Calculation of CO_2 Storage Capacity for Arbuckle Group in Southern Kansas: Implications for a Seismically Active Region

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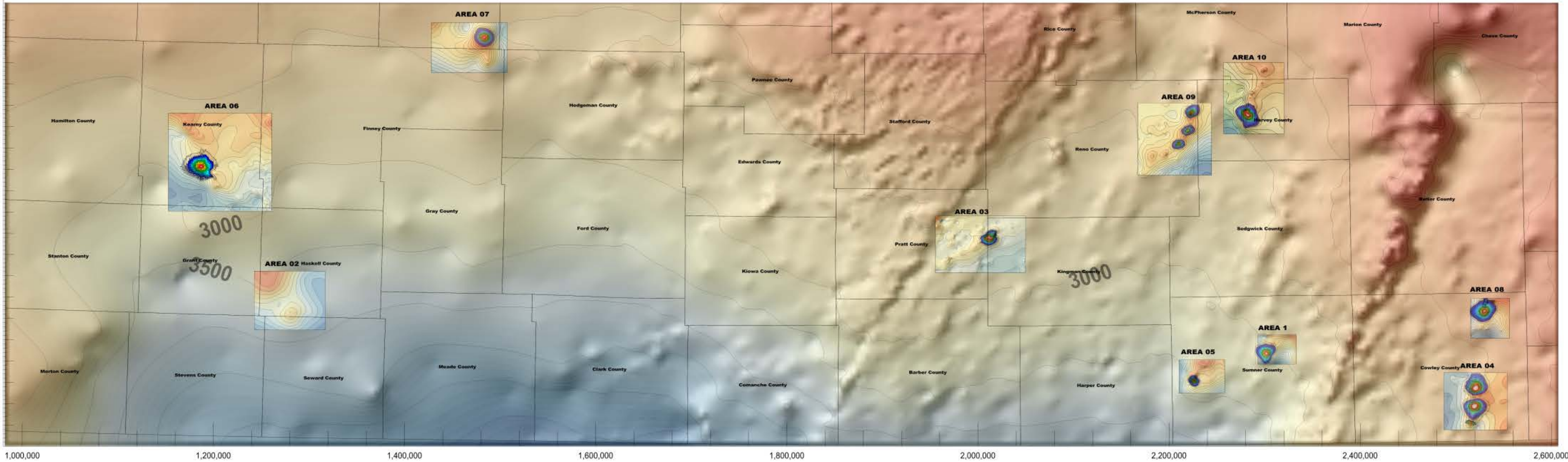
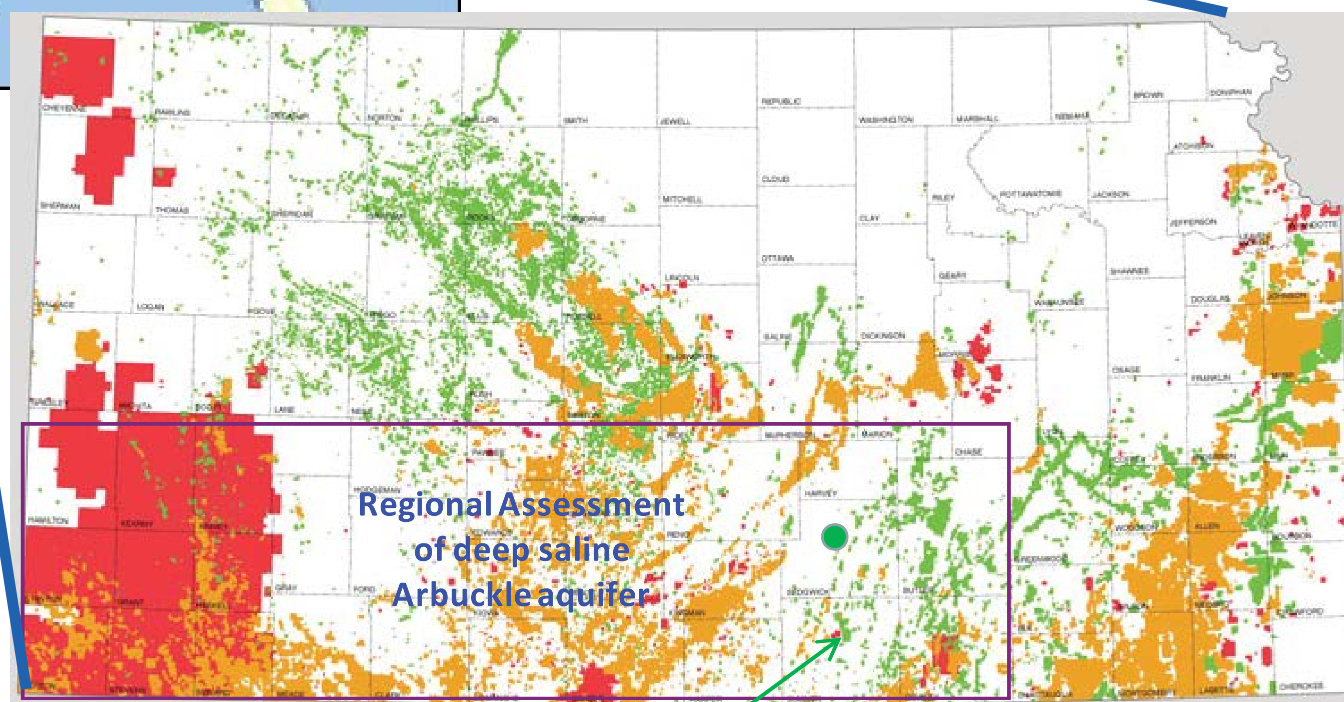
13th International Conference on
Greenhouse Gas Control Technologies
Lausanne, Switzerland
November 18, 2016



Outline

- Modeling CO_2 storage capacity for South-Central Kansas Arbuckle aquifer
- Current state of seismicity and waste water disposal in Sothern Kansas
- How risk of seismicity affects storage capacity

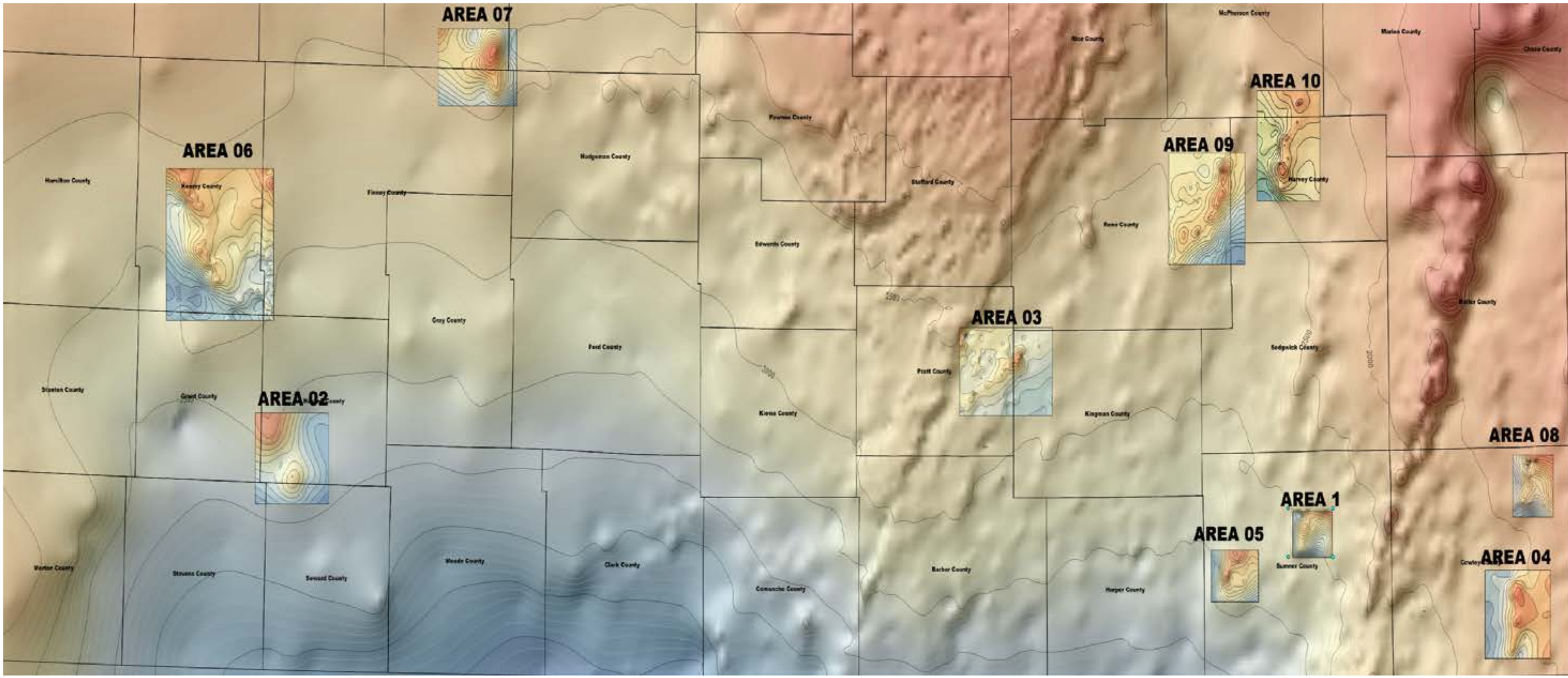
Area of Interest



Plan for Capacity Estimations Study

- Determine formations of interest and outline the area of review
- Select promising sites of interest with known structure (total of 10)
- Gather data
  - Available through existing database at KGS and other sources
  - Drill and core wells, process 3D seismic, well test analysis, process logs, etc.
- Create geologic models for 10 sites and an entire region
- Perform dynamic simulations

