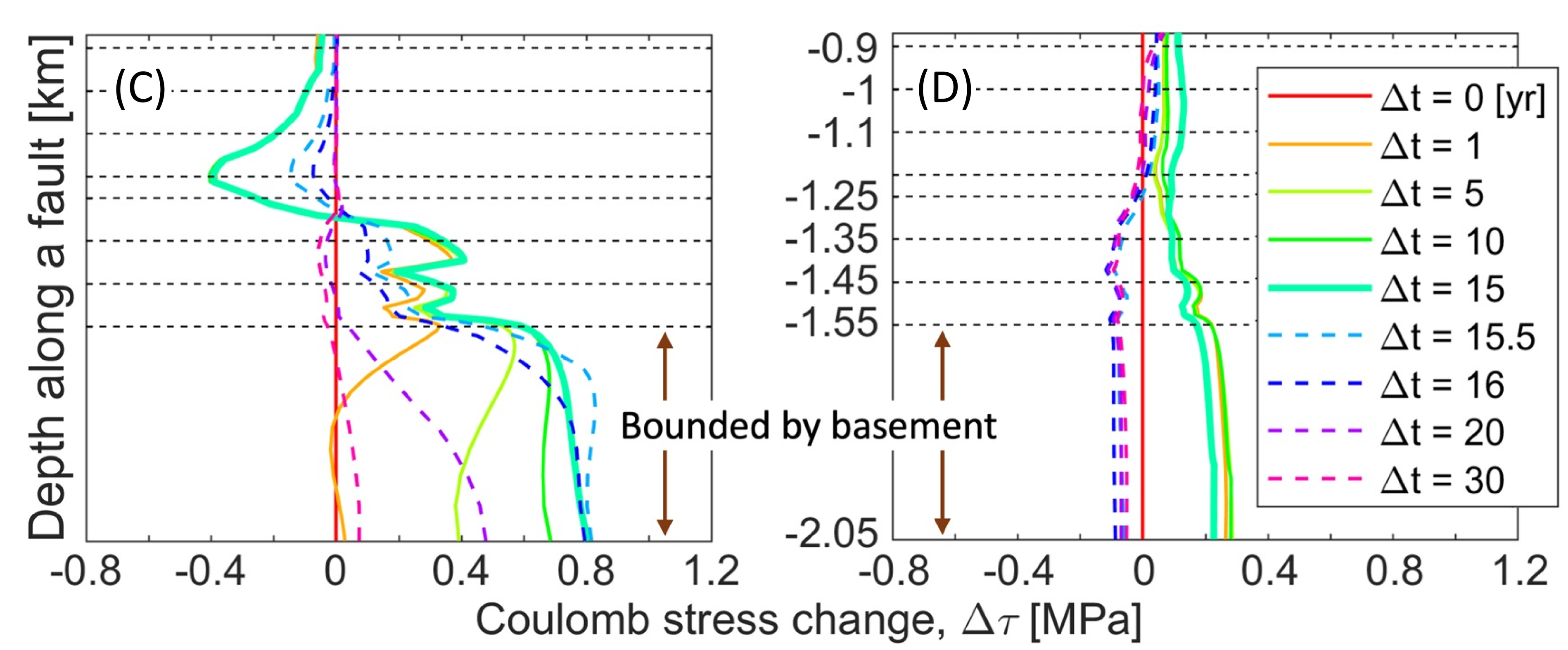
Coupling processes within the Reservoir

- For a conductive fault,
  1. CO_2 penetrates into the fault during injection and accumulates along the fault.
  2. Pore pressure diffuses rapidly across the interface between the reservoir and fault (quick equilibrium state; Figure B).
  3. Mechanically, pore-pressure increases causes compression during injection (negative mean stress; Figure C).
  4. Shut-in eliminates driving force for outward convection which prevents CO_2 migration further into the fault and shrink the reservoir (positive mean stress; extension along the fault), but buoyancy still forces to migrate sequestered CO_2 upward through the fault.
- For a sealing fault,
  1. Hydraulic interaction is impeded by the fault and bounding low-permeability units (caprock and basement), such that CO_2 and pressure accumulate within a reservoir (No pressure S_g and Δp changes).
  2. Stronger mechanical deformation of the reservoir is observed (larger displacement; Figure D).
  3. Shut-in relieves the injection-induced deformation of the reservoir effectively.

Future Works

1. Mechanistic studies with variation in geological heterogeneity and well operations
2. Implementing the field data (e.g. IBDP)
3. Integrating machine-learning approaches to predict pressure and/or stress perturbations associated with geological carbon sequestration.





Stability of Reservoir-Bounding Faults

- For a sealing fault,
  1. Hydraulic barrier against diffusion and transport, which forms CO_2-trapping zone within a reservoir delimited laterally and vertically by surrounding low-permeability units.
  2. Mechanically, intense CO_2 accumulation expands the reservoir and neighboring layers that generates positive displacement in x-direction at the fault
  3. Terminating injection releases stresses acting on the fault zone adjacent to the reservoir, which reduces the magnitude of Δτ over time.
  4. However, the deep portion of the fault adjacent to the basement experiences substantial increment of pore pressure as poroelastic response to reservoir expansion during injection, and also, tends to maintain overpressure even after shut-in, which will enhance the potential of post-injection seismicity at depths.
- For a conductive fault,
  1. Buoyant CO_2 migrate upward through the fault and spreads laterally into shallow permeable units that can attenuate further upward flux of CO_2.
  2. At the beginning of CO_2 injection, the water-wet fault and adjacent formations act as capillary barriers against sequestered CO_2.
  3. Terminating injection eliminates pressure gradients significantly within the reservoir that can prevent further convective propagation of CO_2 plumes through the fault.
  4. However, buoyancy still spread injected CO_2 laterally within the reservoir, and remaining CO_2 may migrate upward through the fault even after shut-in.

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