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Natural Tracers and Seal Analysis of Geologic CO_2 Storage Sites

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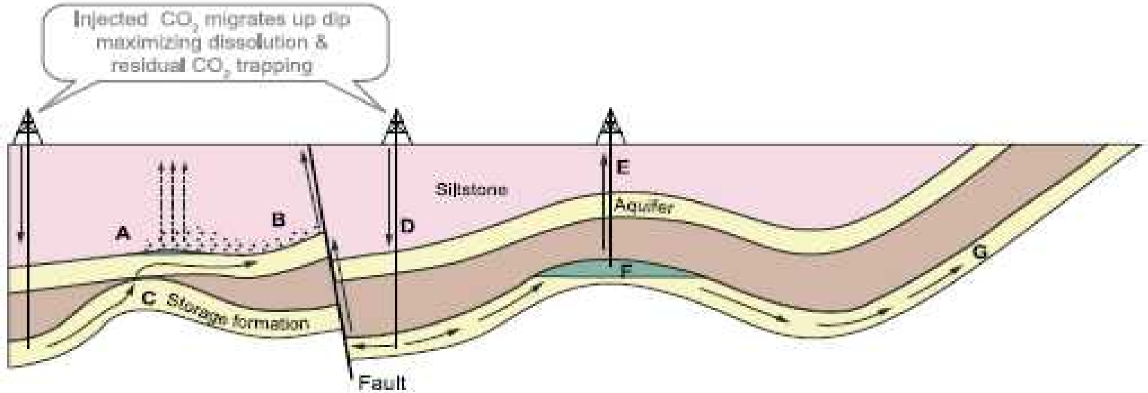
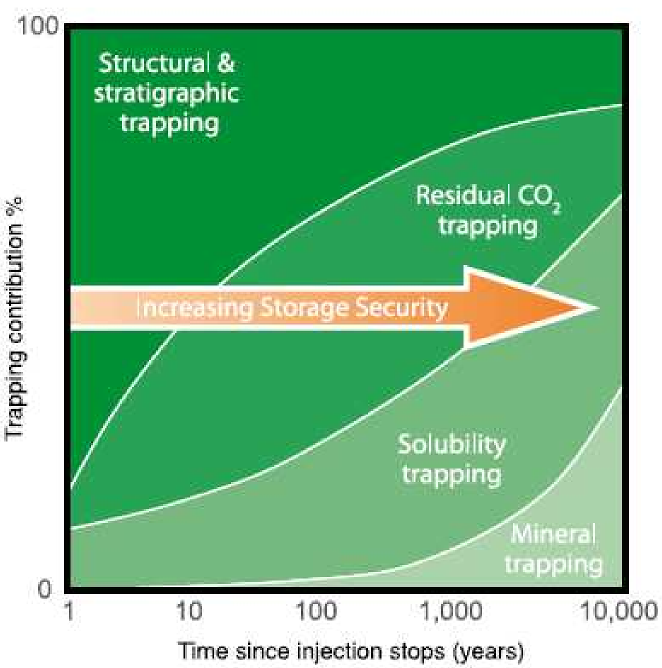
Visit to NETL at Pittsburgh and Morgantown – April 14 & 15, 2009

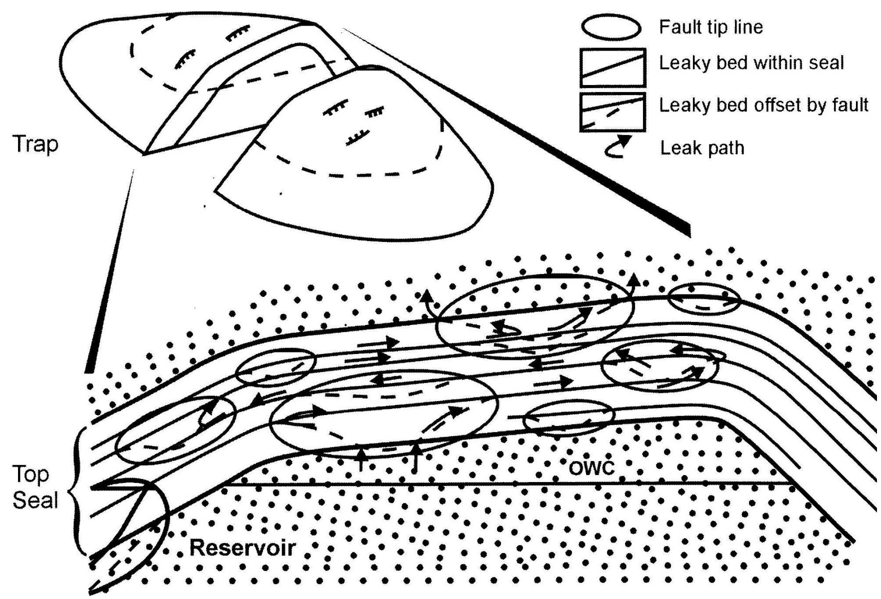
Outline

- **Motivation**
- **Overview of Seal Analysis**
- **Natural Tracers and Seal Assessment**
  - Modeling Study
- **Pump Canyon Site and the Kirtland Formation**
    - Coring program and data collection
    - Preliminary Results and Discussion
- Conclusions and Future Work

Motivation – Importance of Seal Analysis







Images from IPPC (2005) and Ingram and Urai (1999)

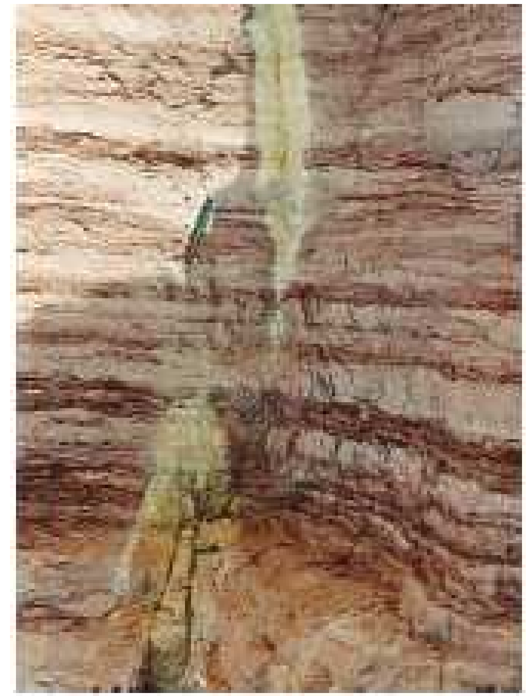
Motivation – Research Challenges

From "Basic Research Needs for Geosciences"

(Office of Basin Energy Sciences, 2007)":

Researchers need to address:

- Transmissivity of faults and fractures
- In situ measurement of fluid-rock interactions and seal properties
- Identification and characterization of flaws in seals at multiple scales
    - Difficult to assess small features/flaws in a large area of interest



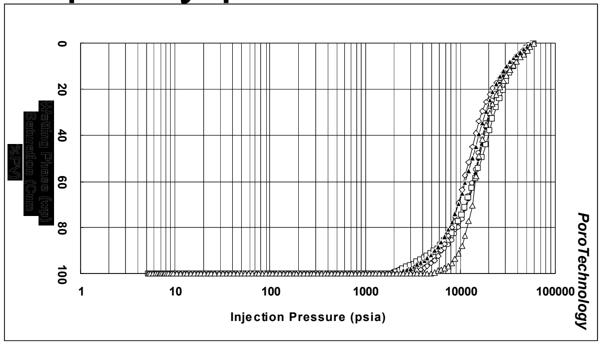
Example: CO_2 breakthrough of mudstones. Evidence of reducing fluids migrating through mudstones in UT (photo courtesy Jim Evans). May be important at Sleipner.

Overview of “Traditional” Seal Analysis

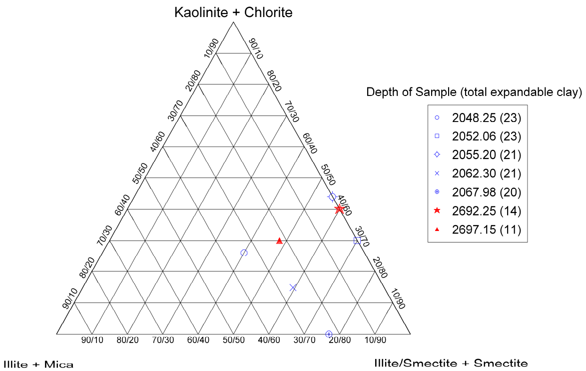
- **Interpretation of mercury injection capillary pressure measurements in high resolution stratigraphic framework**
- **Mechanical seal failure**
- **Fault seal analysis**