Top Arbuckle Structure Map showing Study areas



Core from Lower Arbuckle Injection Interval

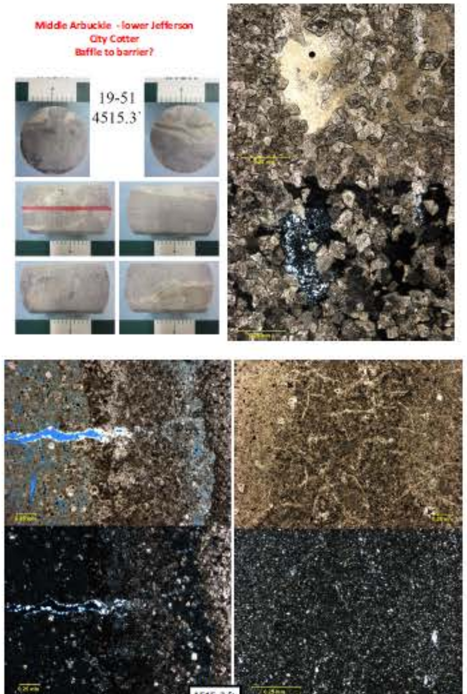
5089-92 ft

5080-83

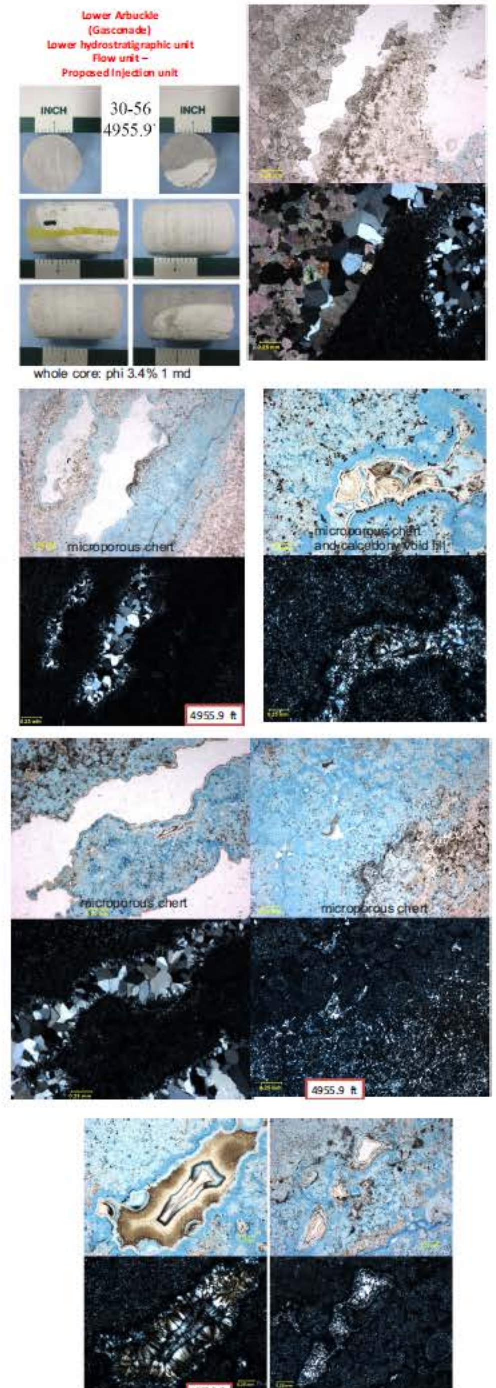
5053-56

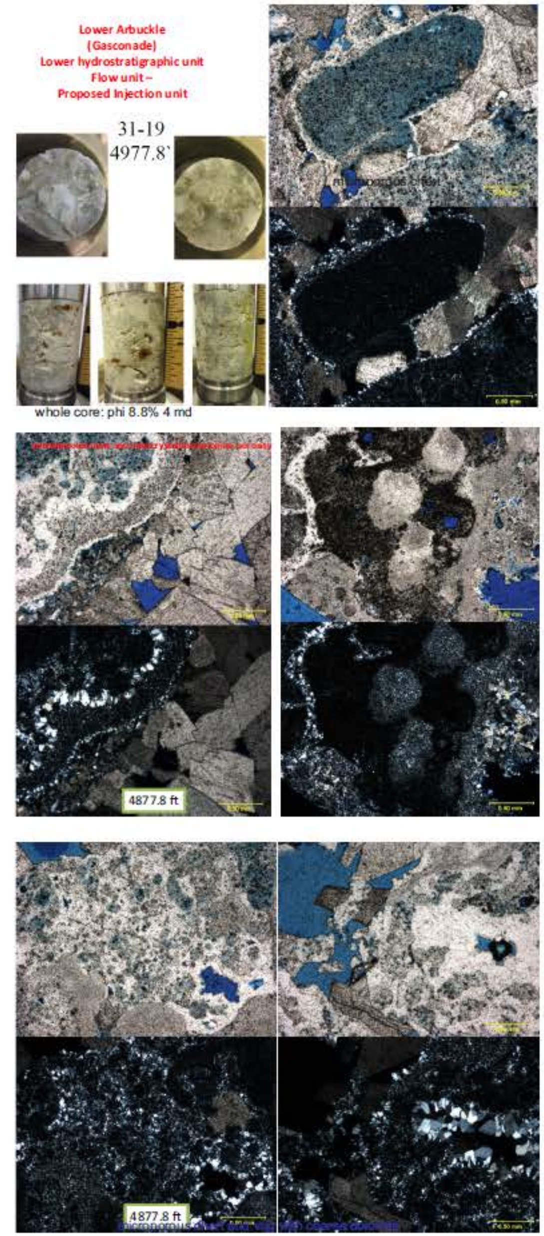
4995-97.7 ft

Thin Sections – Baffle Zone (Mid Arb.)

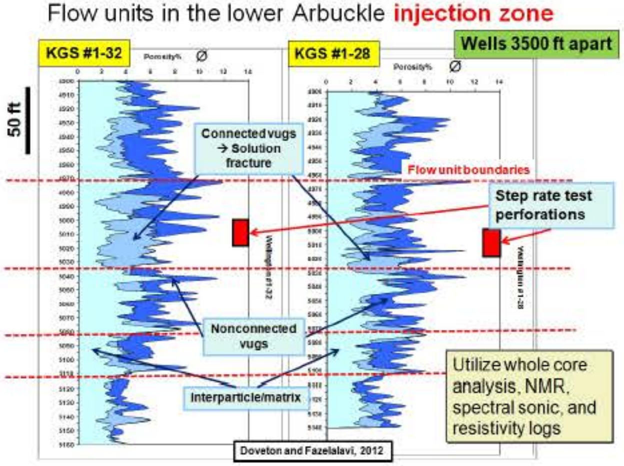


Lower Arbuckle Injection Zone





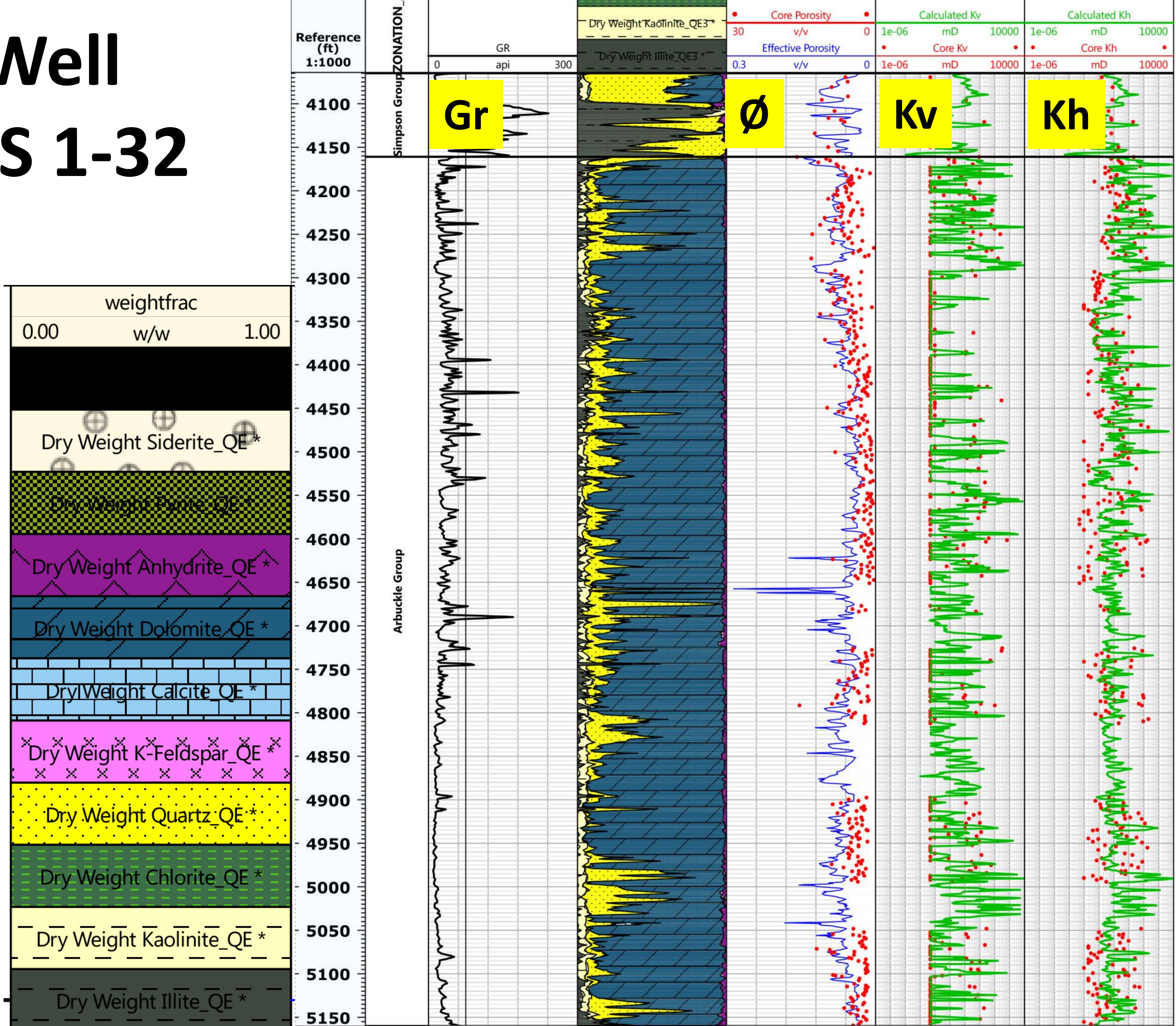
Flow units in the lower Arbuckle **injection zone**



Pairs of photomicrographs
Plane light and crossed nichols

R. Barker, S. Datta, KSU

Well KGS 1-32



weightfrac
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Dry Weight Pyrite_QE *
Dry Weight Anhydrite_QE *
Dry Weight Dolomite_QE *
Dry Weight Calcite_QE *
Dry Weight K-Feldspar_QE *
Dry Weight Quartz_QE *
Dry Weight Chlorite_QE *
Dry Weight Kaolinite_QE *
Dry Weight Illite_QE *
Reference (ft) 1:1000
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GR
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Dry Weight Kaolinite_QE3 *
Dry Weight Illite_QE3 *
Core Porosity
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Effective Porosity
0.3 v/v 0
Calculated Kv
1e-06 mD 10000
Core Kv
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Core Kh
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Simpson Group
Arbuckle Group
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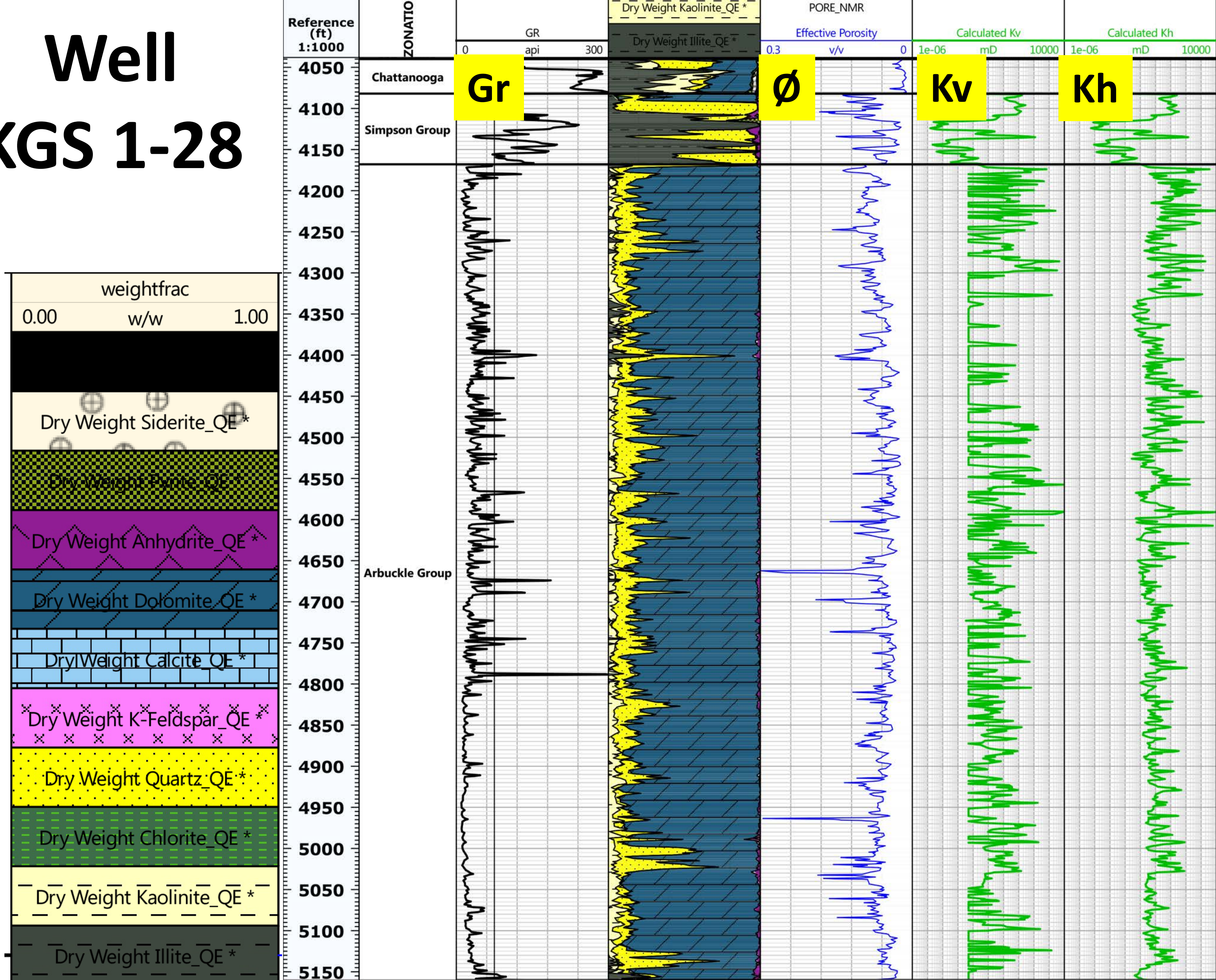
Well KGS 1-28



