Advanced Subsurface Characterization for CO_2 Geologic Sequestration and Induced Seismicity Evaluations

Tiraz Birdie, Lynn Watney, Aimee Scheffer, Jason Rush, Eugene Holubnyak, Mina Fazelalavi,

John Doveton, Jennifer Raney, Saugata Datta, Dennis Hedke, and Jennifer Roberts

Carbon Management Technology Conference

November 19th 2015

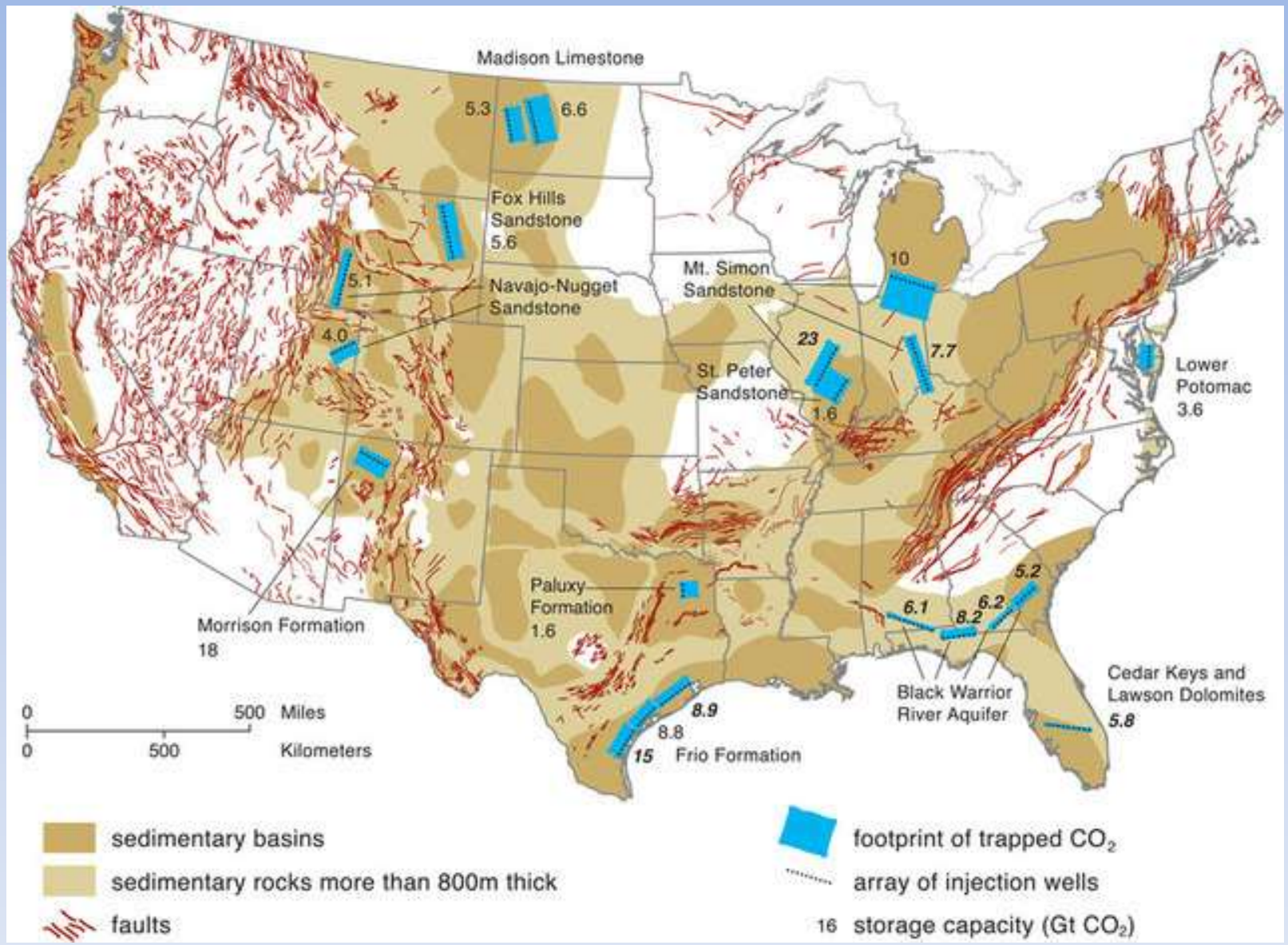
Sugarland, TX

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

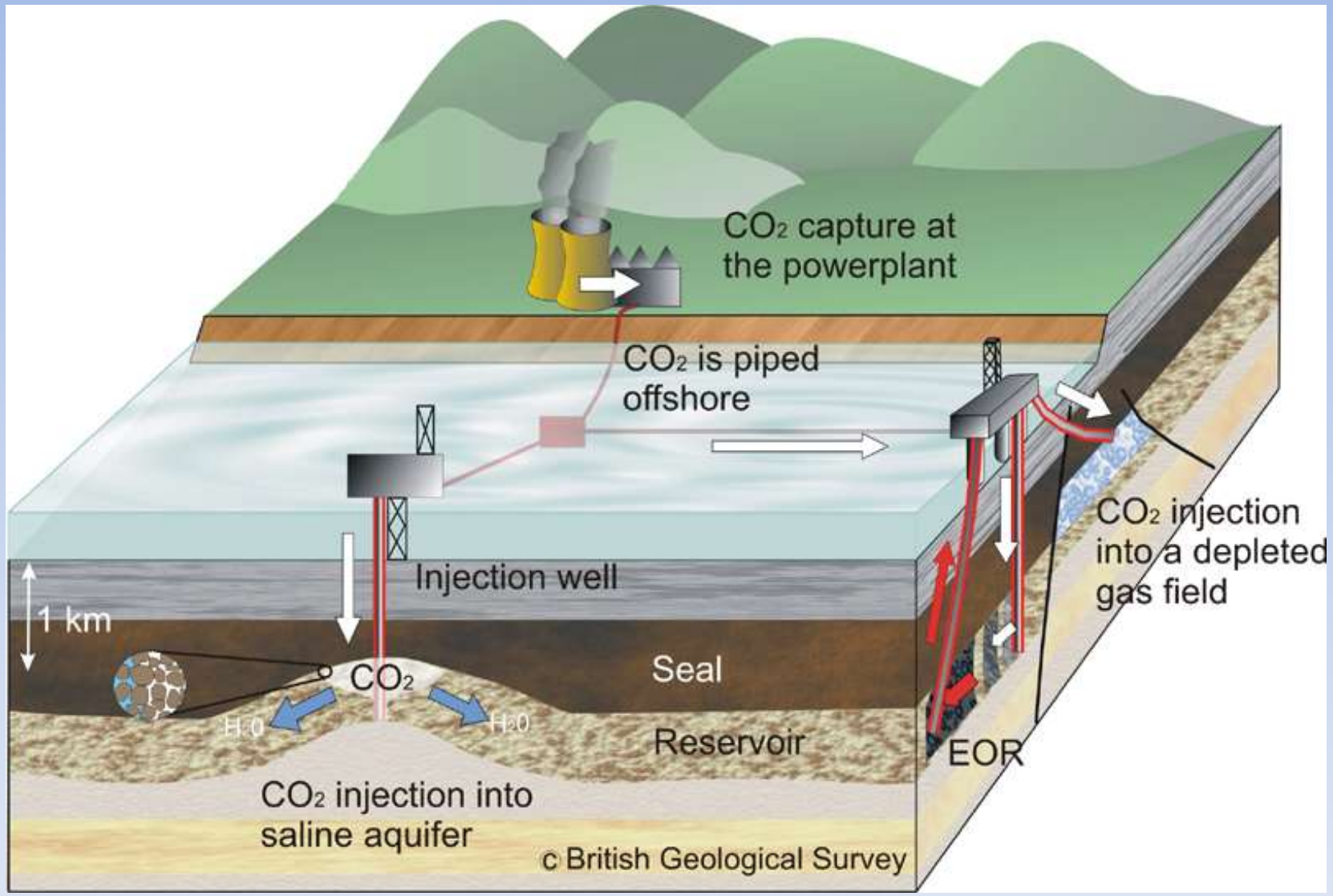
TBirdie Consulting inc

NETL

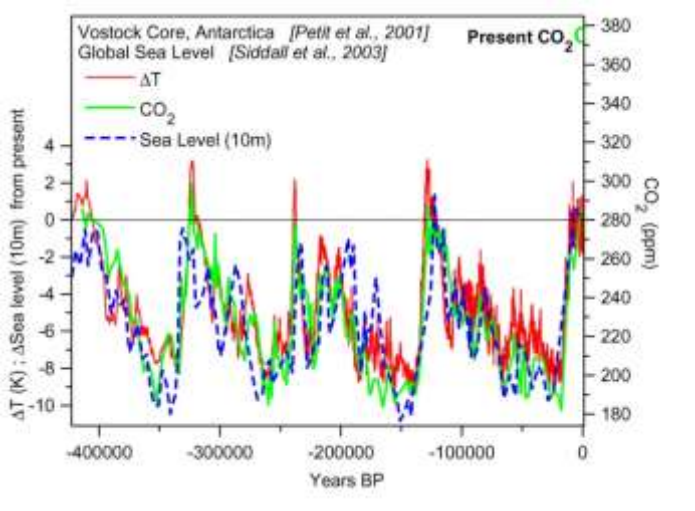
Sedimentary Basins in the US



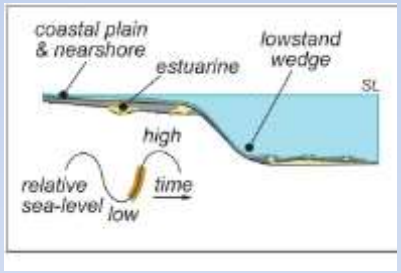
Suitability of Sedimentary Basins for Geologic Sequestration



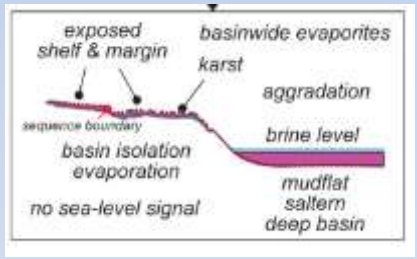
Evolution of Sedimentary Basins

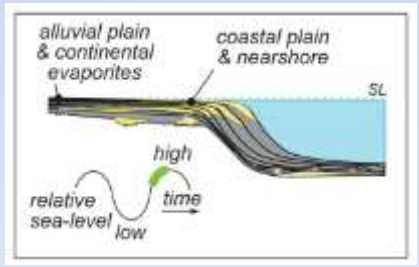


Carbonates

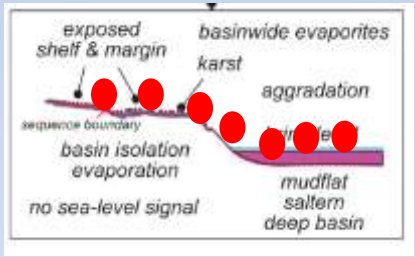


Evaporites





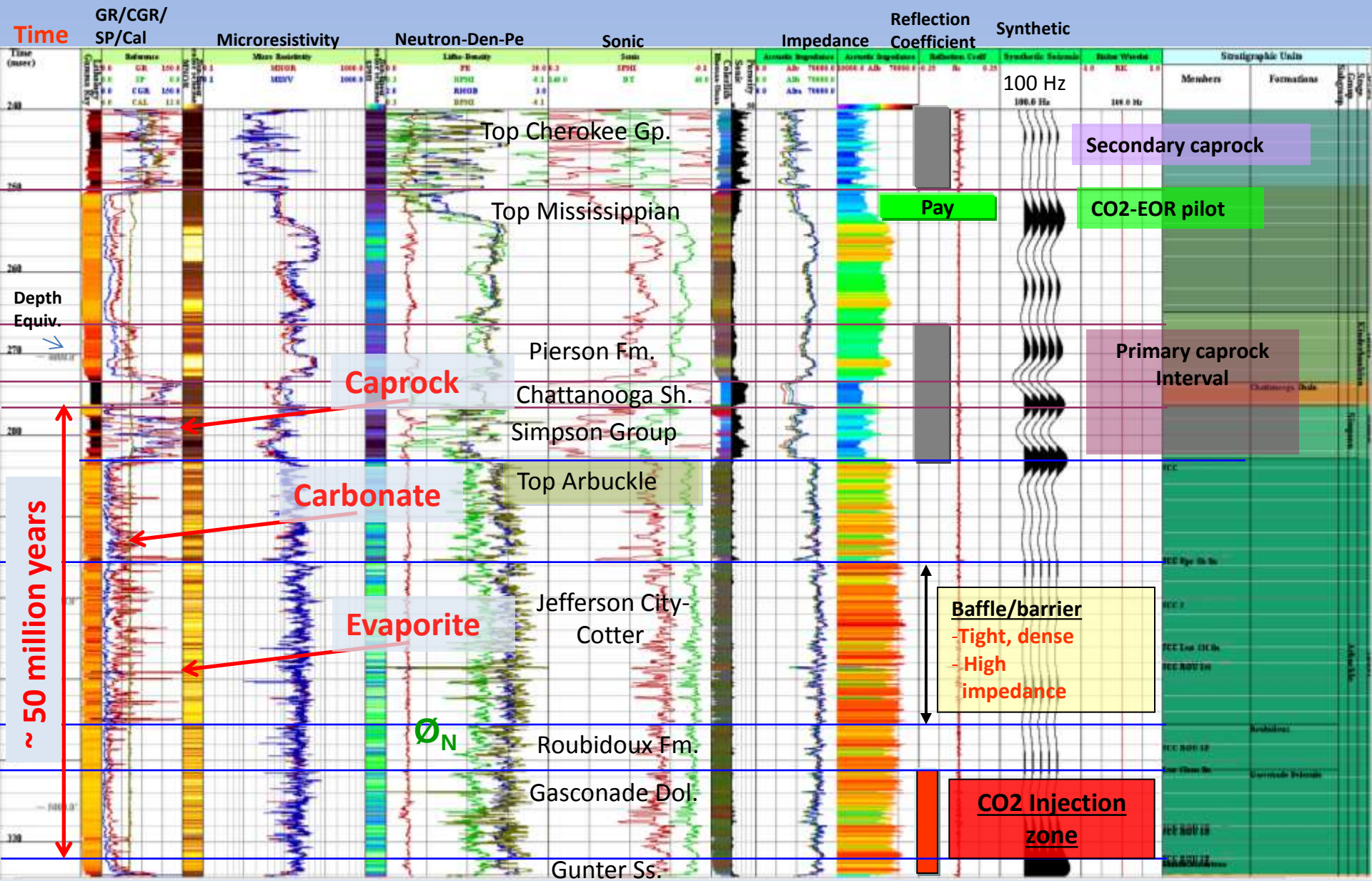
Shales (Caprock)



