SAND2014-19142PE

Seal Analysis

GEOL 571, Reservoir Quality and Caprock Integrity
Guest Lecture
New Mexico Tech
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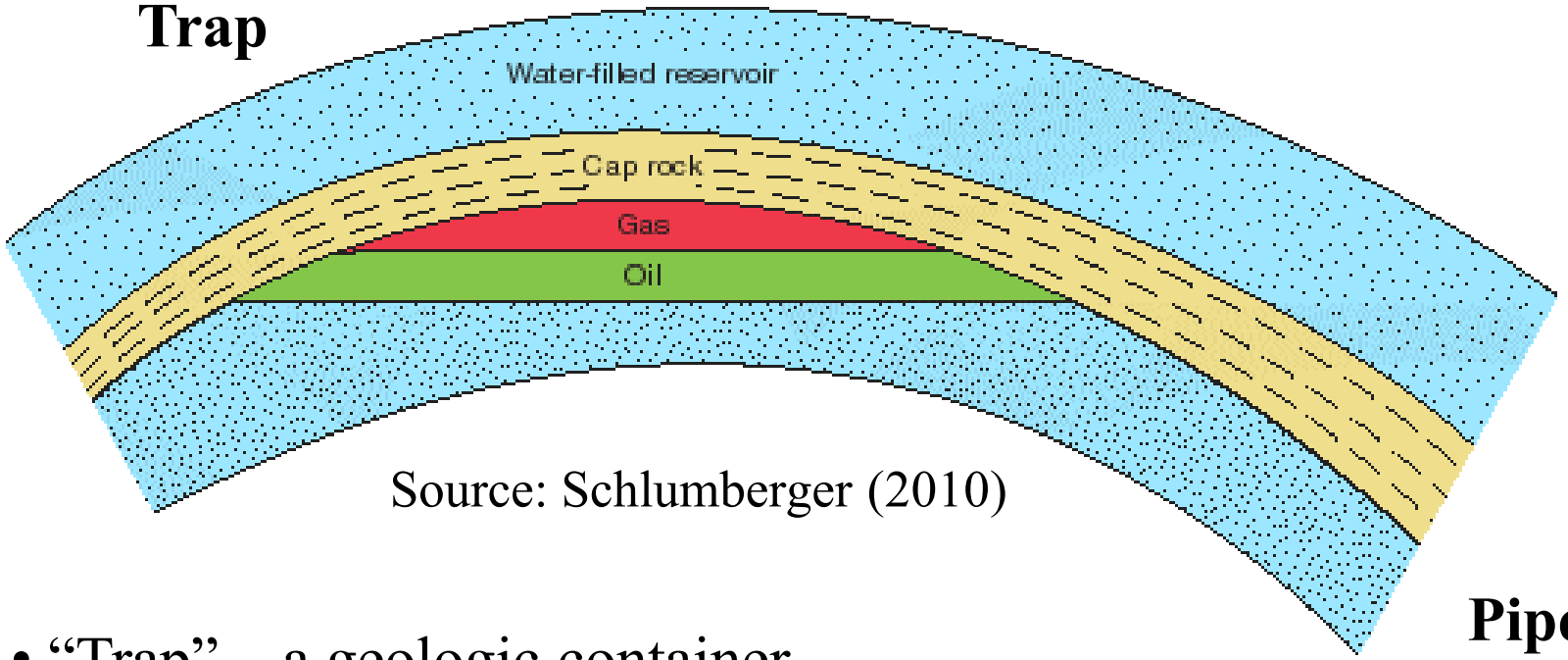
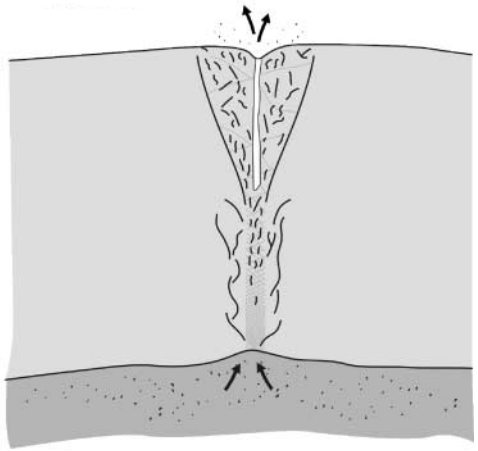
Seal Analysis



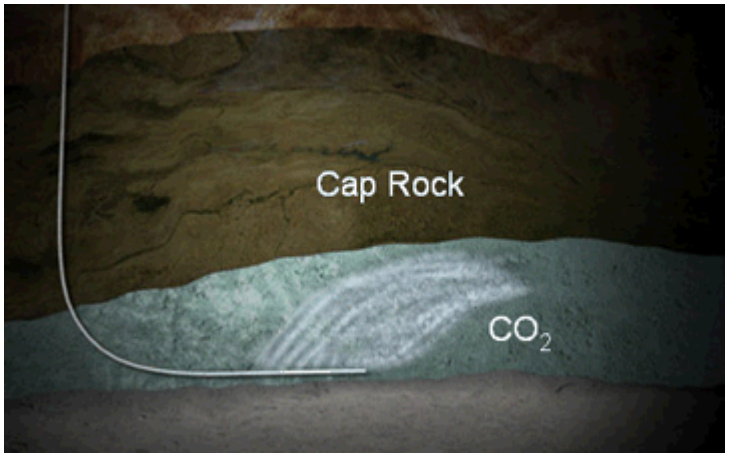
Source: Schlumberger (2010)

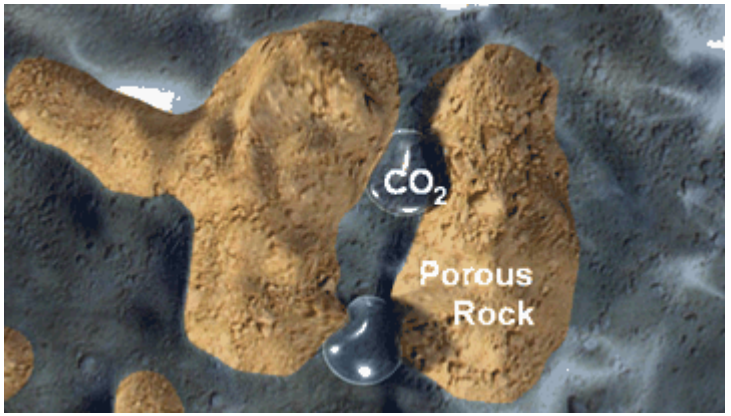
- "Trap" – a geologic container
- Sealing behavior
- Concept of caprock depends on time scales
- "Seal bypass systems" (see Cartwright et al., 2007)

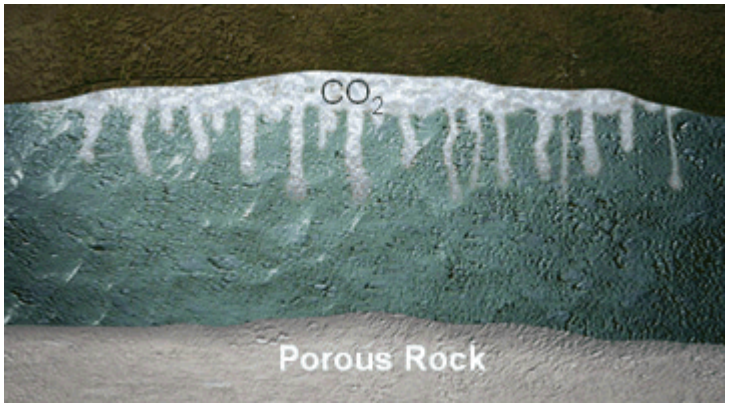
Pipe-type bypass



Trapping Mechanisms







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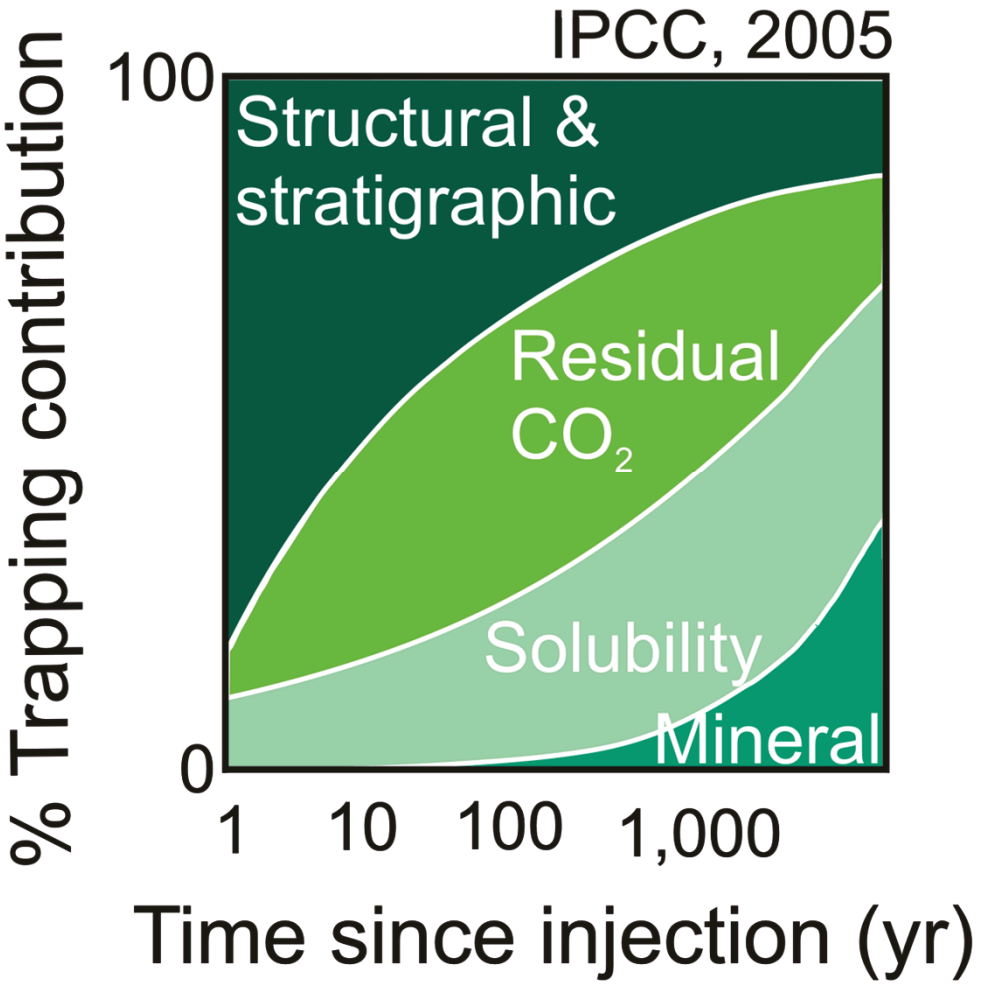
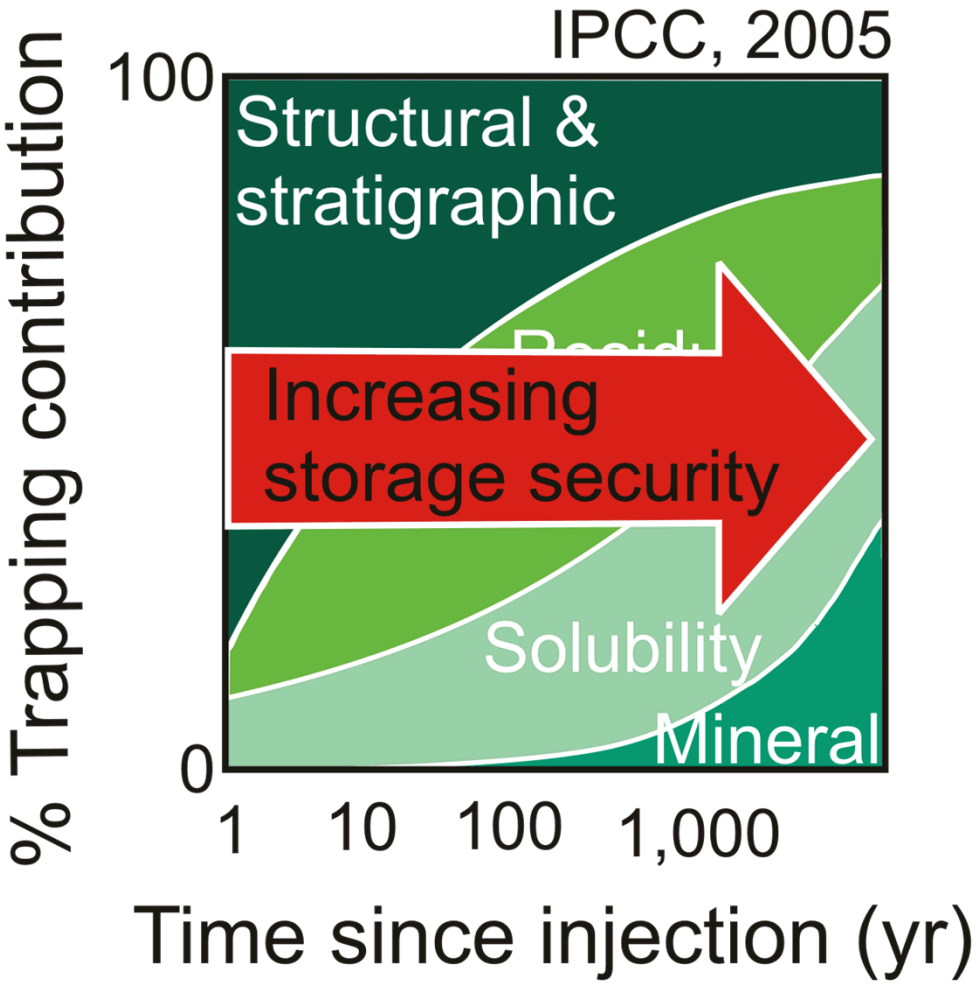
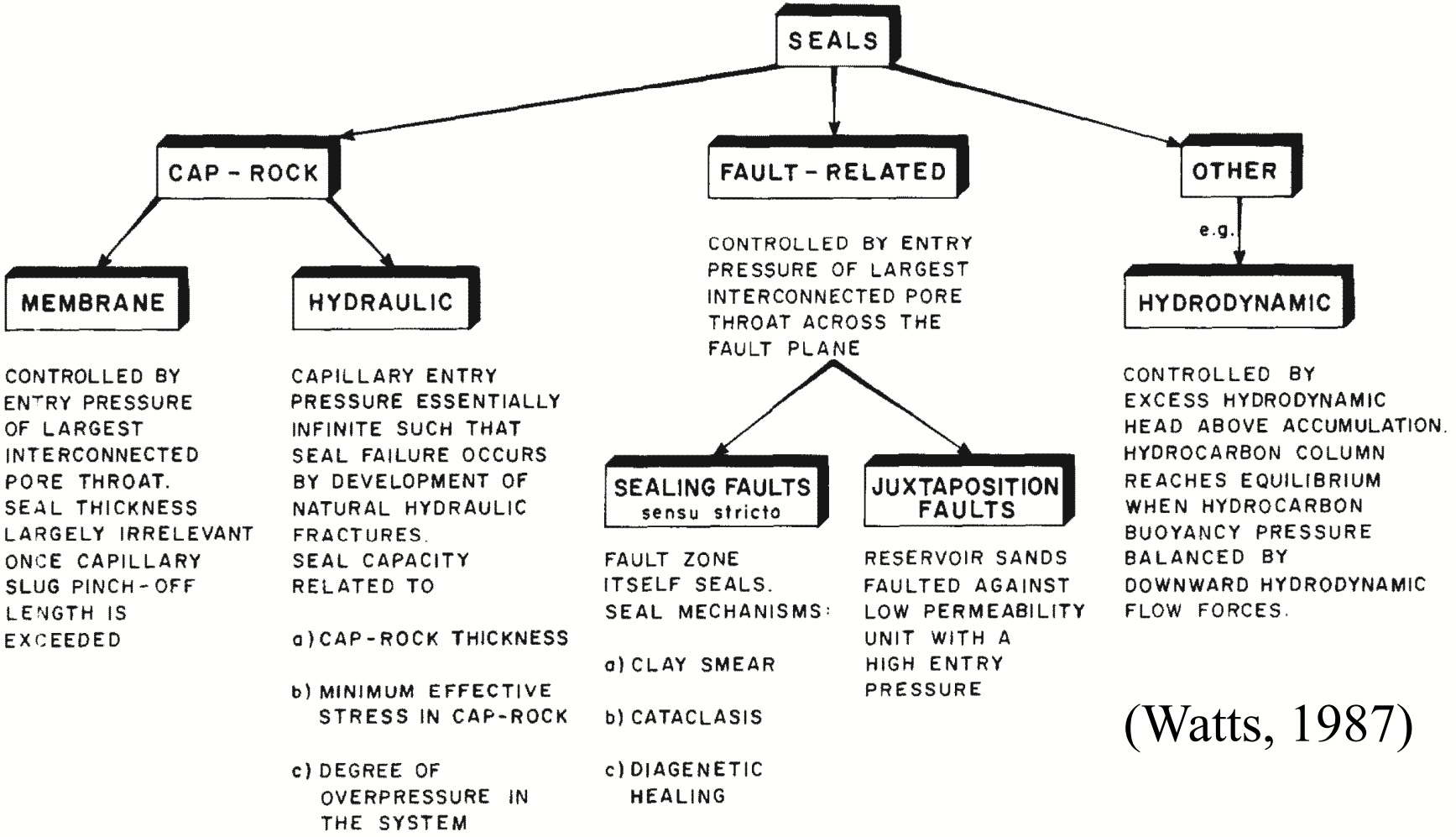