weightfrac
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Dry Weight Siderite_QE *
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PORE_NMR
Effective Porosity
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Calculated Kh
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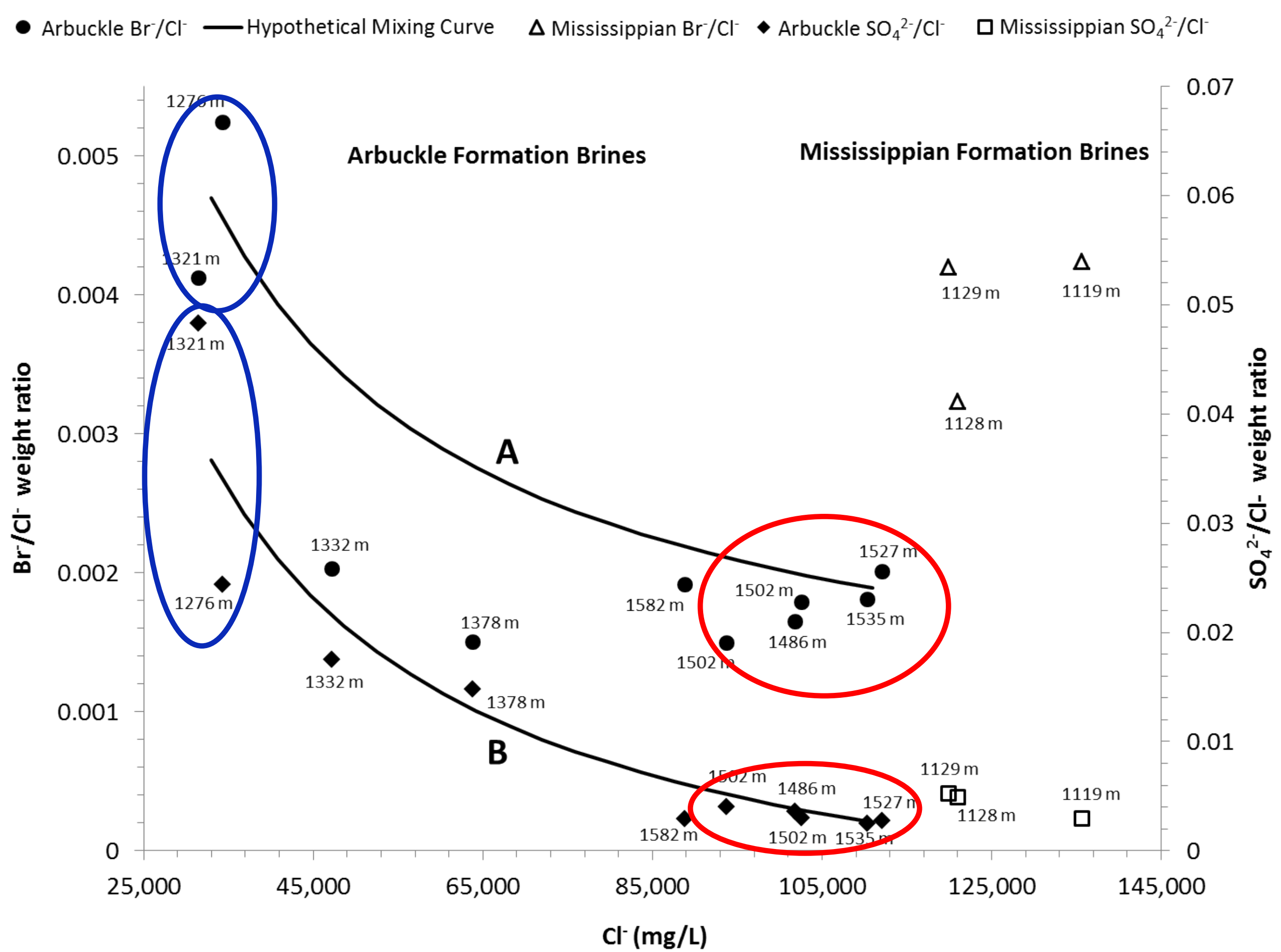
5100
5150
Chattanooga
Simpson Group
Arbuckle Group
Gr
Ø
Kv
Kh

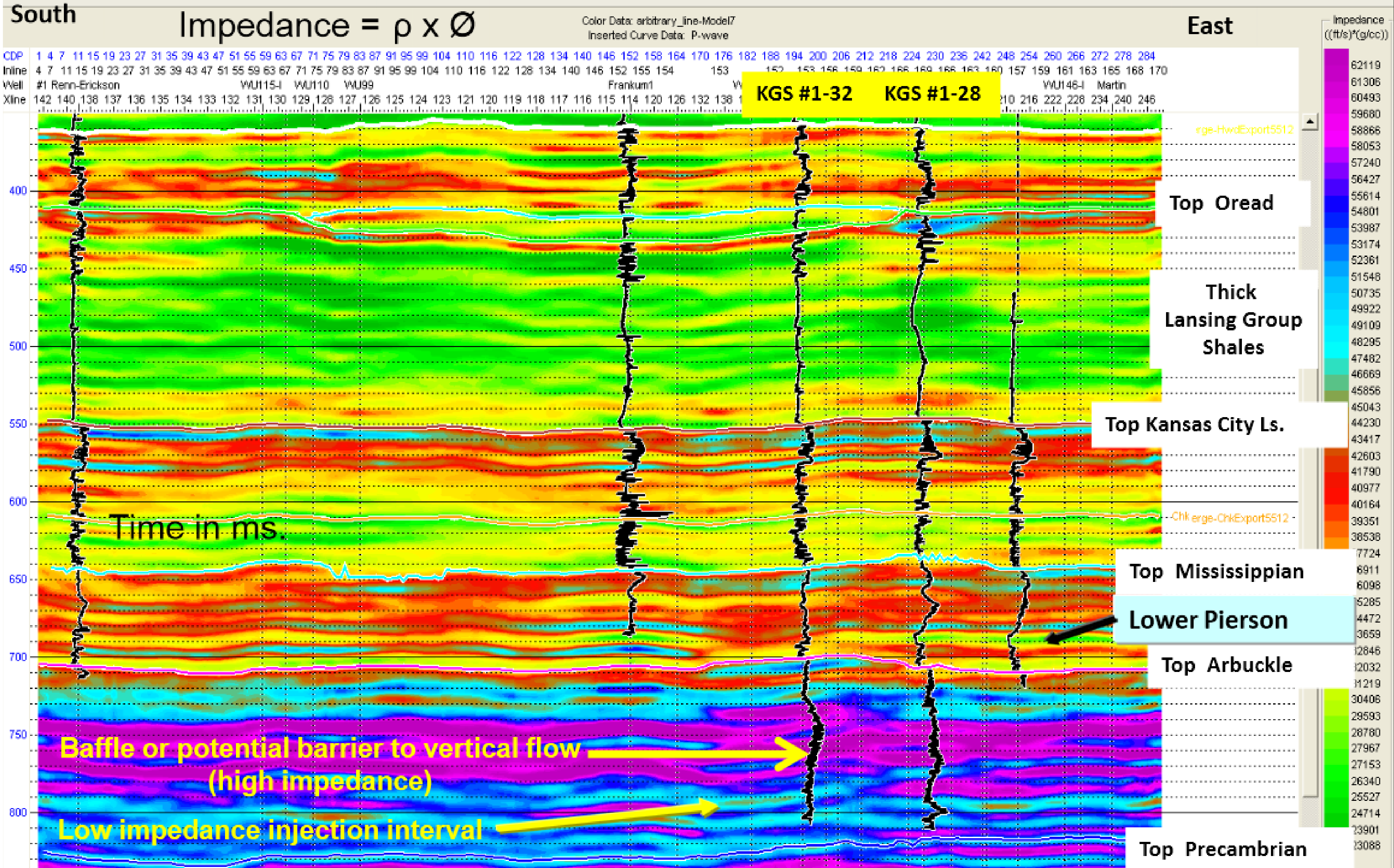
Br^-/Cl^- and SO_4^{2-}/Cl^- Identification of Baffles and Lack of Vertical Communication

- Br^- and Cl^- are conservative during water/rock interactions
- Very useful in detecting brine sources and mixing
- Values for brine of Lower Arbuckle vary substantially from Upper Arbuckle
- Lower Arbuckle brines cluster together
- Upper Arbuckle values more spaced out, suggests smaller baffles



Arbitrary seismic impedance profile – Wellington Field

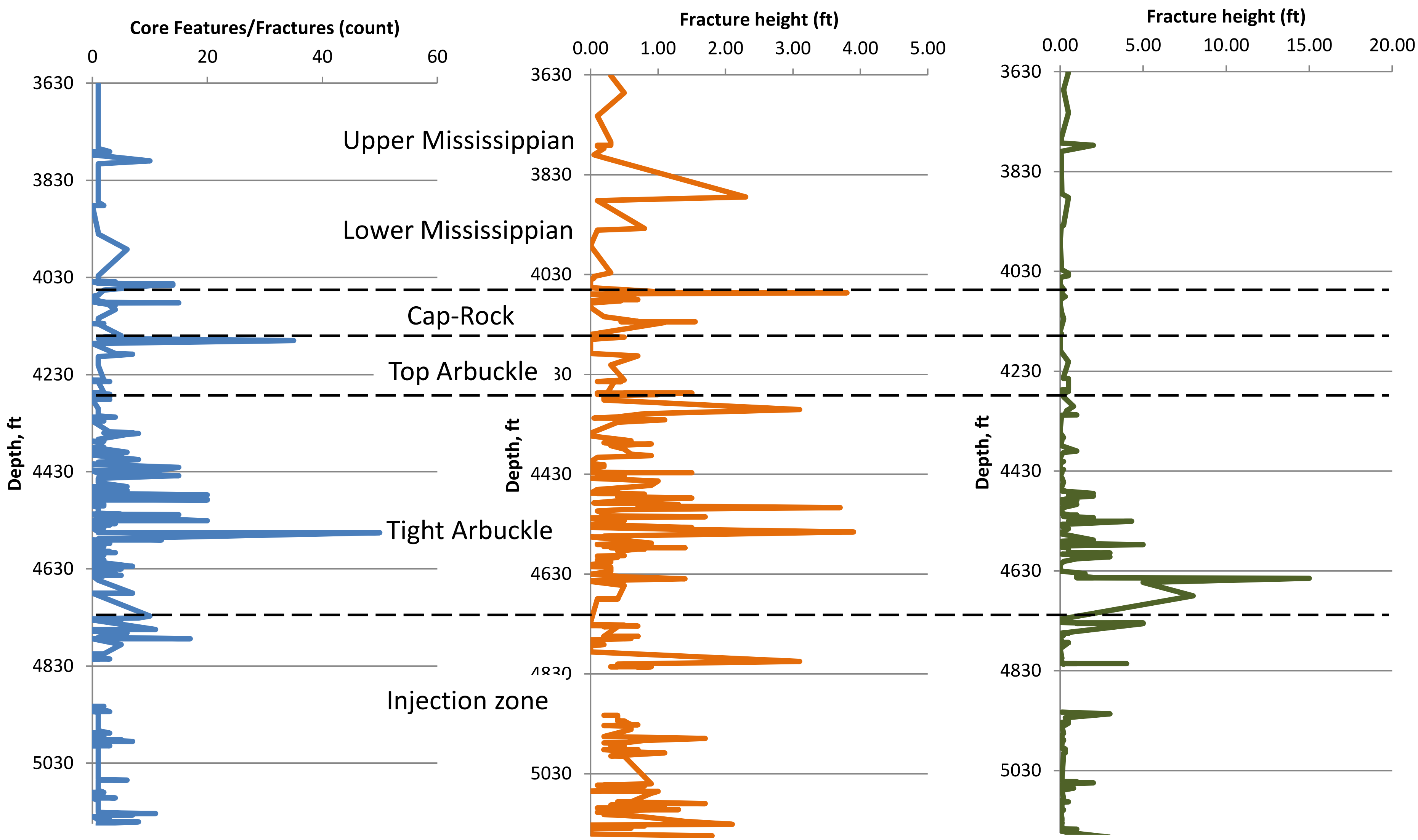
distinct caprock, mid-Arbuckle tight, lower Arbuckle injection zone