Fracture in caprock

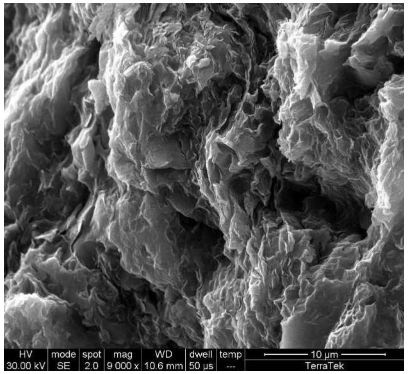
Capillary pressure



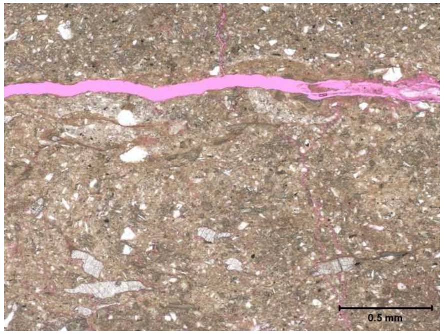
XRD



SEM and EDX



Thin section

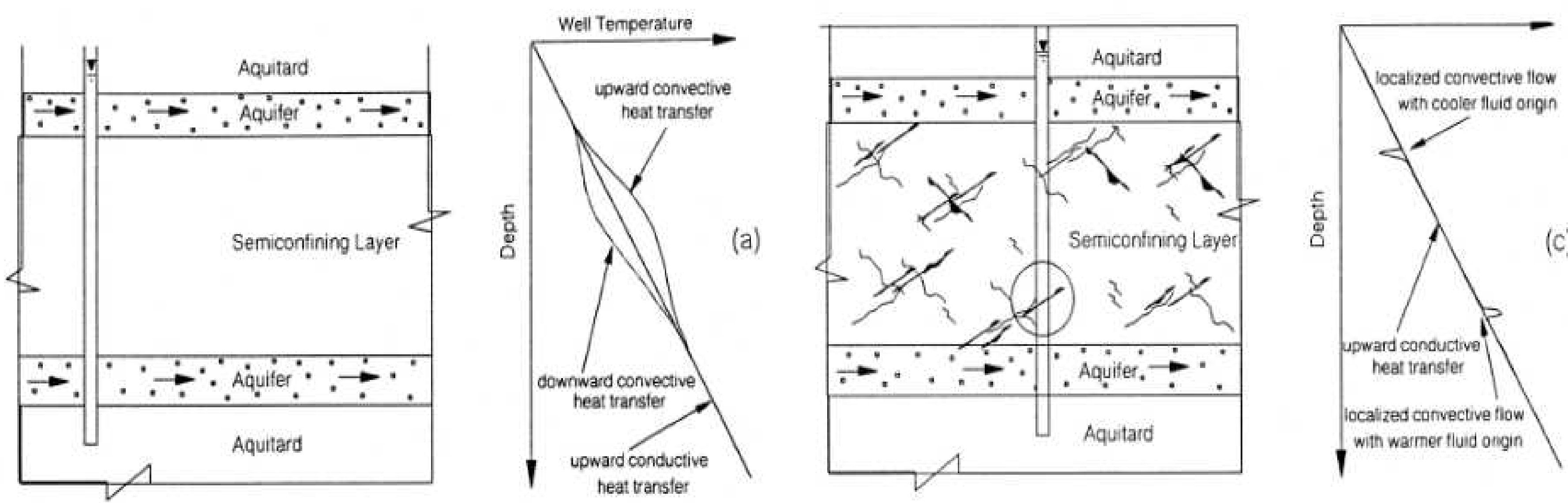


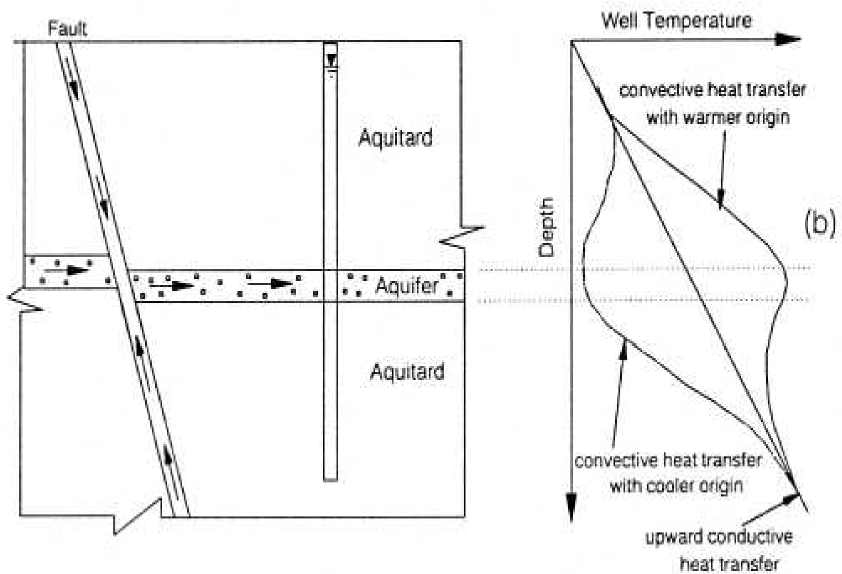
Natural Tracers and Aquitards / Seals

- Helium, chloride, environmental and radioactive isotopes, heat and other natural tracers are useful for understanding:
  - Residence time distributions
  - Diffusional/mixing/advective processes
  - rock-water interactions
  - Double porosity/permeability systems
  - Cross-formational flow

There are many studies on aquitards or seals, espeically for radioactive waste disposal

Heat flow and leaky seals





Mathematical analysis:

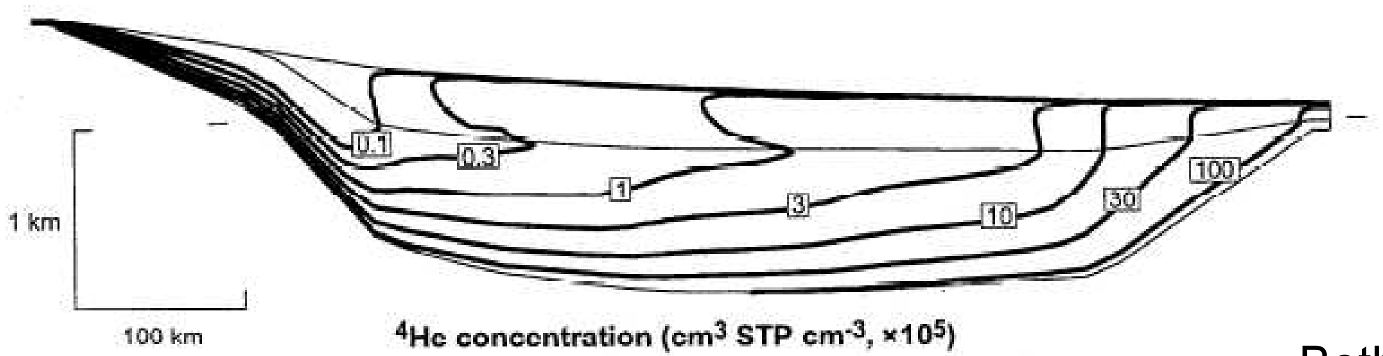
•Direction and magnitude of fluid flow

•Size of fracture apertures

(figures from Ge, 1998)

Focus on Isotopes of Helium

- Studied in basins/locations throughout the world
  - Great Artesian Basin, Australia; San Juan Basin; Paris Basin; Great Hungarian Plain; Carrizo Aquifer, TX; Morsleben, Germany; etc.
- Conservative tracer, multiple sources with characteristic isotopic signatures of $^3He/^4He$
- Study demonstrate helium's usefulness for documenting cross-formational flow or leakage (Ma et al., 2005; Castro et al., 1998)
- **BUT use of natural helium as a seal analysis tool needs development**



Bethke et al., 1999

Helium for assessing caprock: Modeling Approach

1. Pre-injection/screening simulations

- transport of helium-3, helium-4, and temperature across a caprock with or without imperfections

2. Injection simulations

- injection of CO_2 below the caprock using the same conditions of the pre-injection simulations

Criteria of sealing integrity:

- unacceptable leakage is 0.1% yr^{-1} of injected CO_2

Basis of screening tool:

- Evaluate the patterns of helium and temperature and their ability to reveal significant caprock imperfections

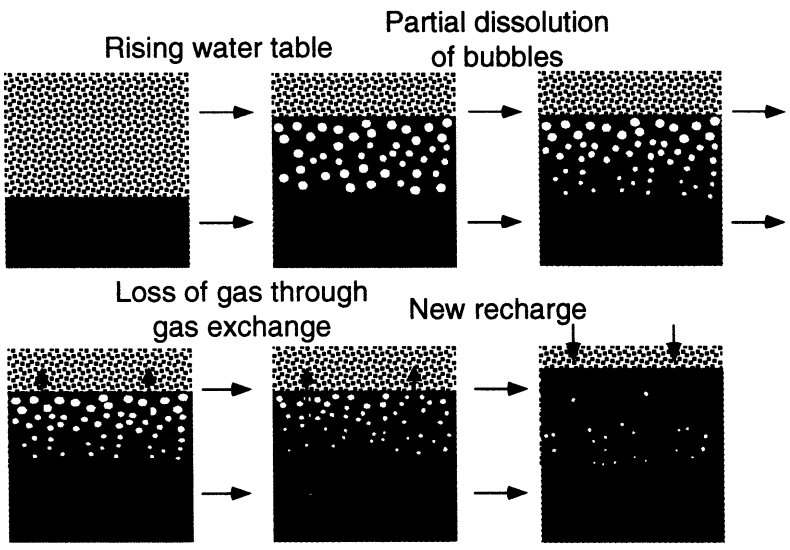
Why does helium come from?

U and Th decay

$$^{4}He_{total} = {}^{4}He_{sol} + {}^{4}He_{rad} + {}^{4}He_{EA} + {}^{4}He_{mantle}$$

^{4}He from air

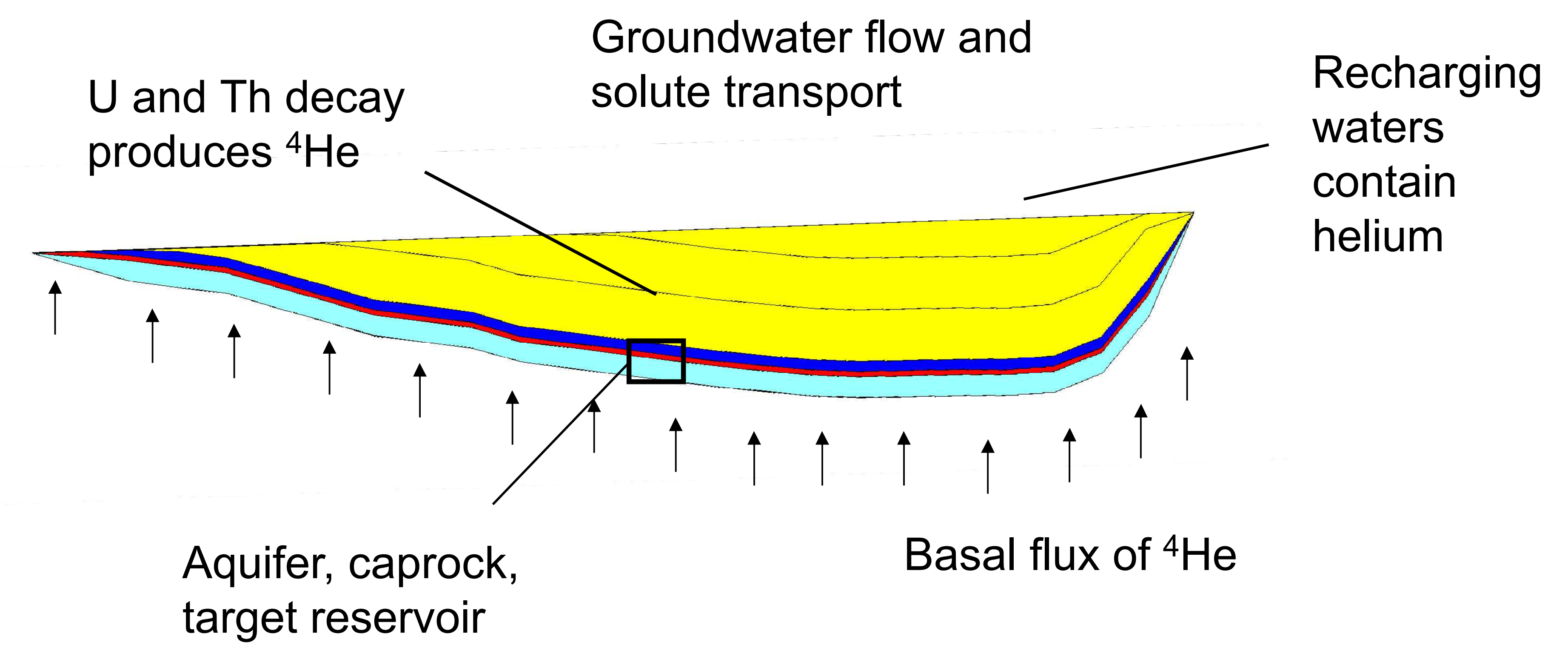
^{4}He from "excess air" (Solomon, 2000)