Trapping Mechanisms

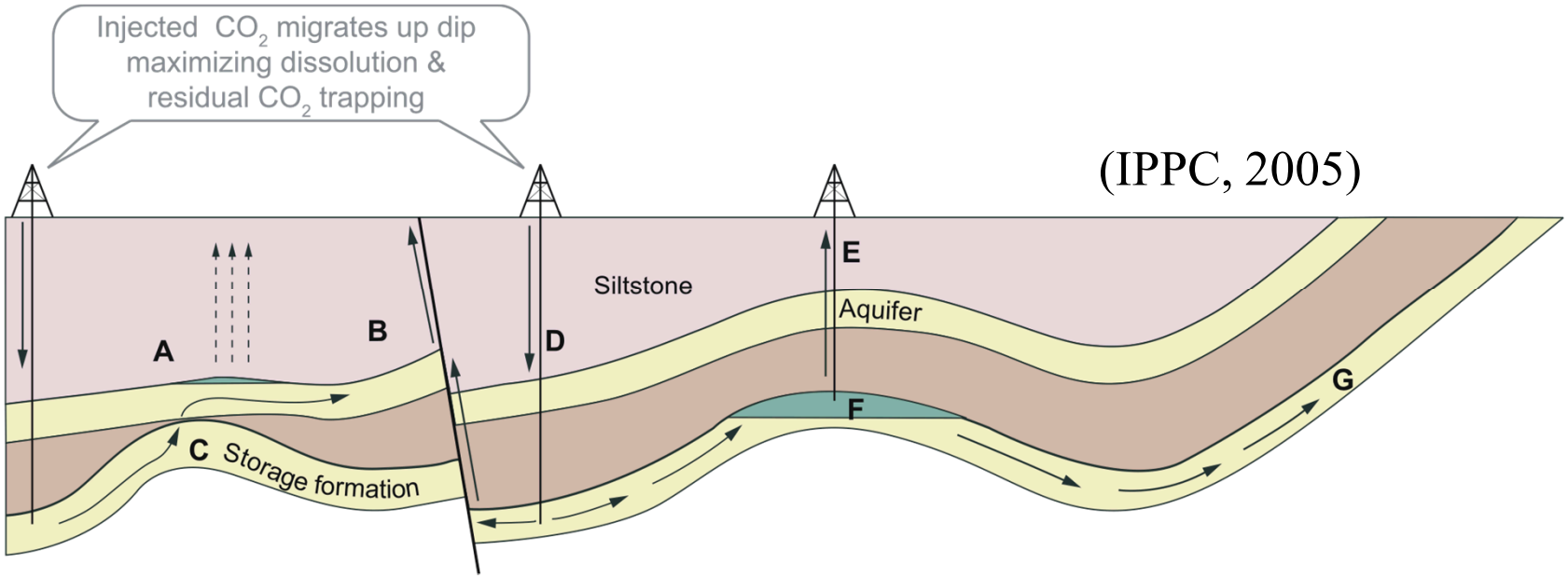


Theoretical aspects of cap-rock and fault seal: N. L. Watts



(Watts, 1987)

Potential CO_2 Escape Routes



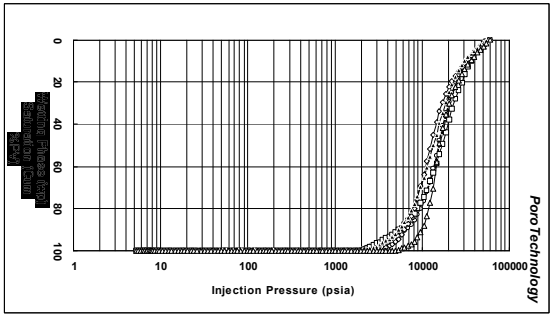
(IPPC, 2005)

Traditional Caprock Analysis

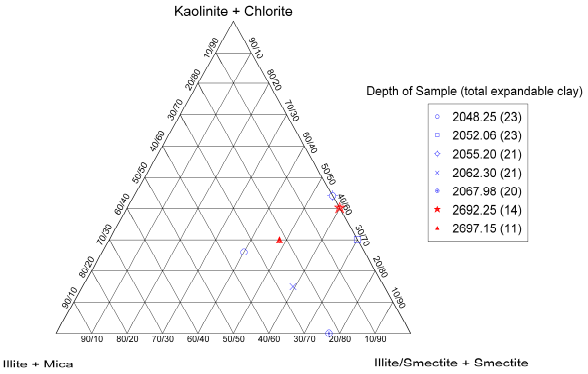
- Capillary properties
- Mechanical seal failure
- Fault seal analysis
- Identification of seal bypass systems (Cartwright et al, 2007)

Fractures in caprock

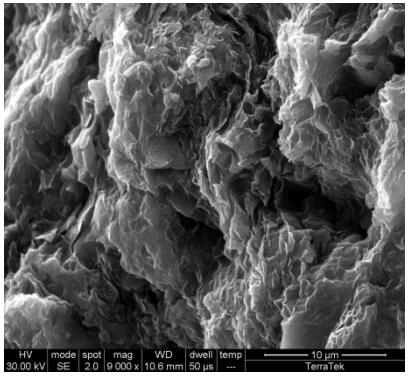
Capillary pressure



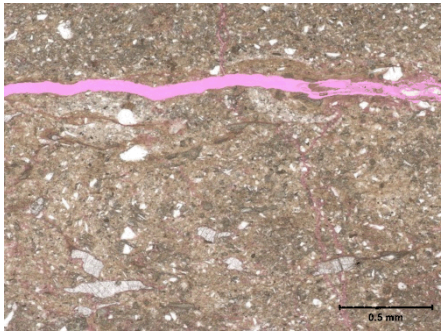
XRD



SEM and EDS

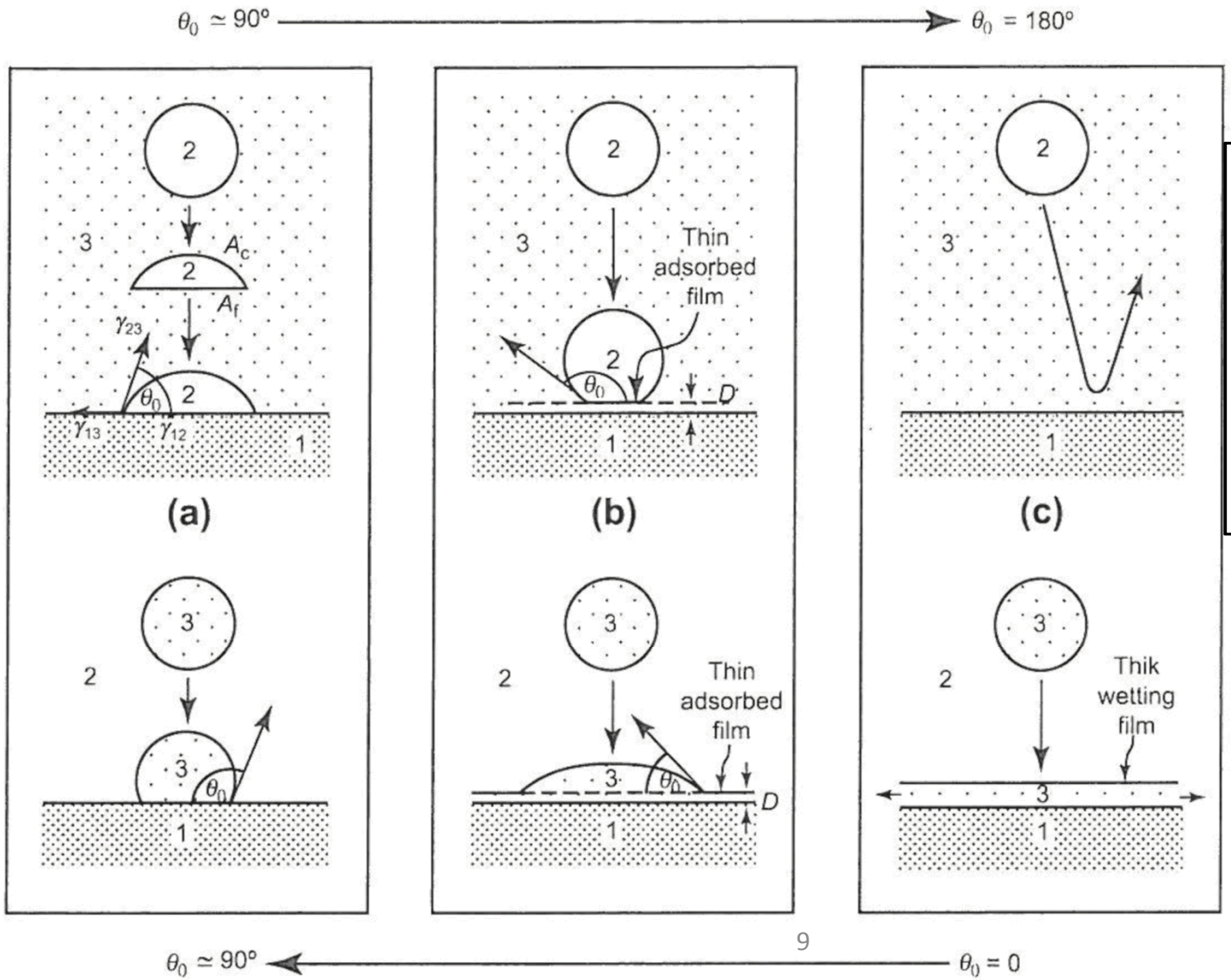


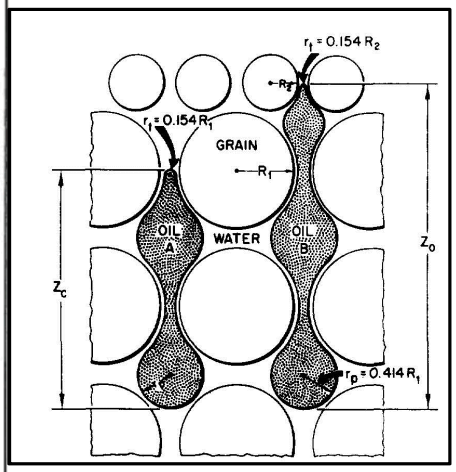
Thin section



Interfacial Energy and Contact Angles

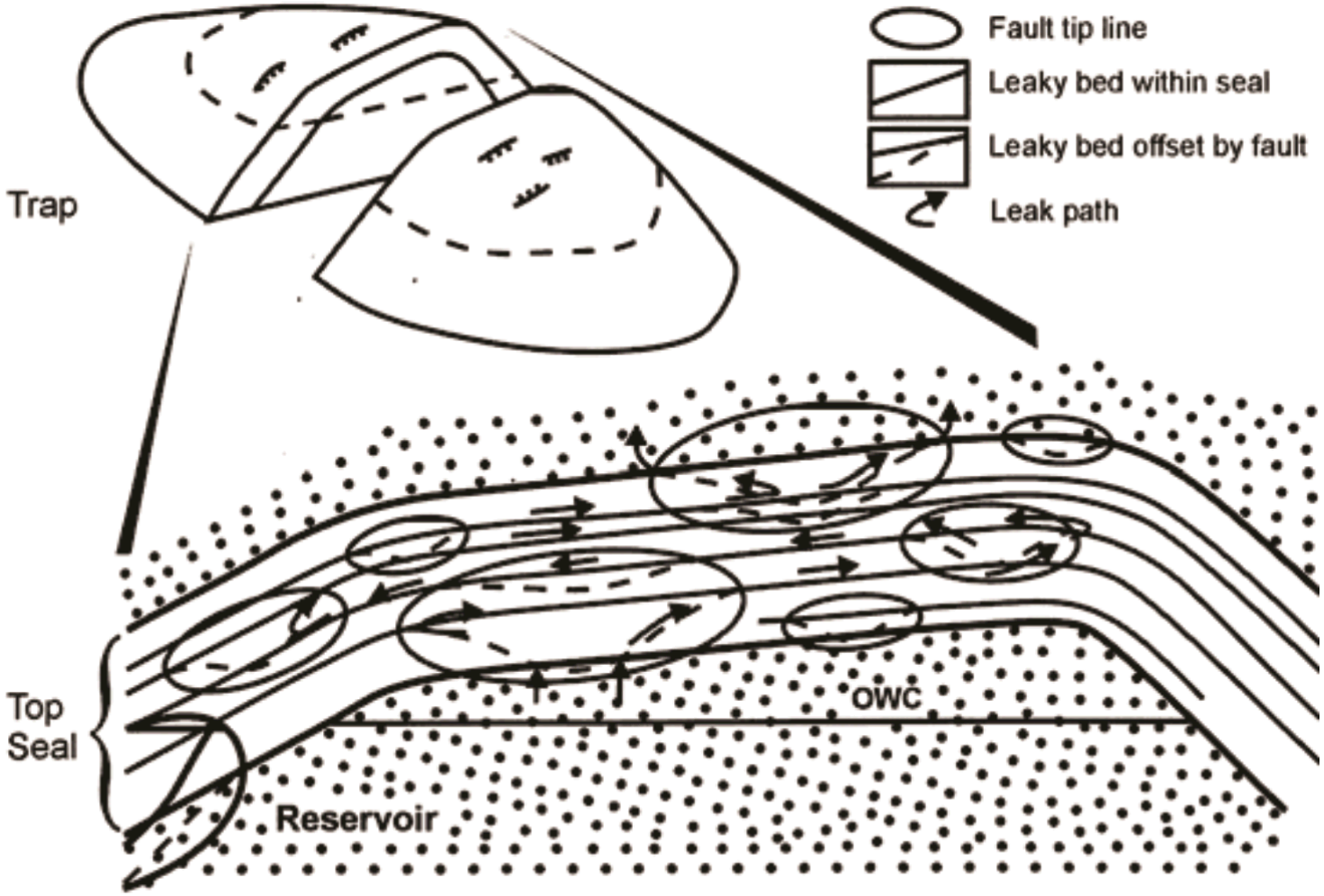
(Israelachvili, 2011)