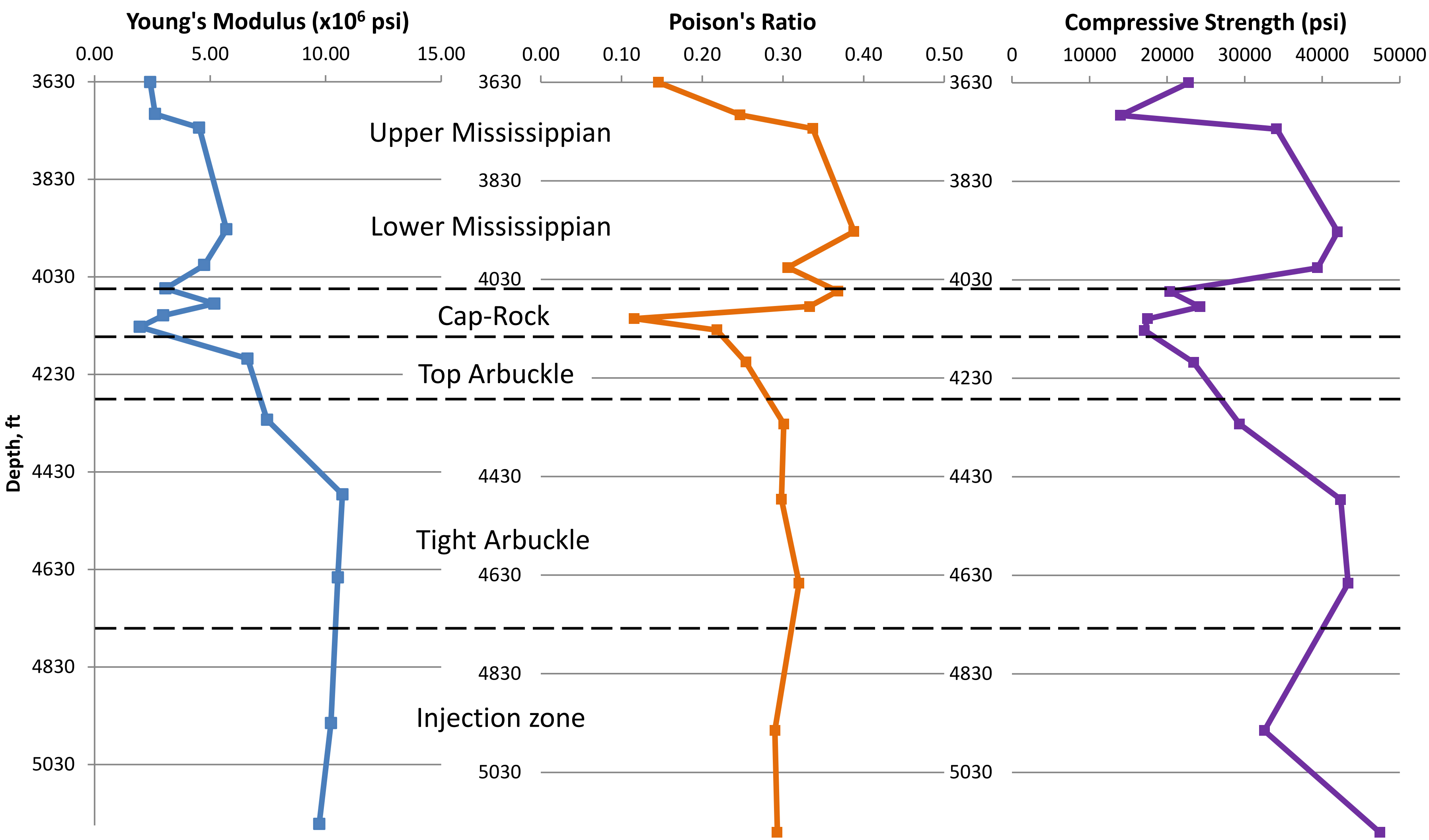
KU Kansas Geological Survey, The University of Kansas

Hedke – DOE/CO2

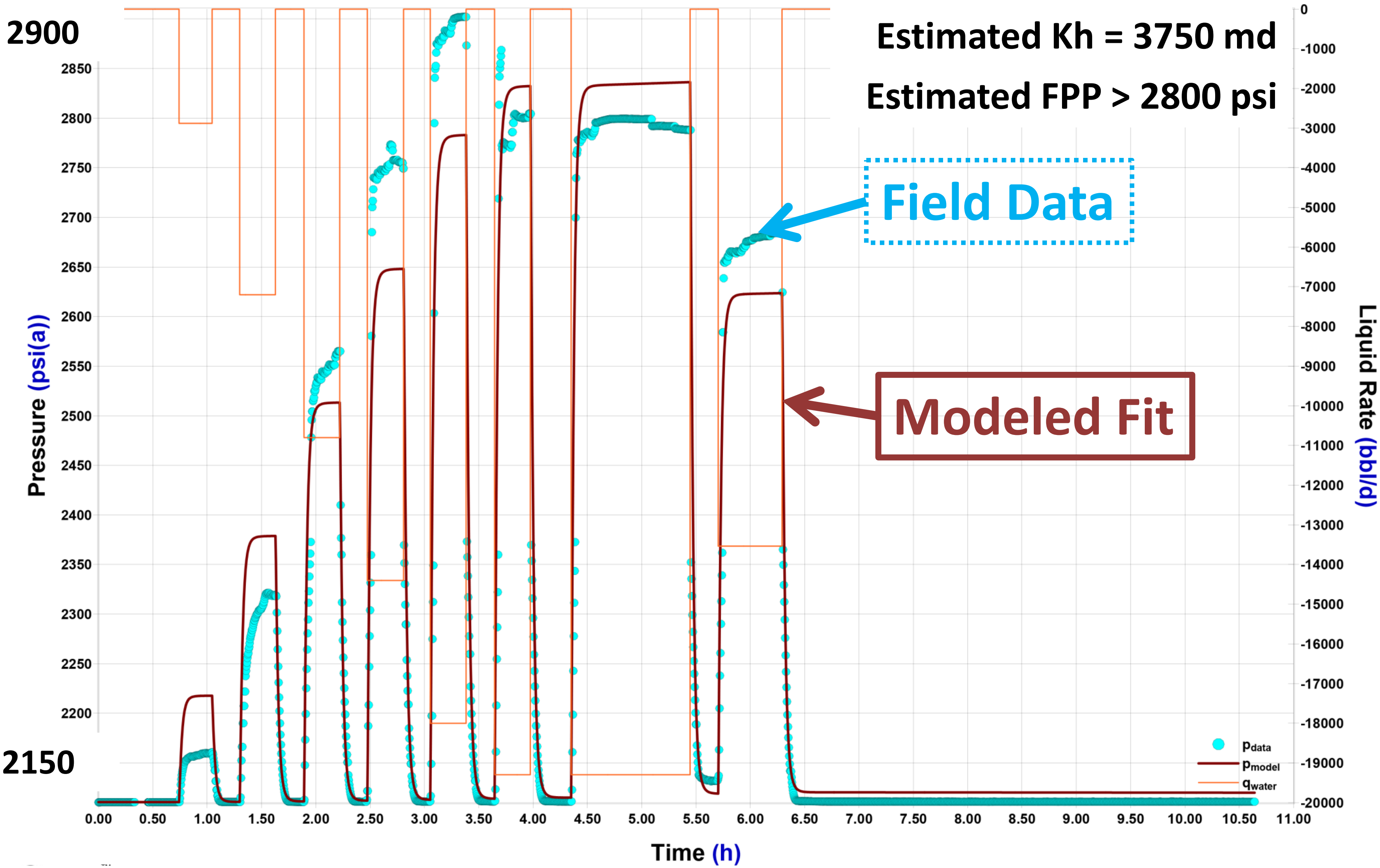
Core Features/Fractures

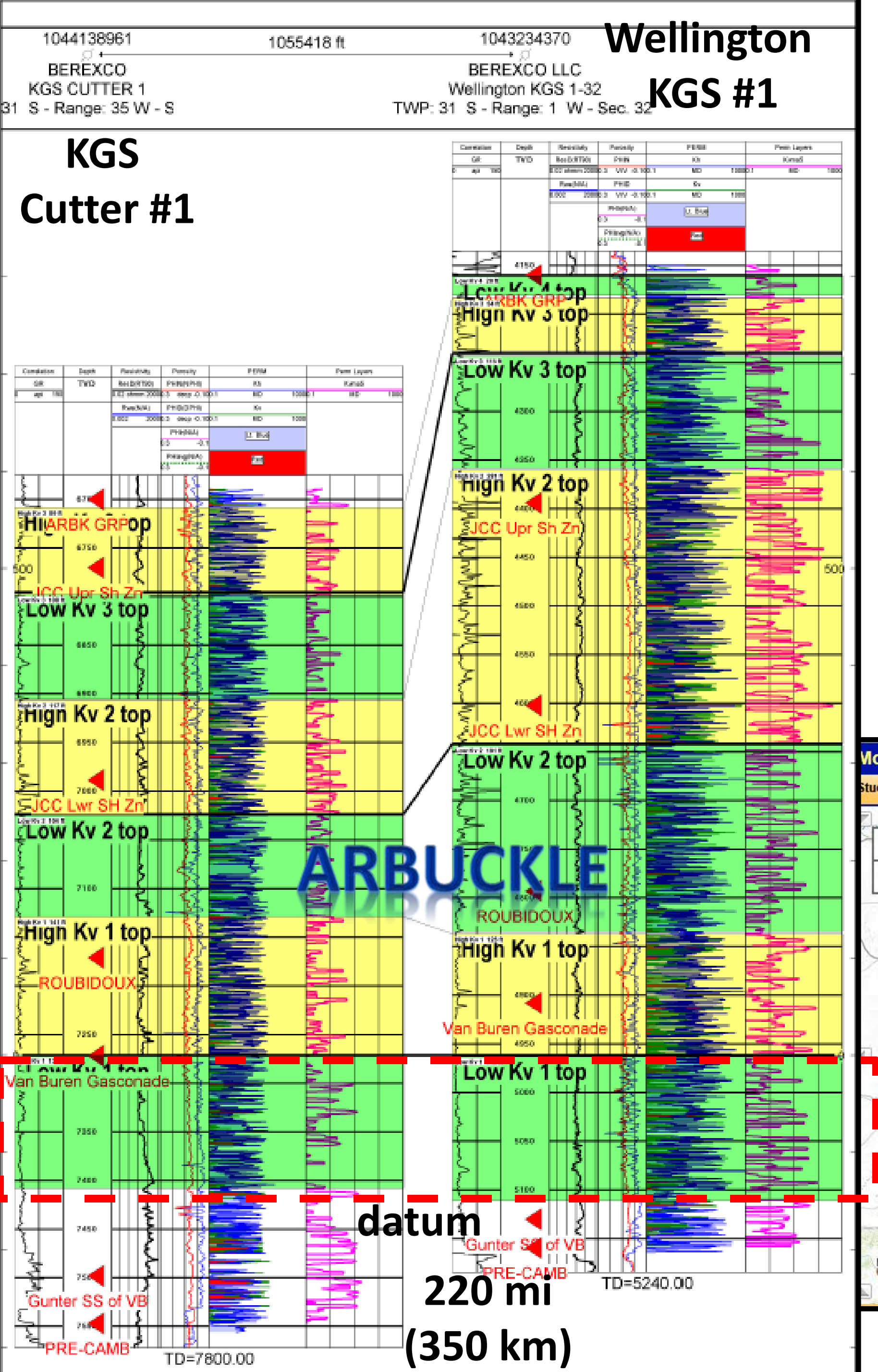


Rock Mechanical Properties vs. Depth



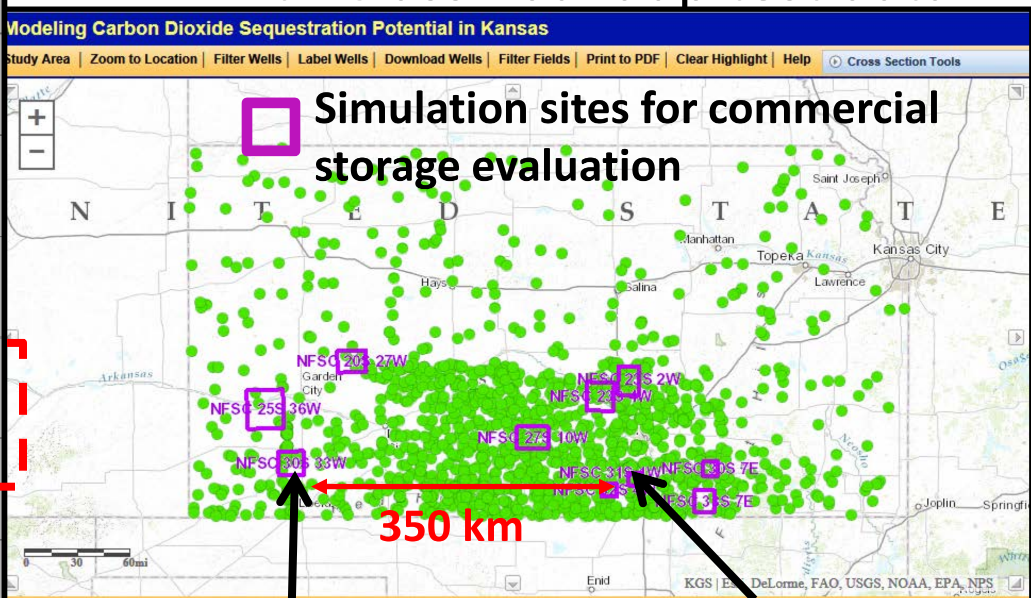
Step Rate Test Analysis
Pressure-Time plot





Computed Kh & Kv in Arbuckle Group for Digital Type Wells (●)