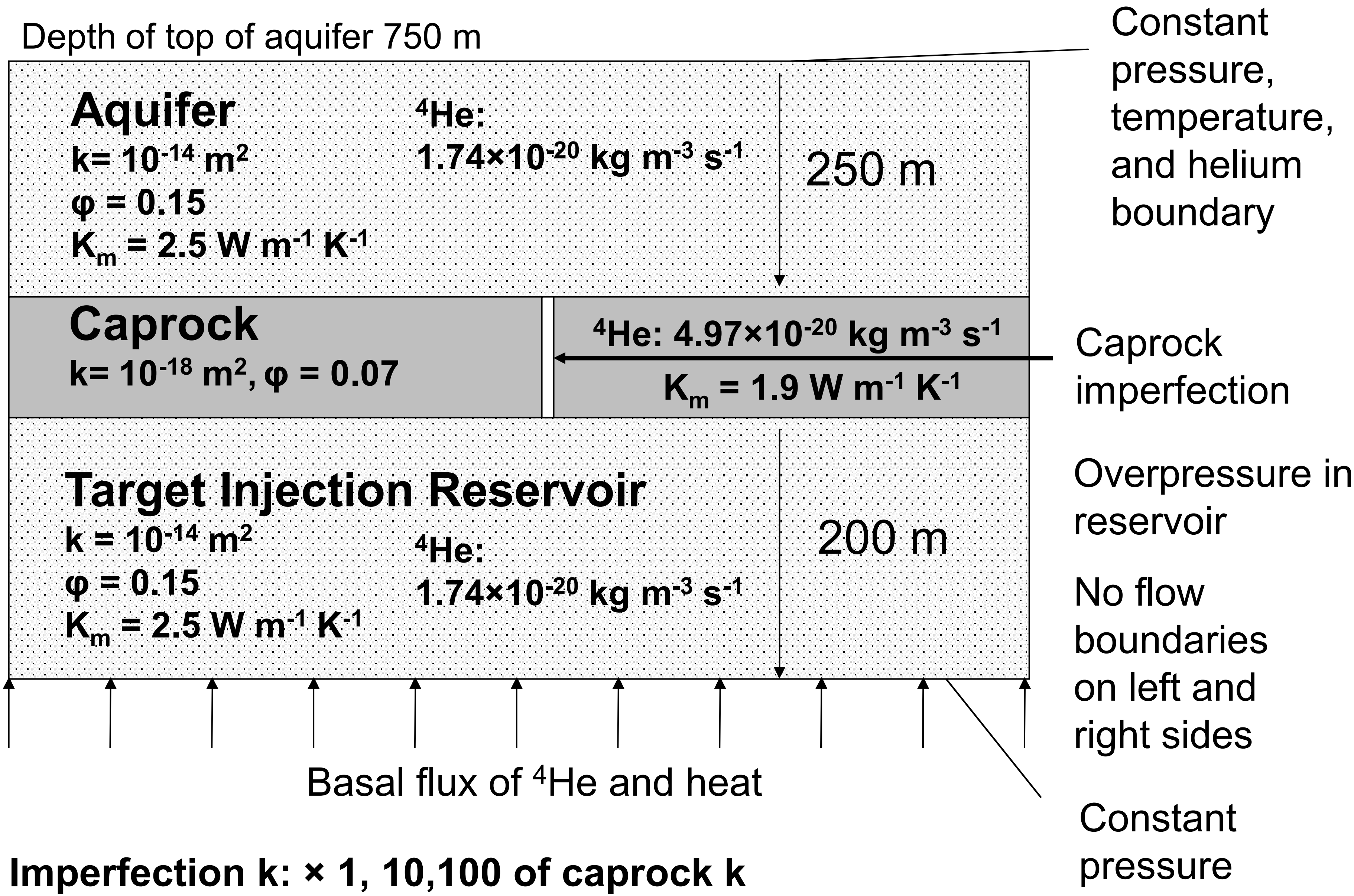
Source of ^{3}He: mantle and neutron captron by Li

Basin Scale Model

$$^4He_{total} = ^4He_{sol} + ^4He_{rad} + ^4He_{EA} + ^4He_{mantle}$$

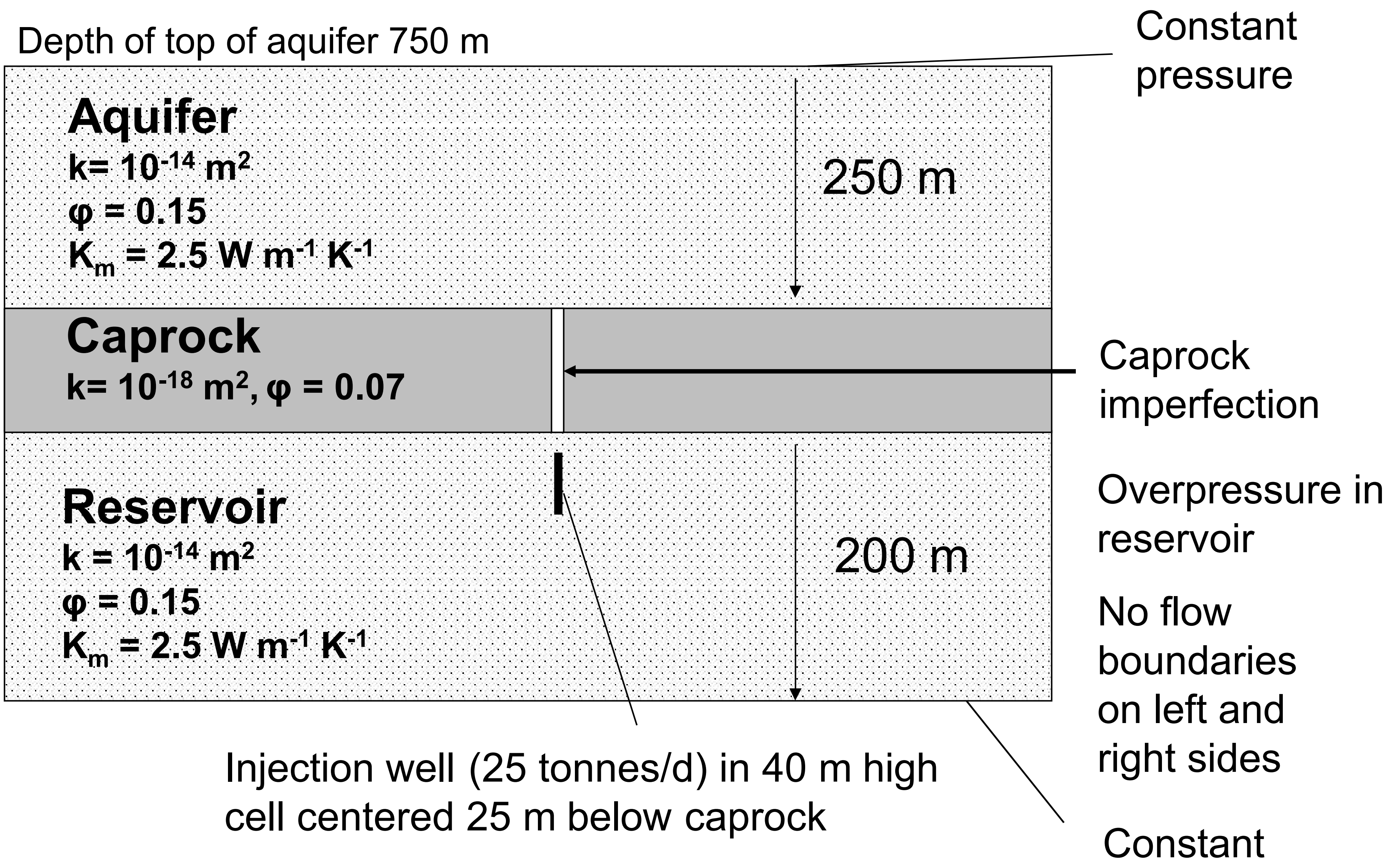


Preinjection



Imperfection k: × 1, 10,100 of caprock k

CO_2 injection



Imperfection k: × 1, 10,100 of caprock k

Simulator – TOUGH2

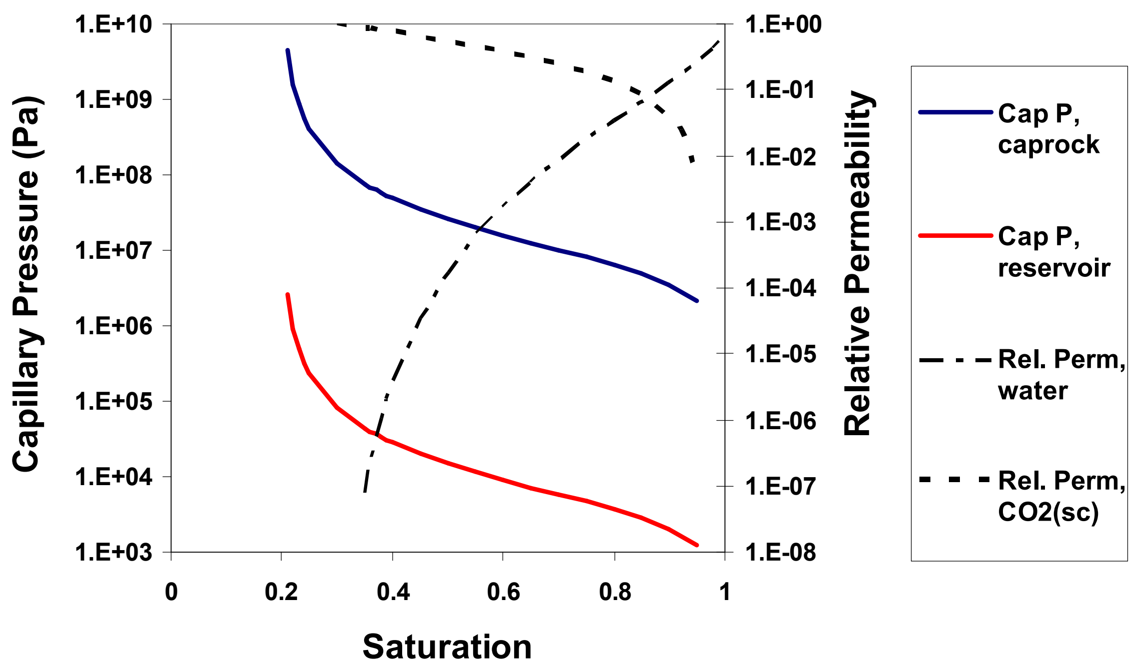
Lawrence Berkeley National Laboratory (Dr. Finsterle)

Noble gas transport (EOSN module)

- In situ production of helium
- Mass-, pressure-, and temperature-dependent diffusion coefficients
- Advective-diffusive transport model
- Heat transport