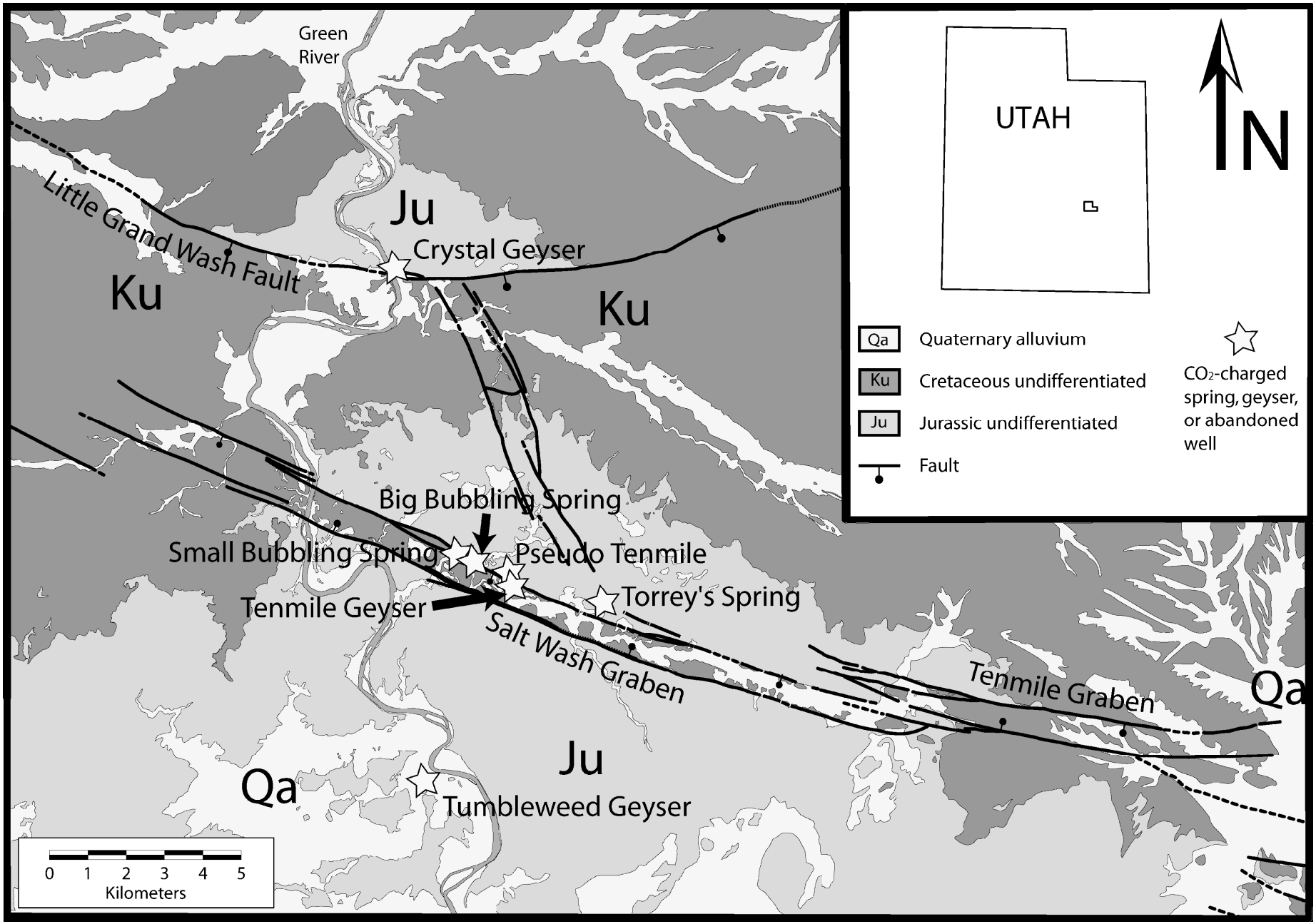


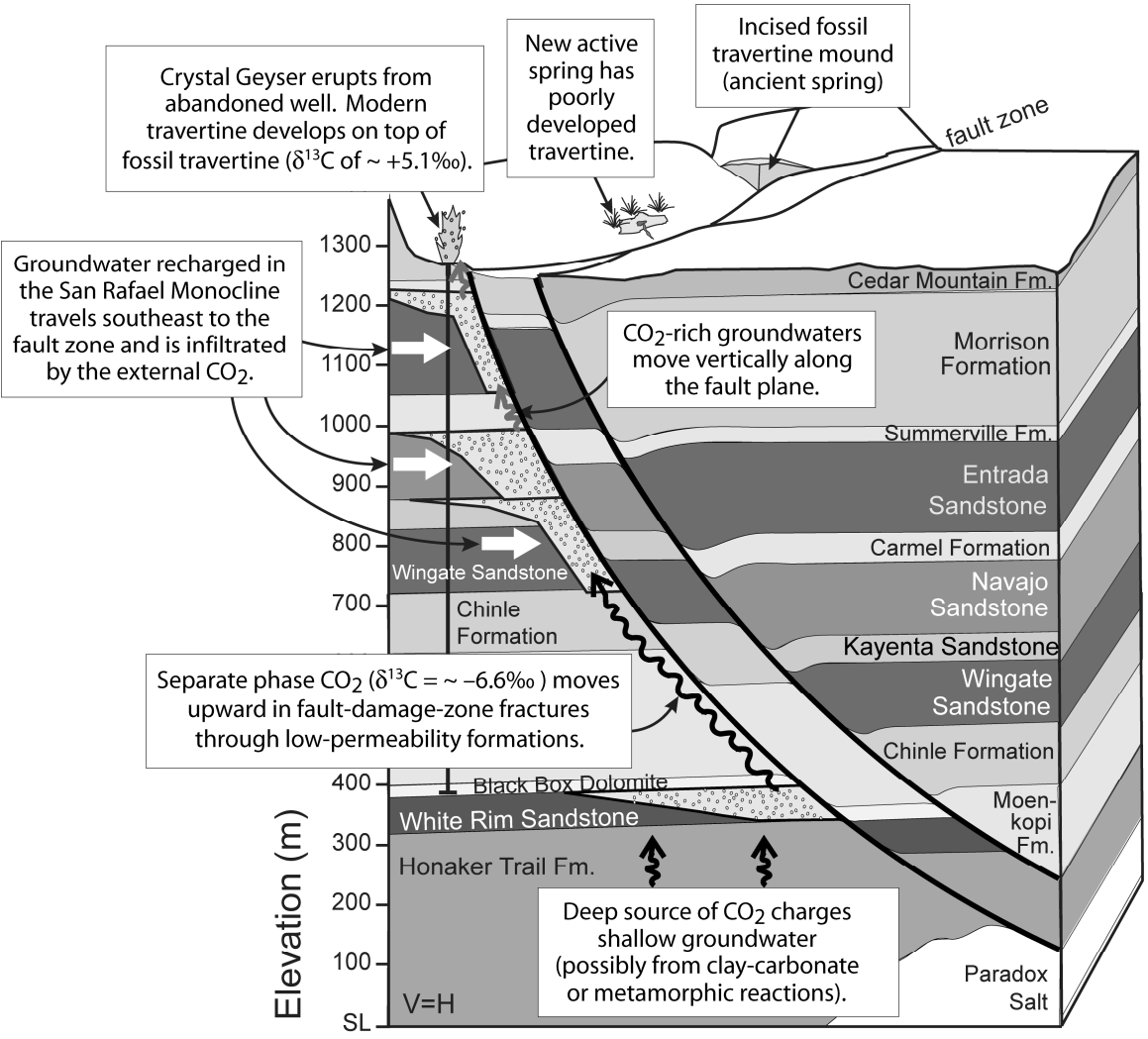
(Berg, 1975)

Fracture Networks and Pathways



(Ingram and Urai, 1999)


Green River
Little Grand Wash Fault
Ju
Crystal Geyser
Ku
Ku
Big Bubbling Spring
Small Bubbling Spring
Pseudo Tenmile
Tenmile Geyser
Torrey's Spring
Salt Wash Graben
Tenmile Graben
Qa
Ju
Qa
Tumbleweed Geyser
0 1 2 3 4 5
Kilometers
UTAH
N
Qa Quaternary alluvium
Ku Cretaceous undifferentiated
Ju Jurassic undifferentiated
Fault
CO2-charged spring, geyser, or abandoned well



Crystal Geyser System, Utah

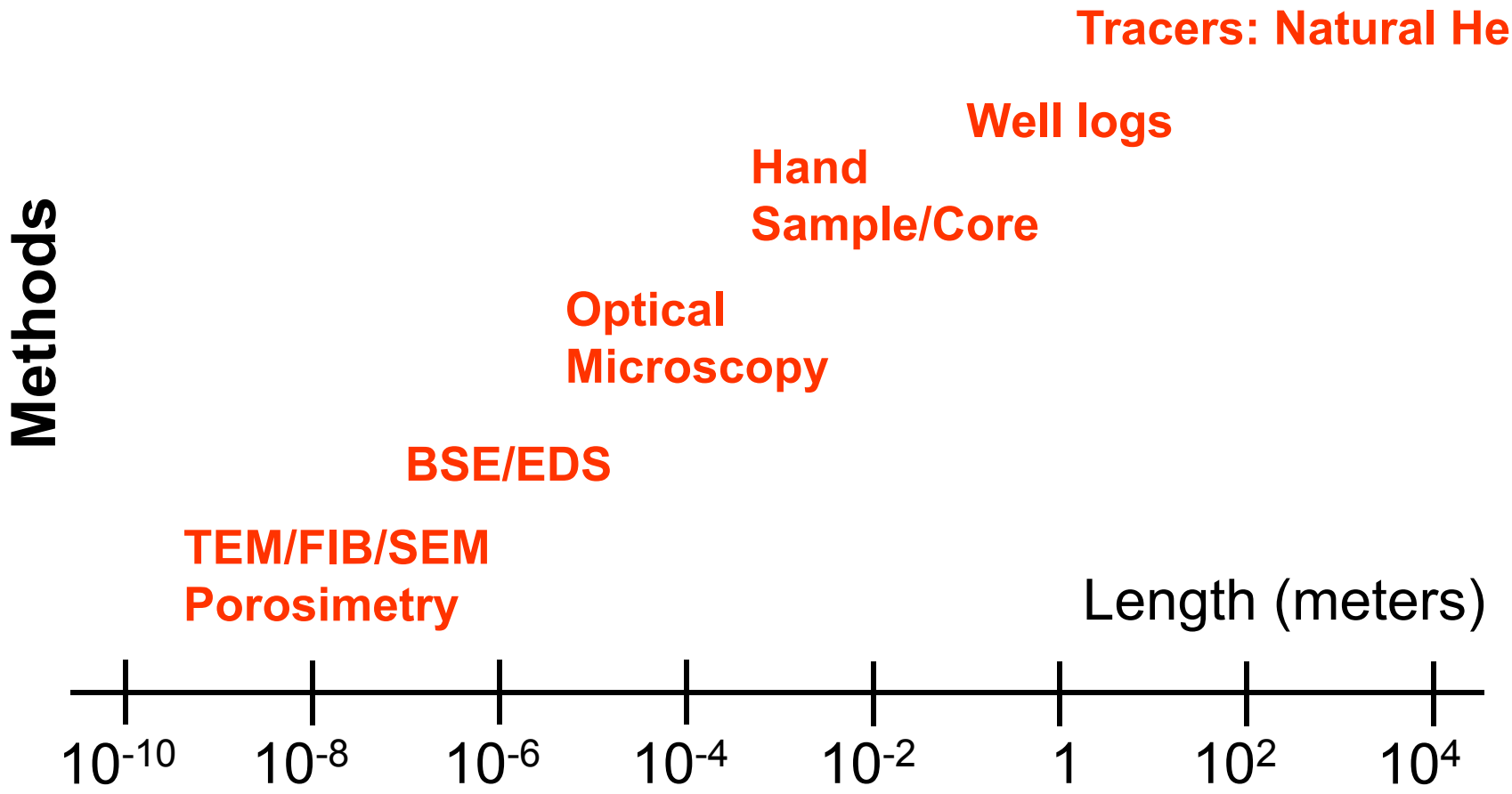
Evans, 2009

Entrada Formation, UT

Summing Up Research Questions

1. What geologic conditions and pore network characteristics contribute to the formation of high quality sealing caprock for CO_2 storage?
2. What governs transport at specific sites: pore networks or “seal bypass systems”? And how is this effectively determined?

Multiscale Investigation of Sealing Behavior



Nanoscale: pore networks & surfaces

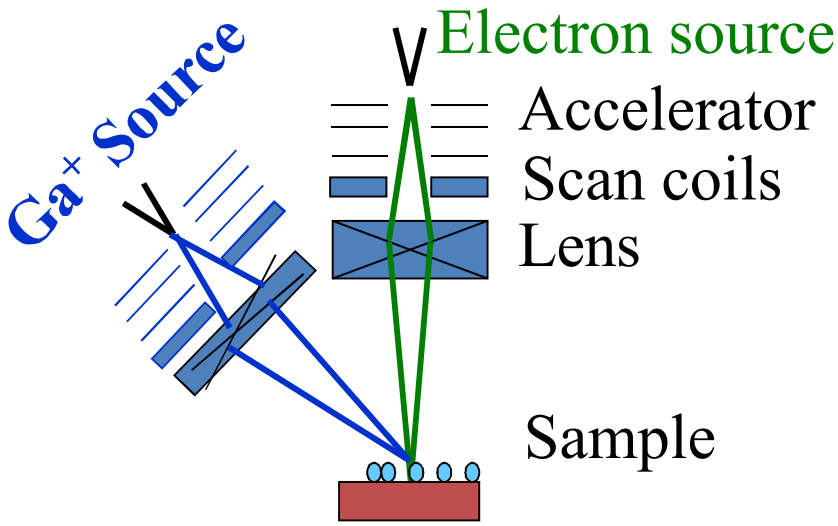
Microscale: large pores and microfractures