Present Day Evolution of Evaporative Cap - Arabian Gulf

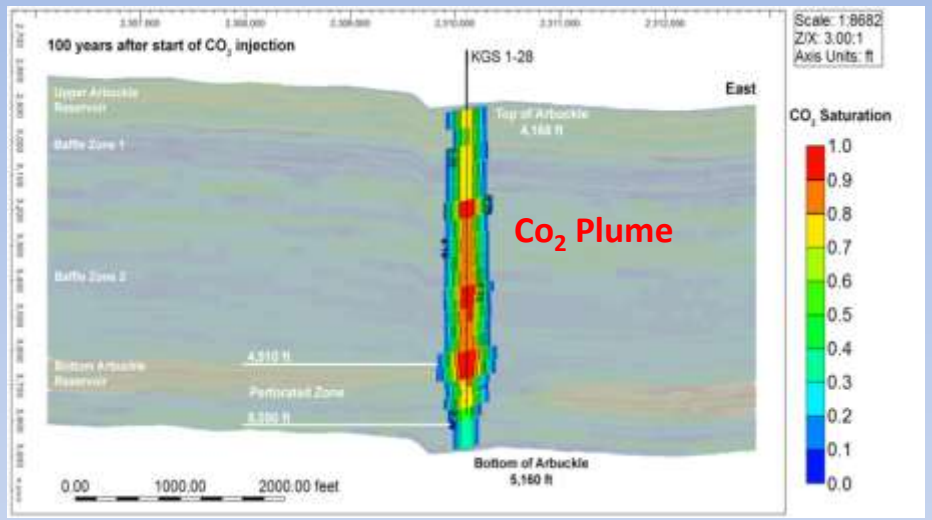
Analog to portions of the Arbuckle CO_2 injection zone at Wellington Field, KS

Tidal Effects Reflected in Geologic Logs

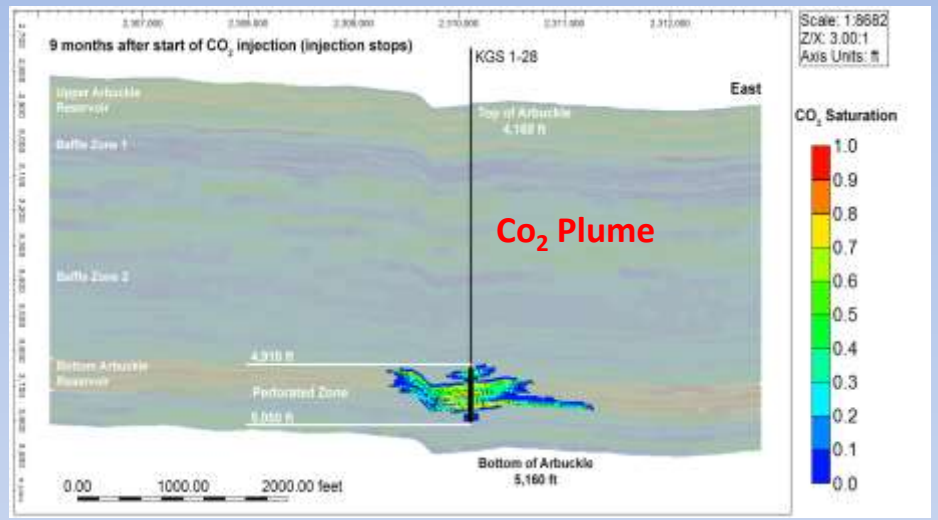


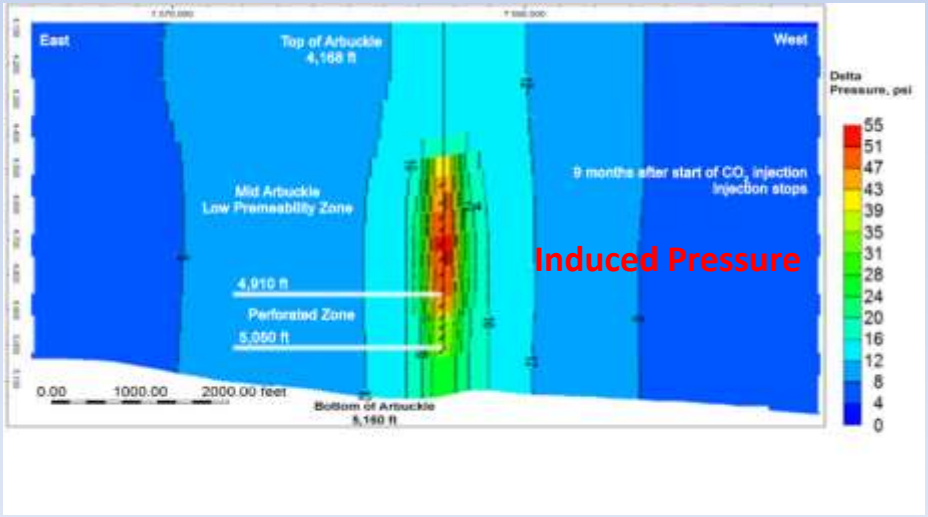
Importance of Characterization on CO2 Plume and Pressure Projections

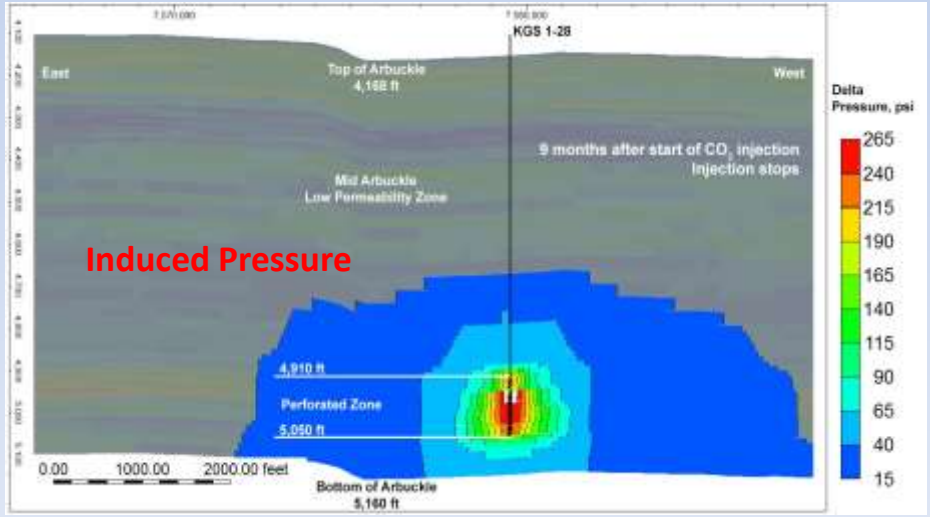
Coarse Vertical Characterization



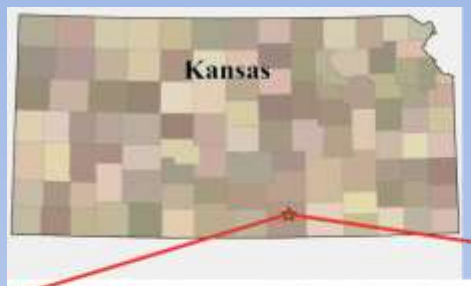
Meter-scale Vertical Characterization

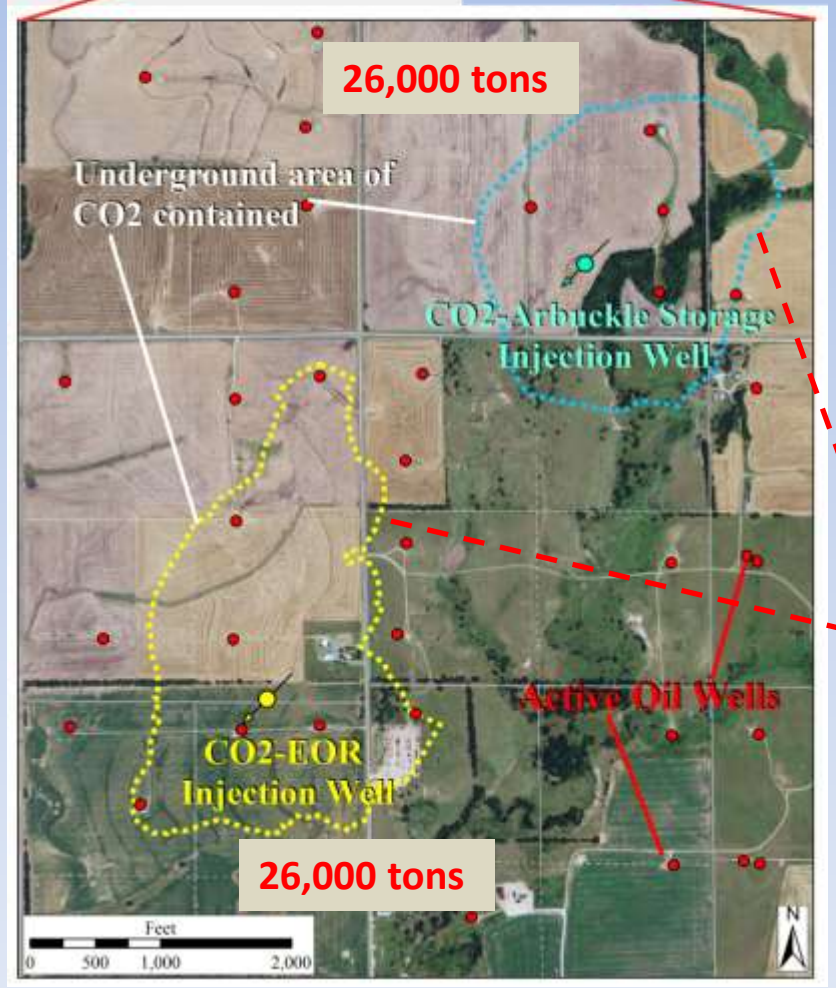


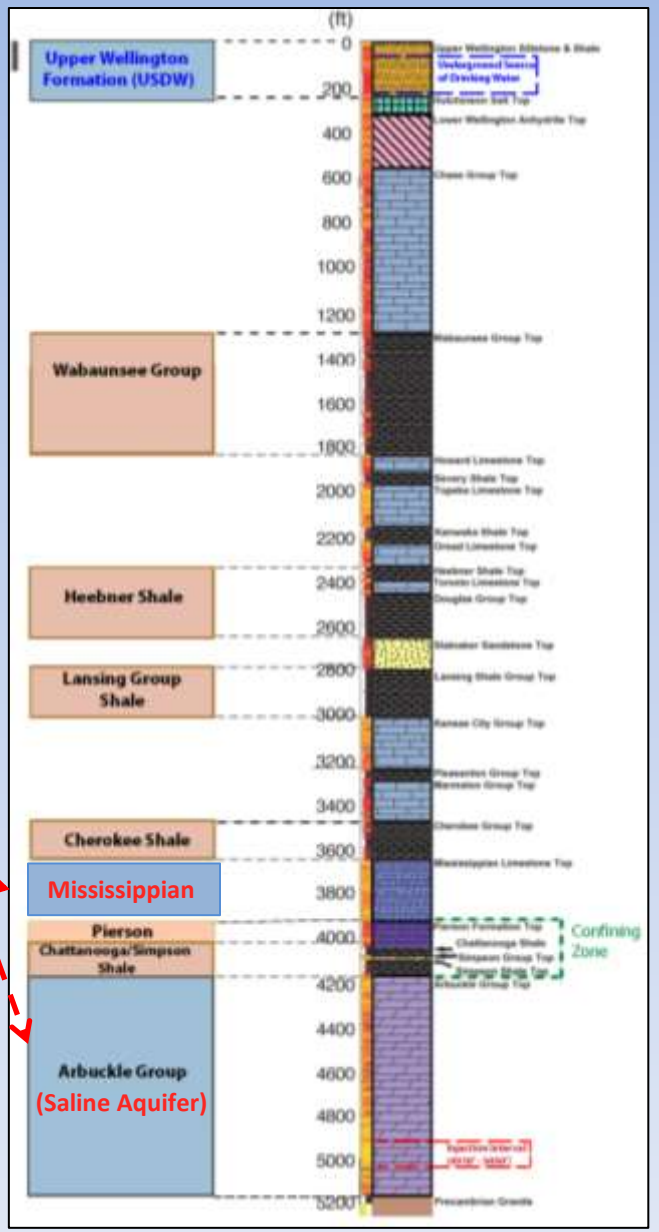




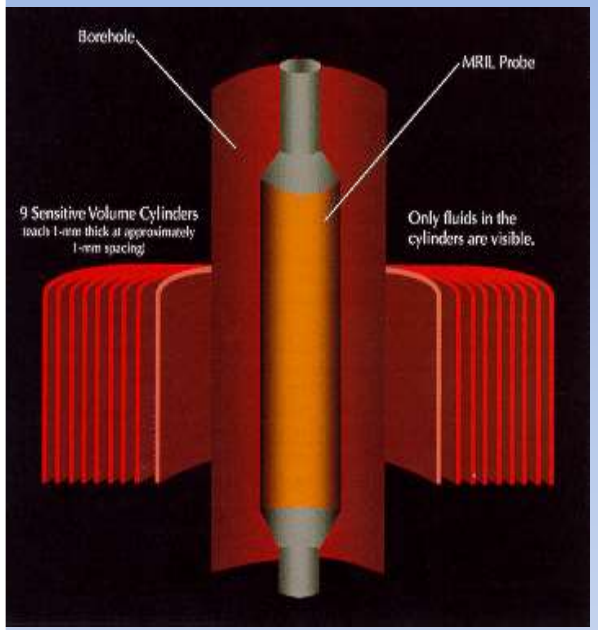
Wellington CO_2 Sequestration and EOR Site