Multiphase flow of water and supercritical CO_2 (ECO2N module)

- van Genuchten-Mualem and Corey models



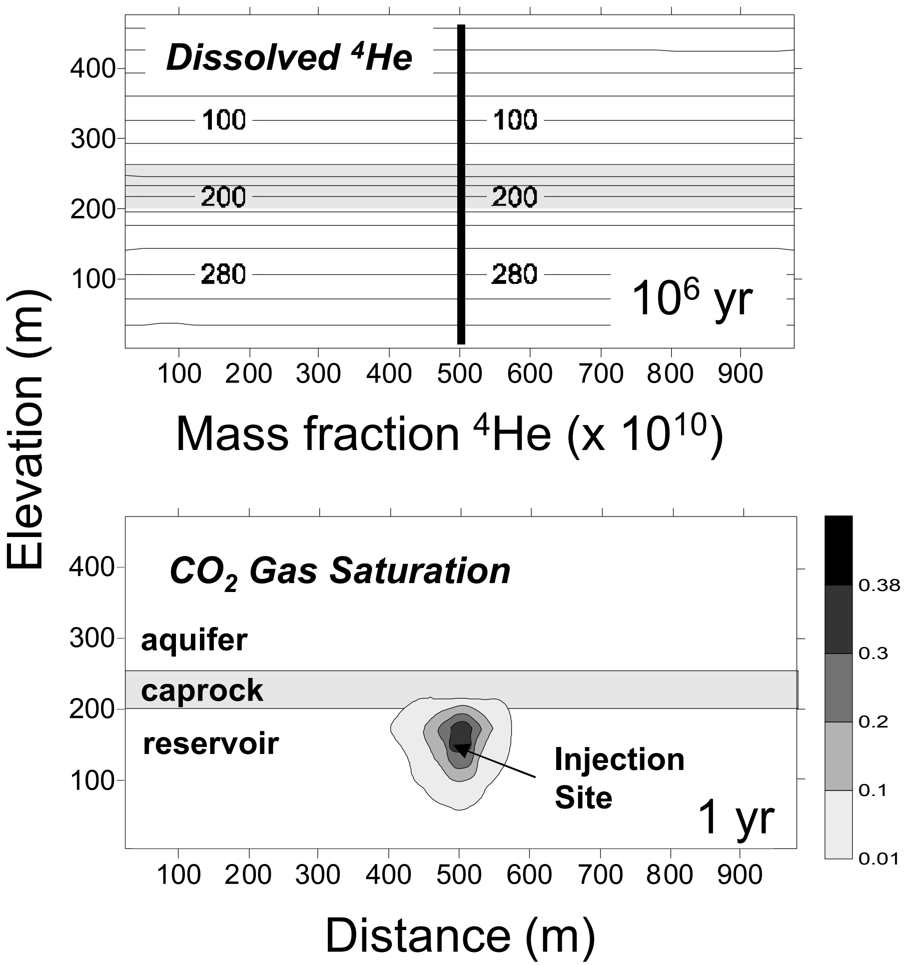
Modeling Results

For air saturated water: 0.077 ($\times 10^{10}$)