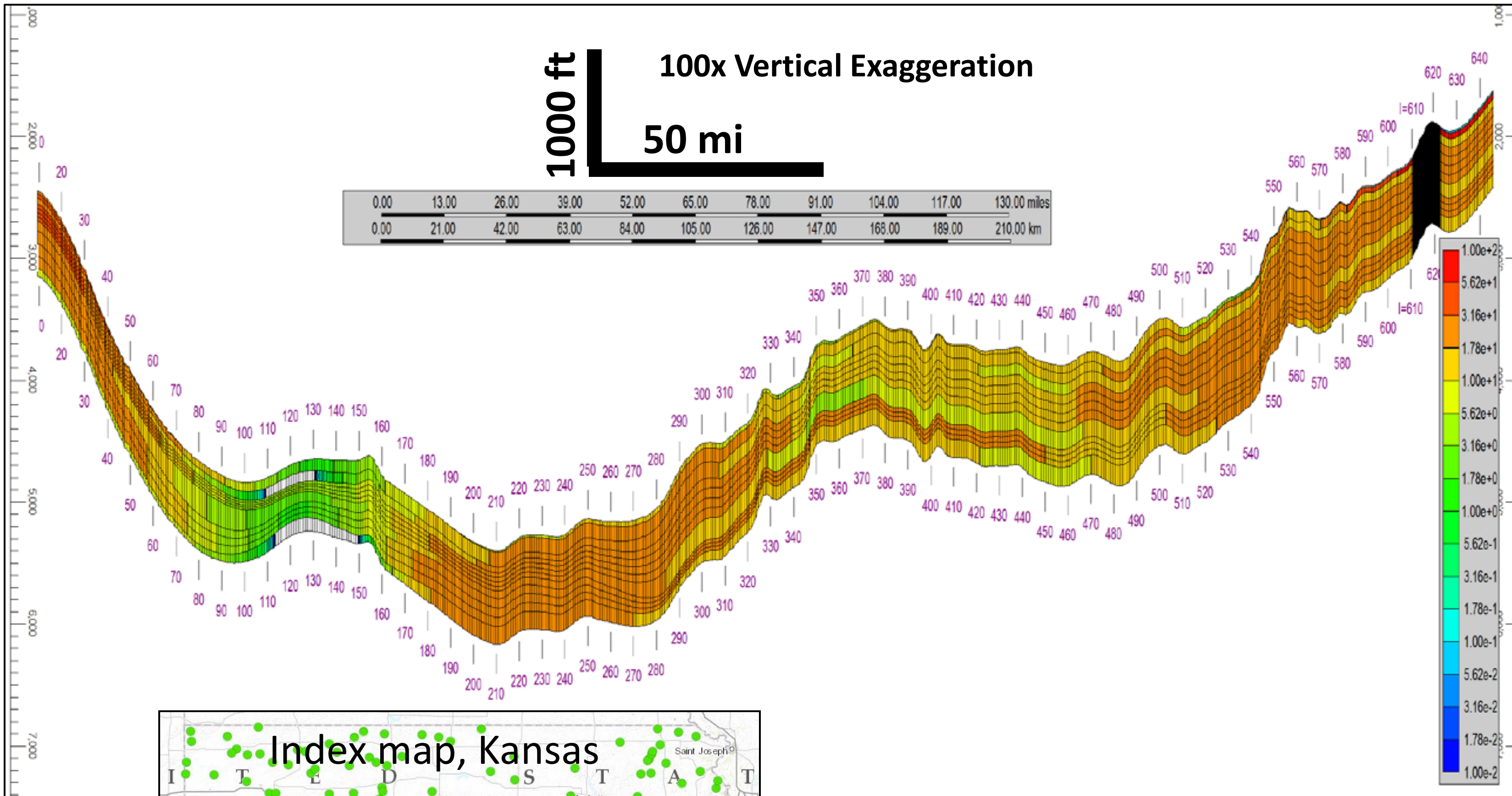
- Correlation of flow units based on K_h & k_v
- Between Cutter and Wellington Fields (350 km apart)
- Testing log-derived permeability with Class I buildup test data

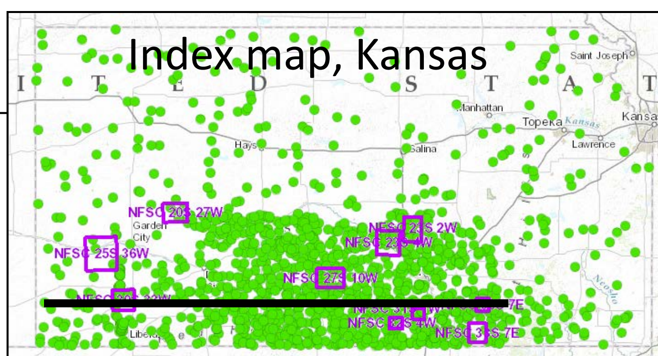


Cutter KGS #1

Wellington KGS #1-32

Structural cross section showing regional Arbuckle flow units, southern Kansas

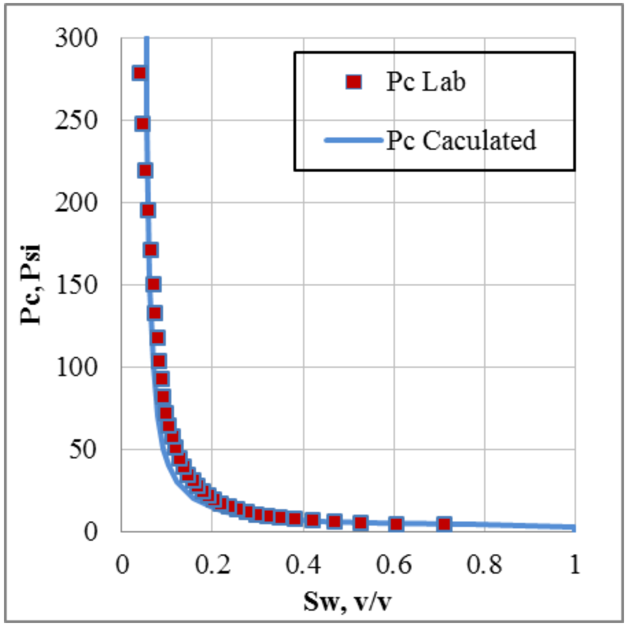


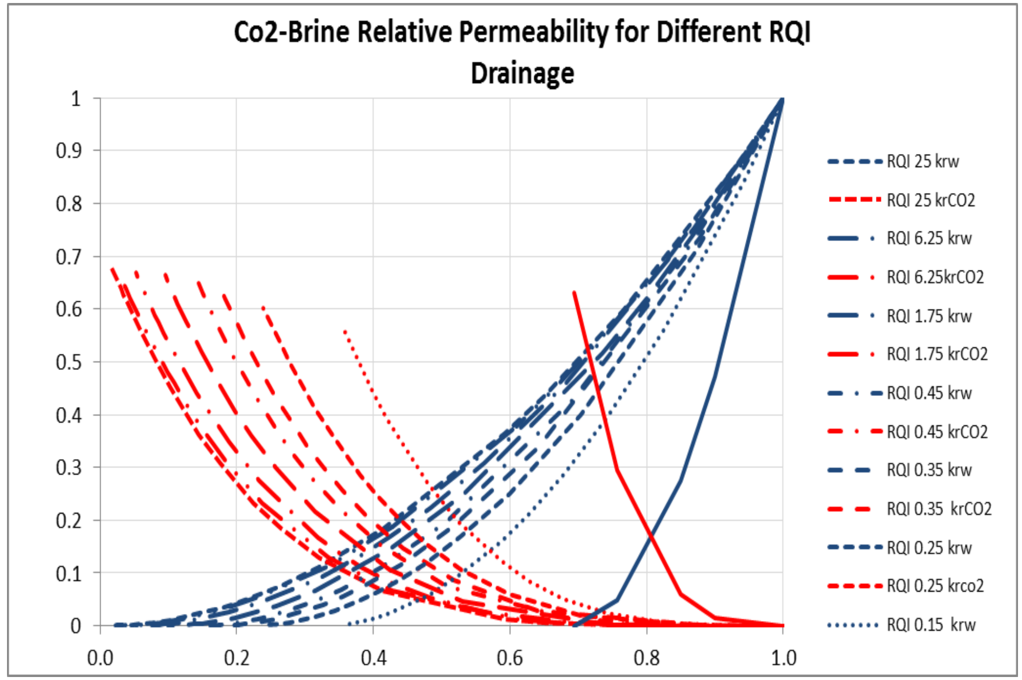


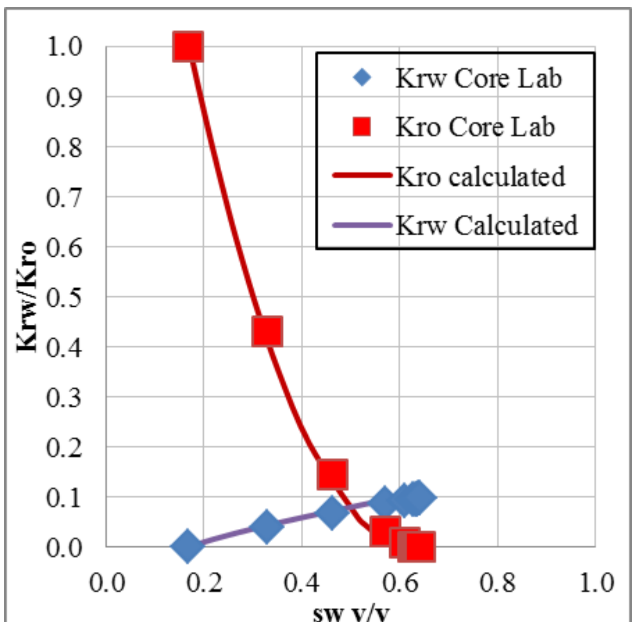
Horizontal Permeability, md

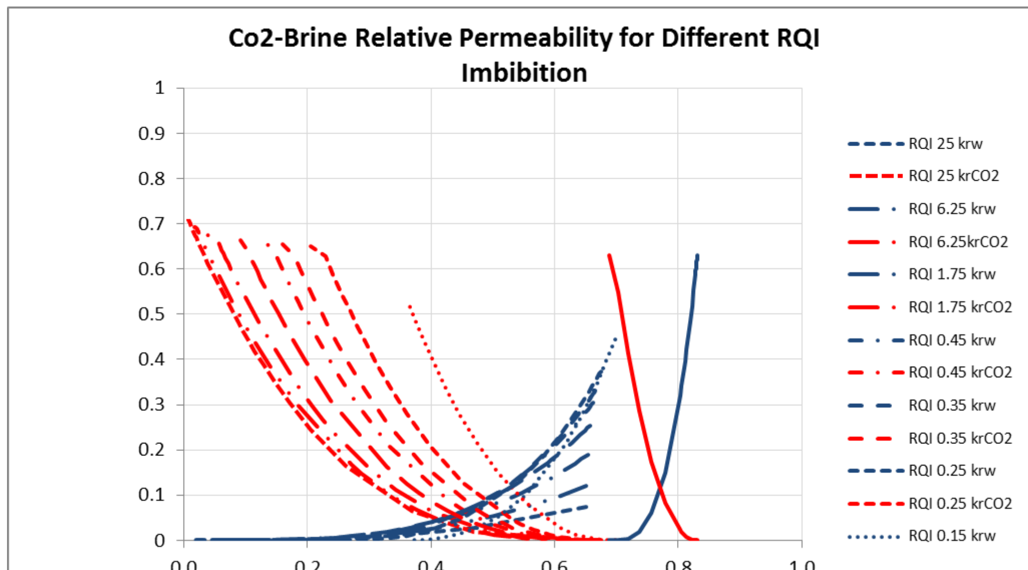
Williams, Gerlach, Fazelalavi, Doveton, KS CO_2

