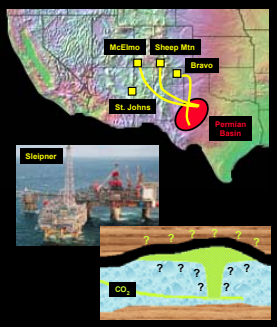
CO_2 reservoirs: Are they natural analogs to engineered geologic storage sites?



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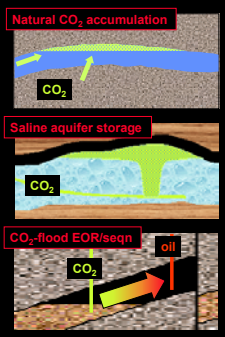
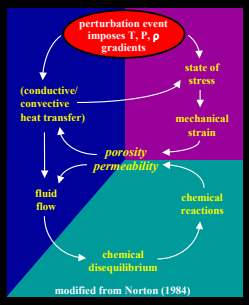
Emplacement scenarios for natural & engineered CO_2 reservoirs



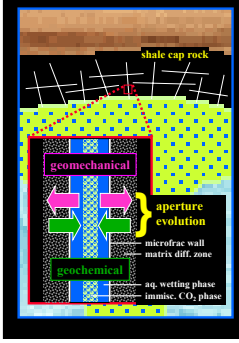
- **Natural CO_2 accumulations**
  - ✓ Emplaced over geologic time frame
  - ✓ Long-term, subtle perturbation
  - ✓ Cap-rock integrity: leaky to secure
- **Engineered CO_2 storage sites**
  - ✓ Emplaced over telescoped time frame
  - ✓ Short-term, dramatic perturbation
  - ✓ Cap-rock integrity: secure required
- **Are these settings analogous?**
  - ✓ Dependence of cap rock integrity on the rate, duration, and focality of CO_2 influx
  - ✓ A given cap rock may perform differently in natural and engineered settings

Reactive transport modeling: an advanced simulation method for geologic systems



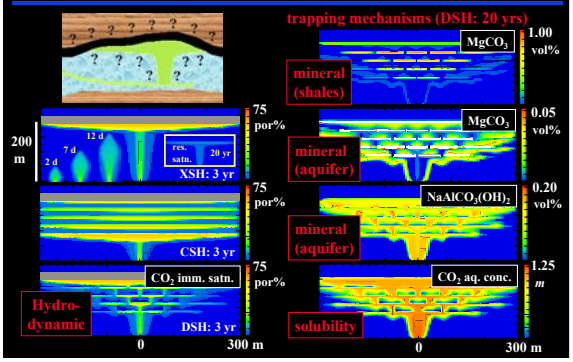
- **LLNL's NUFT, GEMBOCHS, & LDEC**
  - ✓ State-of-the-art simulation package

Cap rock integrity hinges on the interplay of geochemical & geomechanical processes

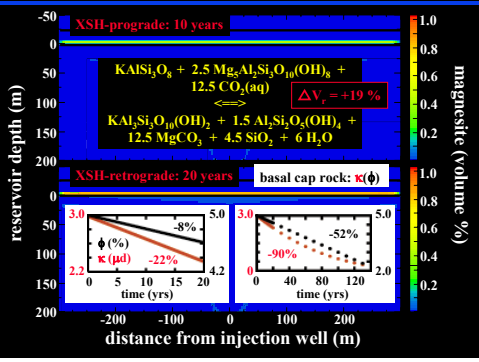


- **Geochemical alteration**
  - ✓ Mineral diss/pptn reactions triggered by the chemical perturbation
  - ✓ Compositional properties of the cap rock, reservoir, & injection fluid
  - ✓ Tends to enhance seal integrity of shale
- **Geomechanical deformation**
  - ✓ Microfrac mobilization triggered by the pressure (effective stress) perturbation
  - ✓ CO_2 influx rate, duration, & focality; reservoir perm & lateral continuity
  - ✓ Tends to degrade seal integrity of shale
- **Relative effectiveness controls the evolution of cap rock integrity**

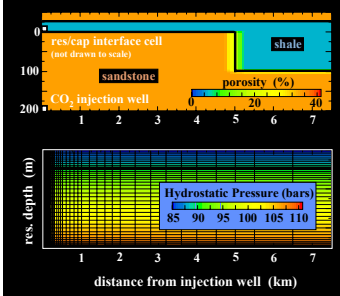
Reactive transport modeling of geologic CO_2 sequestration at Sleipner