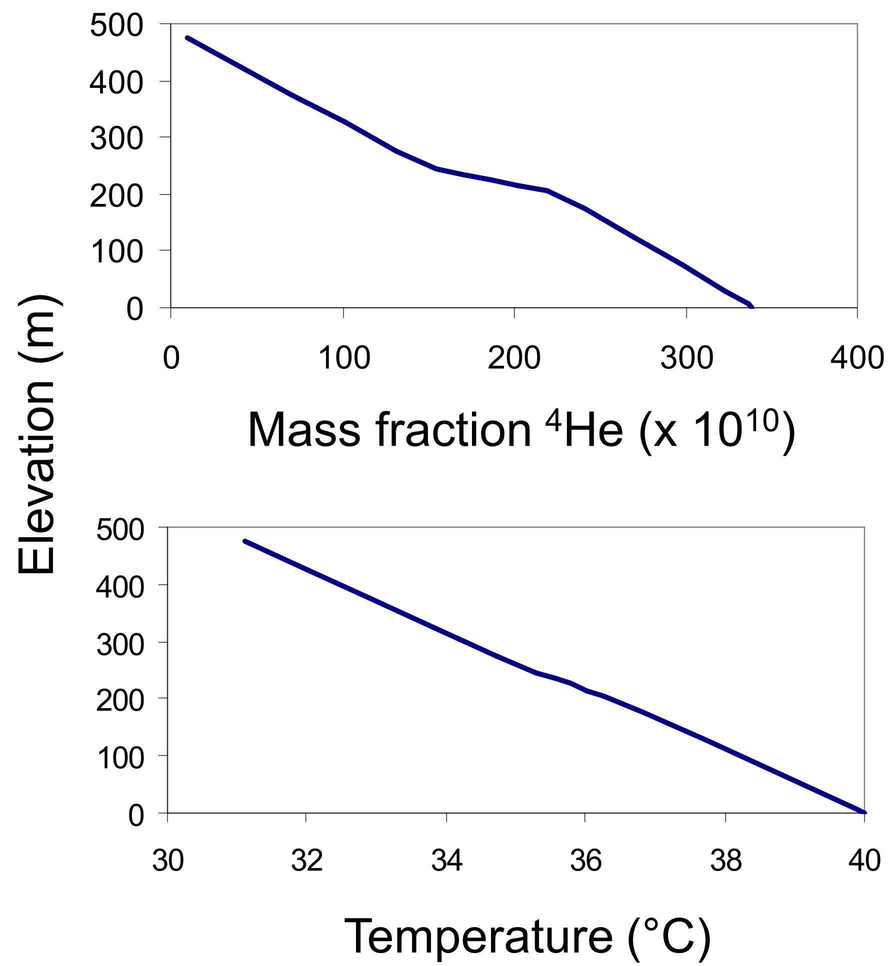
Laboratory precision: ±1%

No imperfection in caprock

0% yr^{-1} leakage



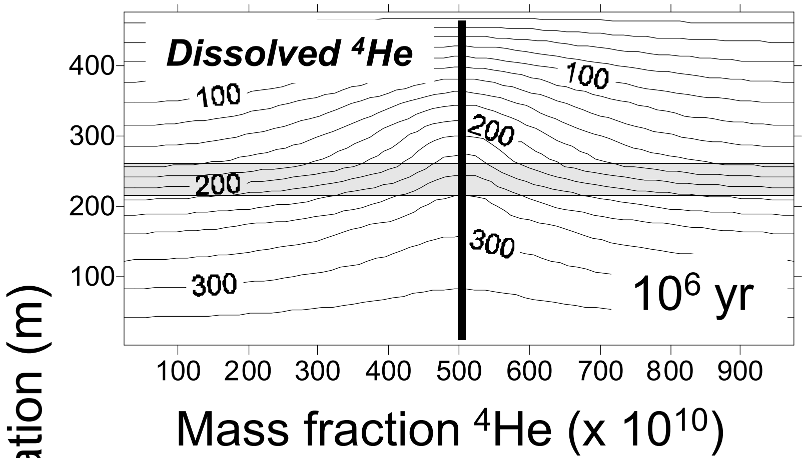
Vertical profiles

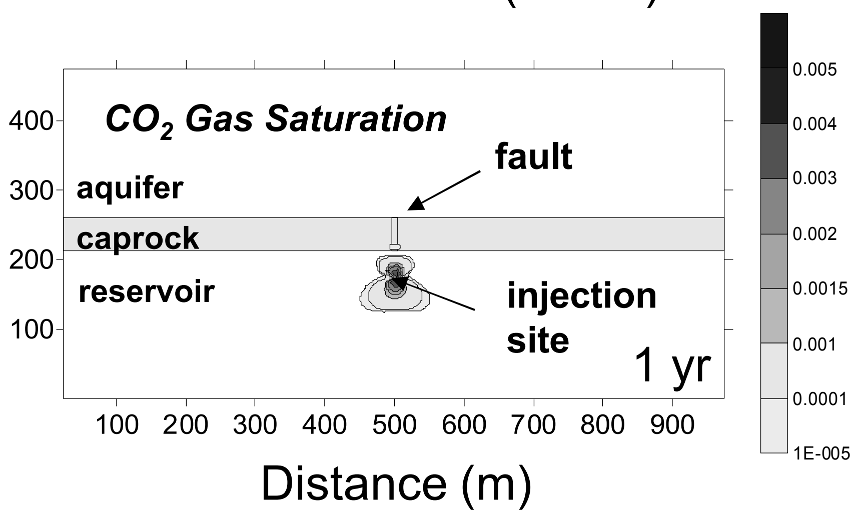


Modeling Results

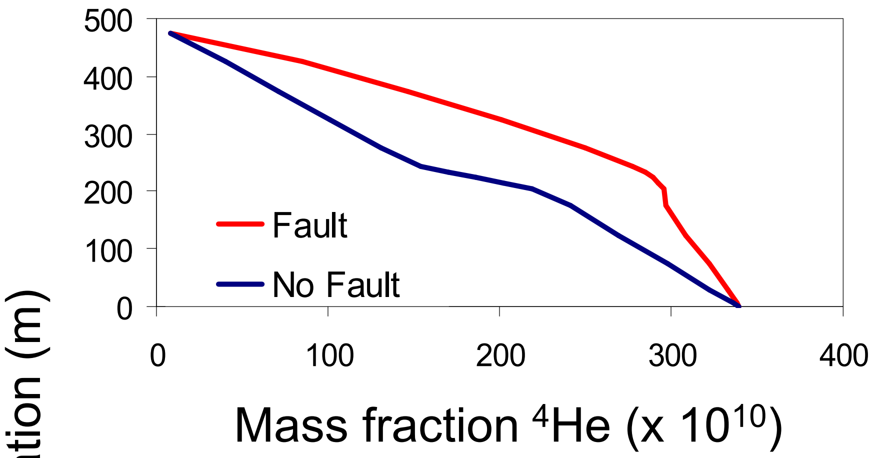
Imperfection: $k_{caprock} \times 10$

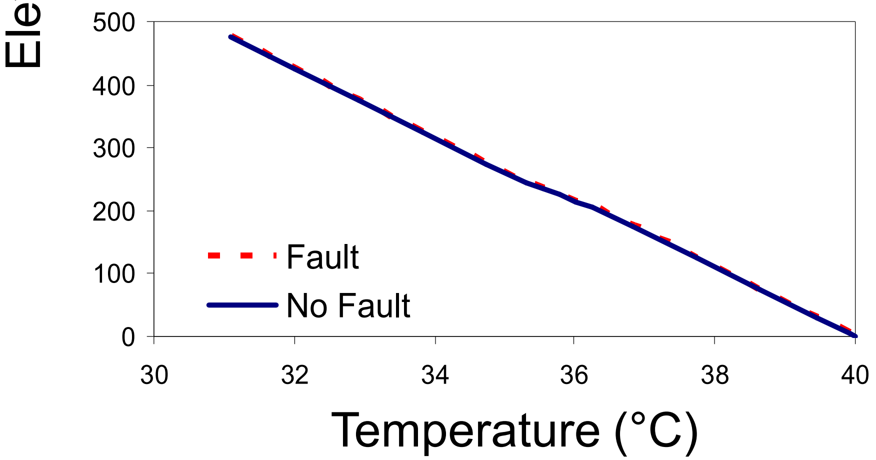
0.1% yr^{-1} leakage





Vertical profiles

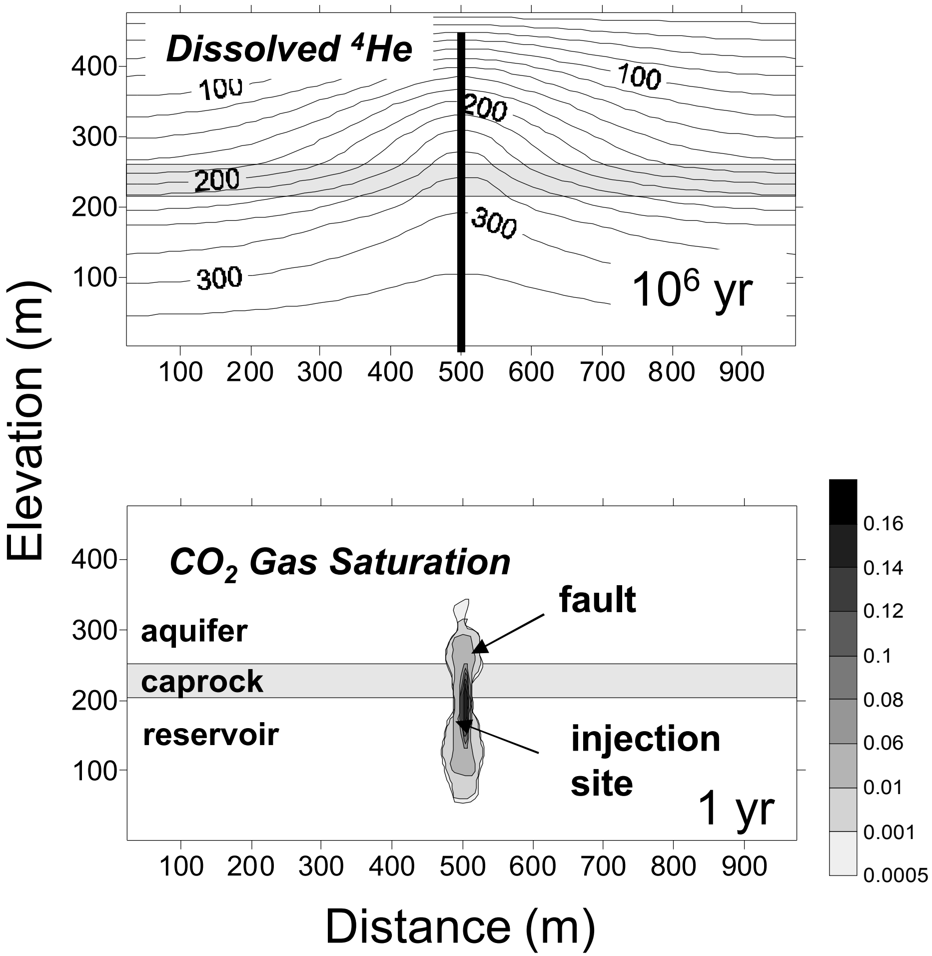




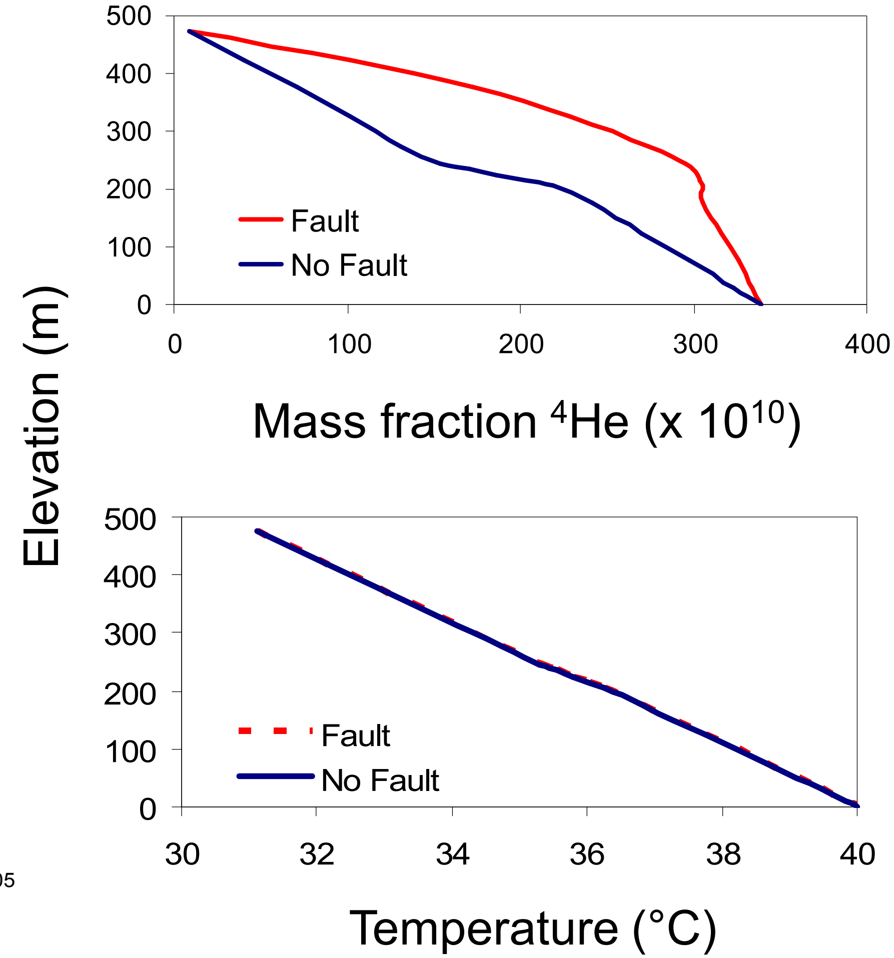
Modeling Results

Imperfection: $k_{caprock}$ × 100

7% yr^{-1} leakage



Vertical profiles

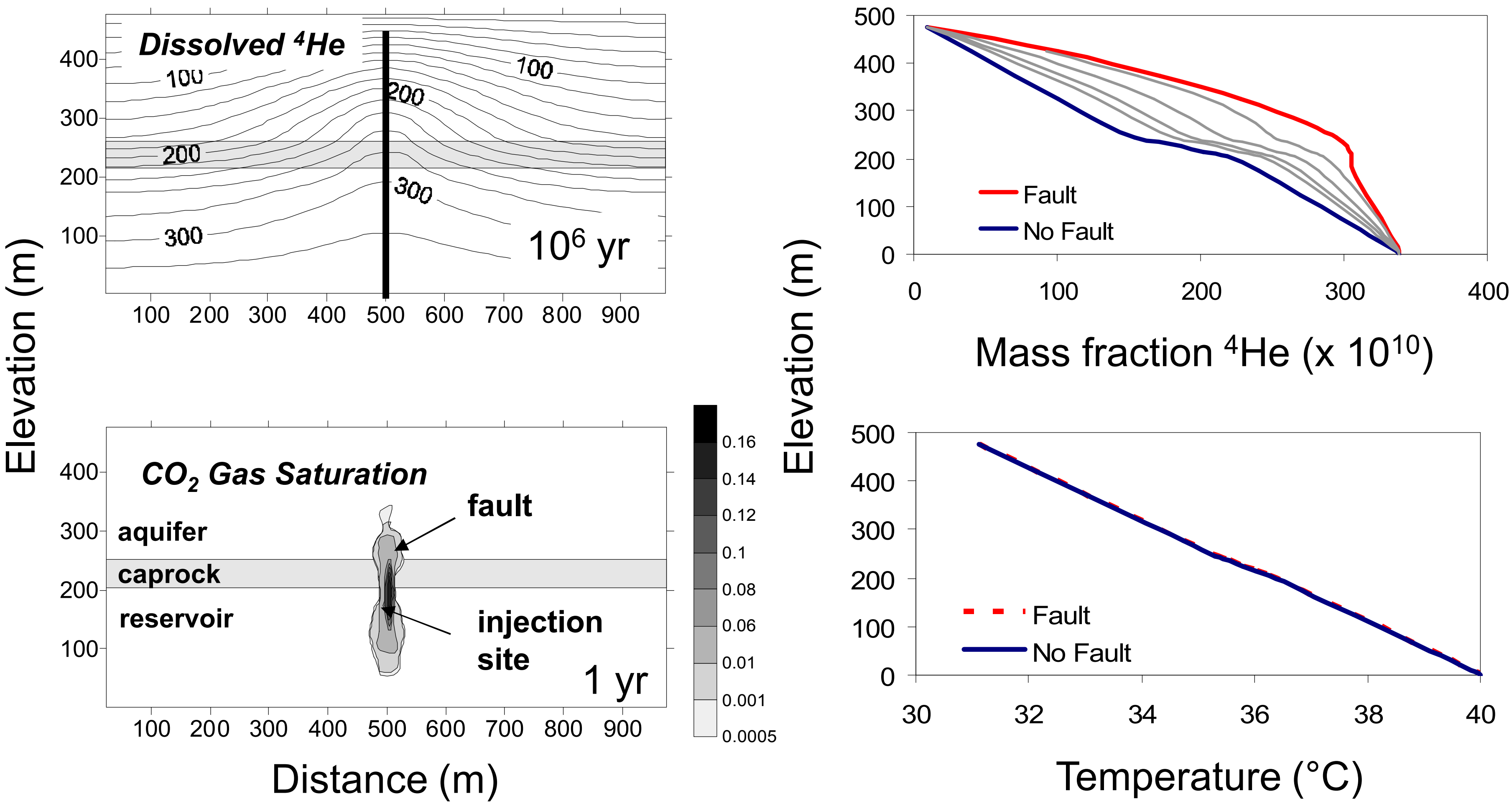


Modeling Results

Imperfection: $k_{caprock}$ × 100

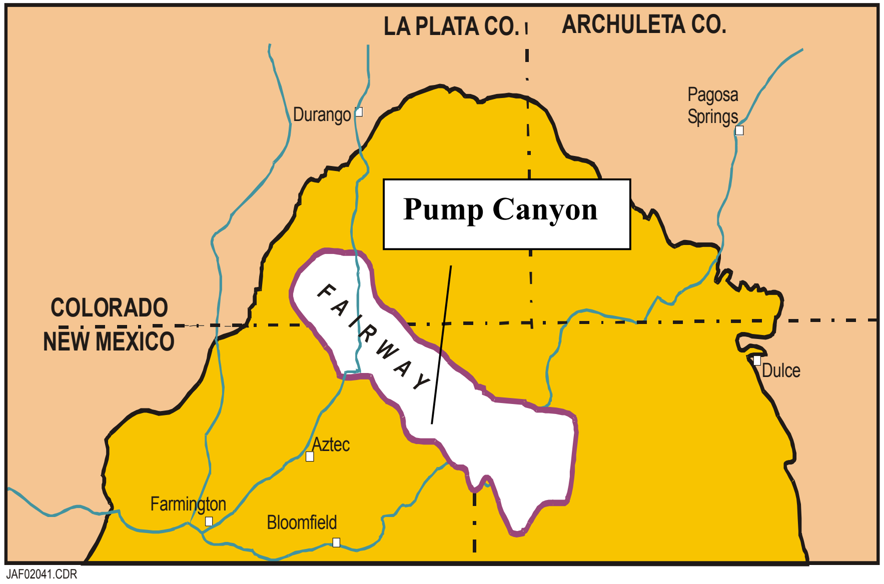
7% yr^{-1} leakage

Vertical profiles



Discussion

- Models show that helium reveals imperfections
- Sensitivity analysis underway
- None of this matters unless it can work in the field