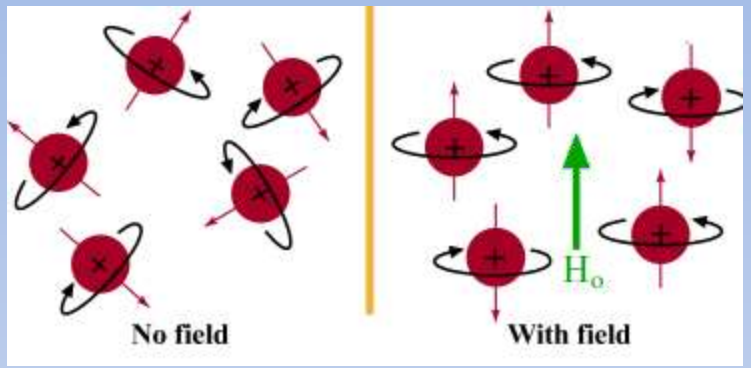




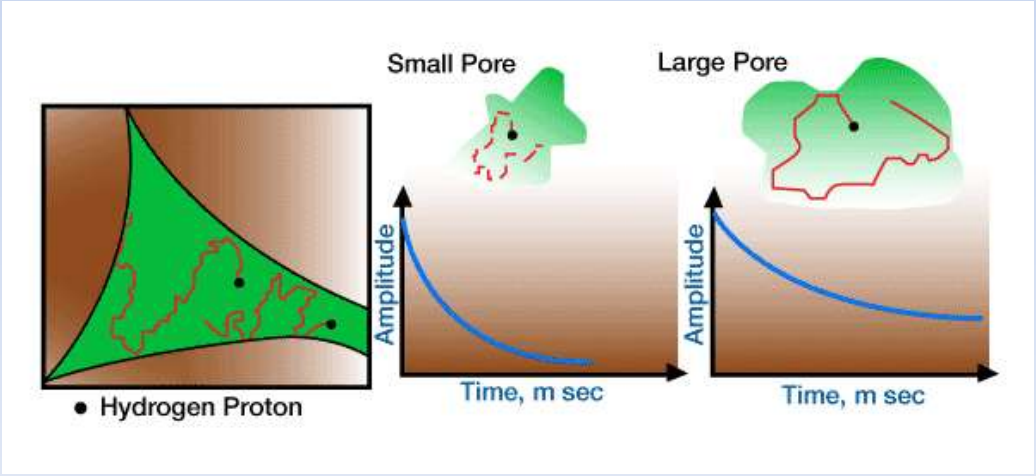


Nuclear Magnetic Resonance Image Logging





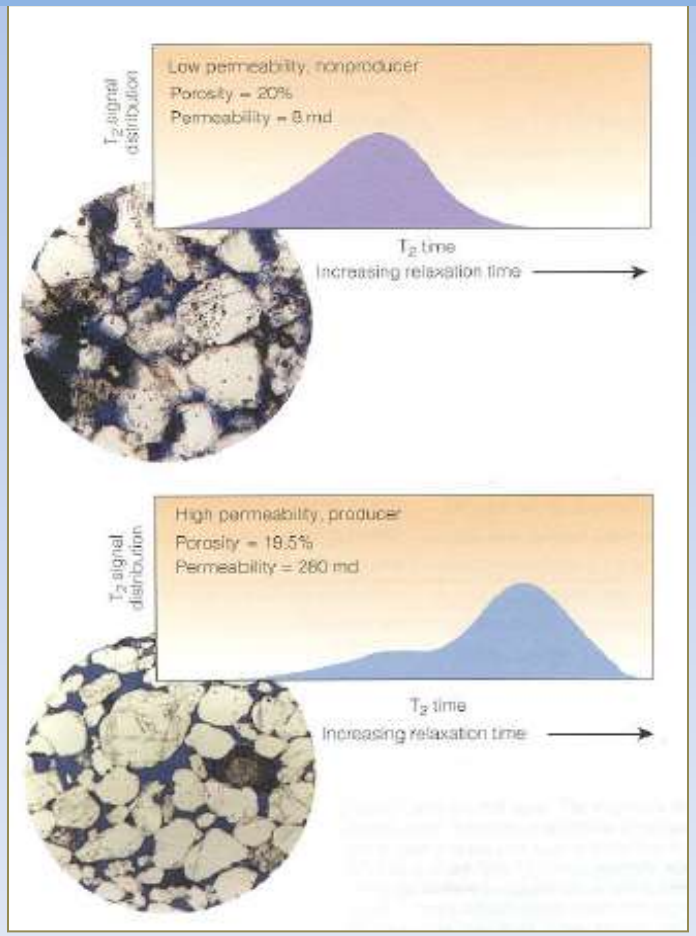
Effect of Pore Space on Time to Return to Equilibrium



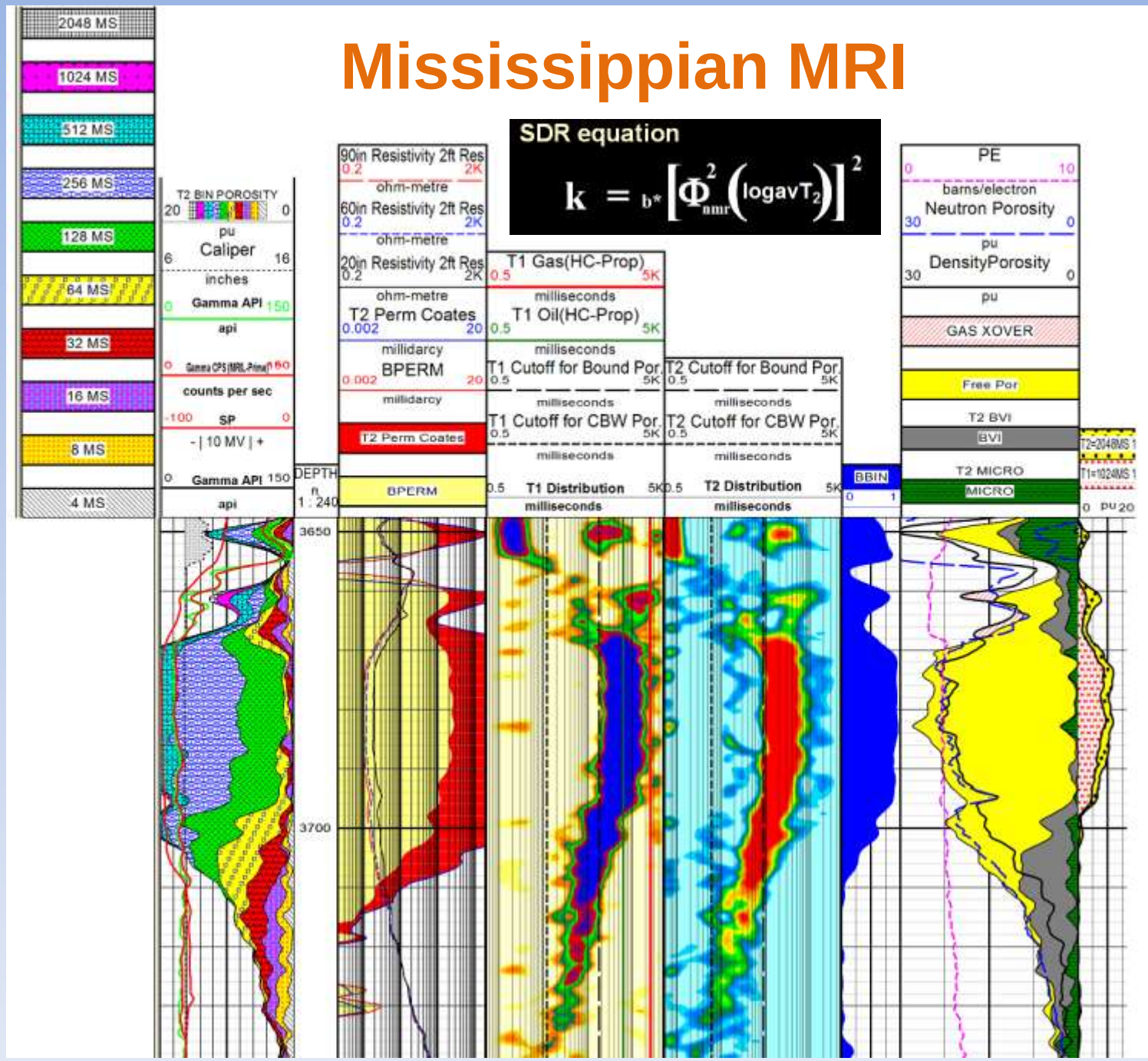
NMR Variables and Their Influence on Petropohphsical Properties

T1 Time: Time to align the protons with the magnetic field

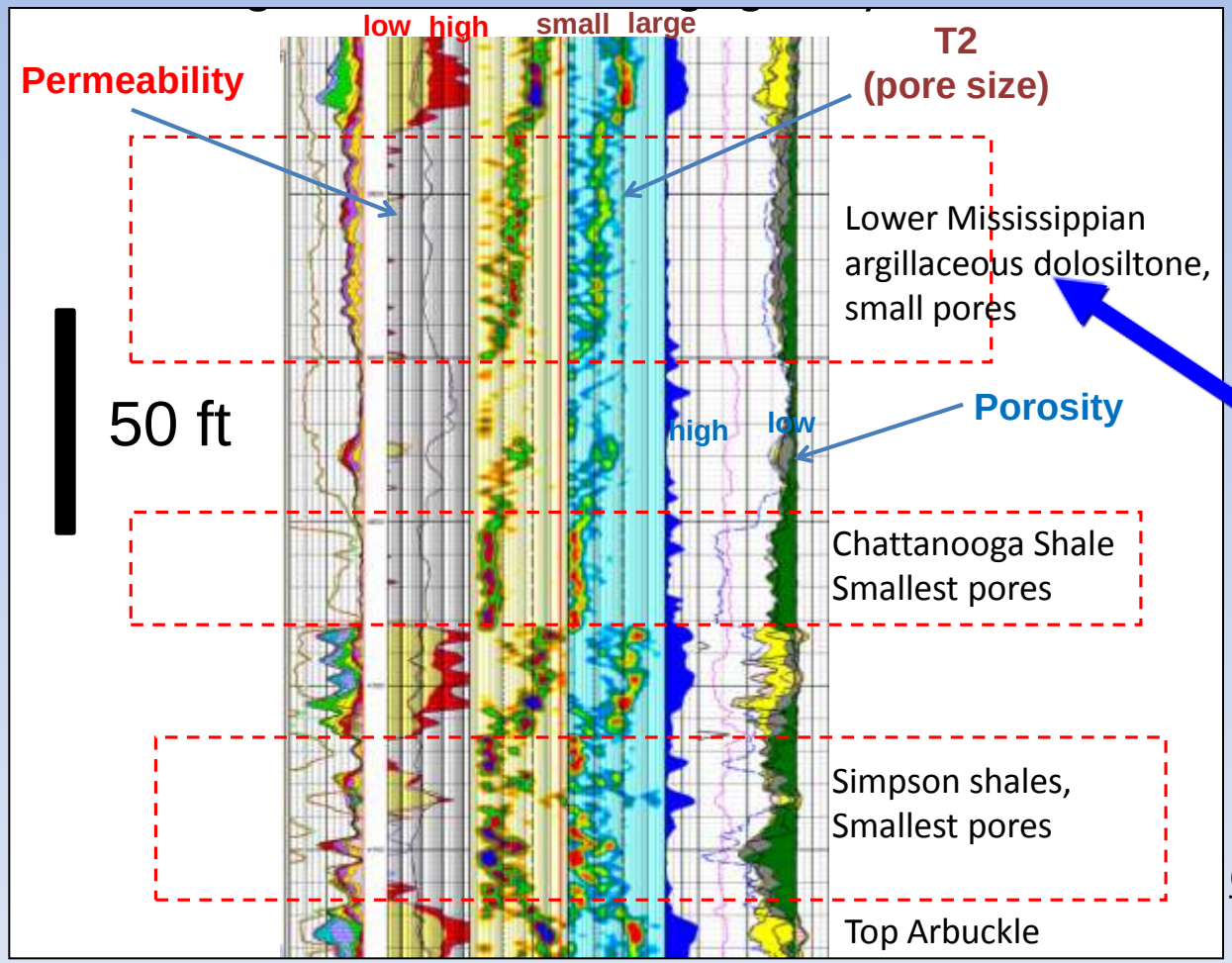
T2 Time: Time for protons to recover, through bulk, diffusion, and surface relaxivity