Mesoscale: core, outcrop, well logs, fractures

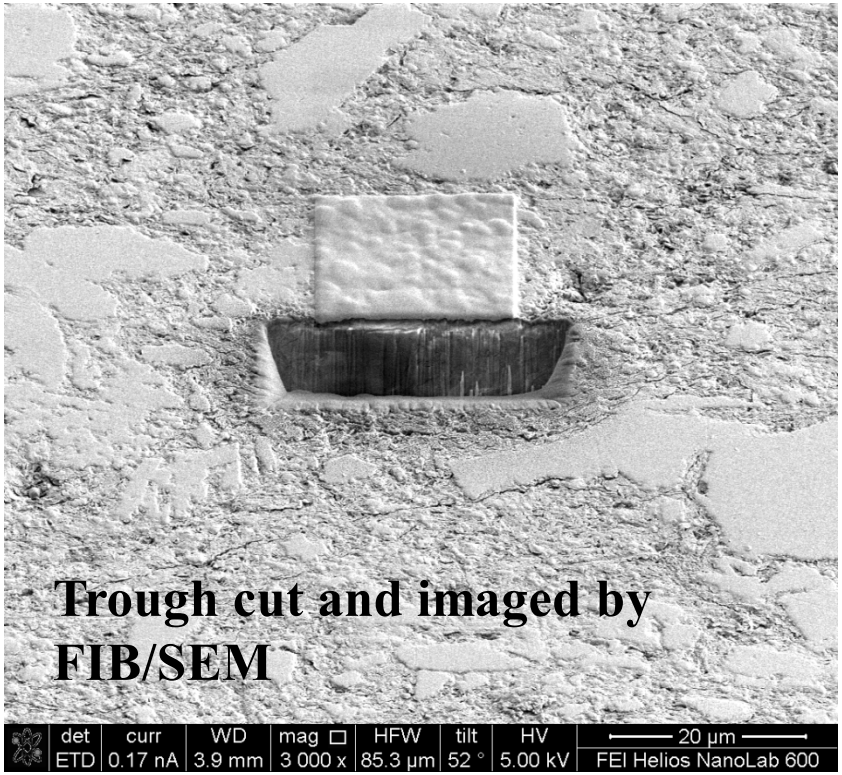
Macroscale: Formation/ reservoir

Microscopy: Pore Network Examination

Dual beam focused ion beam/scanning electron microscopy

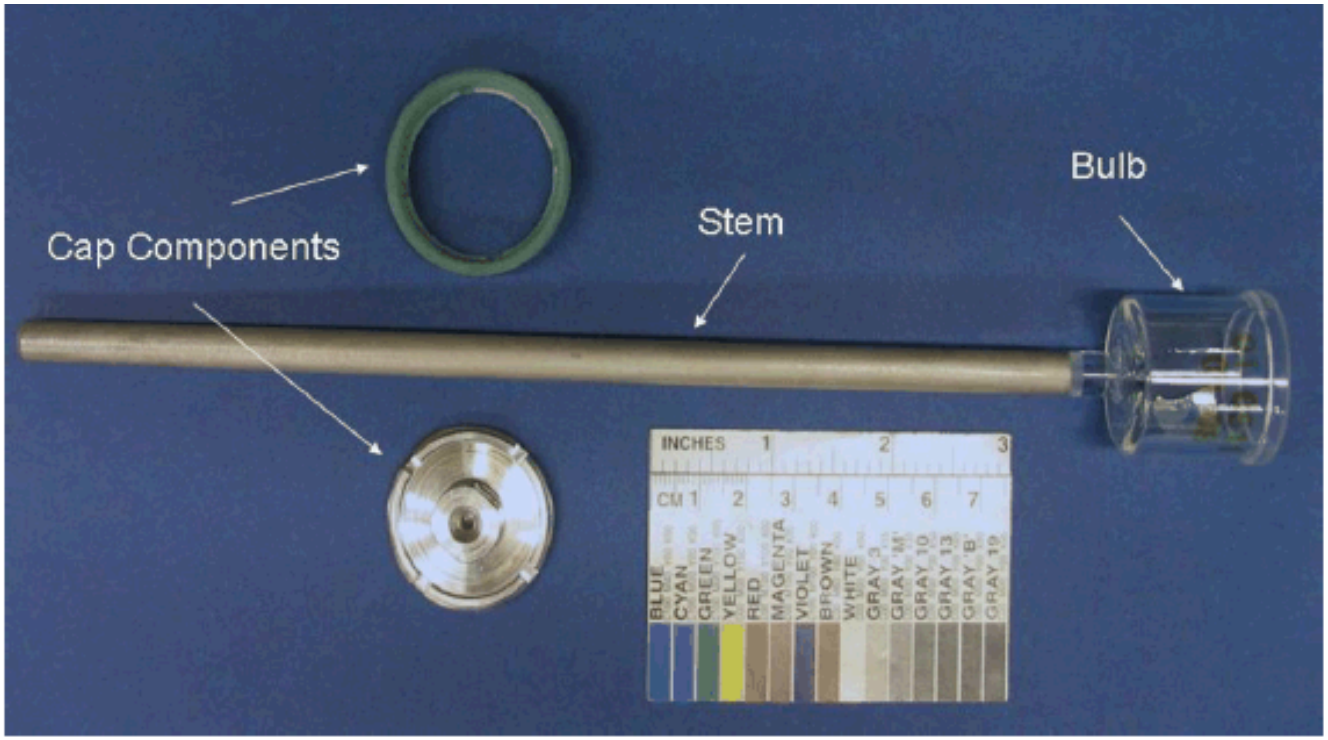


(Kotula, 2009)

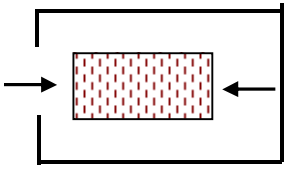


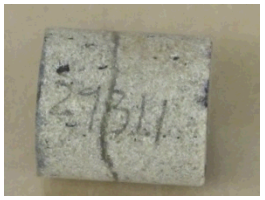
Final serial section analyzed by transmission electron microscopy with analysis of characteristic X-rays

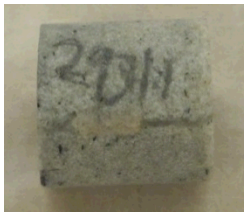
Mercury Intrusion Porosimetry



Sample in bulb is intruded directionally by mercury



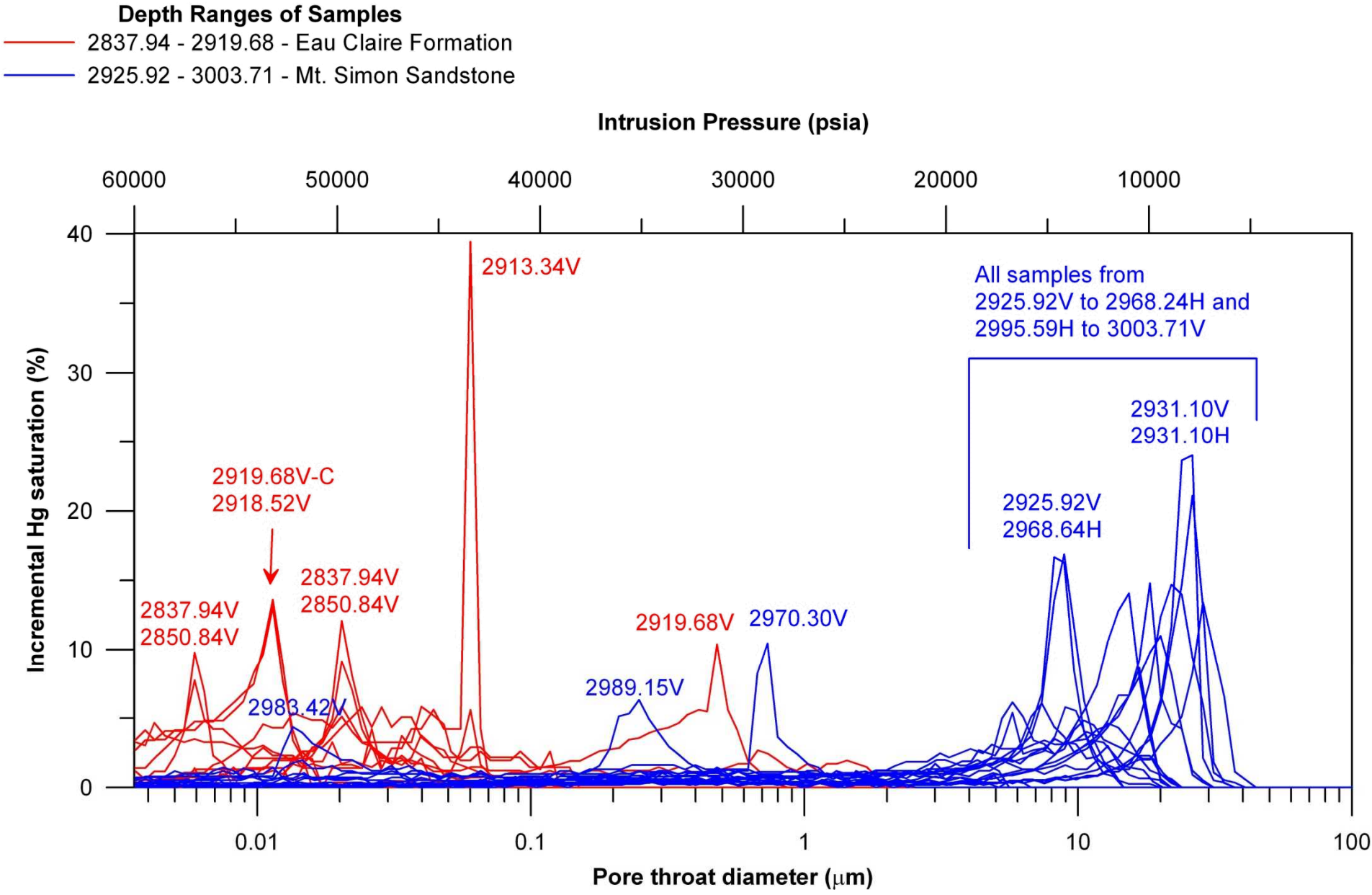




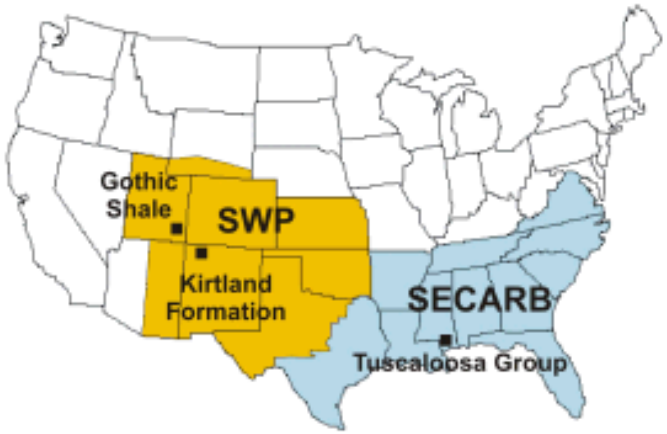
(Sigal 2009)

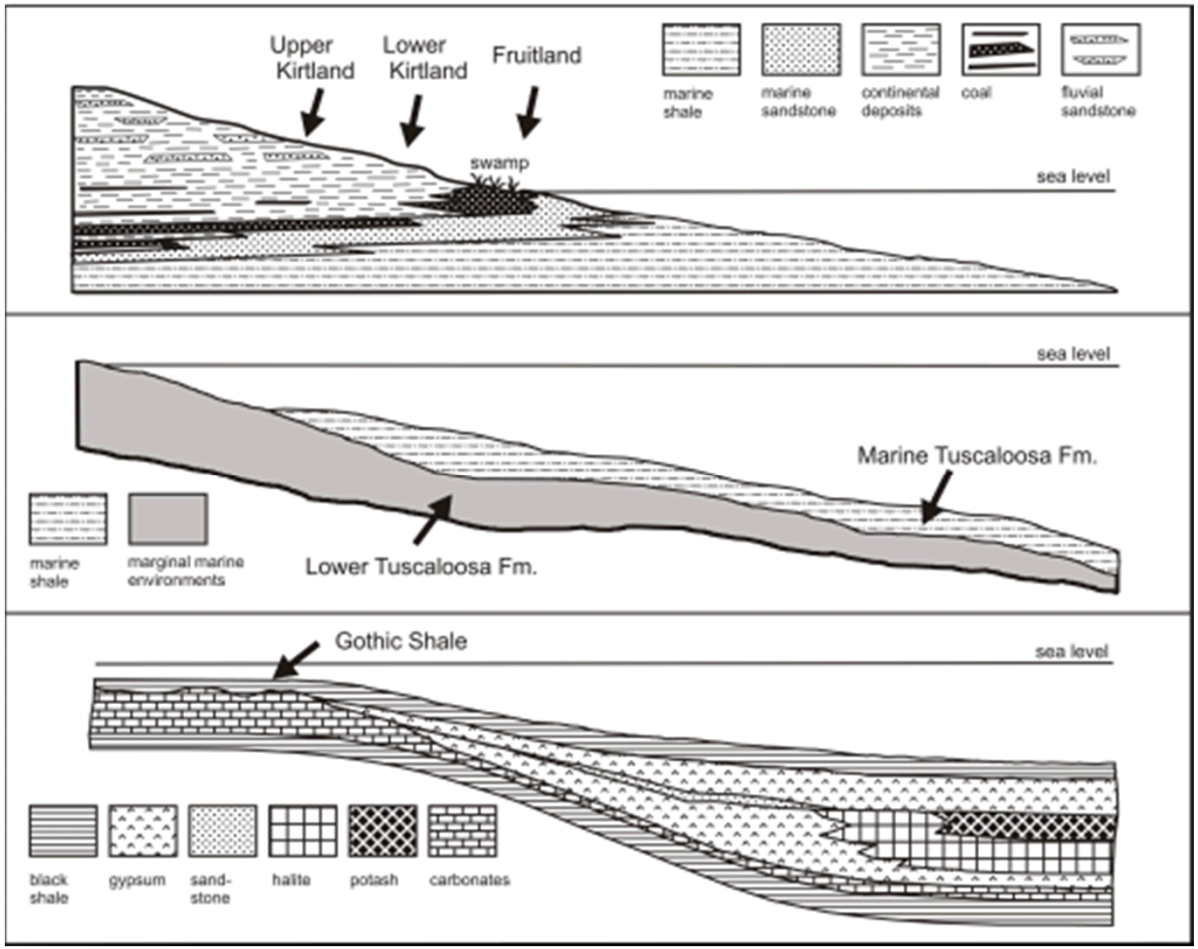
$$d = \frac{4\gamma\left|\cos\theta\right|}{P_c}$$

$$P_{groundwater/air} = P_{air/mercury}\frac{\left(\gamma_{groundwater/air}\cos\theta_{groundwater/air}\right)}{\left(\gamma_{air/mercury}\cos\theta_{air/mercury}\right)}$$

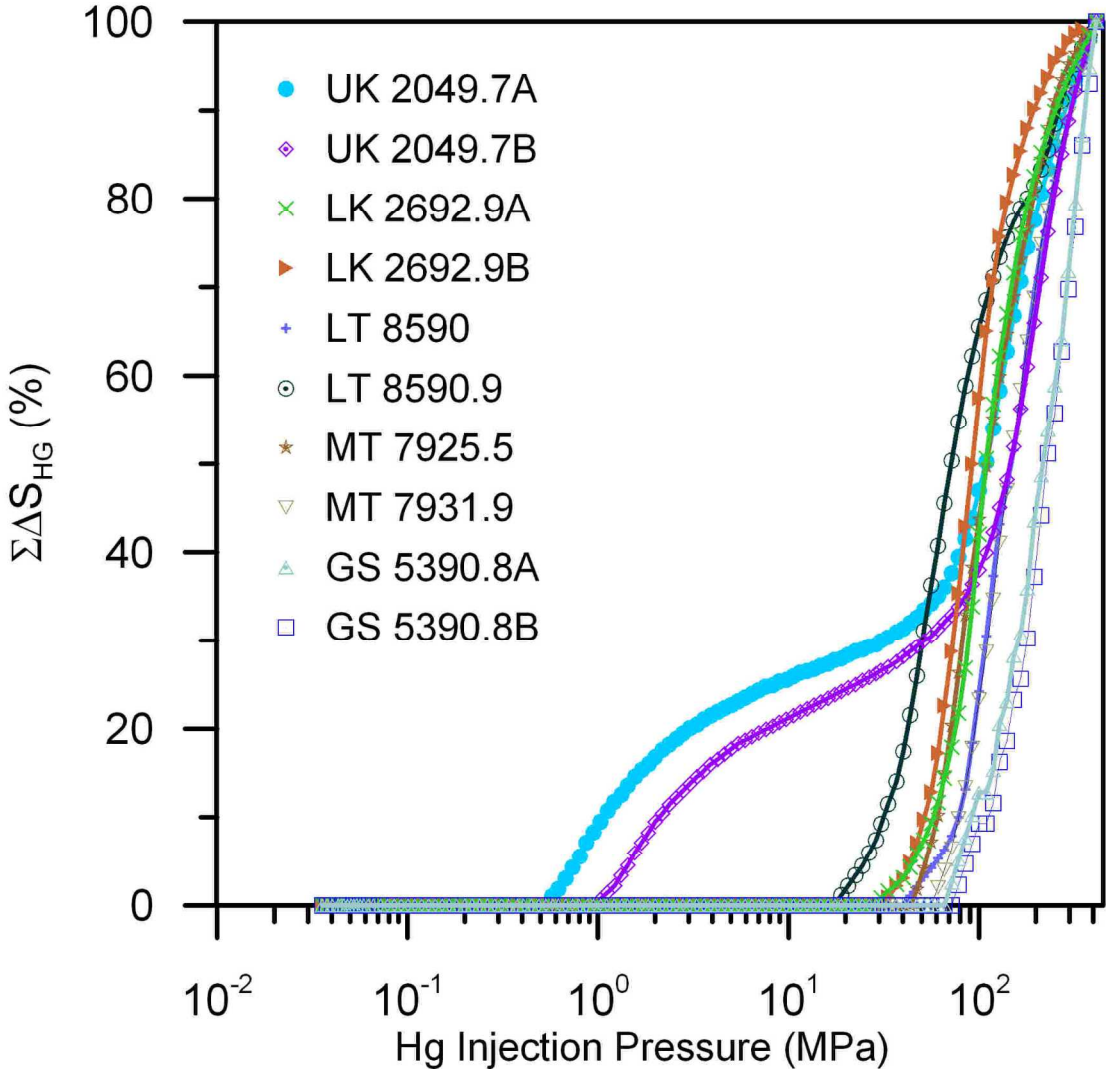

Depth Ranges of Samples
2837.94 - 2919.68 - Eau Claire Formation
2925.92 - 3003.71 - Mt. Simon Sandstone
Intrusion Pressure (psia)
60000
50000
40000
30000
20000
10000
Incremental Hg saturation (%)
40
30
20
10
0
2913.34V
All samples from
2925.92V to 2968.24H and
2995.59H to 3003.71V
2931.10V
2931.10H
2919.68V-C
2918.52V
2925.92V
2968.64H
2837.94V
2850.84V
2837.94V
2850.84V
2919.68V
2970.30V
2989.15V
2983.42V
0.01
0.1
1
10
100
Pore throat diameter (μm)