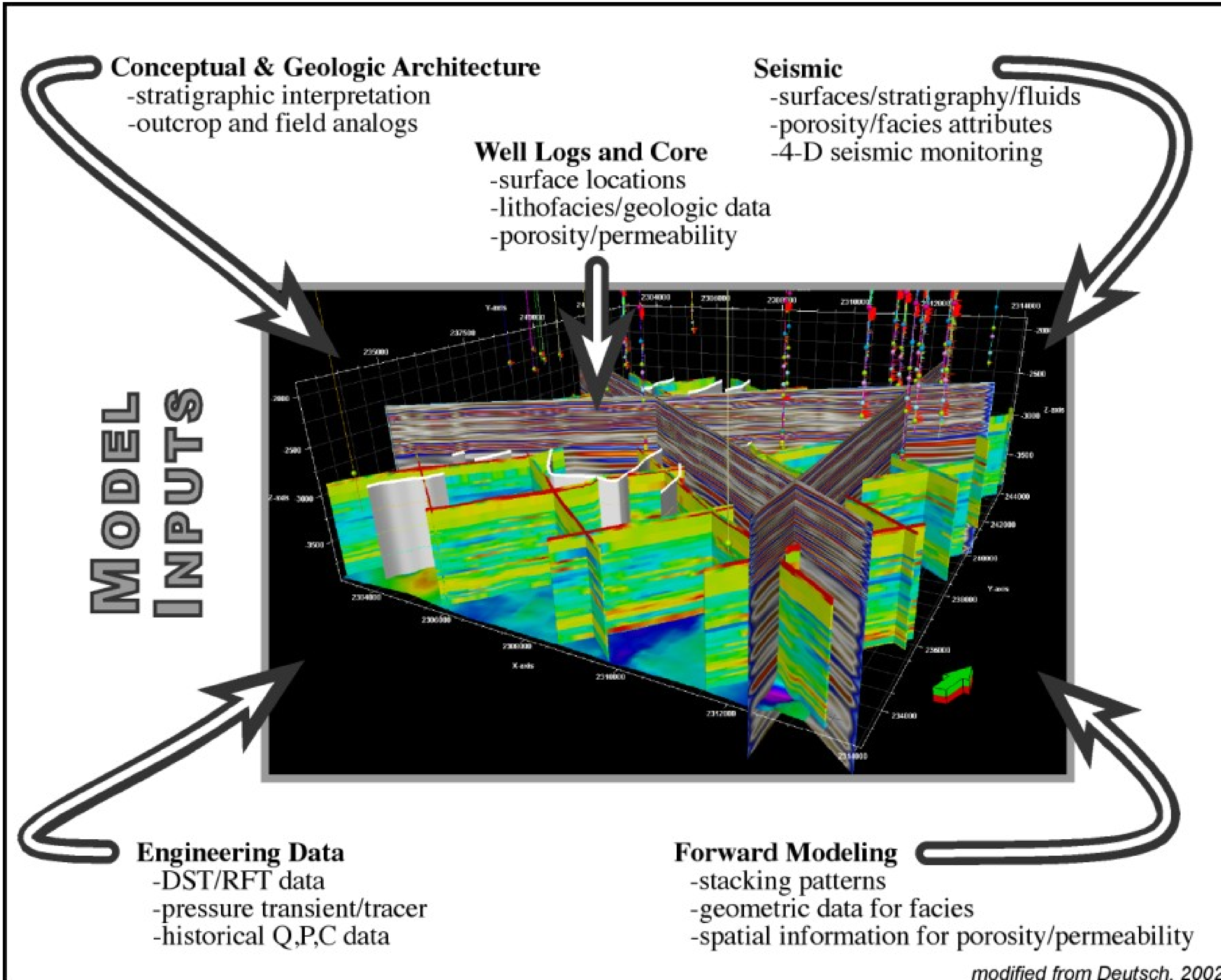
Relative Permeability and Capillary Pressure



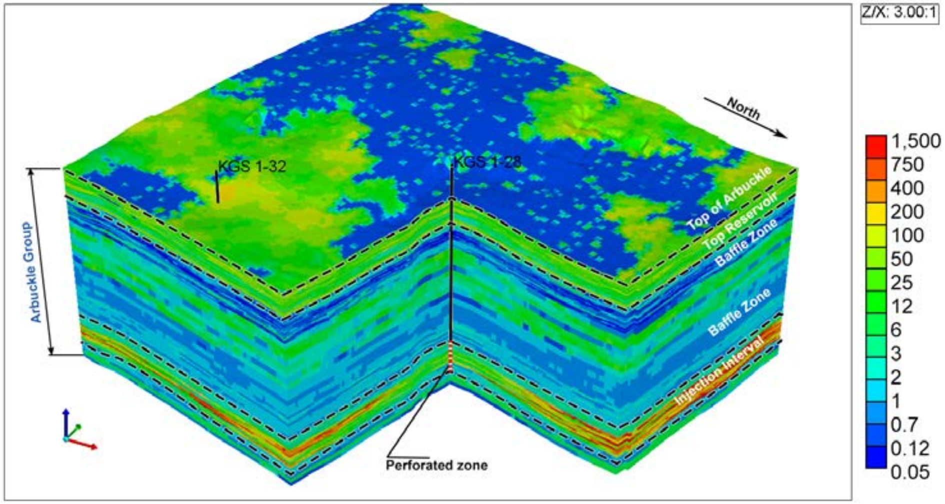




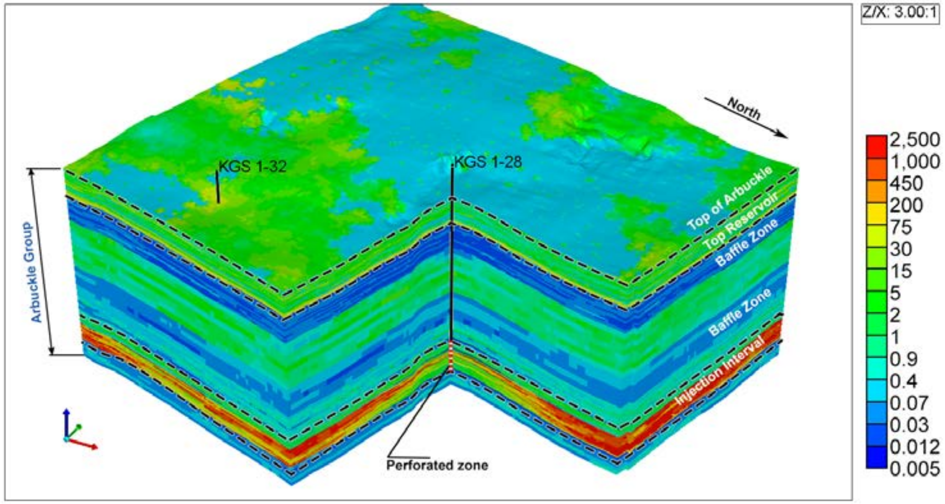



Conceptual & Geologic Architecture
-stratigraphic interpretation
-outcrop and field analogs
Well Logs and Core
-surface locations
-lithofacies/geologic data
-porosity/permeability
Seismic
-surfaces/stratigraphy/fluids
-porosity/facies attributes
-4-D seismic monitoring
MODEL INPUTS
Engineering Data
-DST/RFT data
-pressure transient/tracer
-historical Q,P,C data
Forward Modeling
-stacking patterns
-geometric data for facies
-spatial information for porosity/permeability
modified from Deutsch, 2002

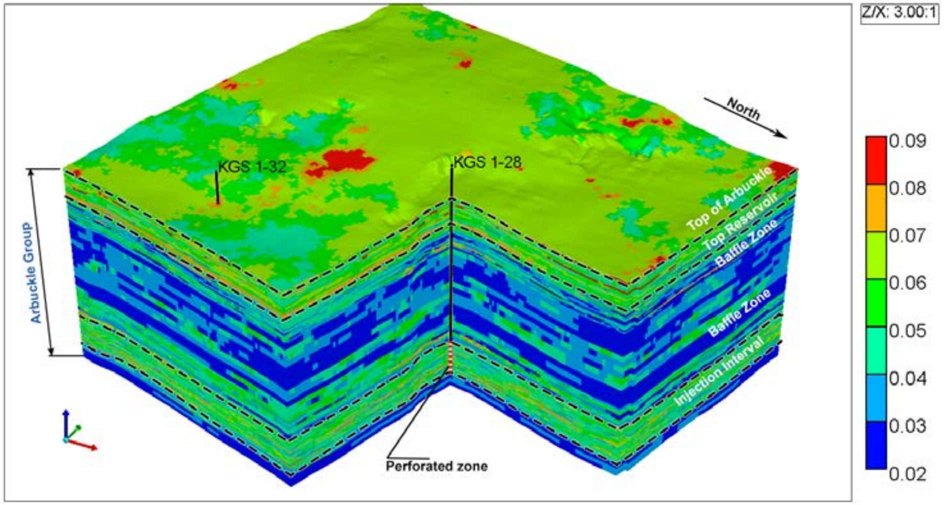
Permeability (K90)



Permeability (Vertical)