Coring Program – Motivation and Overview

Seal analysis and CO_2 containment assessment:
Develop methodology for characterizing sealing quality

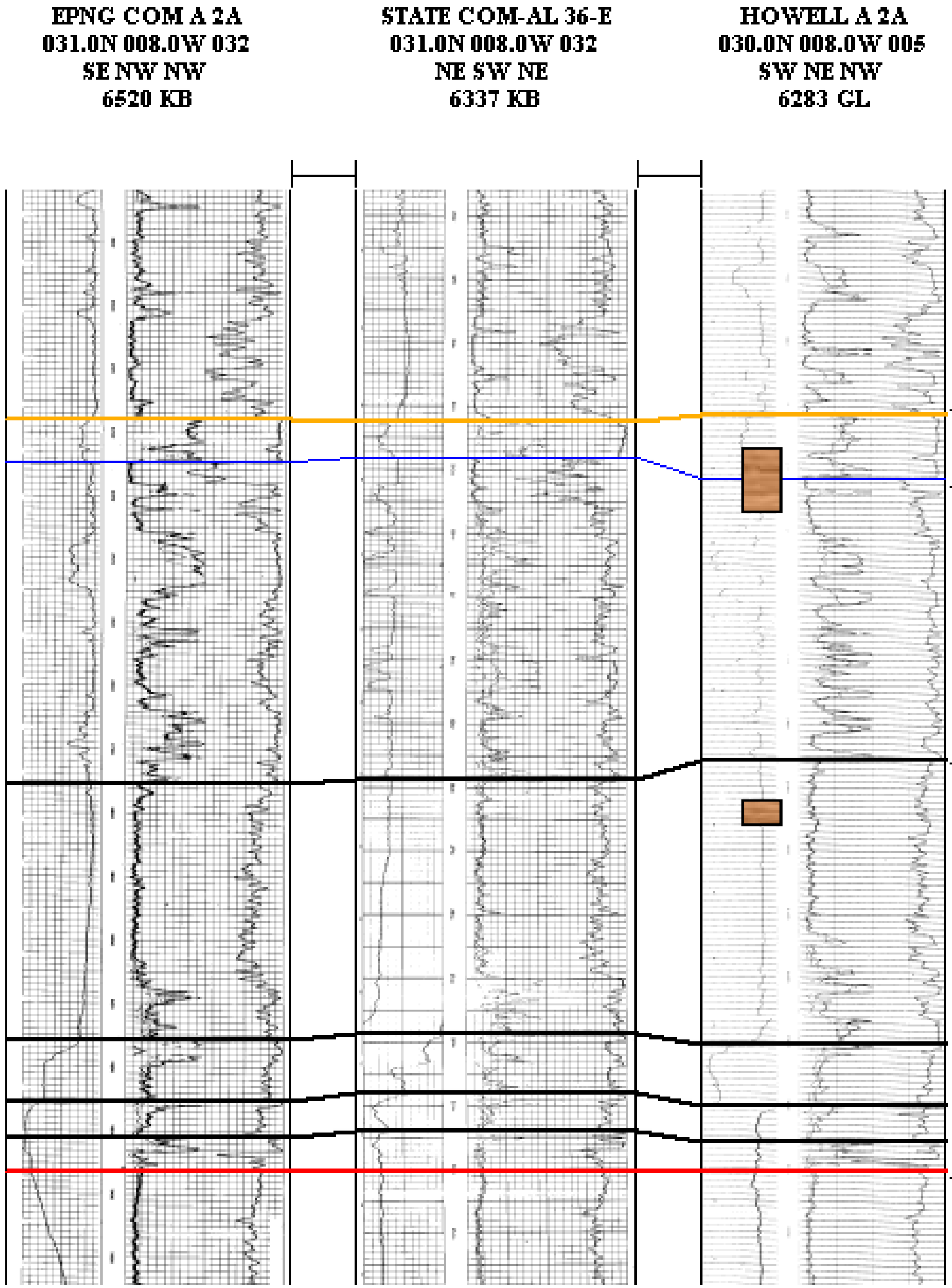
Approach:
Focus on geologic controls on sealing quality by integrating petrological, petrophysical, porosimetry, geomechanical, isotopic, and geochemical data

Unique research question:
Can natural helium be used to characterize sealing quality for CO_2 storage?