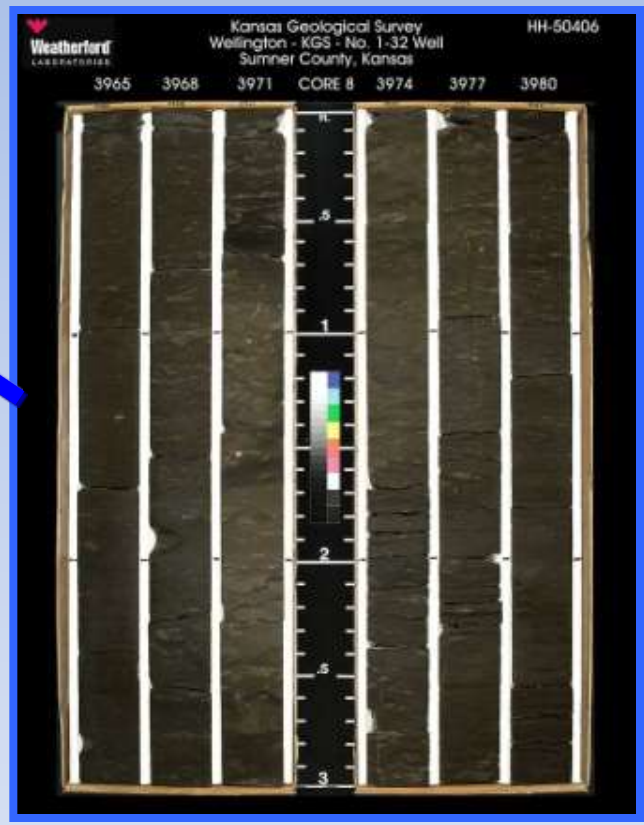


Mississippian MRI



Caprock MRI



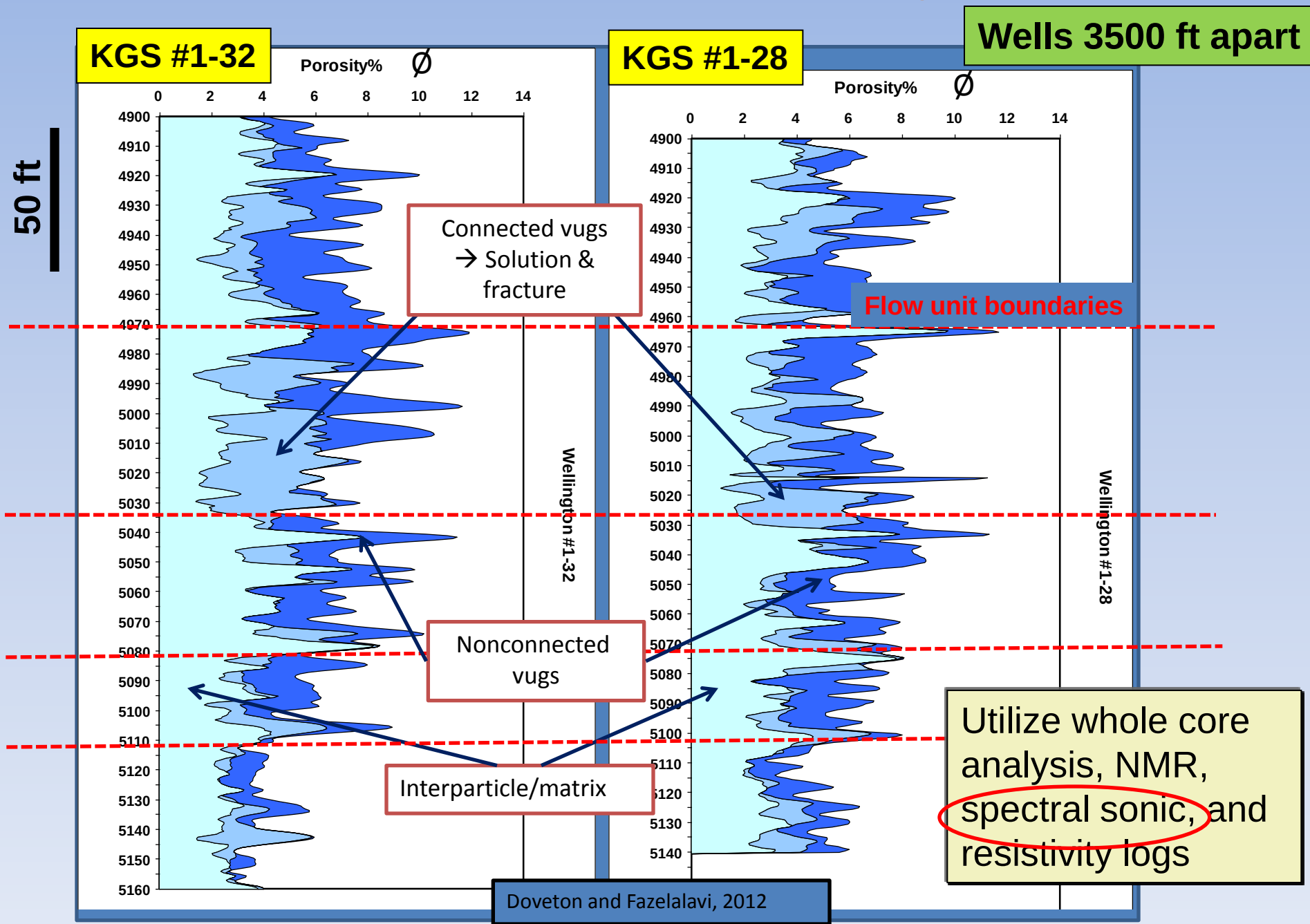


Caprock evidence of lower Miss. :

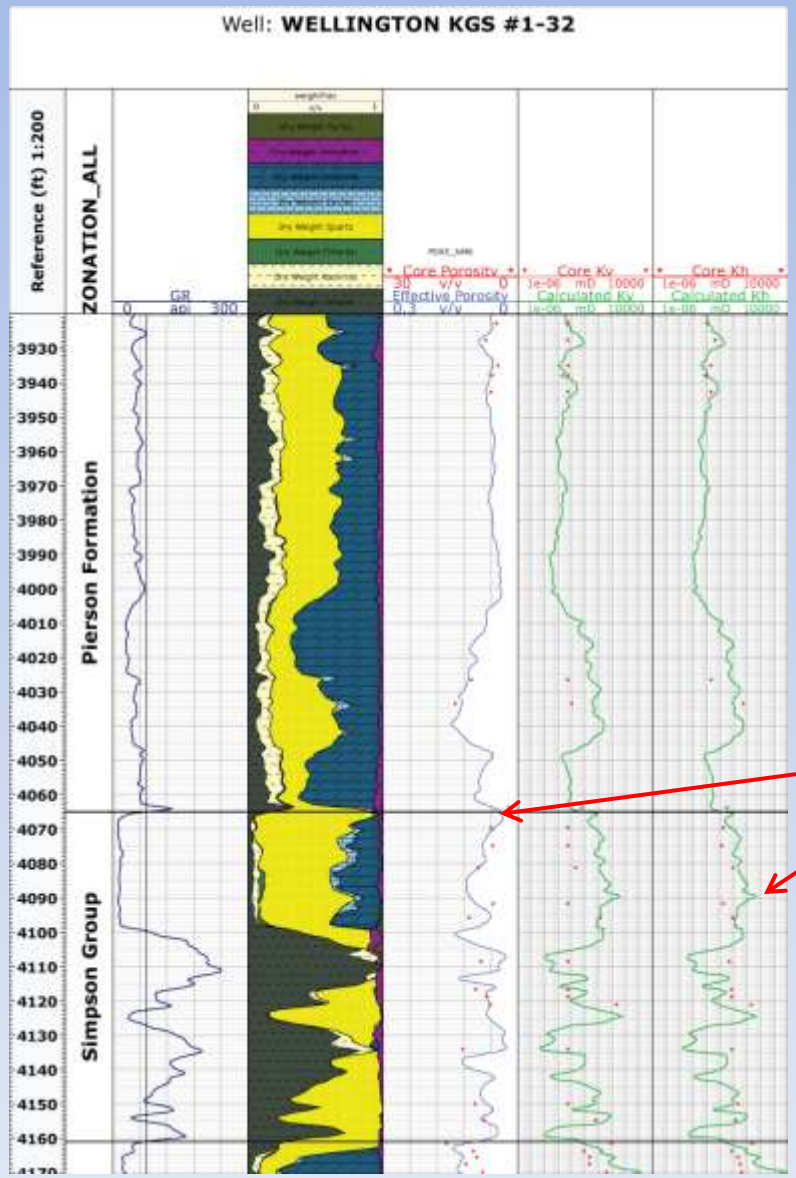
- Micro-nano darcy perm
- Quiet fracture wise
- Organic matter ~2% TOC

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

Flow Units in the Lower Arbuckle Injection Zone



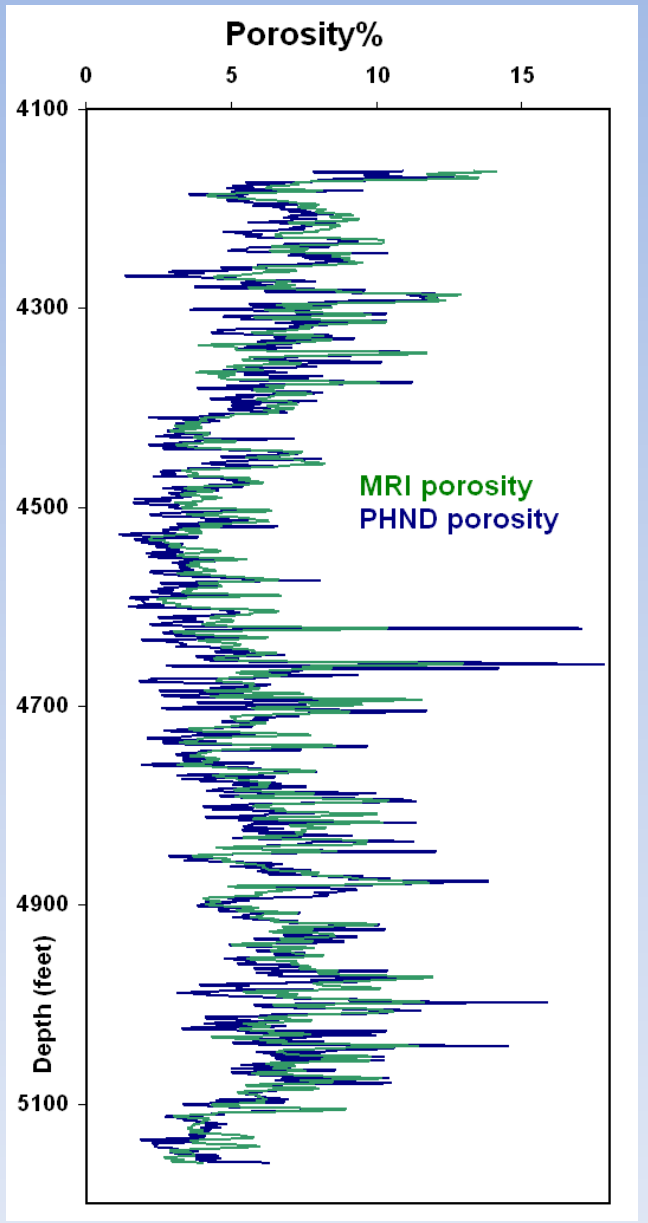
Porosity and Hydraulic Conductivity Comparsion with Core Data



Good match with core data

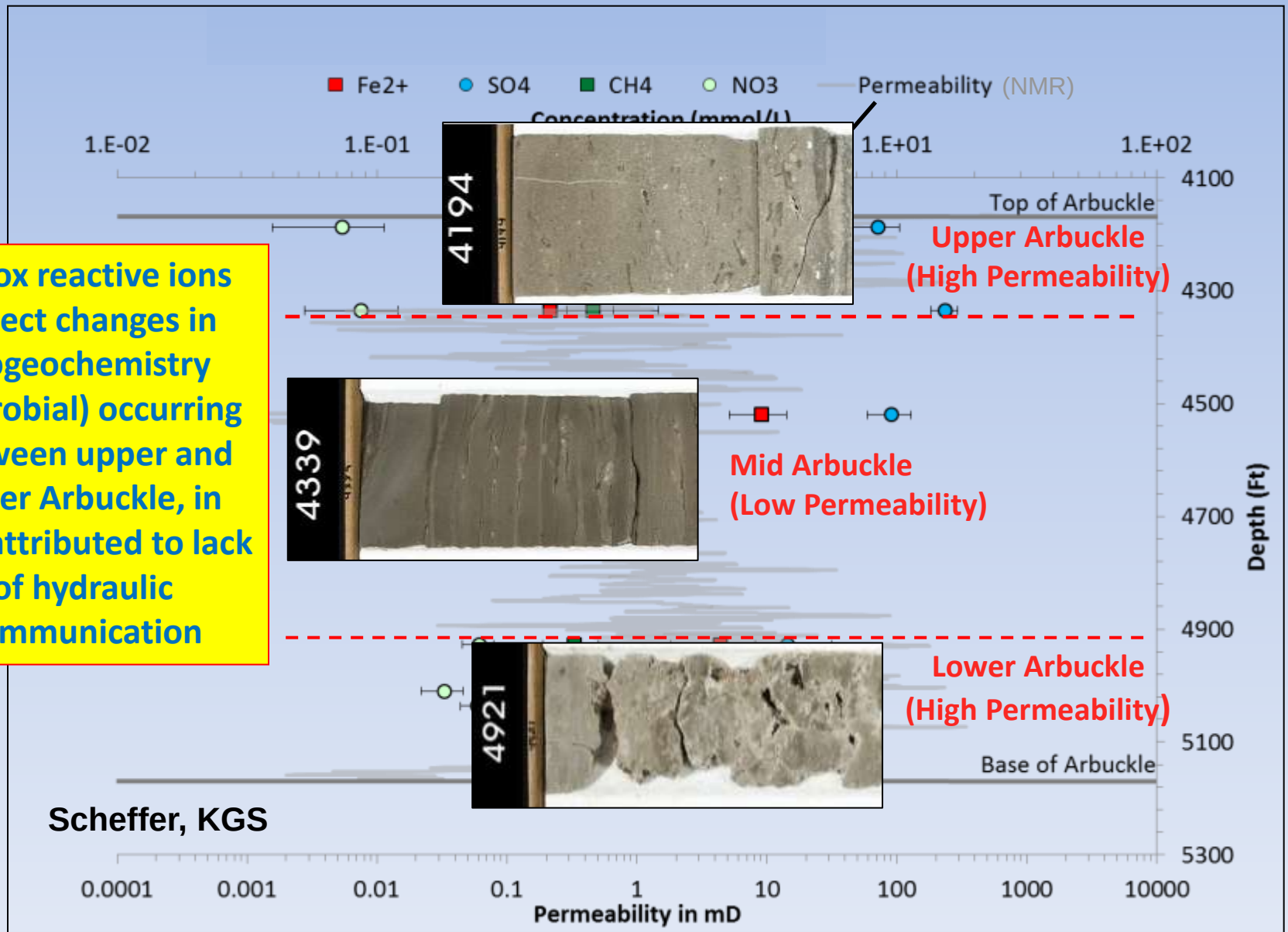
MRI and PHND Estimates of Porosity

MRI effective porosity and neutron-density crossplot porosity in the Arbuckle of Wellington #1-32