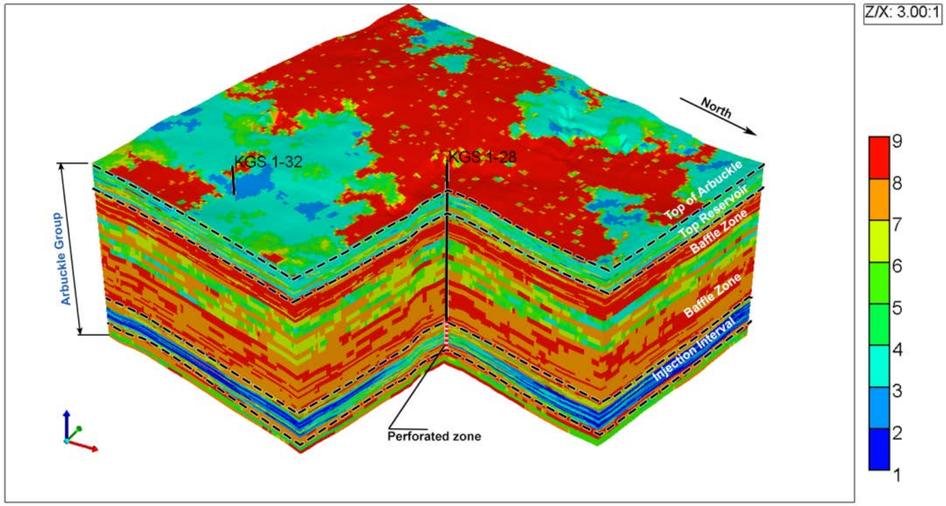


Rock Type Based on RQI

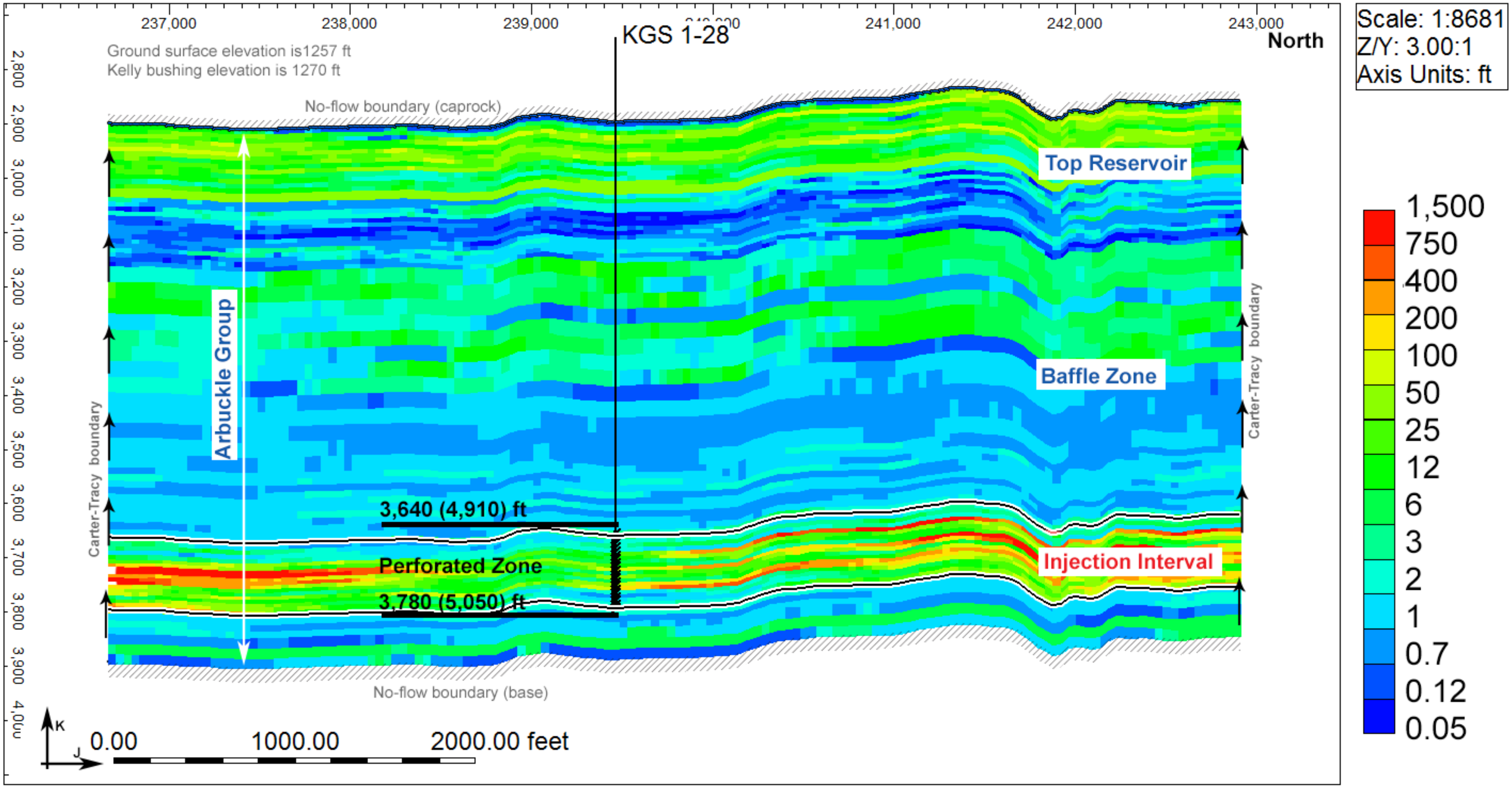


Rock Type Based on RQI

$$RQI = 0.0314\sqrt{Perm/_{Porosity}}$$



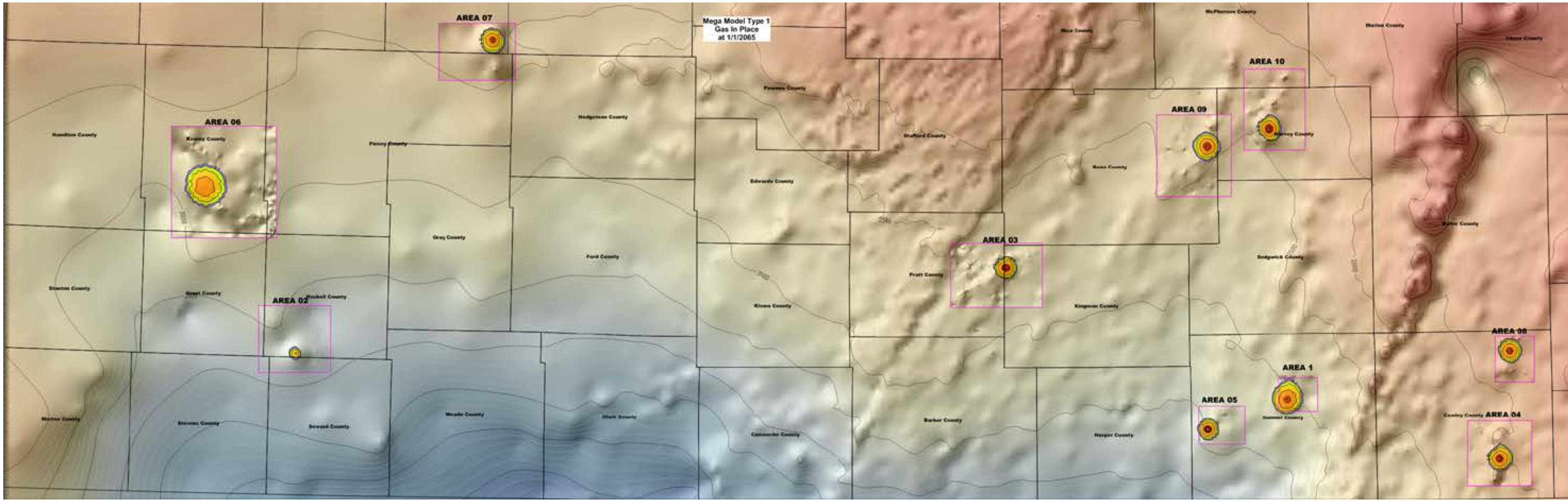
Dynamic Simulation Model

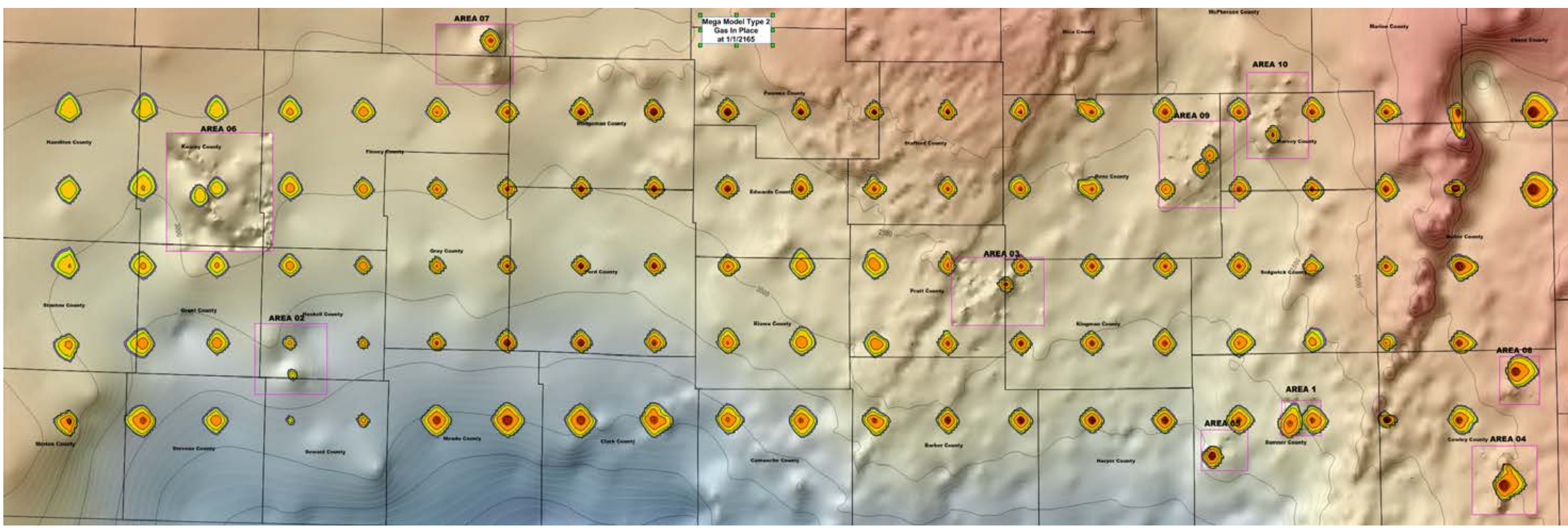


Simulated commercial storage capacity in the Arbuckle saline aquifer for 10 sites

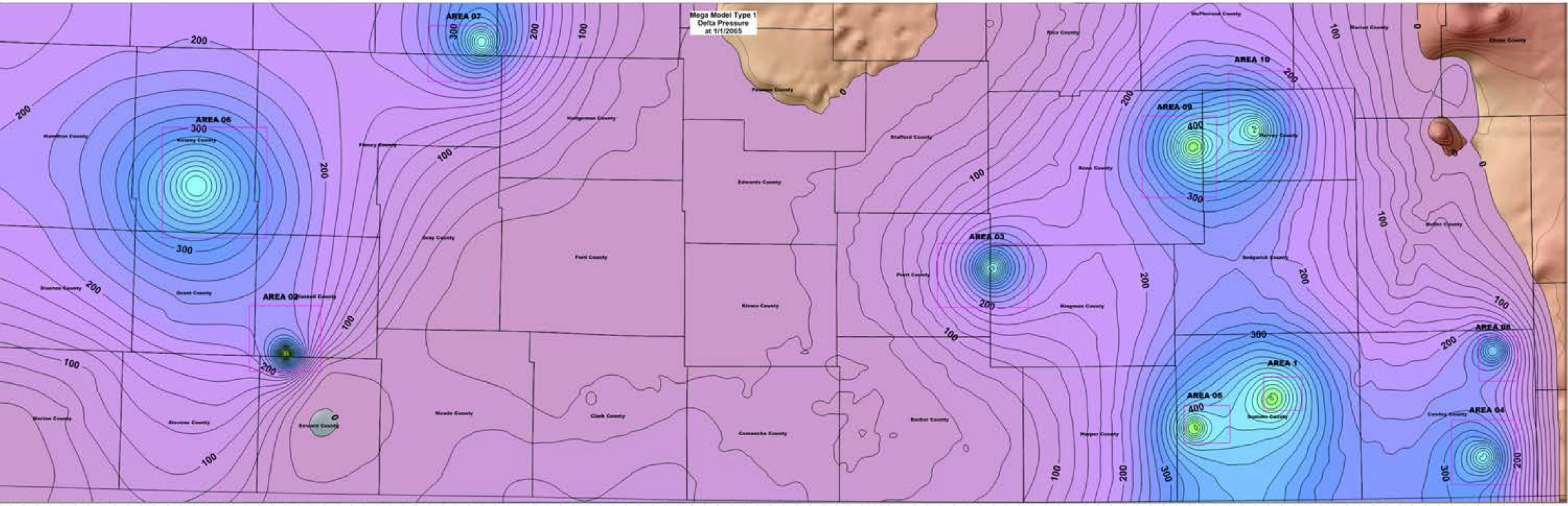
Area	Estimated Storage Capacity (P50), million tonnes	Area, km^2	Gross Thickness, m	Net Reservoir Thickness, m	Porosity, %	Average Permeability, md	Depth, m	Limiting Injection Pressure, bar	Reservoir Pressure, bar
1	79	1.4	300	66	5	25	1184	187	144
2	1	5.2	223	49	4	15	1508	223	175
3	49	6.1	258	57	6	15	1388	210	162
4	121	6.6	240	53	6	15	1170	179	138
5	55	1.4	300	66	5	19	1581	240	185
6	98	2.4	205	45	6	23	1310	194	150
7	71	1.2	209	46	3	31	1266	189	145
8	104	2.6	240	53	6	20	1089	169	130
9	98	5.8	230	51	6	18	1377	206	158
10	104	5.4	208	46	6	25	1224	183	141
Regional Model	4000	821	243	54	5	21	1288	195	150

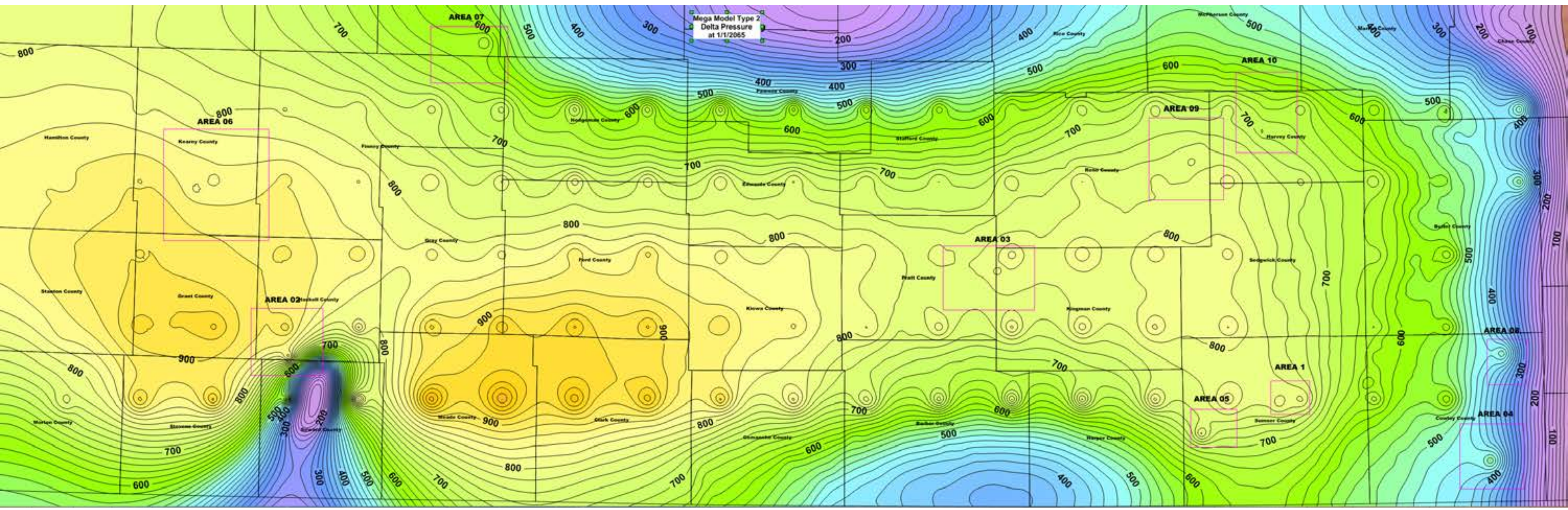
CO_2 Spatial Distributions: 10 sites vs Max Capacity