Core Points

Goal: 120 ft total

Reality: 60 ft total



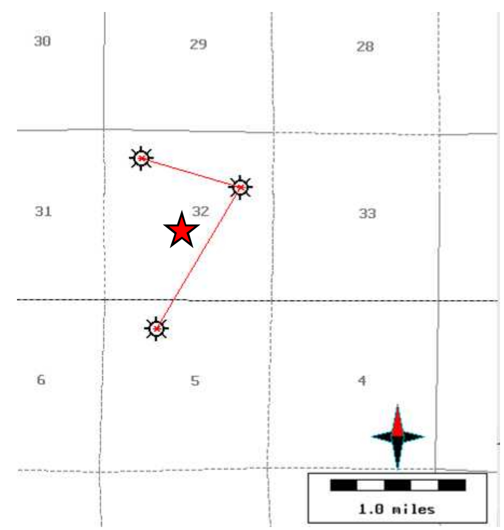
Ojo Alamo

Upper Kirtland and Farmington Sandstone Member

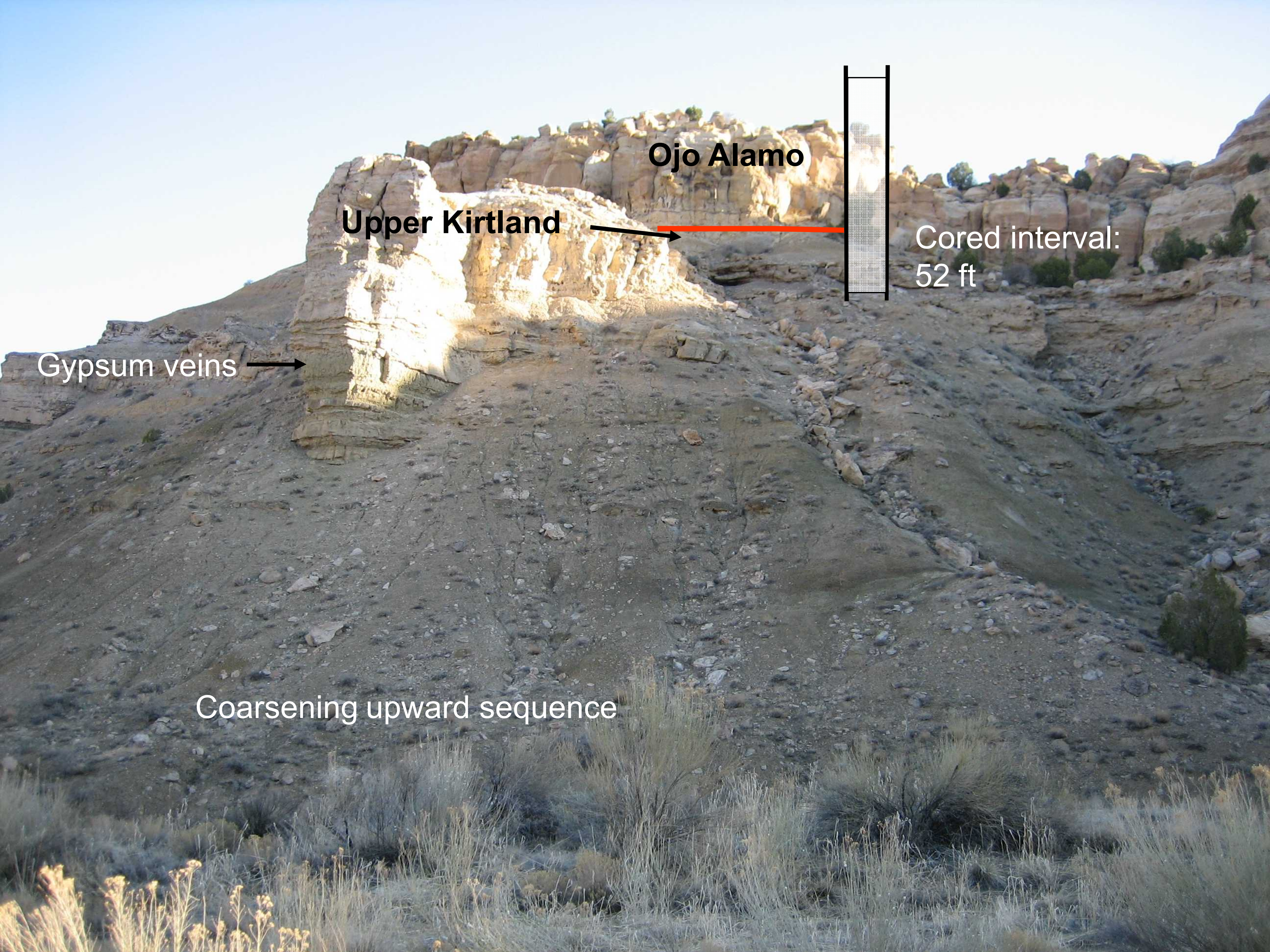
Lower Kirtland Shale

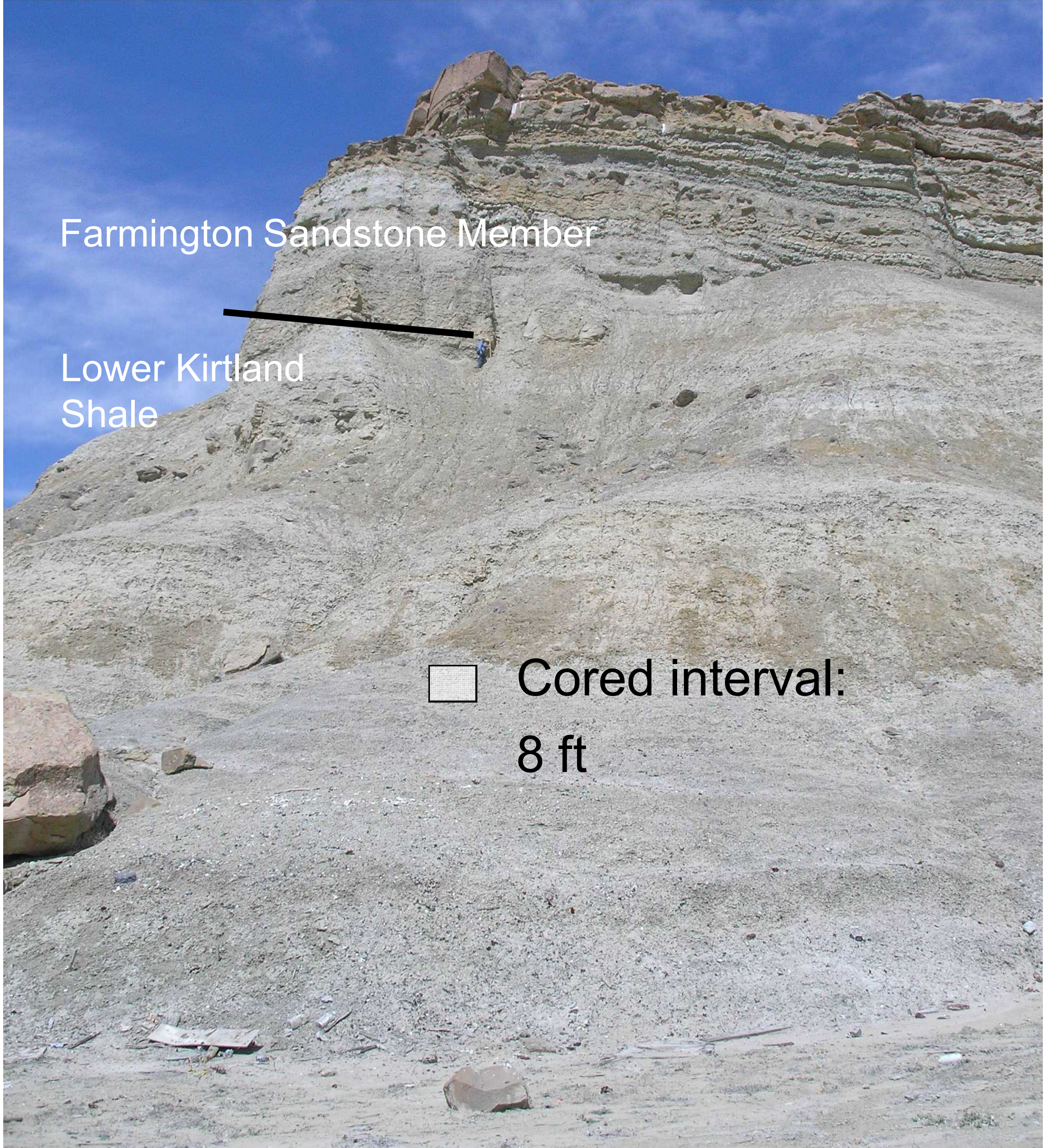
Fruitland

Pictured Cliffs



(Well logs from ConocoPhillips)


Ojo Alamo
Upper Kirtland
Cored interval:
52 ft
Gypsum veins
Coarsening upward sequence



Farmington Sandstone Member
Lower Kirtland
Shale
Cored interval:
8 ft

Core Analysis Program - Methods

Examine core in field → Cut plugs

Preserve samples with portable vacuum line

Geomechanical properties:
Possion's ratio, Young's modulus
Multistage compression testing

Core plug preservation in field: vacuum-tight canisters for preserving noble gases in pore fluids (collection procedure developed by Martin Stute)

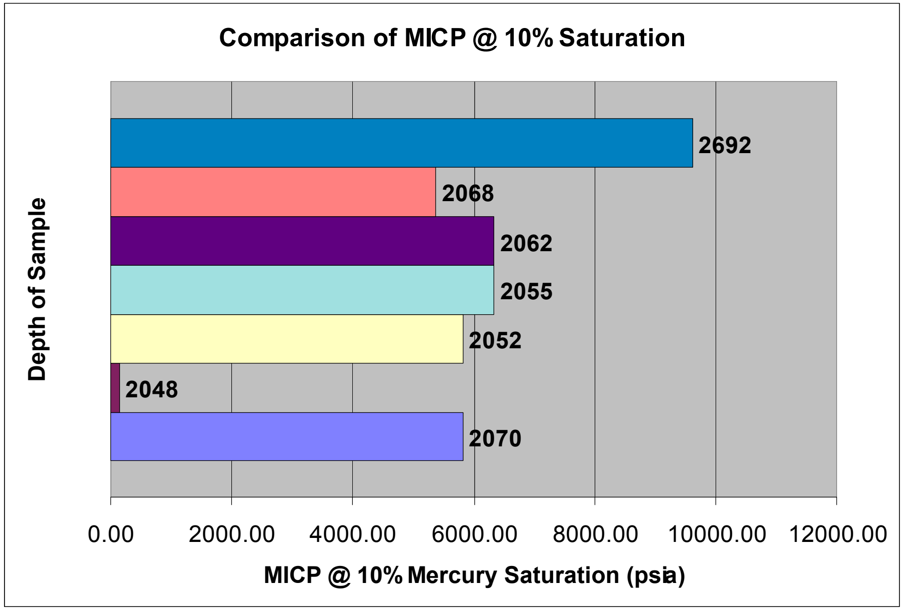
Petrological description:
SEM, XRD, TOC, LCSM
Thin section analysis

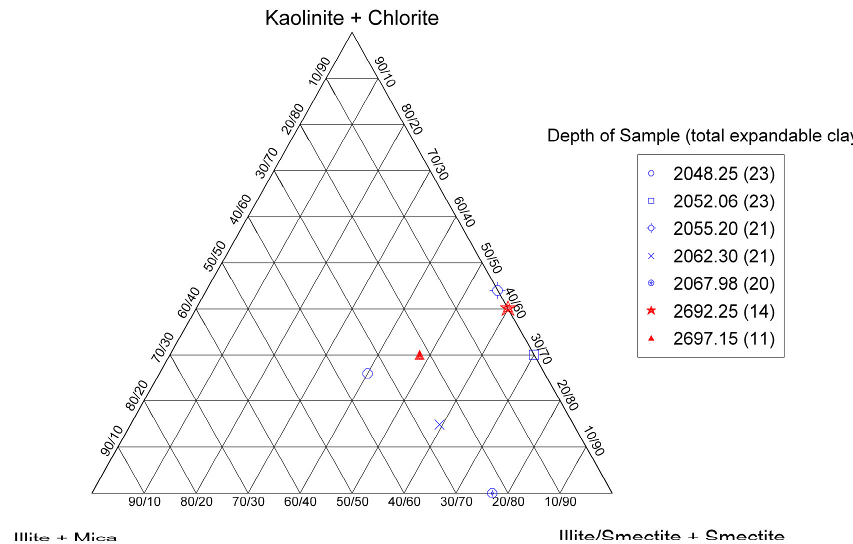
Petrophysical properties:
TRA method (Terra Tek)
Permeability, porosity, porosimetry

Fracture analysis:
Fracture type, orientation, dip, mineral fill, assessment of failure potential of natural fractures

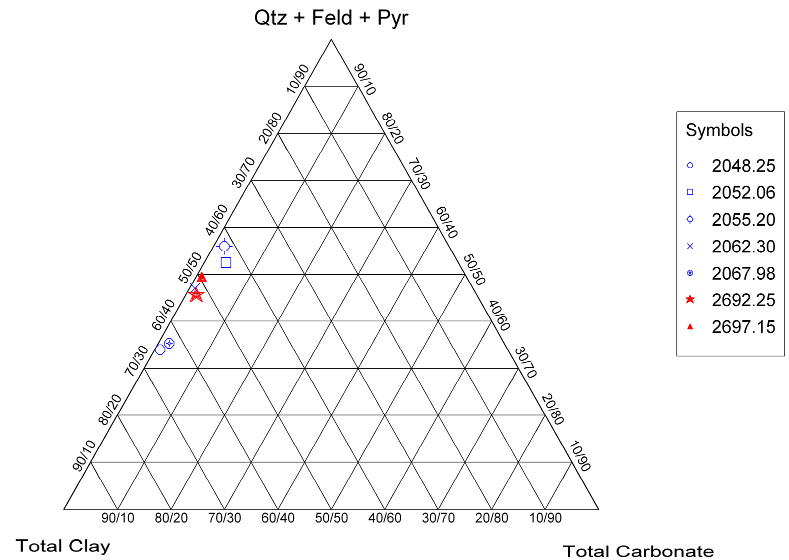
Tests with CO_2:
Gas breakthrough pressure
CO_2 adsorption

Field Study – Upper and Lower Kirtland





- Matrix is argillaceous with predominantly smectite and mixed layer illite-smectite
- Evidence of soil forming processes
- Authigenic quartz is present
- Voids left by organic matter
- Matrix-hosted intercrystalline microporosity



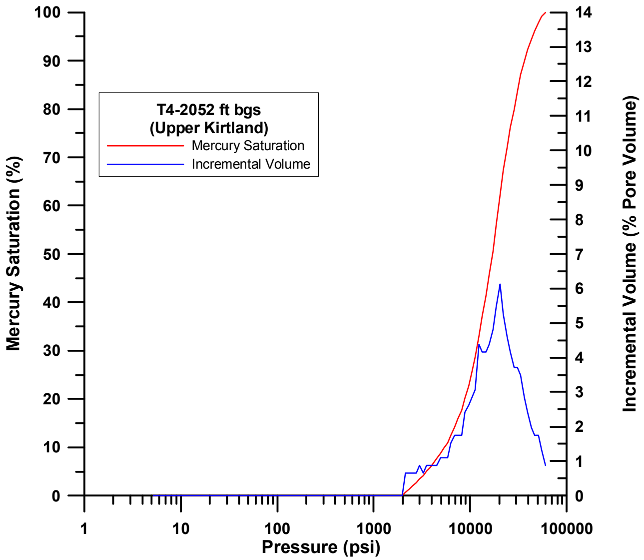
Field Study – Upper Kirtland

Detailed interpretation of MICP with regard to petrography

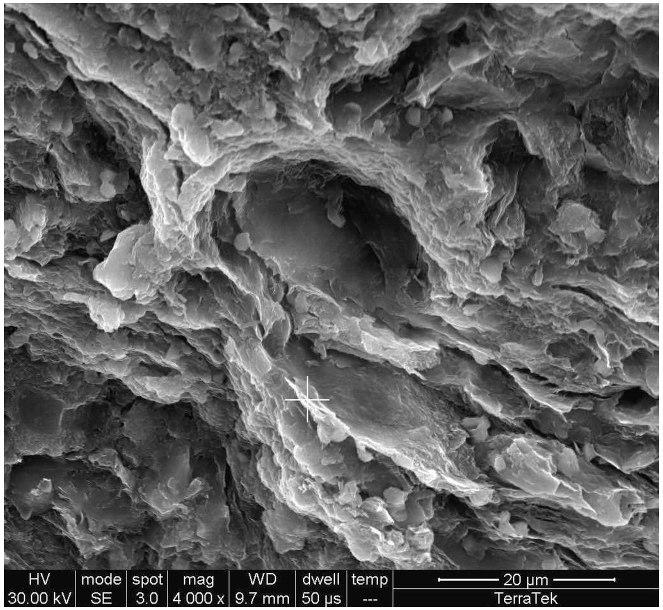
•Porosity types – root cast, fractures lined with illuviated clays