Mineral trapping significantly enhances the seal integrity of shale cap rocks

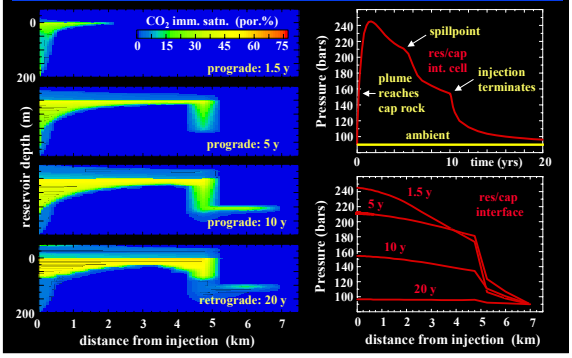


Simulation domain for evaluating ΔP during engineered & natural CO_2 influx

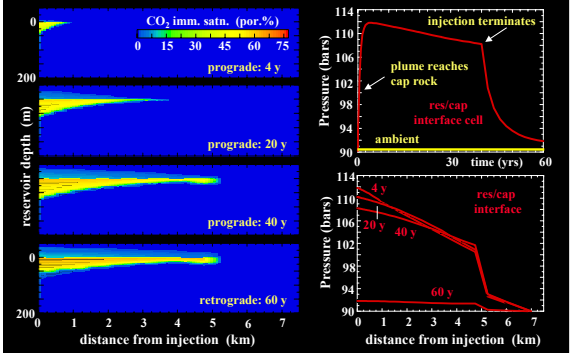


- Engineered CO_2 influx
  - ✓ 10,000 ton/yr
  - ✓ Pro/retrograde: 10/10 yr
  - ✓ Sleipner analog
- Natural CO_2 influx
  - ✓ "fast" 1,000 ton/yr
  - ✓ "slow" 100 ton/yr
  - ✓ Pro/retrograde: 40/20 yr
- Commonalities
  - ✓ Shale perm: 3 μd
  - ✓ Res. perm: 300 md
  - ✓ Isothermal: 37°C

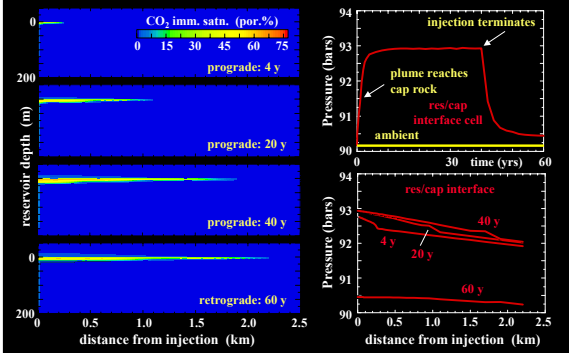
Influx-induced pressure perturbation: engineered injection



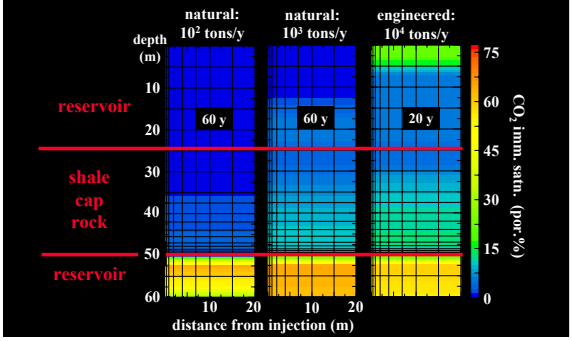
Influx-induced pressure perturbation: "fast" natural accumulation



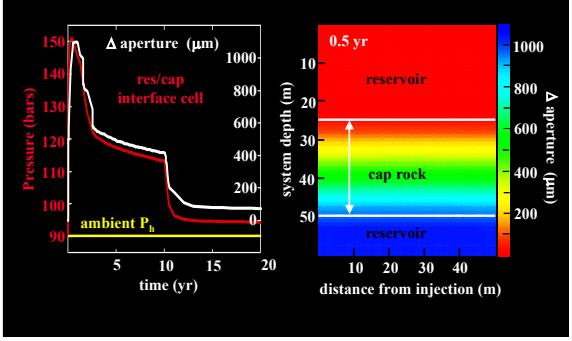
Influx-induced pressure perturbation: "slow" natural accumulation



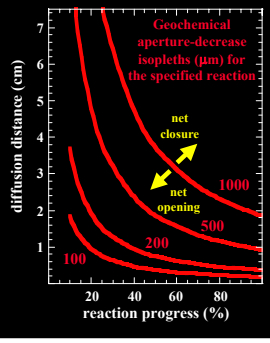
CO_2 migration into undeformed shale cap rock through increased capillary pressure



LDEC simulation of aperture evolution: laterally confined (2 km) 300 md reservoir



Conceptual framework for geochemical counterbalancing of geomechanical effects



- **Aperture change due to a given diss/pptn reaction depends on:**
  - ✓ Volume fraction of the reactant mineral assemblage
  - ✓ Volume change of reaction
  - ✓ Extent of reaction progress
  - ✓ Effective diffusion distance
- **K-feld + Mg-Chl + CO_2 (aq) <=> Magnesite + Musc + Kaol + Qtz**
  - ✓ Volume fraction: 0.1425
  - ✓ Volume change: +19%
  - ✓ Conservative example
  - ✓ Natural analog documented

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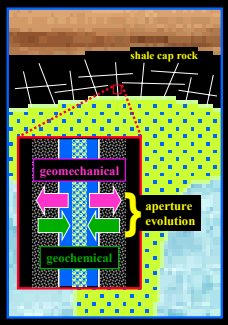

- **Long-term cap rock integrity**
  - ✓ Hinges on relative effectiveness of geochem & geomech processes
- **Natural analog concept**
  - ✓ Hinges on dependence of this interplay on CO_2 influx parameters
- **Natural vs. engineered settings**
  - ✓ Geochem alteration likely similar
  - ✓ Geomech deformation likely distinct; implies distinct cap-rock performance
  - ✓ Counterbalancing appears feasible
- **More data needed!**
  - ✓ CO_2 influx parameters
  - ✓ Detailed compositional analyses