Conclusion: there is a good match between MRI porosity and lithology-corrected neutron-density porosity which is a useful cross-validation of these logs

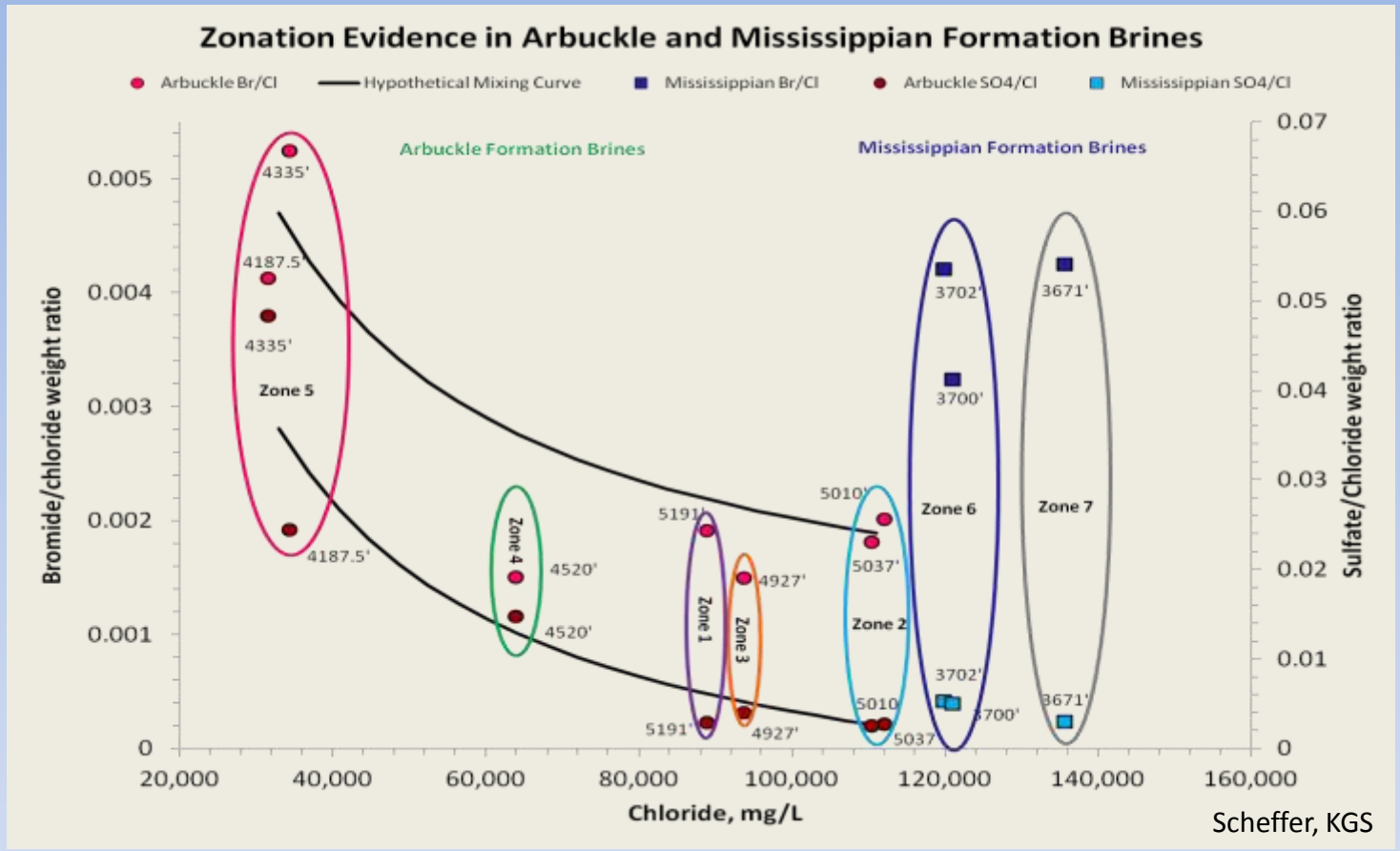
Permeability Profile of Arbuckle



Redox reactive ions reflect changes in biogeochemistry (microbial) occurring between upper and lower Arbuckle, in turn attributed to lack of hydraulic communication

Scheffer, KGS

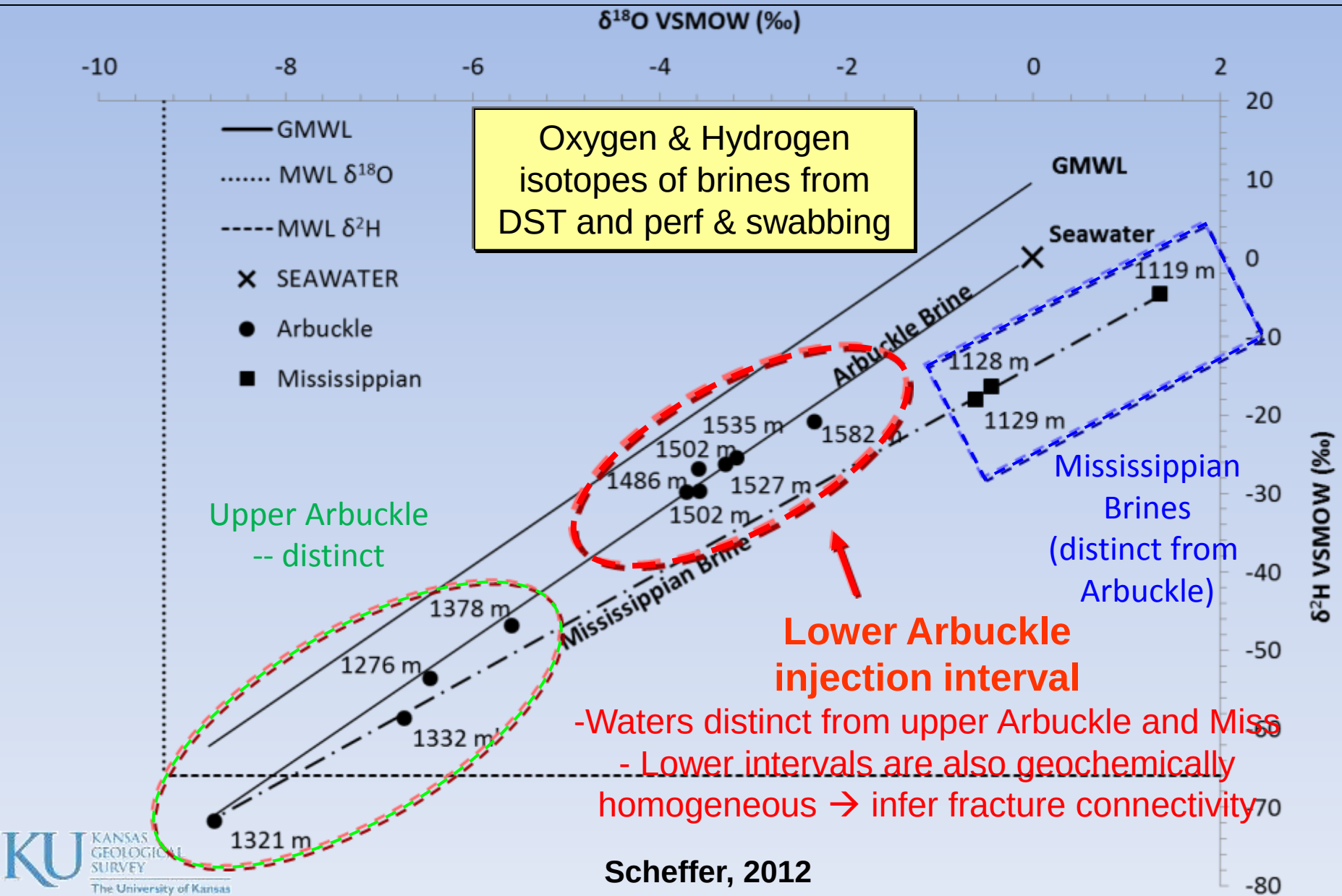
Ion Based Verification of Baffle Zone and Caprock



Scheffer, KGS

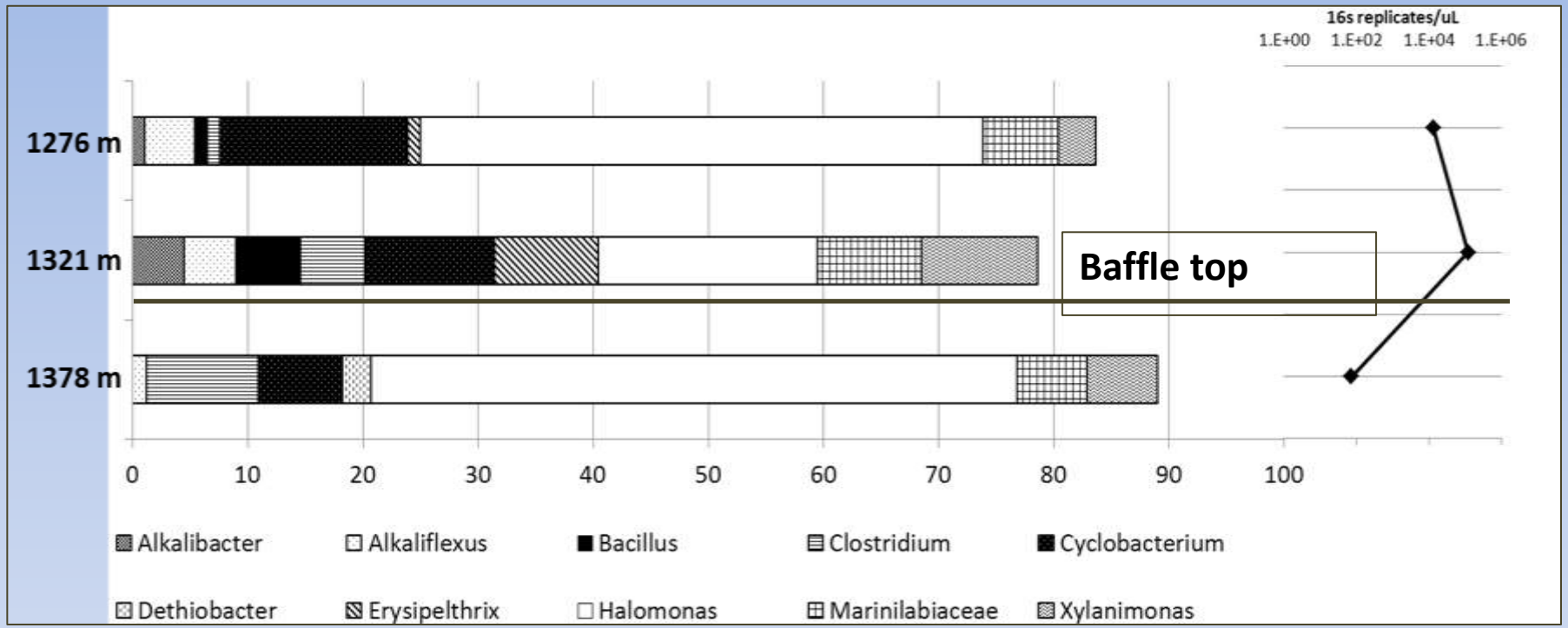
- **Brine of Lower Arbuckle vary substantially from Upper Arbuckle**
- **Lower Arbuckle brines cluster together**
- **Upper Arbuckle values more spaced out, suggests smaller baffles**