•Clay types and sand and silt grains: Smecitic composition (spot EDX)

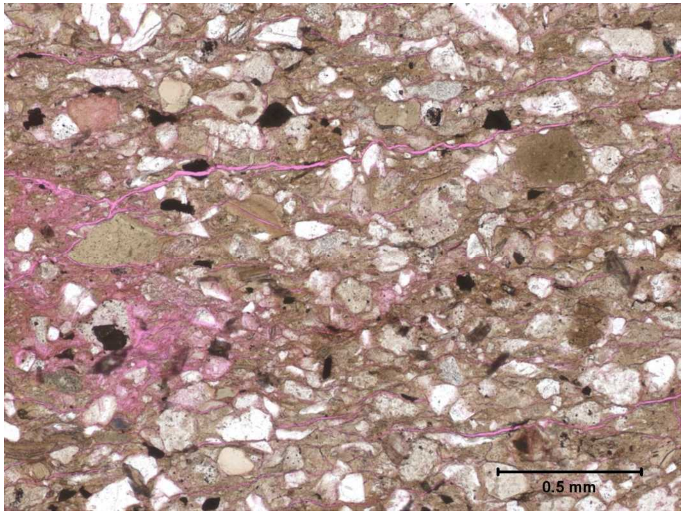
•Lamination in illuviation features



SEM



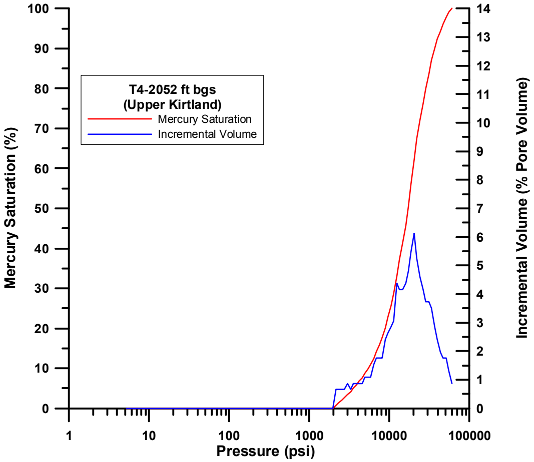
Thin section



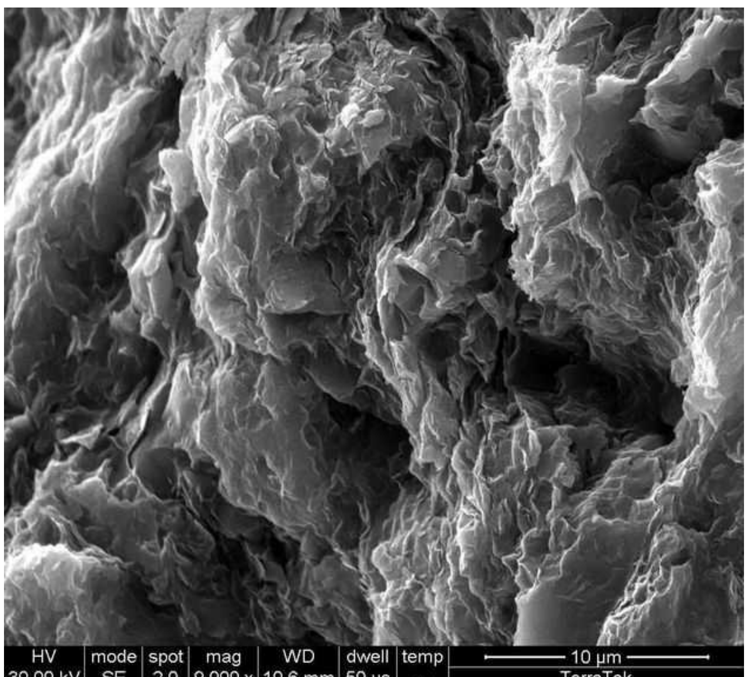
Field Study – Lower Kirtland

Silty argillaceous mudstone. Clays are mainly I/S, illite, and chlorite, with minor smectite.

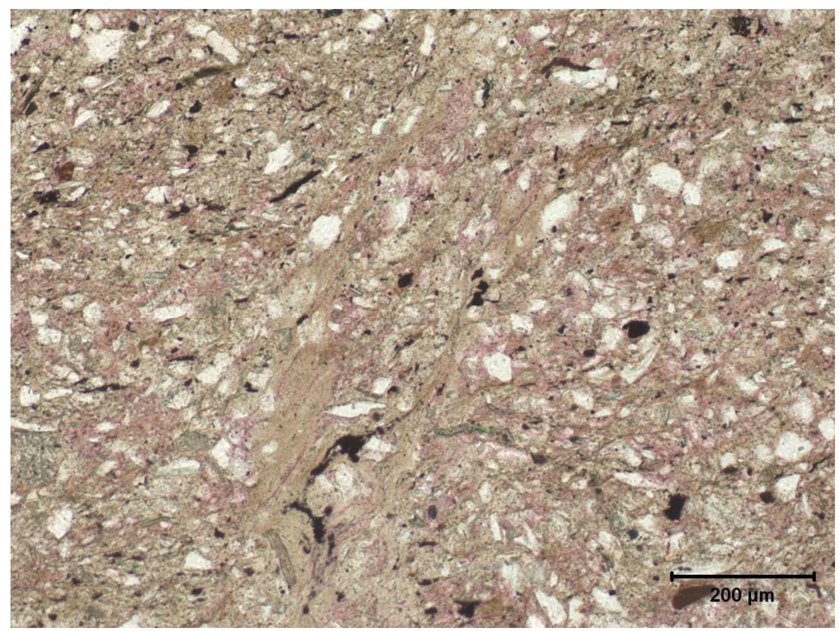
Dark pore on SEM may represent fluid pathways or voids associated with oxidized carbonaceous amterial.



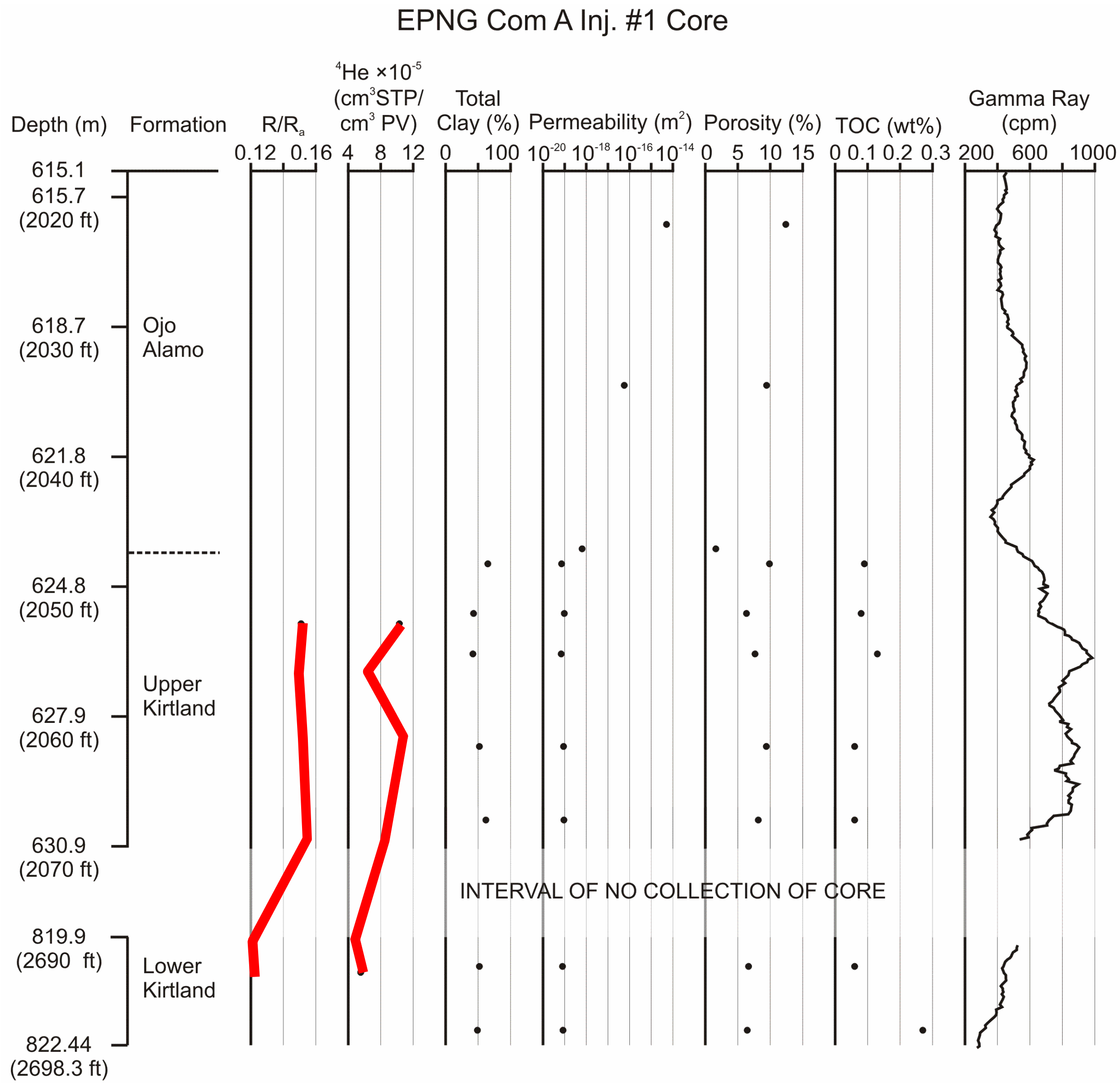
SEM



Thin section



Field Study – Parameters vs Depth



Conclusions and Future Work

- Modeling indicates helium may be a useful "imperfection" assessment tool
- 3D model being developed for the Pump Canyon site
  - Model will incorporate helium transport and be calibrated if possible with the field data
- MICP data and petrographic work indicate high quality seals, but may be reactive to acidic fluids

Future work at Sandia: Phase III and BES study of high resolution real-time imaging of multiphase flow in fractures