What governs transport at specific sites: pore networks or “seal bypass systems”? And how is this effectively determined?

(Heath et al., 2011)
Multi-Scale Caprock Evaluation

Nanoscale: pore networks & surfaces
Microscale: large pores and microfractures
Mesoscale: core, outcrop, well logs, fractures
Macroscale: Formation/reservoir

Tracers: Natural Helium
Well logs
Hand Sample/Core
Optical Microscopy
BSE/EDS
TEM/FIB/SEM
Porosimetry

Methods

Length (meters)

10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^2 10^4

Small-Scale First: Breakthrough Pressure & Sequence Stratigraphy

(modified from Schieber, 1999)
Types I through III are previously described (in 2D) by Desbois and Urai (2008)
Kirtland Formation, Pump Canyon Site, San Juan Basin

Approximate location of CO₂ injection well

Upper Kirtland Formation

Gypsum veins

Coarsening upward sequence

Cored interval: 52 ft

Ojo Alamo

Upper Kirtland

Huerfano Bentonite Bed

Datum

Lower Kirtland Formation

Anchita Formations and Puddy former beds

Anchita Sandstone Member of Kirtland Formation

Upper Shale and Sandstone Members of Kirtland Formation

Pictured Cliffs Sandstone
Farmington Sandstone Member

Lower Kirtland Shale

Cored interval: 8 ft

Potential Seal Bypass Features
1D Advection-Only Model

[Diagram showing depth from Ojo Alamo/Kirtland Contact (m) vs. [4He] (cm$^3$ STP/cm$^3$ H$_2$O) with data points and lines for Upper Kk and Lower Kk.]

1D Advection-Diffusion Model

[Diagram showing depth from Ojo Alamo/Kirtland Contact (m) vs. [4He] (cm$^3$ STP/cm$^3$ H$_2$O) with data points and lines for various diffusion rates and Upper Kk and Lower Kk.]
Major Findings and Conclusions

Pore Network Scale
- Distal depositional environments, deep burial, and organics contribute to high capillary-breakthrough pressure caprocks
- Pore-lining composition is not typically directly indicated by XRD
- Paucity of knowledge on wettability of typical pore-lining phases for CO₂/brine systems limits prediction of capillary sealing
- Will CO₂-organic interactions alter sealing quality?

Core and Well Log Scale
- Fractures identified in core and FMI; mineralization is common that includes potentially reactive phases (carbonates)
- Connectivity indicated by mineralization, but permeability is difficult to ascertain

Formation Scale
- Abundant potential seal bypass features exist within the Kirtland Formation – fractures, discontinuities (also see work by Tom Wilson), and methane saturations
- Need for assessment of connectivity
- Of the total helium-4 produced since deposition, a large portion still resides in the pore fluids
- Inventory of helium suggests low fluid flux
- Some gas stripping processes occurred, possibly in situ, but the helium content is still high
- Helium generally supports lack of a strong bypass system
**Recommendations**

- Carefully plan locations of fluid sampling for natural tracers in caprock and reservoir to support model testing

- For assessing fracture connectedness:
  - Measure isotopes of fracture mineralization
  - Evaluate cross seal flow with helium and other tracers (e.g., methane)

- Characterize fracture types in core to augment FMI logs:
  - Sandia is developing discrete fracture modeling at the outcrop scale to estimate potential CO₂ and/or brine fluxes through fracture networks in caprock

- Preserve core against drying
Kirtland Formation lies above the world's largest coalbed methane play.