Isotopic Verification of Baffle Zone and Caprock



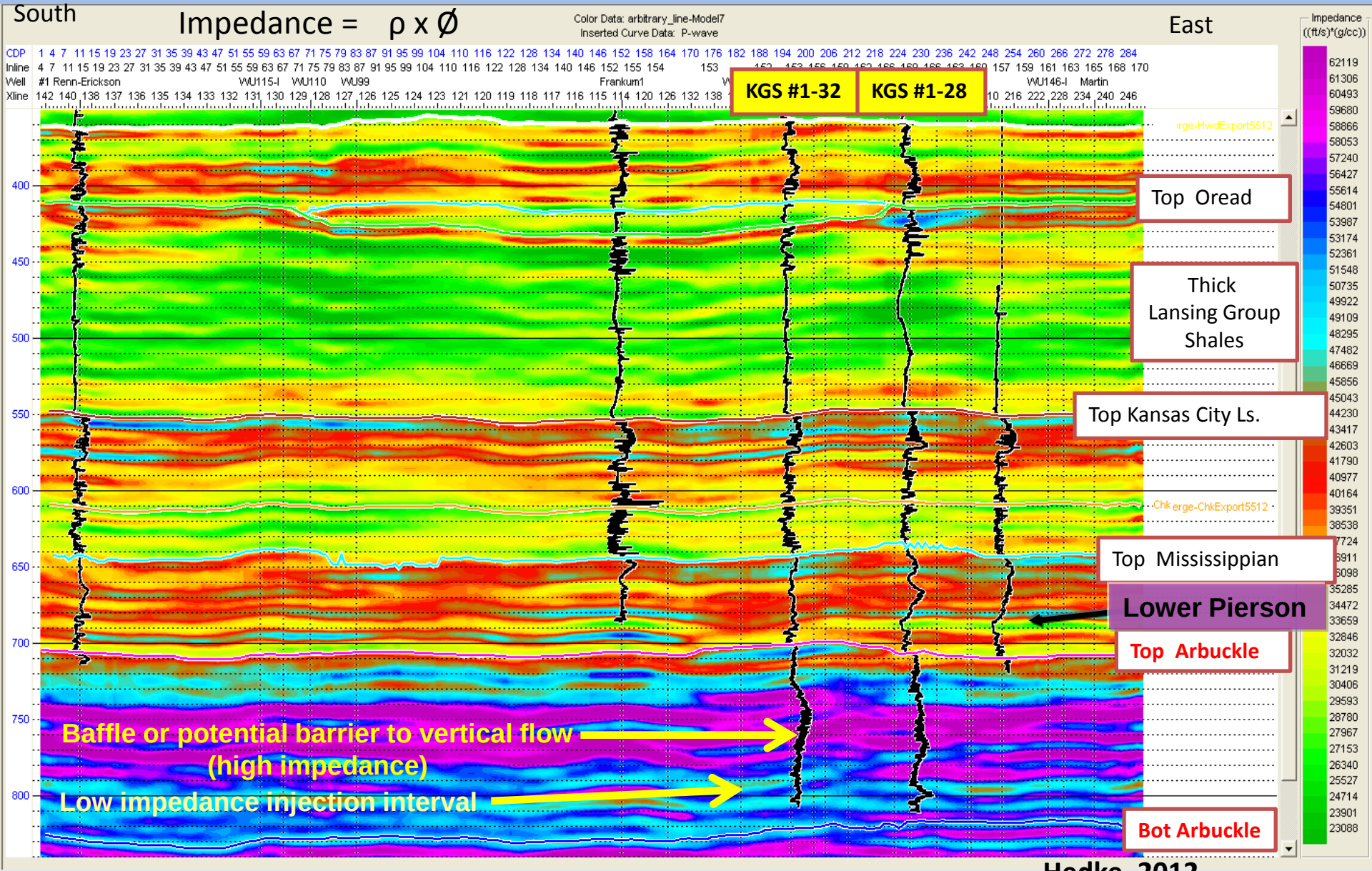
Scheffer, 2012

Microbial Ecology and Validation of Baffle Zone



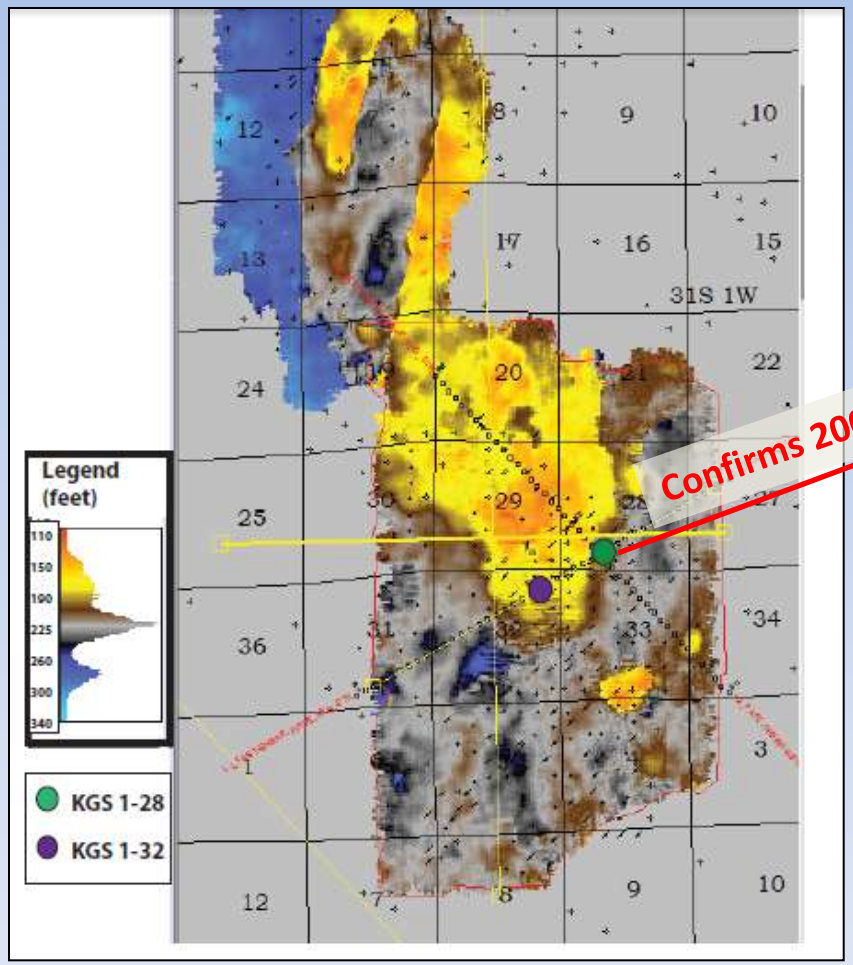
- Lowest biomass coincides with low perm zone (Lower JCC) and low DOC
- Highest biomass coincides with high perm and high concentrations of sulfate
- Same 9 genera were found in brine from Upper Arbuckle depths
- Brine from tight zone had 7 genera; 3 less and 1 unique
- Supports mixing of Upper Arbuckle and some degree of separation below

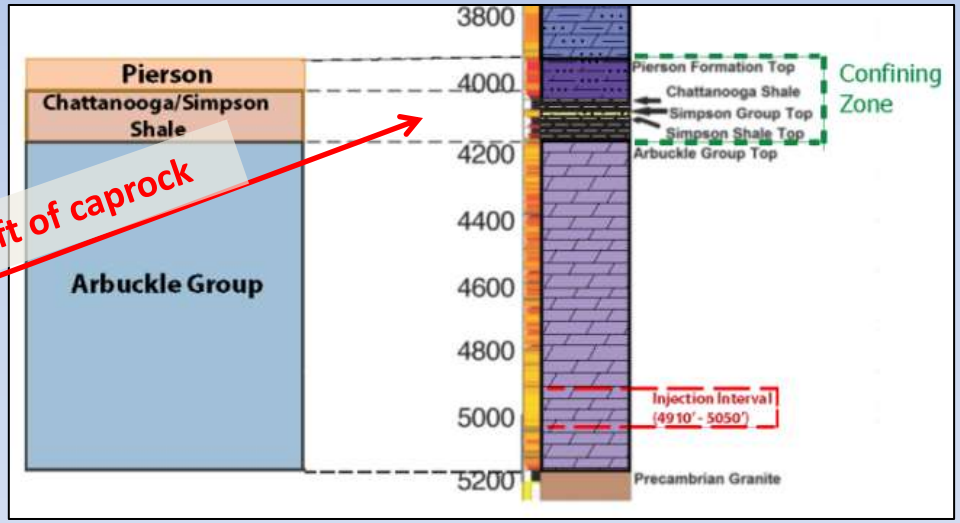
Seismic Profile Confirms Permeability Stratification in Arbuckle