Caprocks Examined for Pore Network Properties and Sealing Characteristics

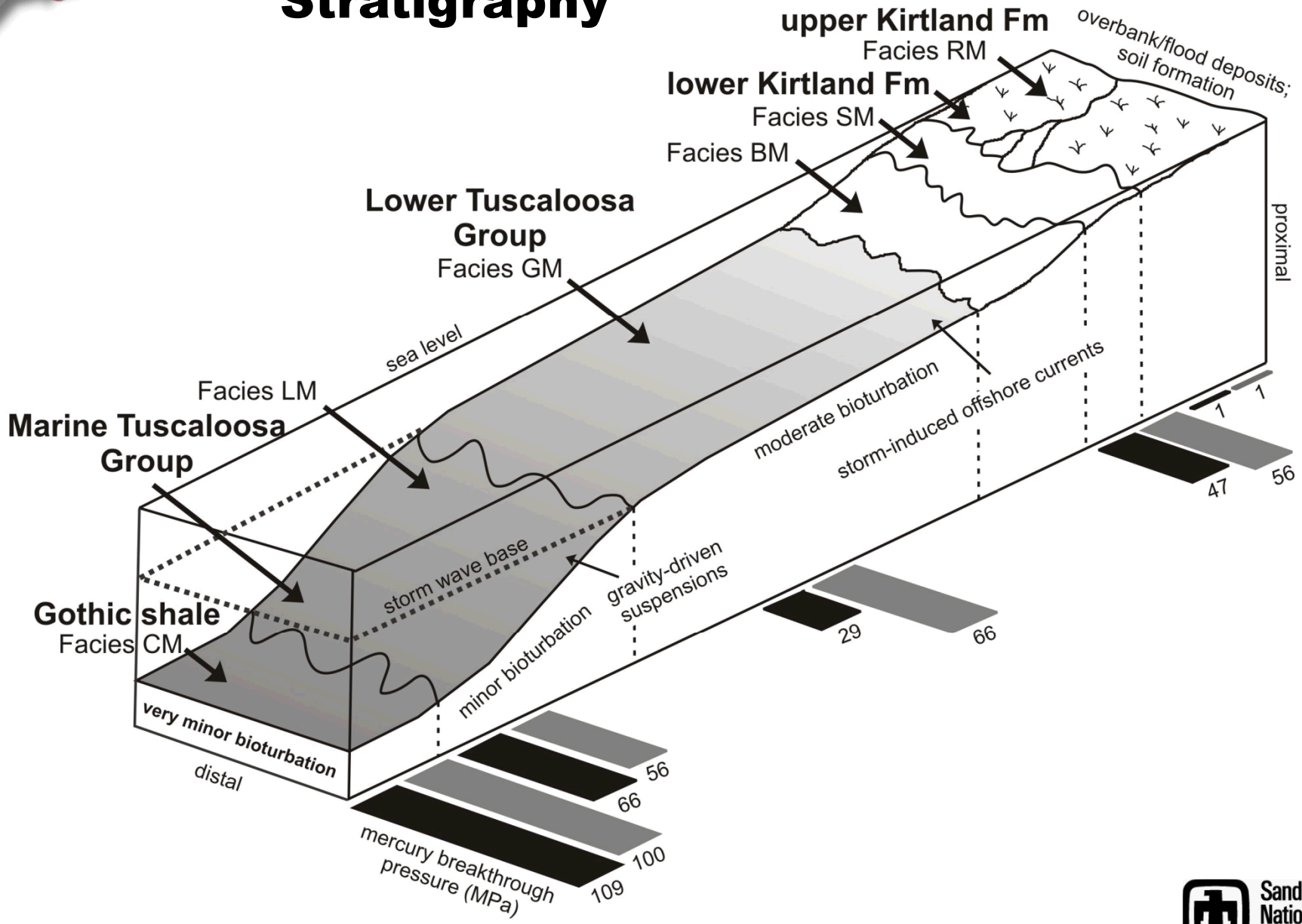




Results: Mercury Intrusion Porosimetry



Breakthrough Pressure and Sequence Stratigraphy



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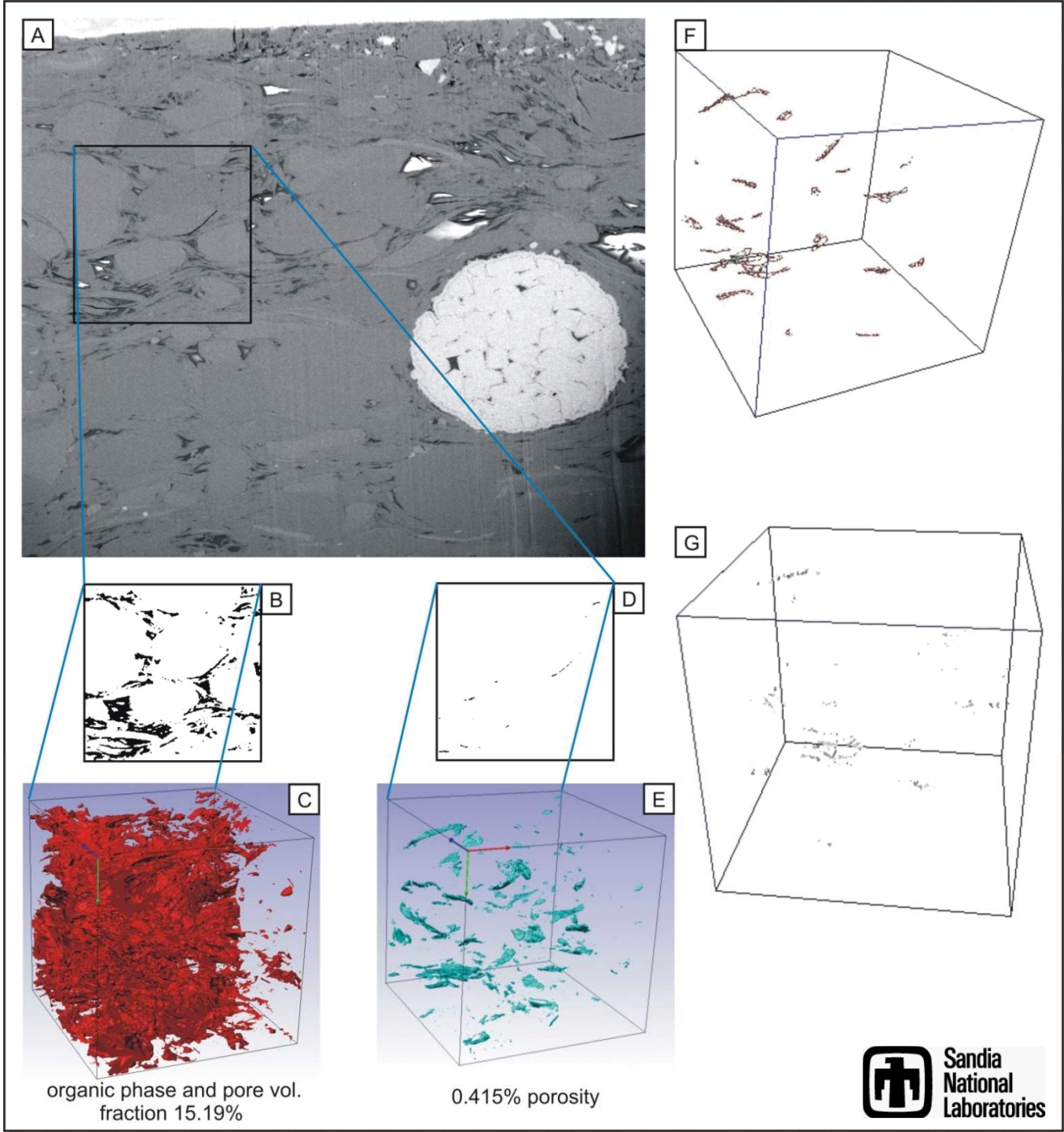
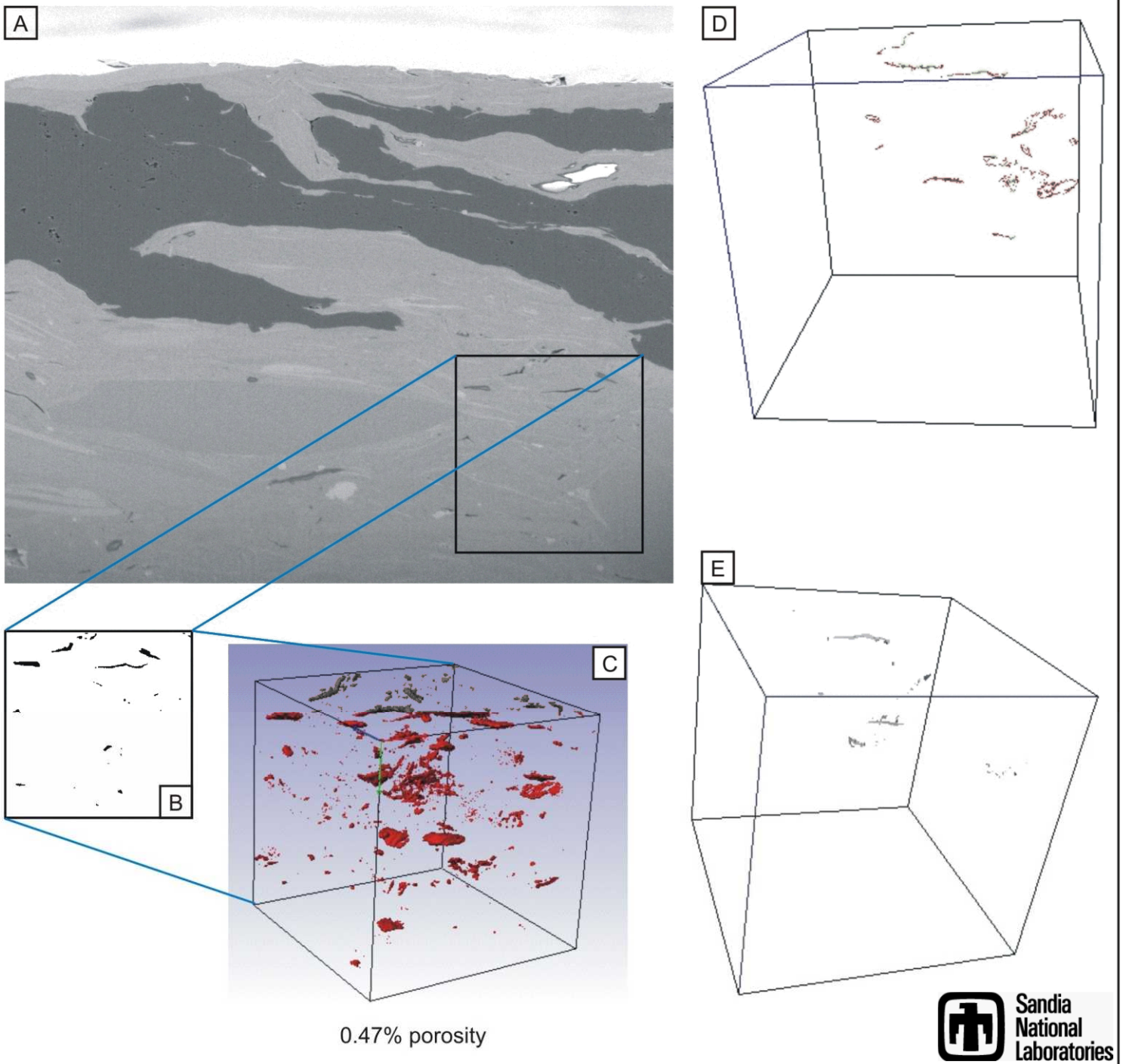
Results