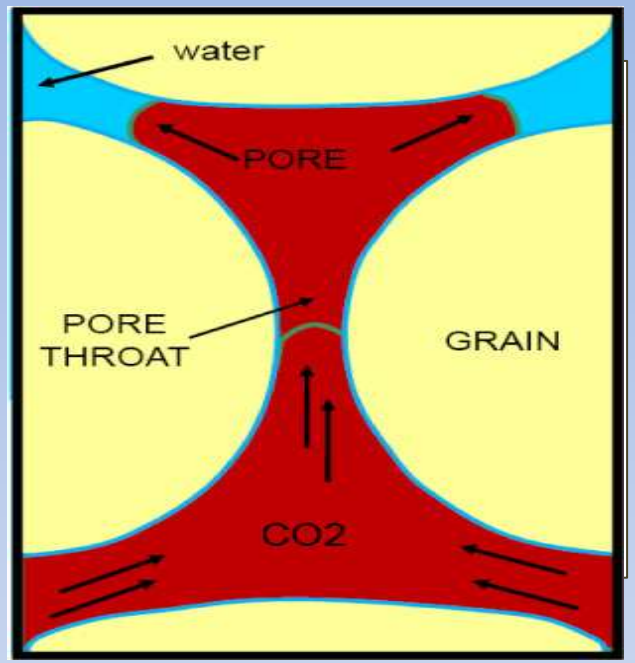
Hedke, 2012

Seismic Structure Mapping Confirms Regional Presence of Caprock



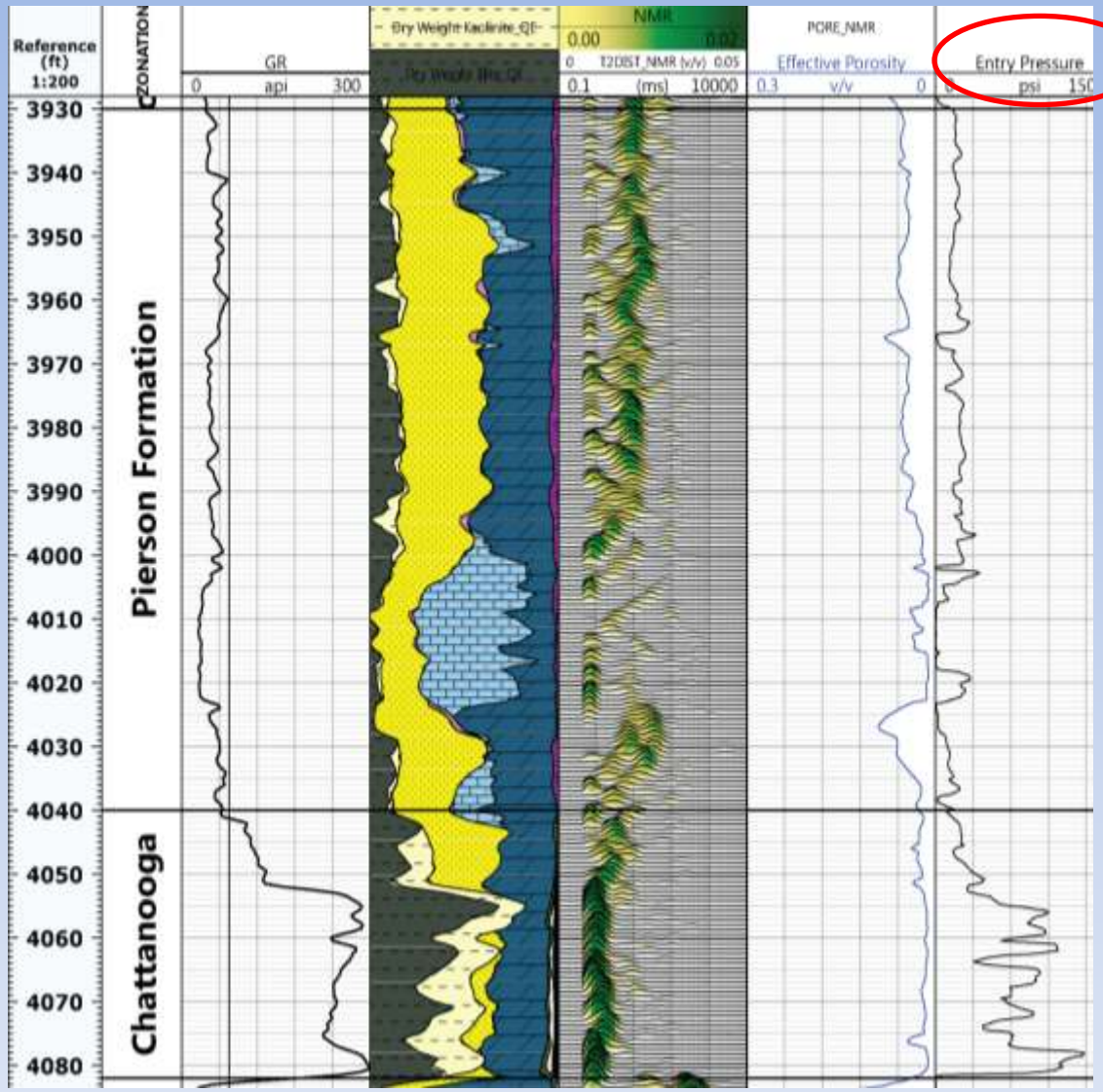


Entry Pressure Analysis



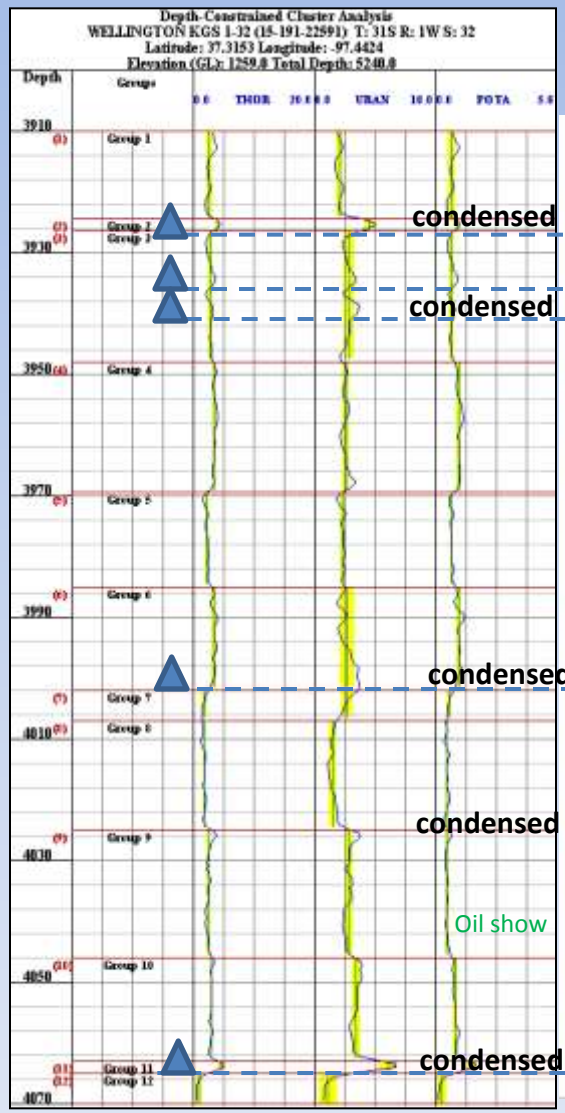
- Pore size and T2 relaxation

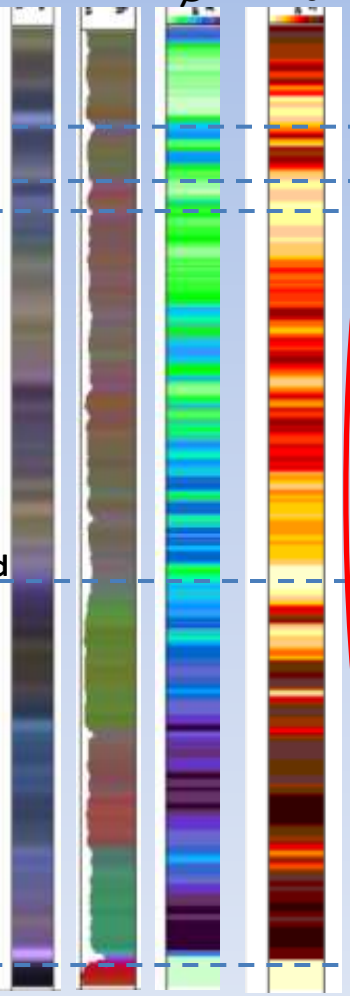
$$Pc = k * \frac{1}{T2}$$

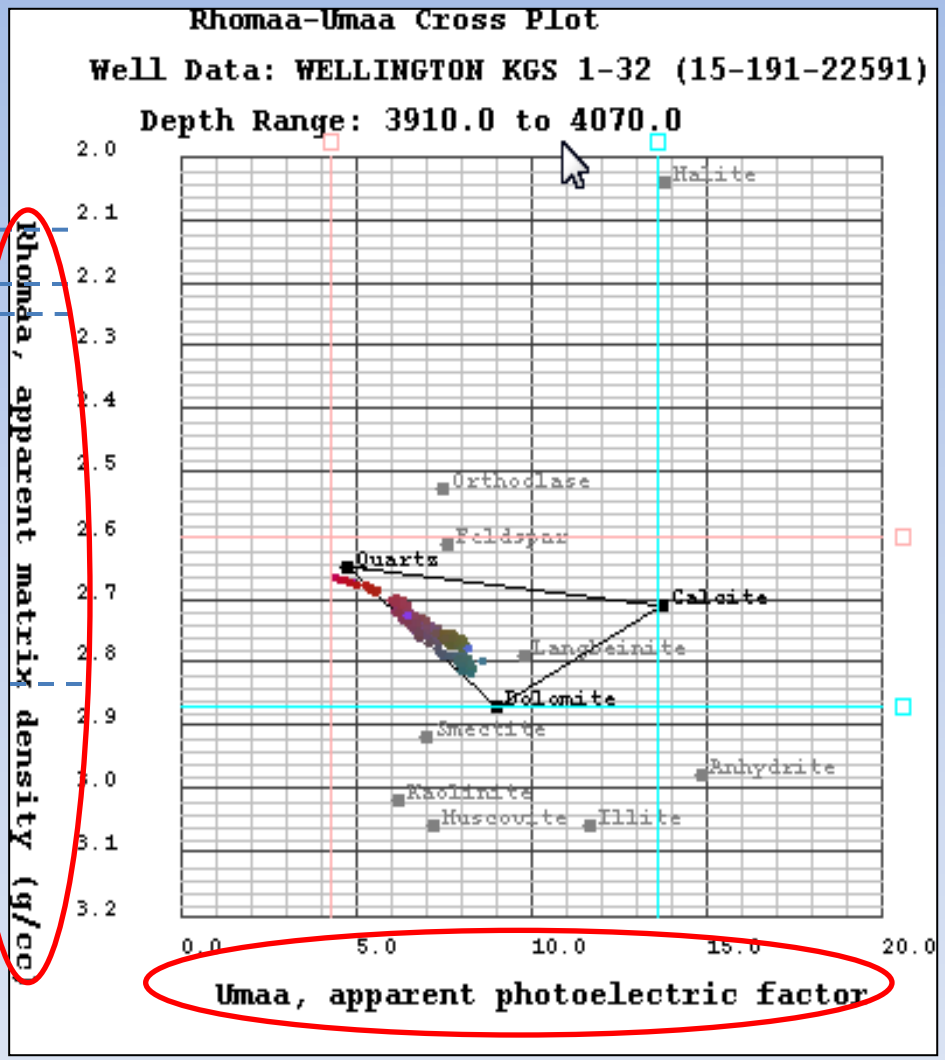


Rhomaa-Umma Analysis

Depth-Constrained Clustering using Potassium, Uranium, Thorium

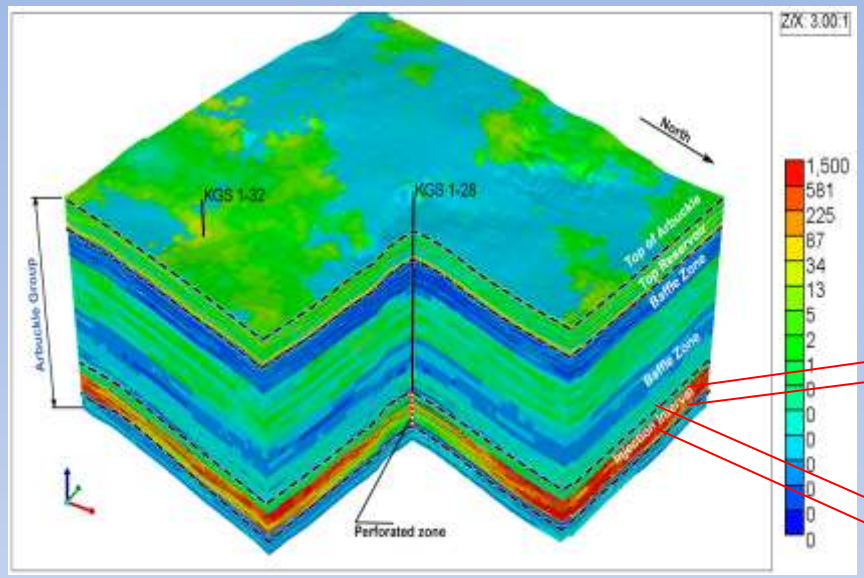






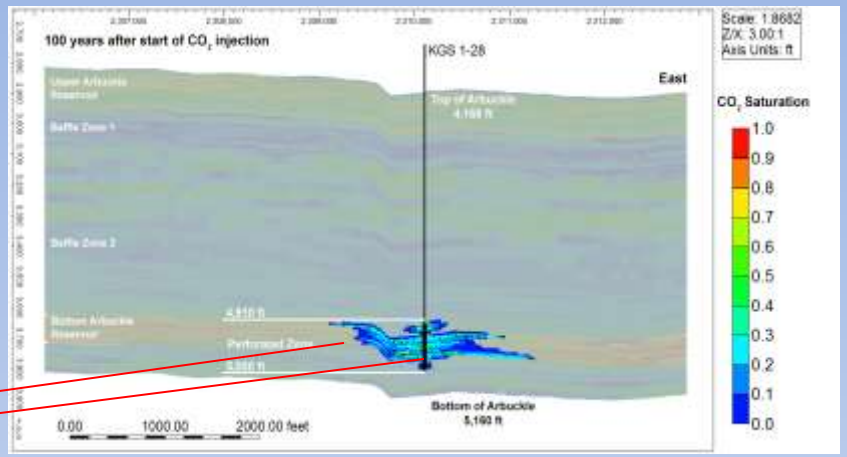
▲ Significant flooding surface from core description

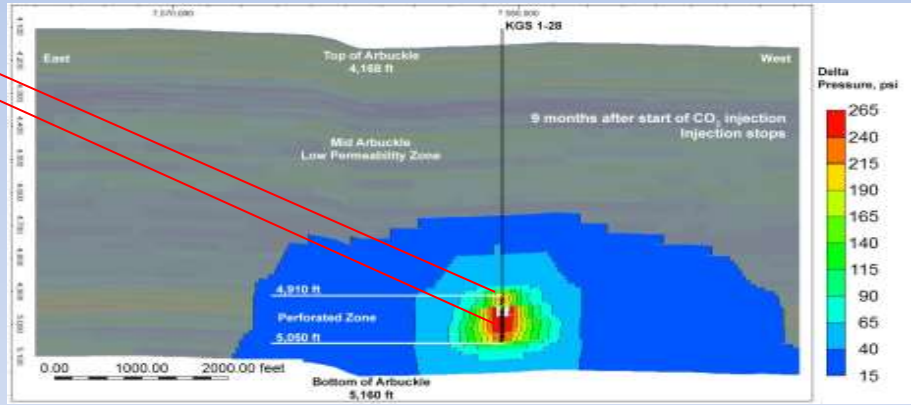
Simulated Plume and Pressure Projections

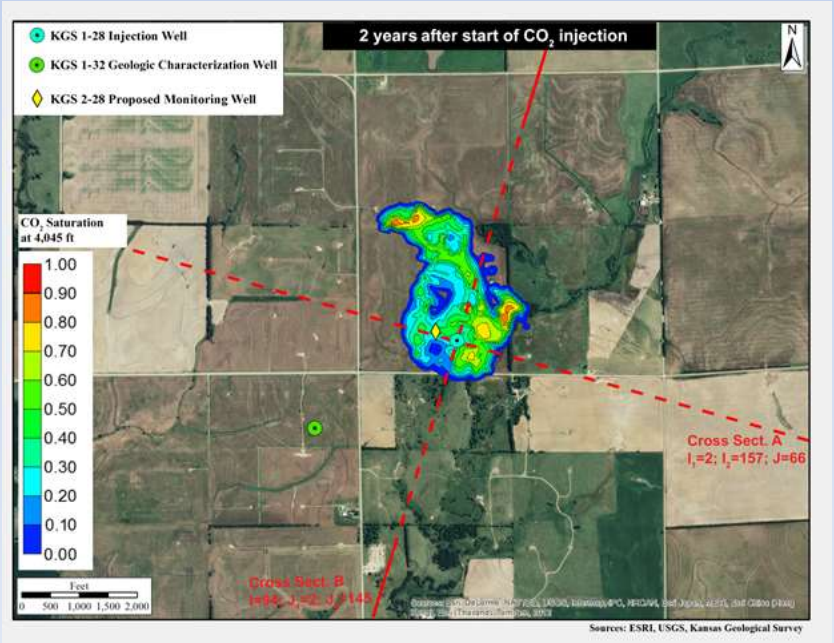


Holubnyack, Rush, Fazelalavi (KGS)

Injection zone

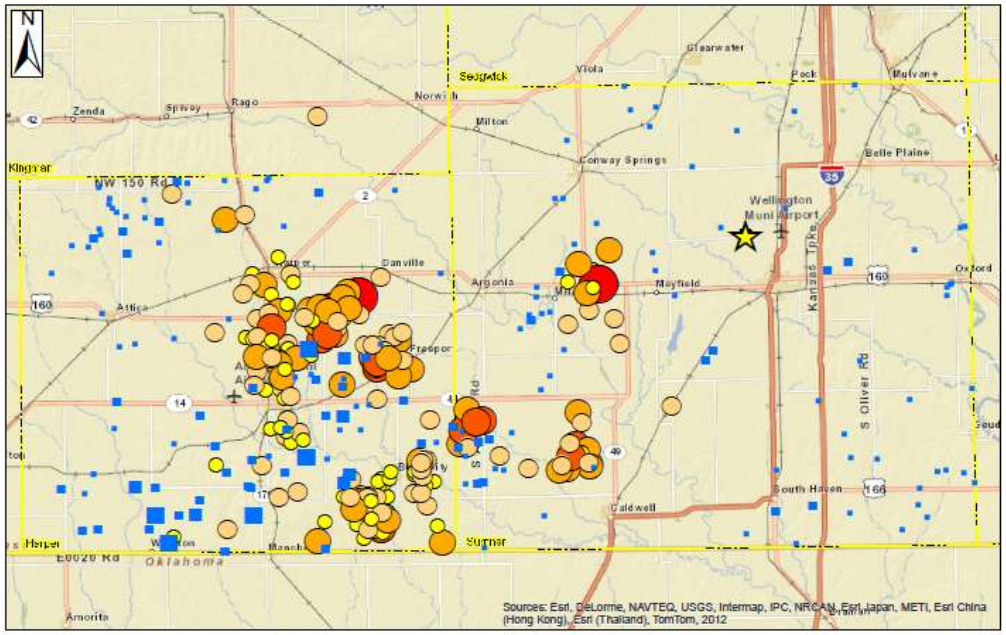






- **Baffle Zones keep CO2 plume and pressures confined deep in the Arbuckle injection zone**

Earthquake Trends in Southern Kansas



Salt Water Disposal (2014) NEIC Earthquakes (Jan 2014-June 2015)