Gothic shale example of FIB/SEM serial and 3D analysis



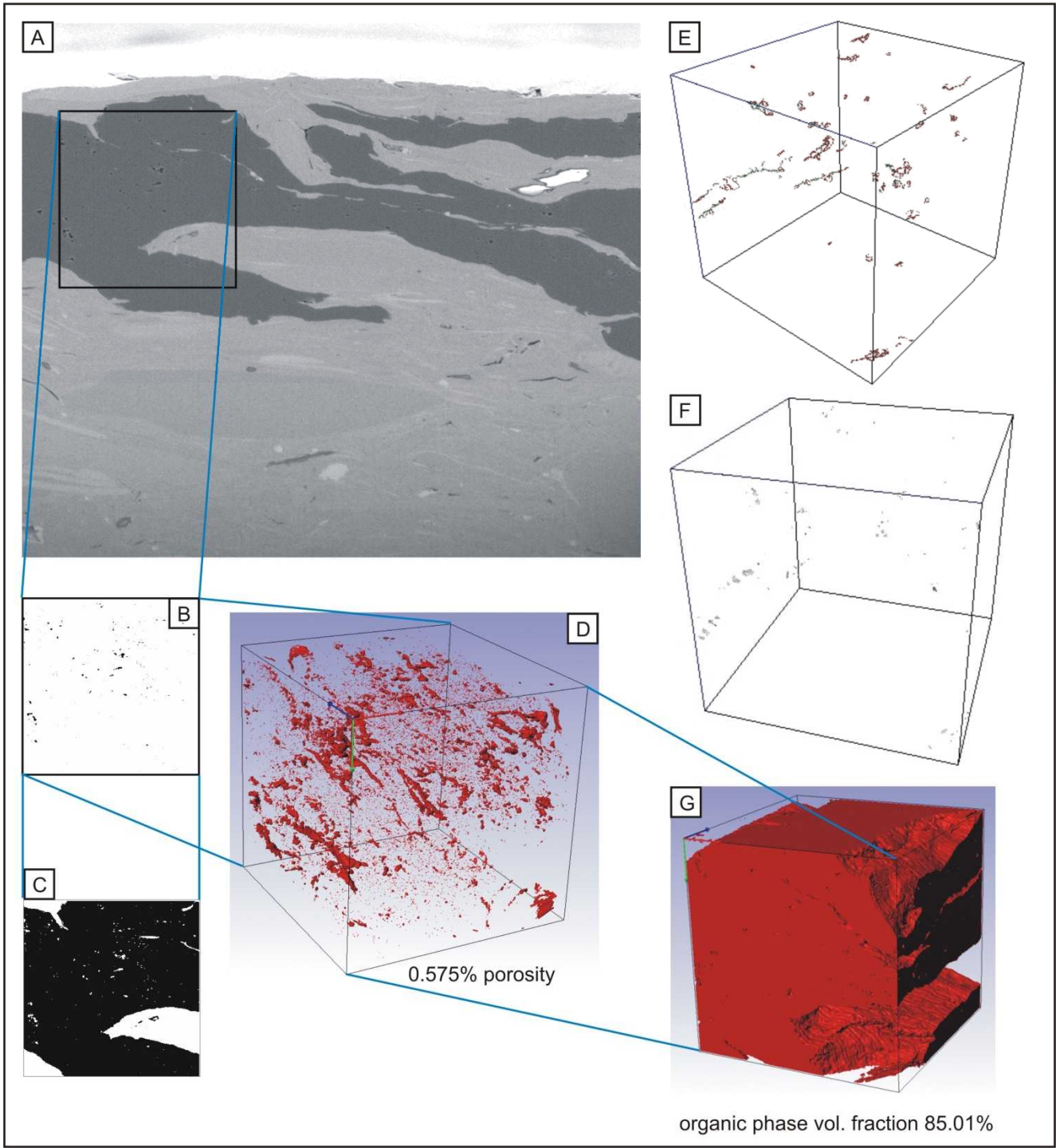
Results

Marine Tuscaloosa Group example of FIB/SEM serial and 3D analysis



Results

Marine Tuscaloosa Group example of FIB/SEM serial and 3D analysis



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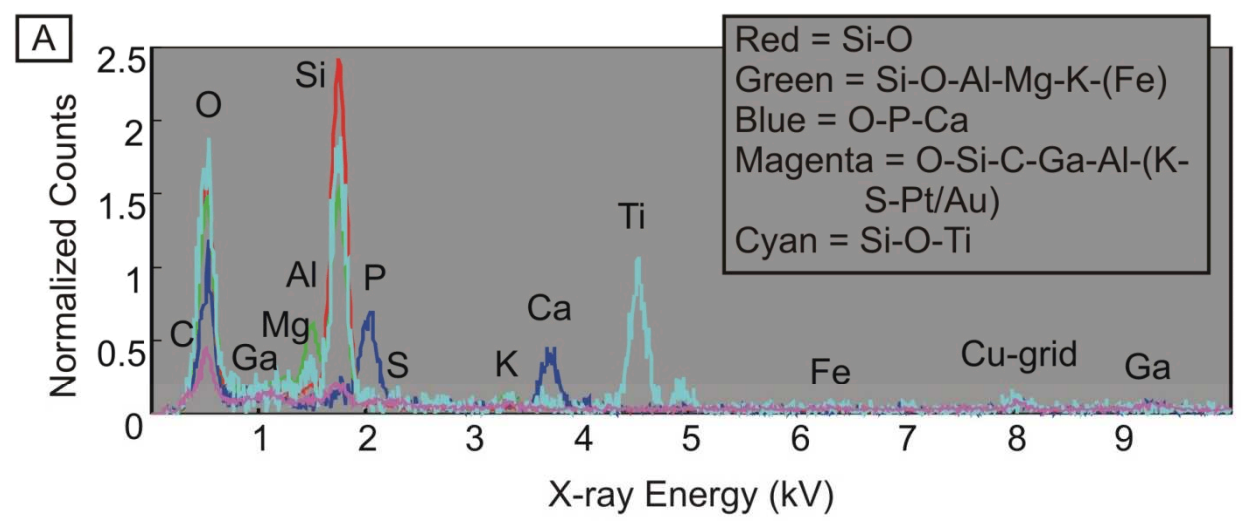
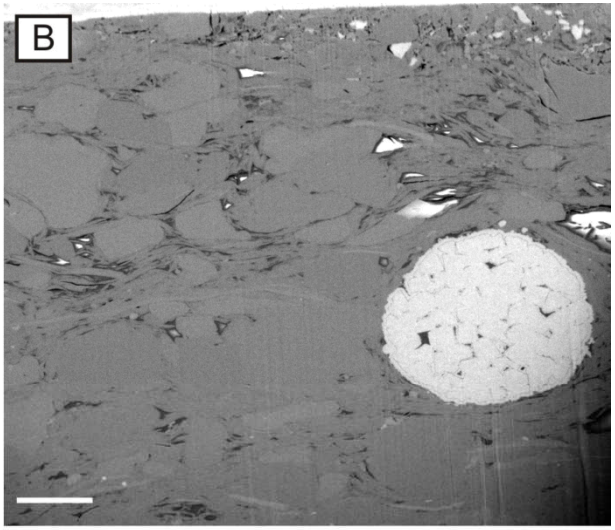
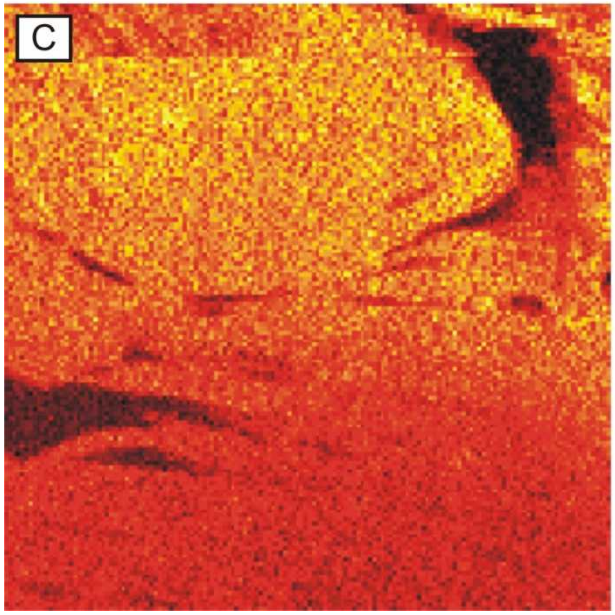
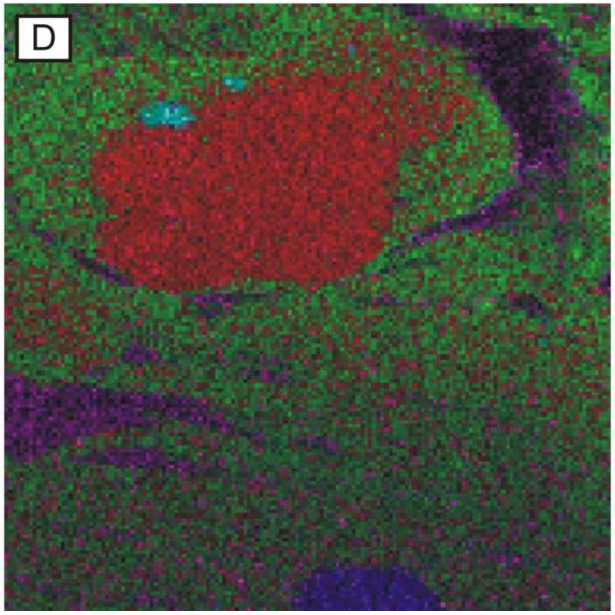
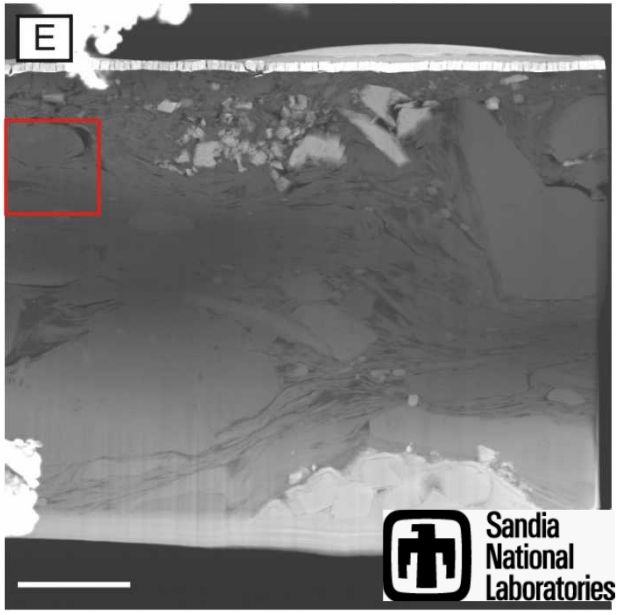
Results: Examination of Pore-lining Phases











Major Findings and Conclusions

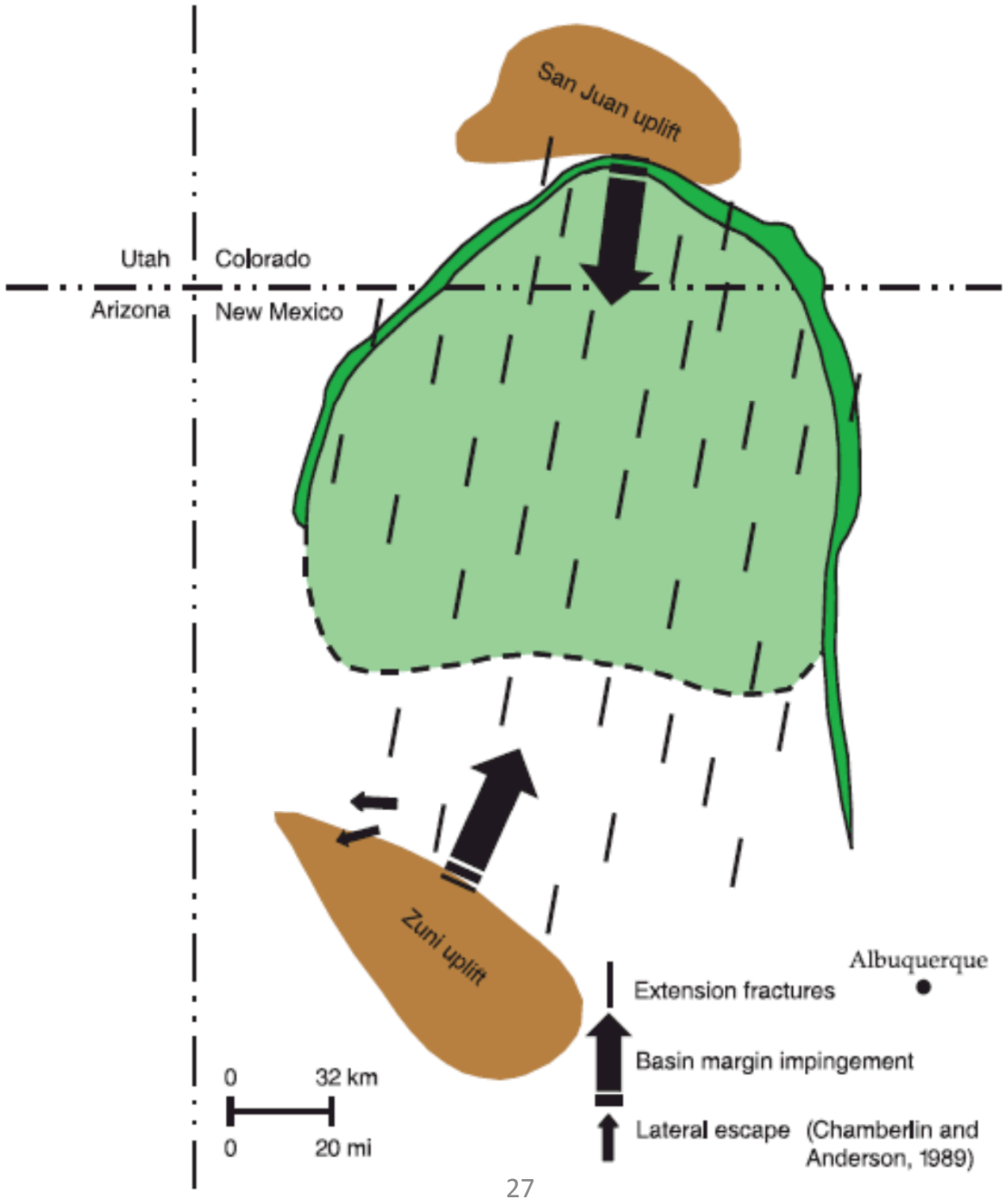
- Primary depositional environmental and current depth of burial strongly control pore network sealing quality, which generally increases from proximal to distal.

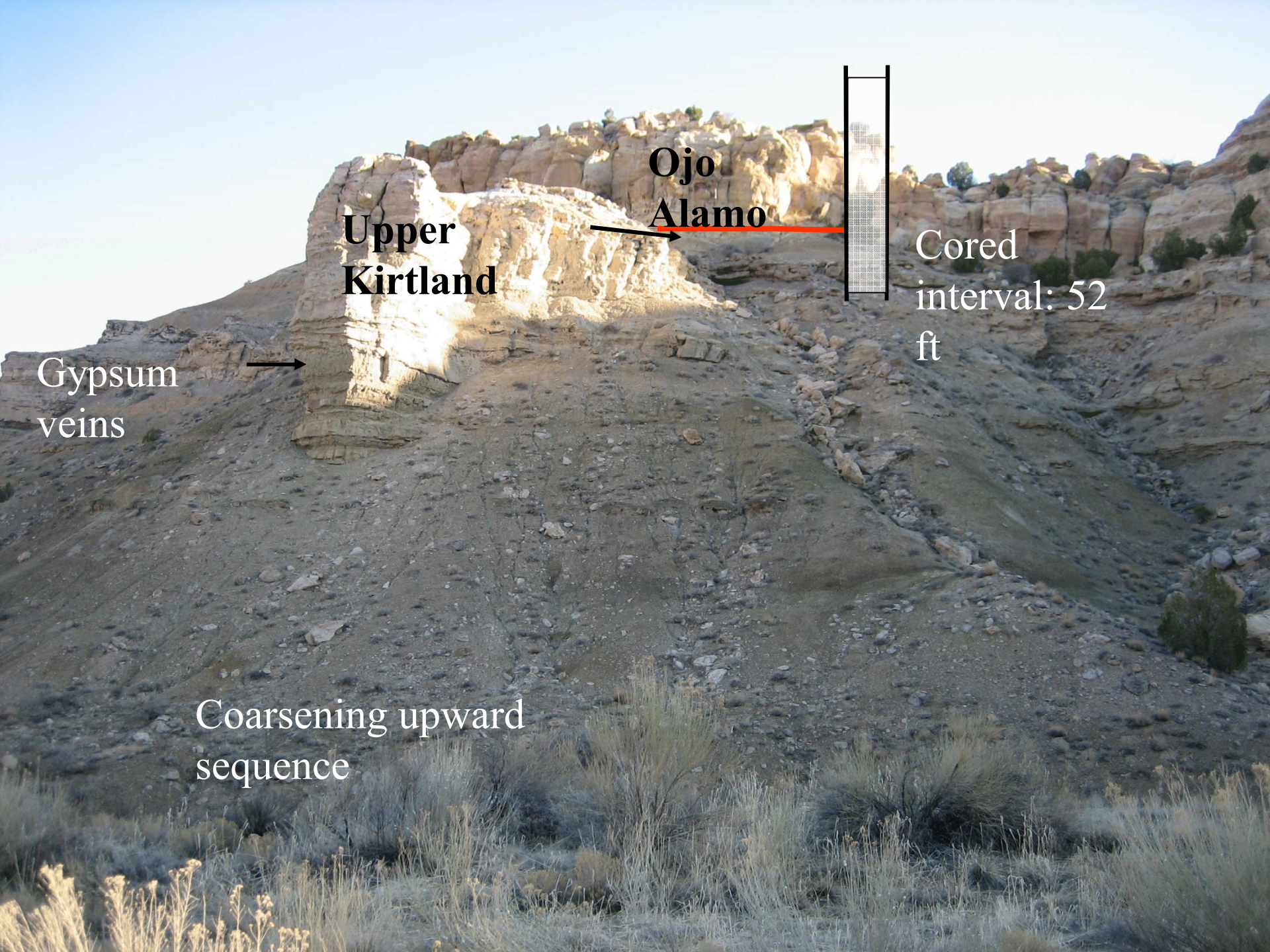
- Pore-lining phases are not directly indicated by XRD, and more measurements on wettability for caprock solid phases are needed.