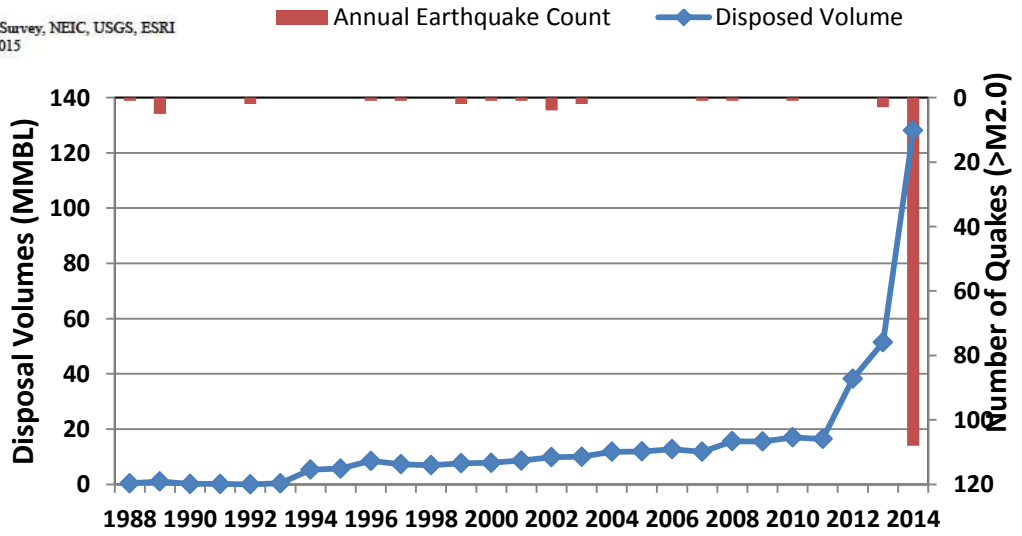
million BBLS
- 0.5
- 2.5
- 5.0
- 10.0

magnitude
- 1.9 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 5.0

Wellington CO2 Injection Site

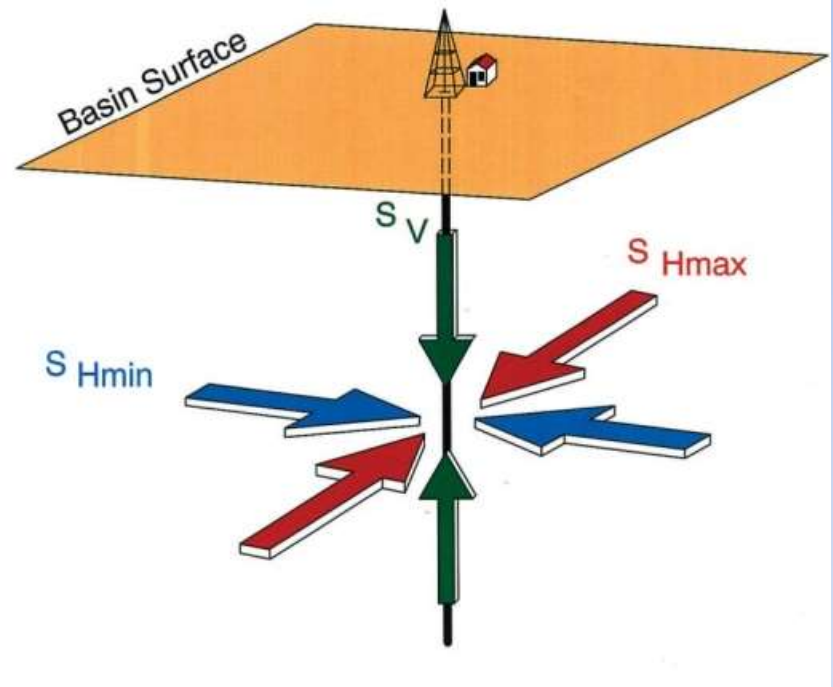
Miles
0 5 10 20

Kansas Geological Survey, NEIC, USGS, ESRI
Map printed 6/24/2015

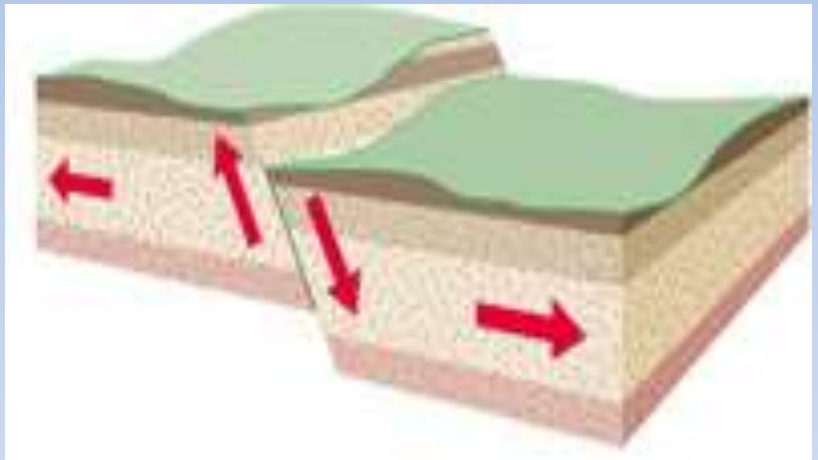


Induced Seismicity - Physical Mechanisms

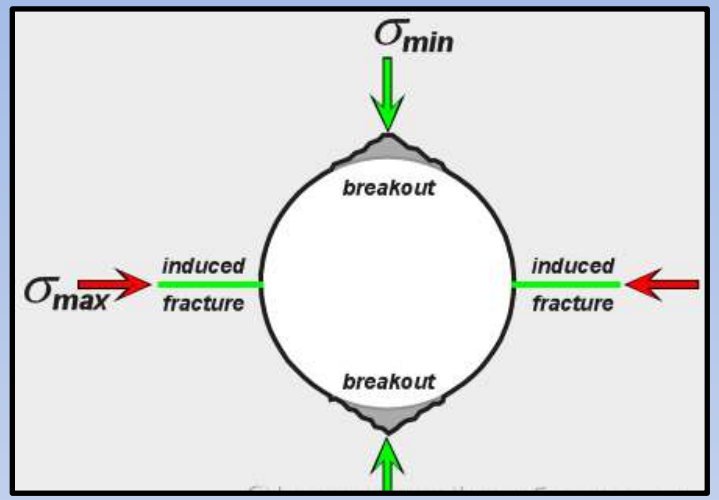
Subsurface stress field

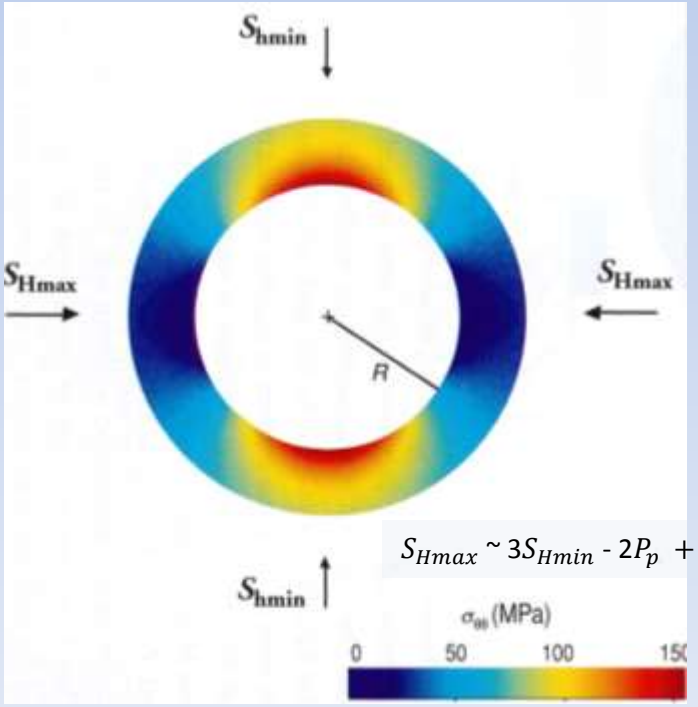


Faults slips when principal stresses exceed threshold



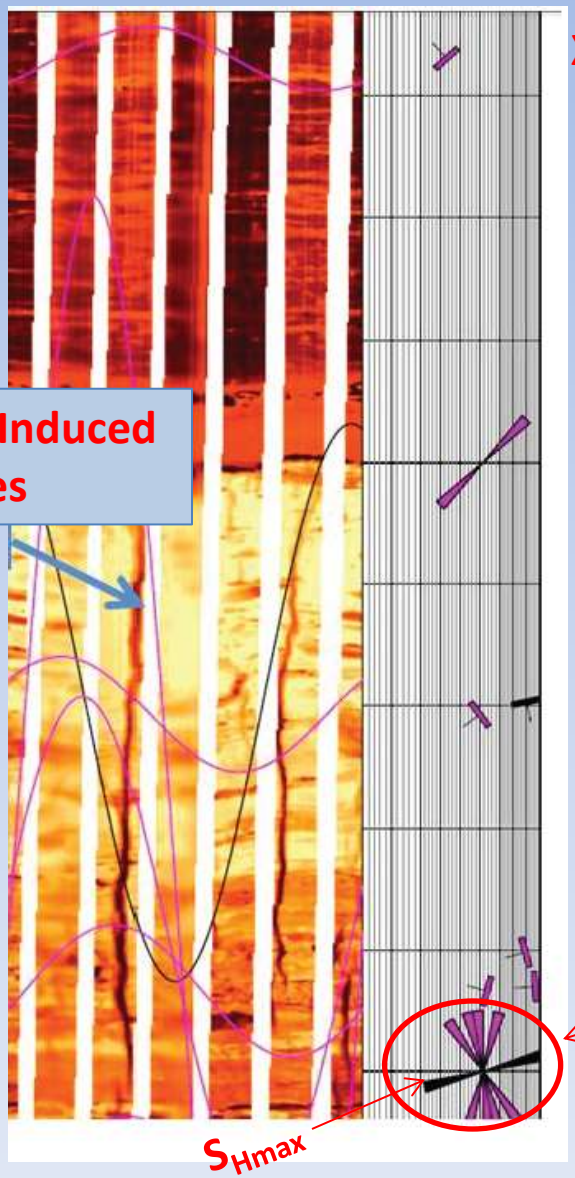
Drilling Induced Fractures and Leak-off Test Used to Estimate Principal Stresses



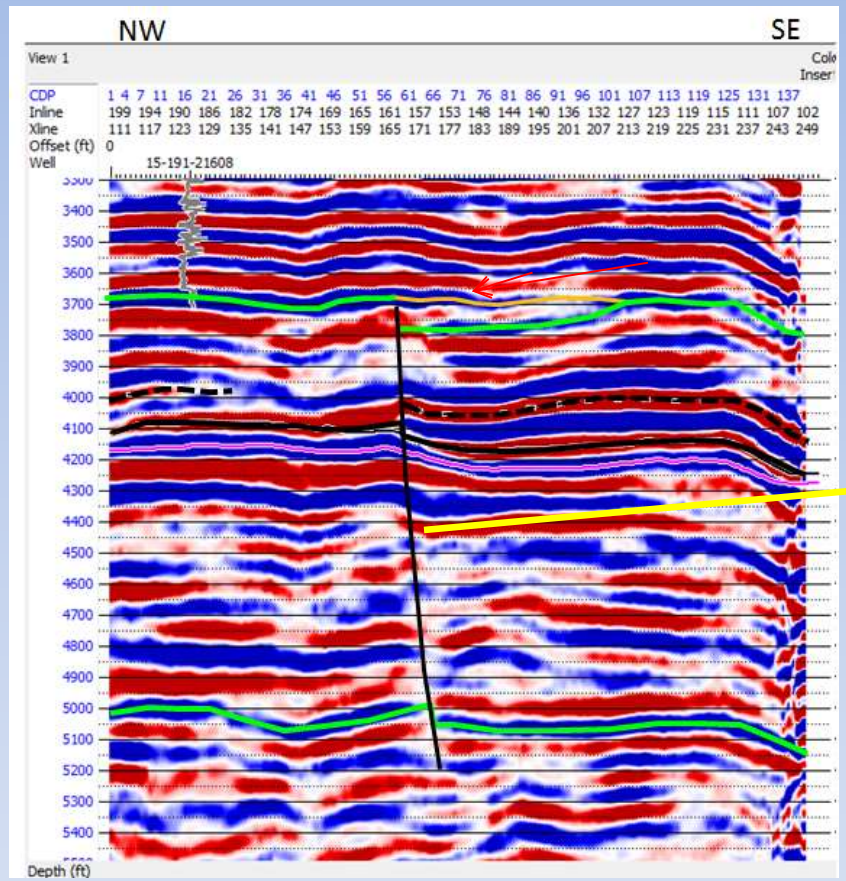


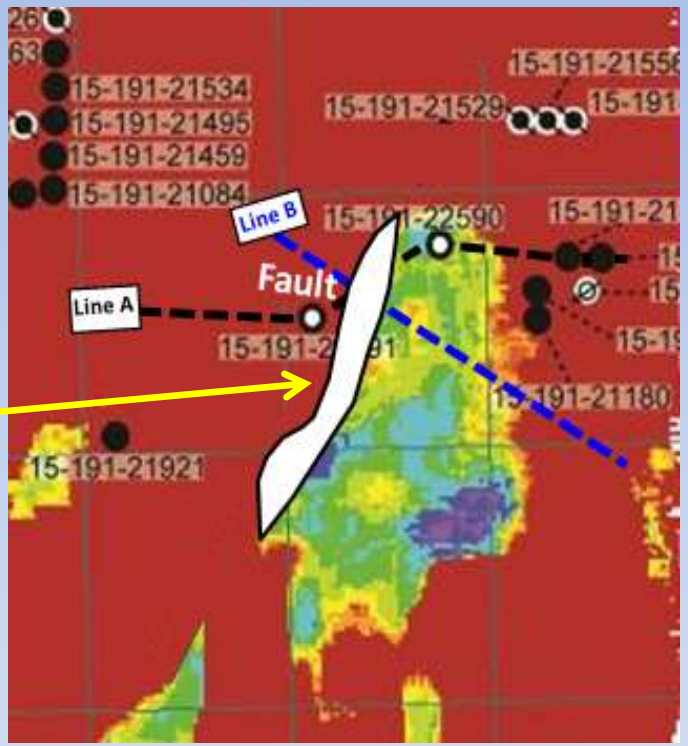
$S_{Hmax} \sim 3S_{Hmin} - 2P_p + 0.1(S_{hmin} - P_p)$

Drilling Induced Fractures



Fault Identification





- **Extensive data acquisition required to identify faults and assess seismic risk regionally**

3D Stress Analysis Used to Estimate Fault Slip Tendency

- **ST= 0.3 (lower than of 0.5 for fault slippage)**