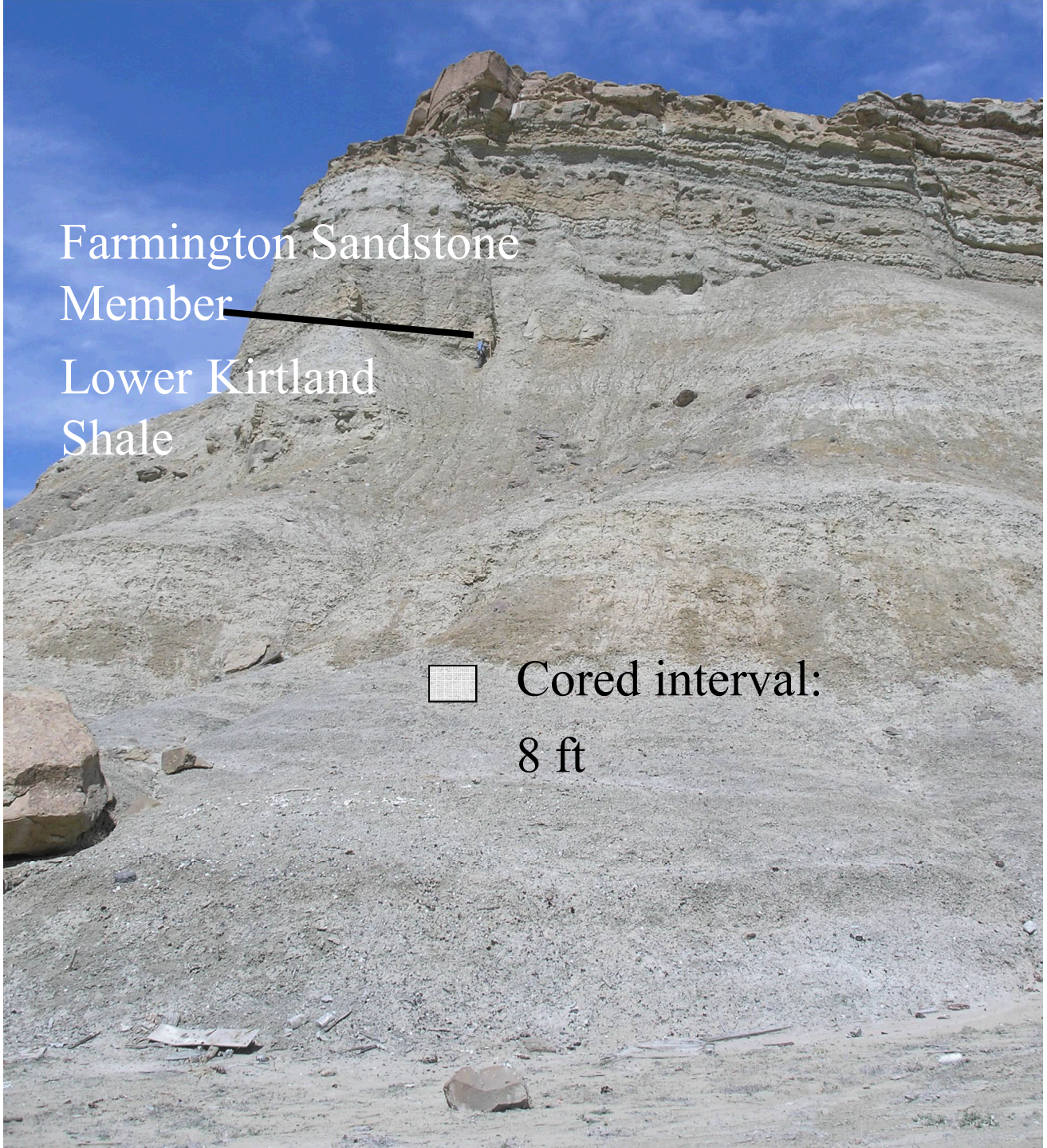
- Deeper seals may have poorer capillary sealing if muscovite-like wetting dominates.

Main Questions, Research Objectives

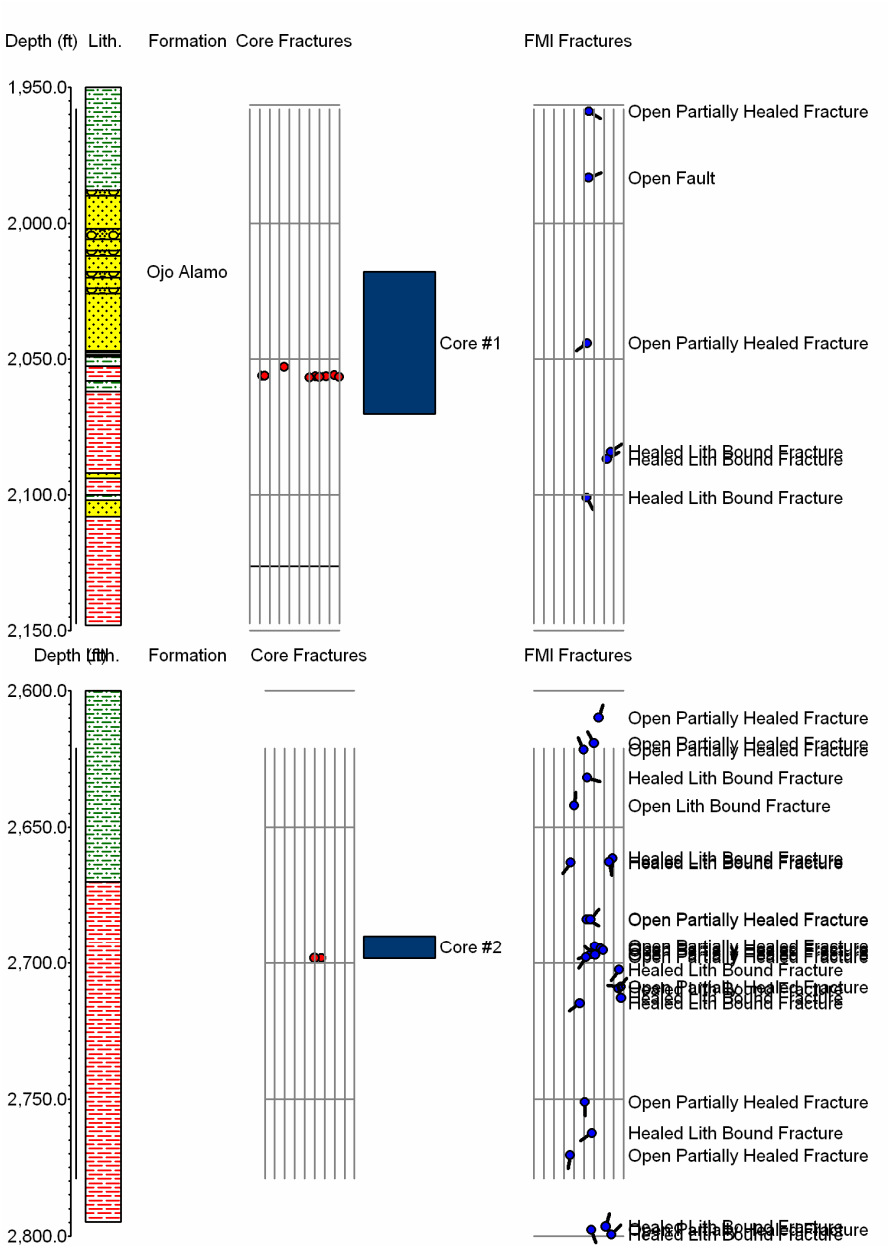
1. What geologic conditions and pore network characteristics contribute to the formation of high quality sealing caprock for CO_2 storage?
2. **What governs transport at specific sites: pore networks or "seal bypass systems"? And how is this effectively determined?**


San Juan uplift
Utah
Colorado
Arizona
New Mexico
Zuni uplift
Albuquerque
Extension fractures
Basin margin impingement
Lateral escape (Chamberlin and Anderson, 1989)
0
32 km
0
20 mi

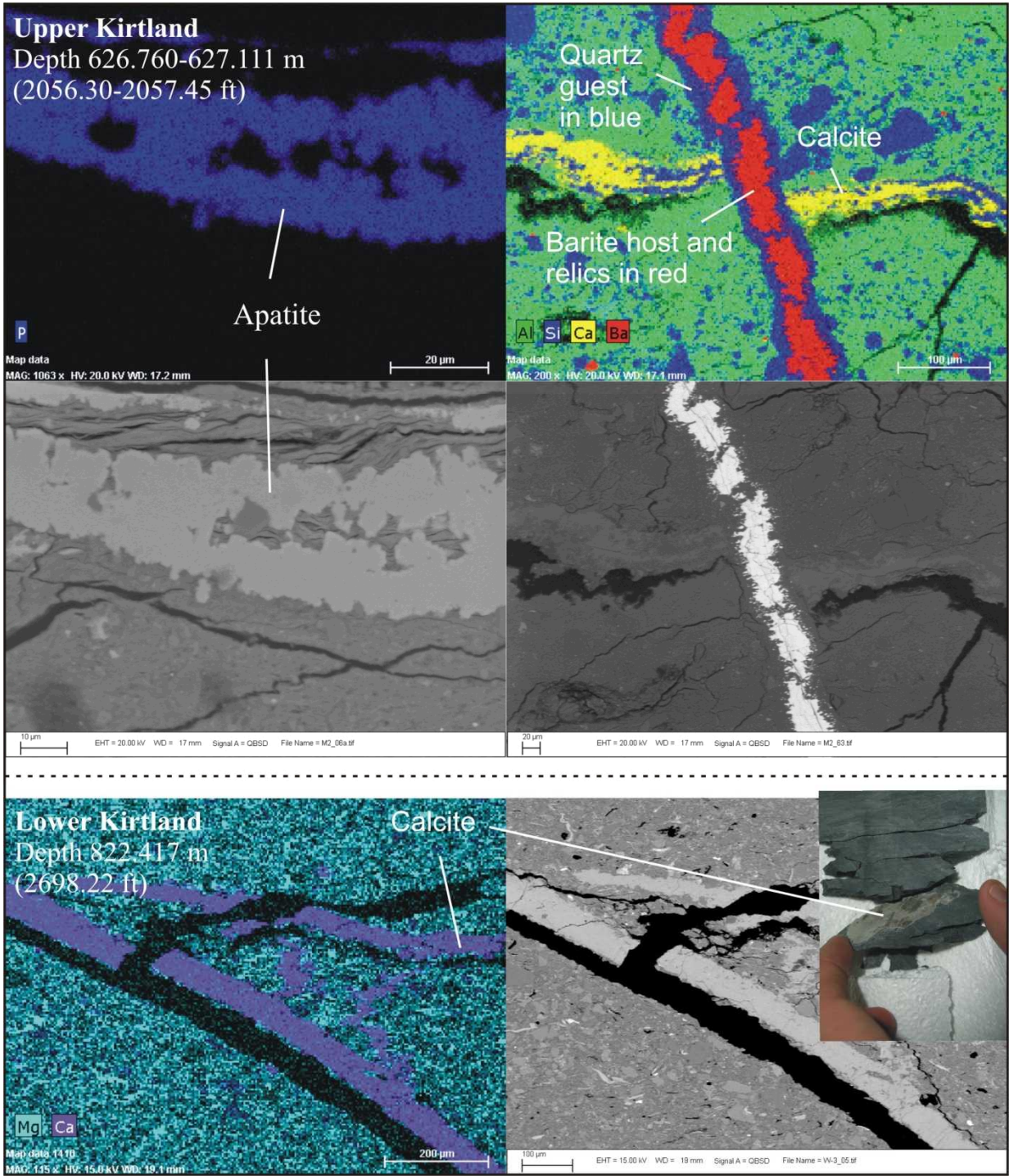

Ojo Alamo
Upper Kirtland
Cored interval: 52 ft
Gypsum veins
Coarsening upward sequence


Farmington Sandstone Member
Lower Kirtland Shale
Cored interval:
8 ft

Potential Seal Bypass Features



Potential Seal Bypass Features



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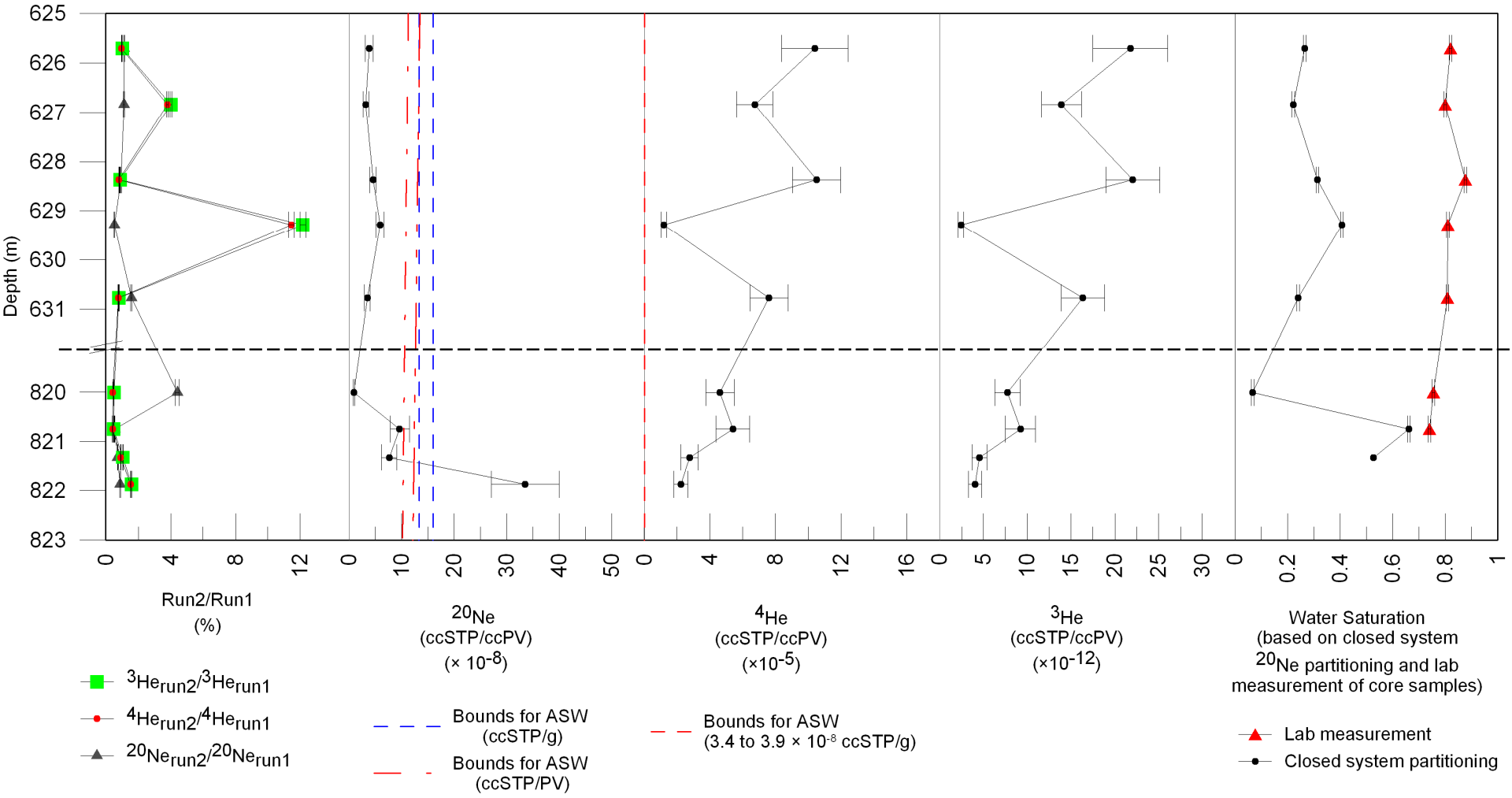
Results: Noble Gas Data



$^{3}He/^{4}He$ ratios normalized by $^{3}He/^{4}He$ of atmosphere (R/Ra) range from 0.12 to 0.16

Major Findings and Conclusions

- Abundant seal bypass features exist within the Kirtland Formation; but helium data does not support a seal bypass system.

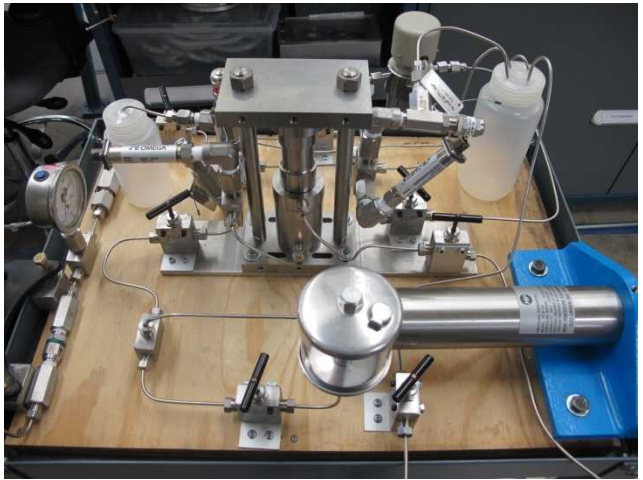
Research Needs

- Relative role of CO2 and/or brine through natural versus man-made seal bypass
- Rates of CO2 leakage through (sub-seismic) fractures and fracture networks
- Leakage metrics for local and global situations – extensive versus intensive metrics
- Dynamic controls on fracture-related transport of CO2 and/or brine

•Surface and intermolecular-related forces need to be included in caprock assessment

- •Dry-out processes – CO_2 will be injected as an anhydrous phase
- •Wettability data for typical caprock phases

(from Heath et al., 2013, COMPRES meeting)



Discussion:

Dealing with Uncertinaty

- Large-scale injection tests
- Risk and performance assessment

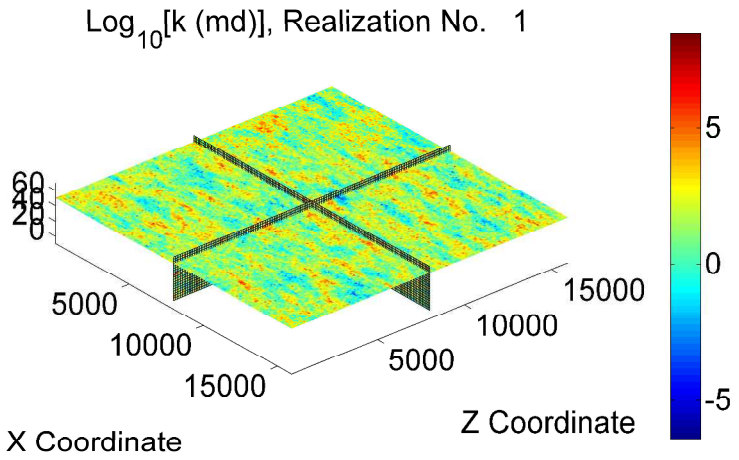
Methods

1. Geostatistics:

Coregionalization and SGSIM

(Rautman and McKenna, 1997; Deutsch and Journel 1992)

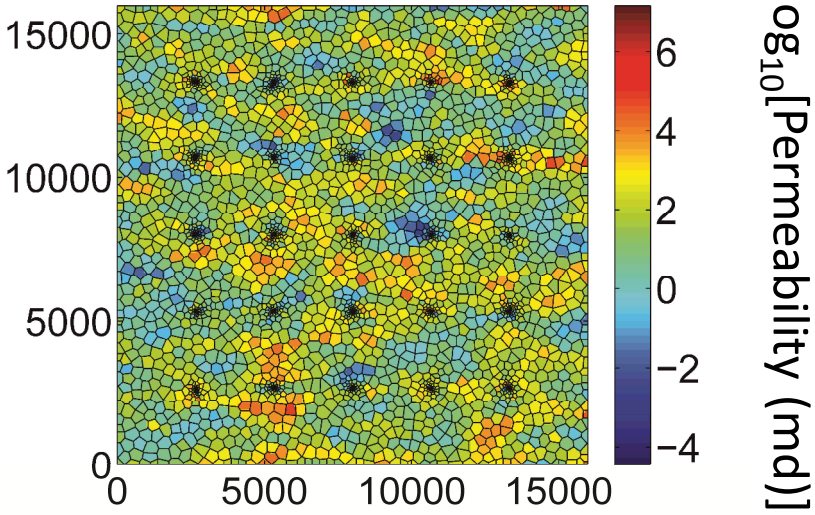
r^2= **0.25 or 0.75**

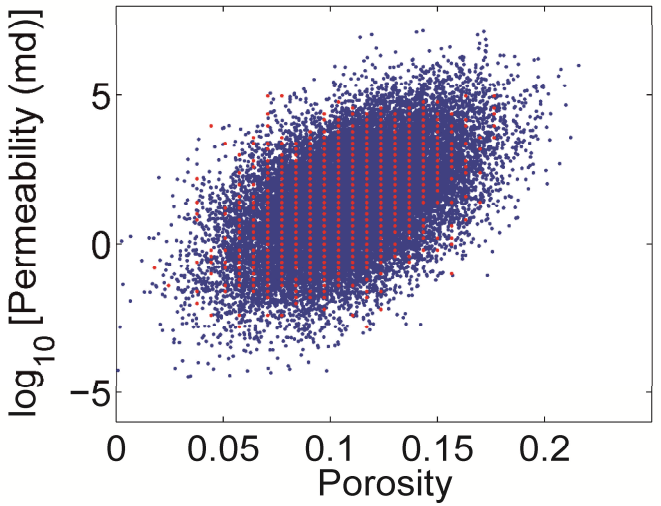


(from Heath et al., 2012, NETL presentation)

2. Multiphase Flow:

TOUGH2-ECO2N

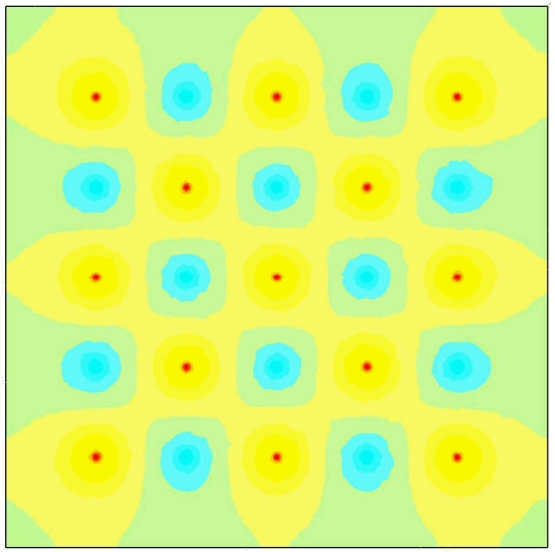




Methods: Base Cases

Time = 36 days

Injection and Extraction



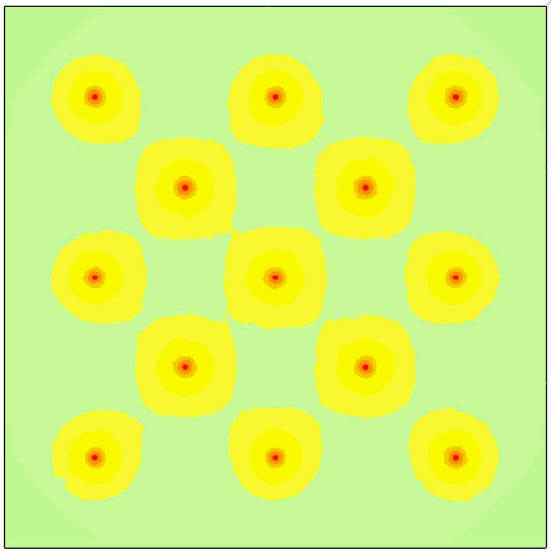
16 km

Press. (Mpa)

2.83e7

1.44e7

Injection only

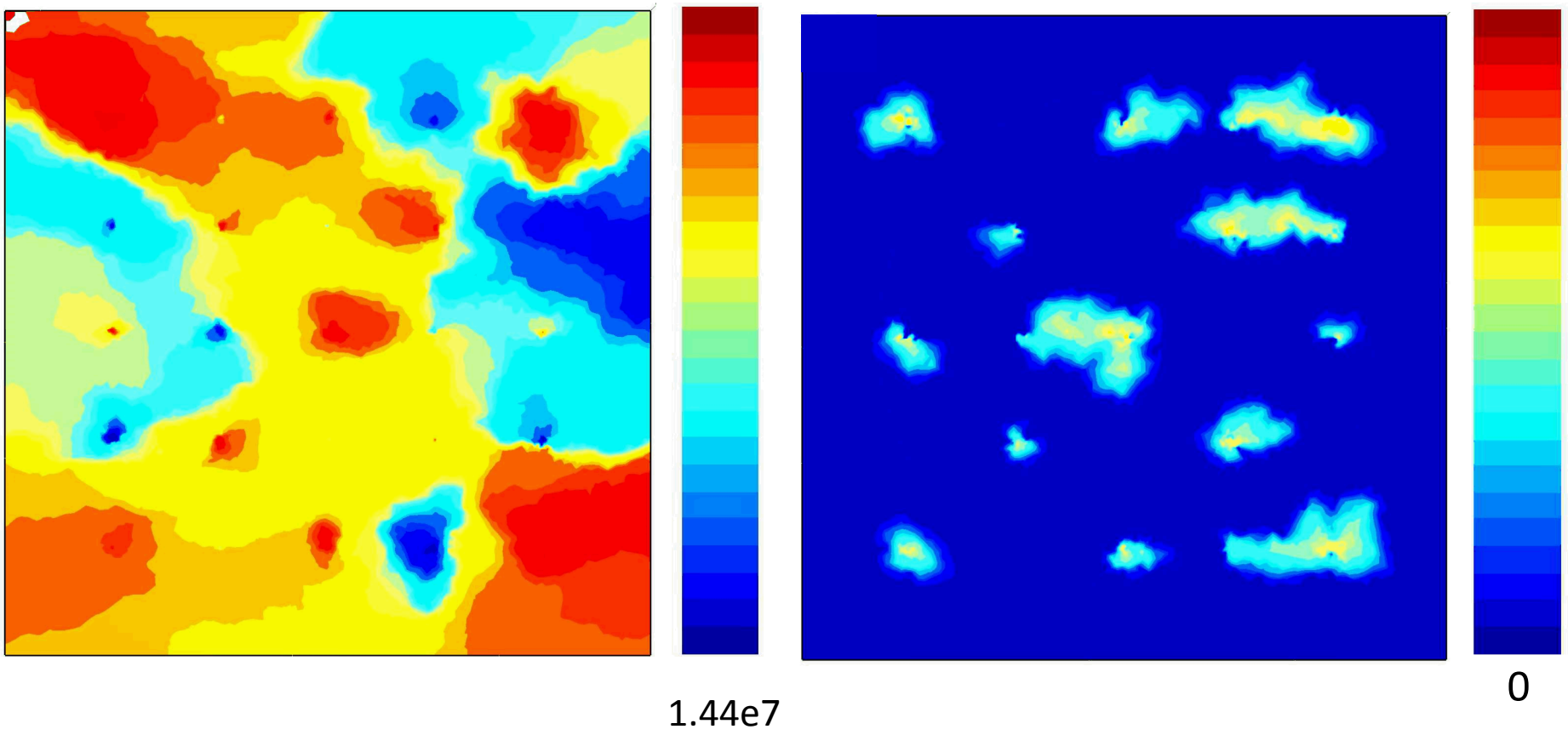


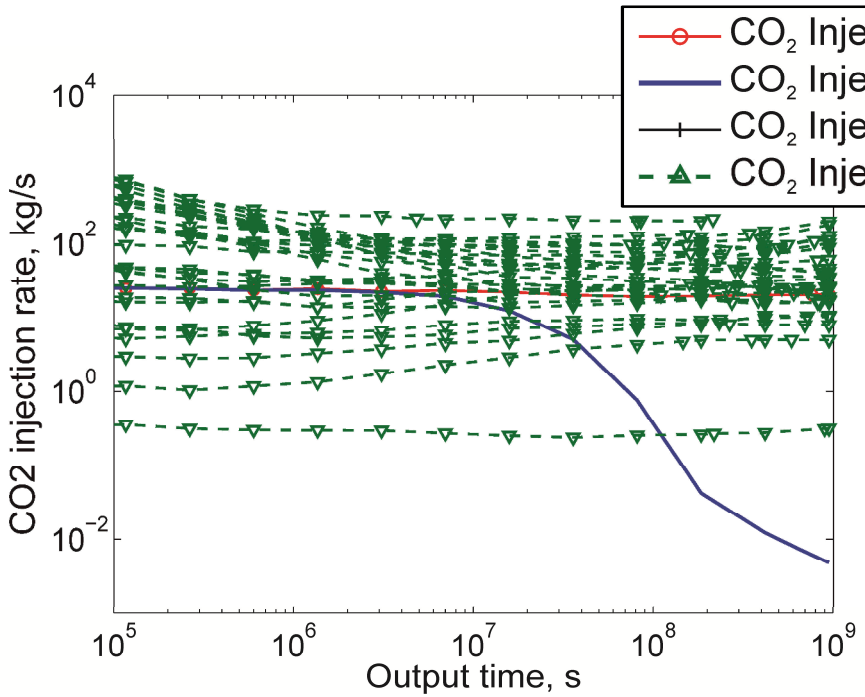
16 km

- Permeability = 29.7 md; porosity = 11.1 % (Finley, 2005)
- CO_2 injection with or without brine extraction
- Maximize flow rates: constant pressure at wells
- Closed reservoir
- Homogenous and heterogeneous cases

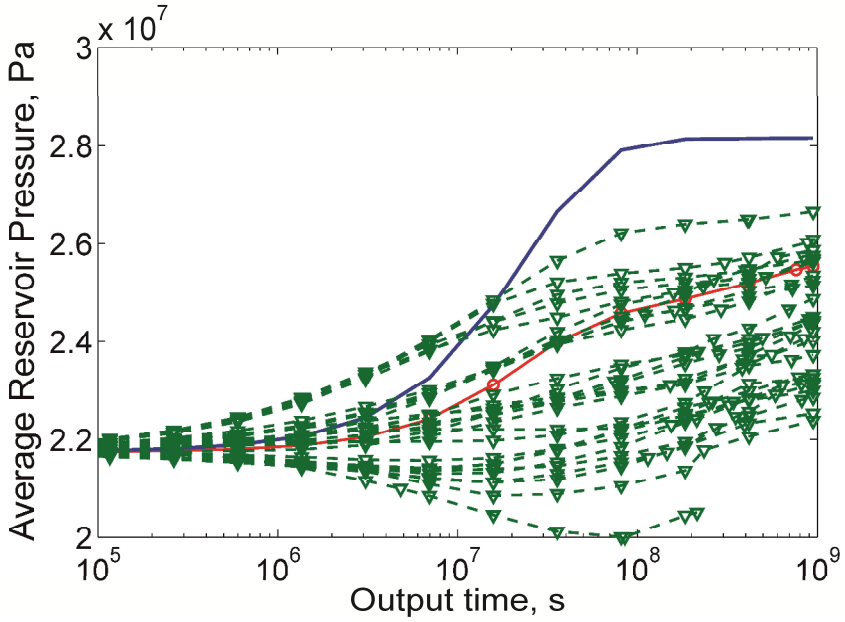
Heterogeneous Example

Time = 6 years





Extreme variation in injection rate for a set of simulations



Heterogeneous cases display a range of behaviors

30 geostatistical realizations