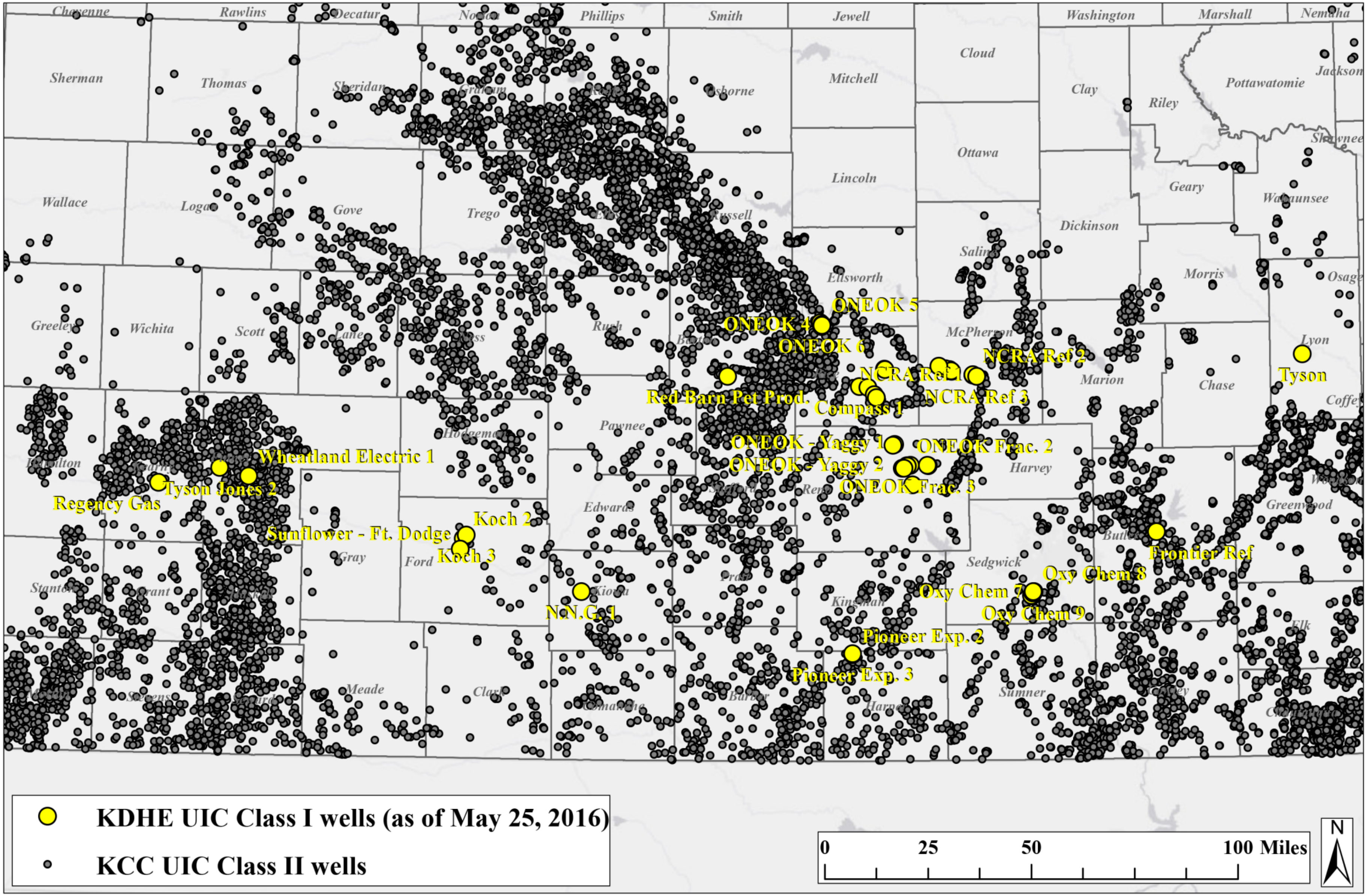


Predicted Delta Pressure Distributions: 10 sites vs Max Capacity



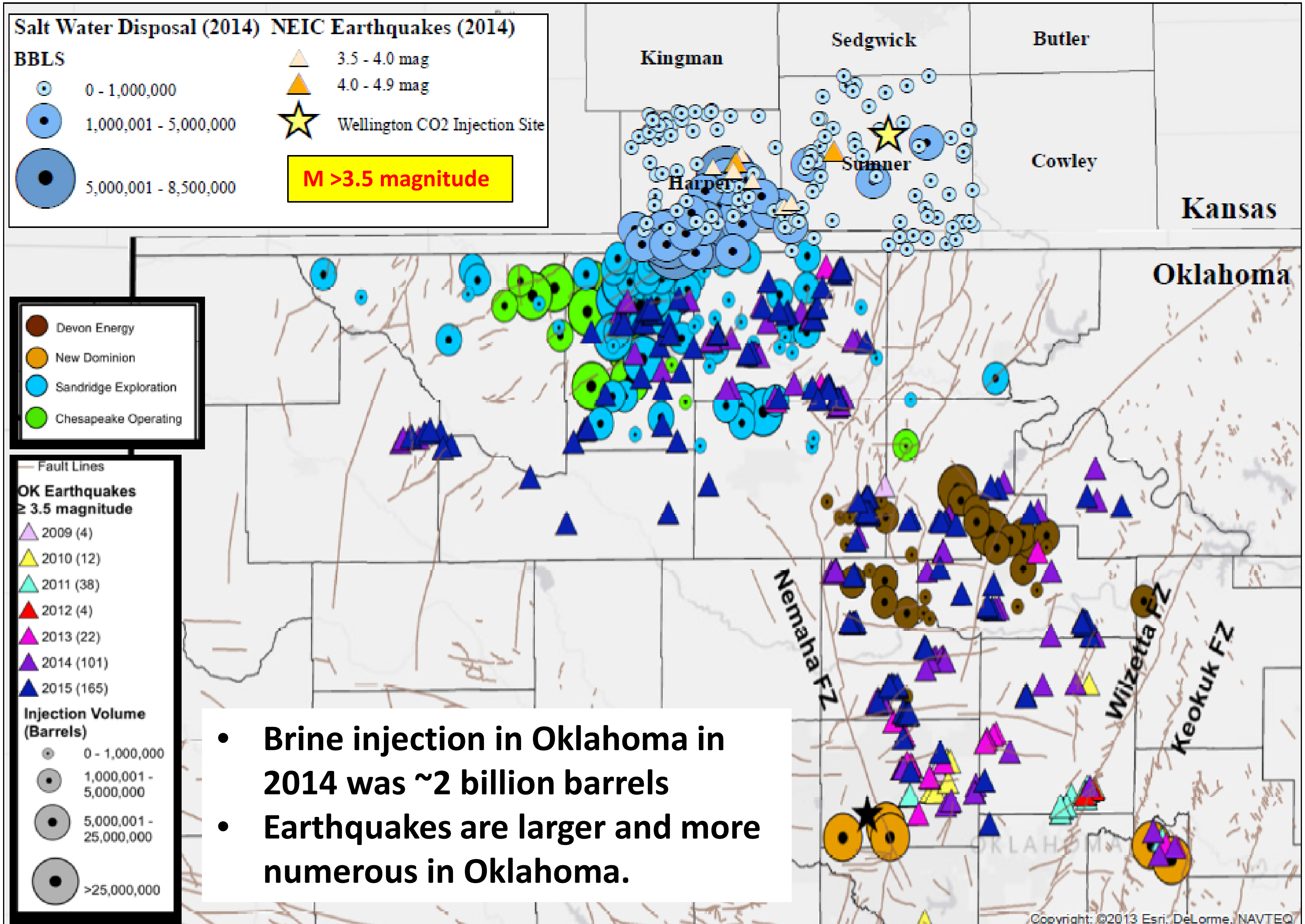


Kansas Disposal Wells



Sources: Kansas Department of Health and Environment, ESRI, USGS, Kansas Corporation Commission, Kansas Geological Survey

Earthquakes and geology in central KS and OK



- Brine injection in Oklahoma in 2014 was ~2 billion barrels
- Earthquakes are larger and more numerous in Oklahoma.

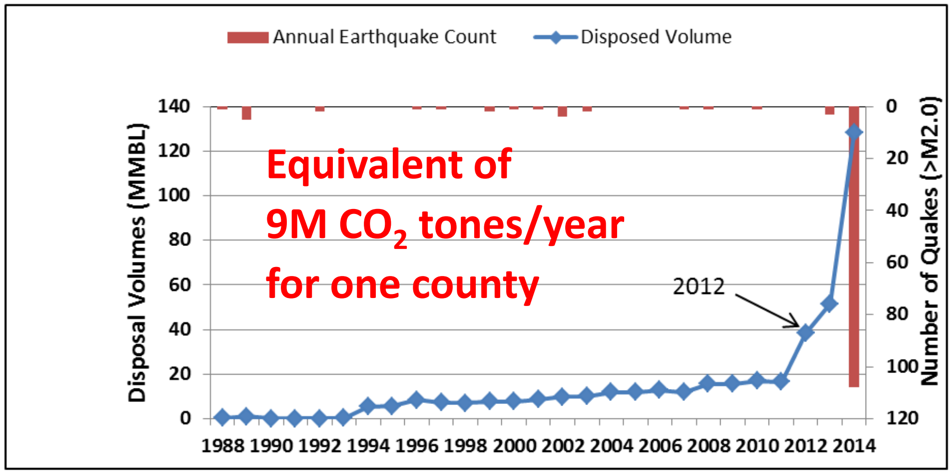
Map printed by J. Hollenbach 12/8/2015

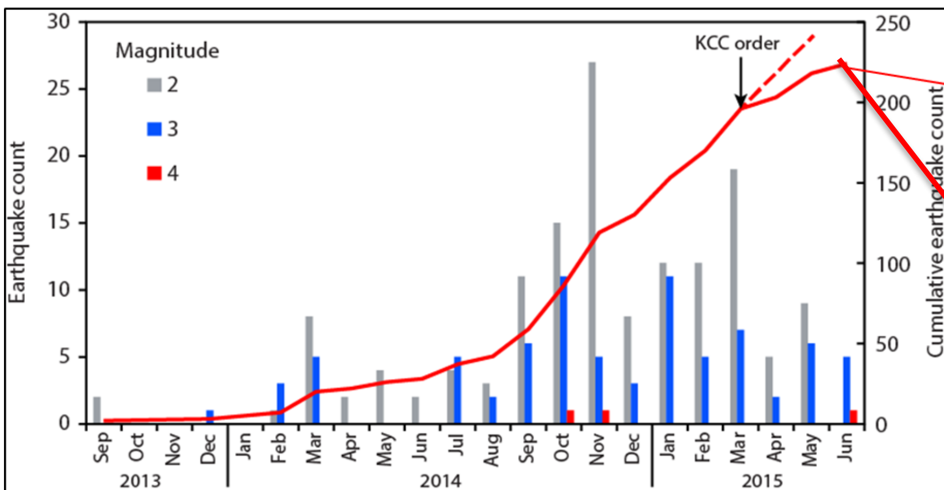
0 25 50 Miles

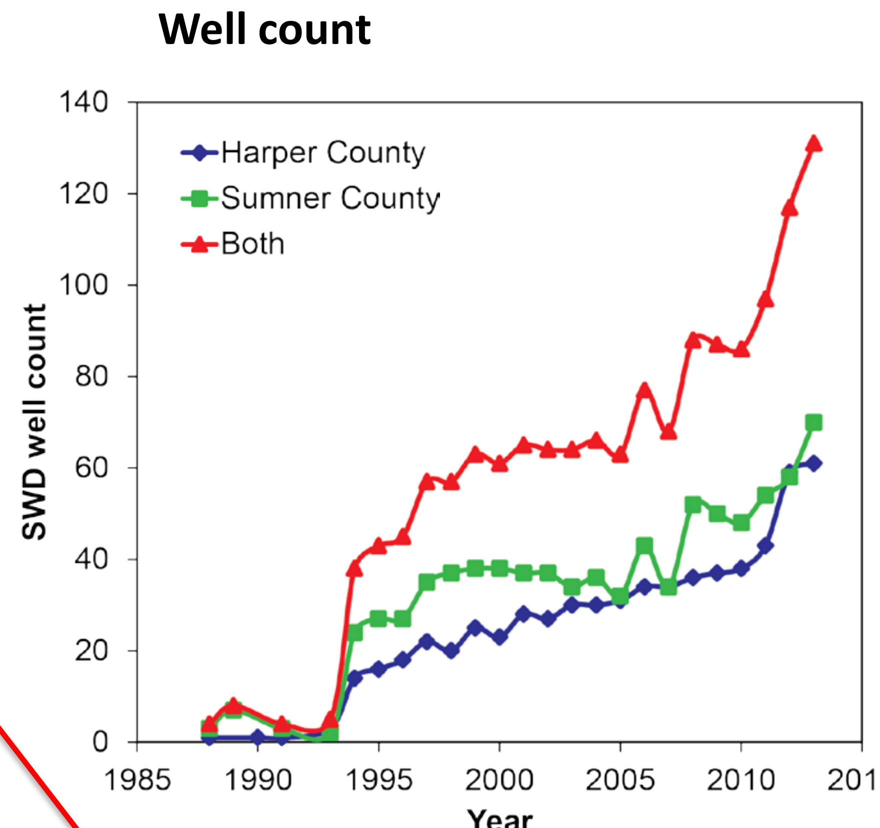
N

Sources: Kansas Geological Survey, Kansas Corporation Commission, NEIC, USGS, ESRI, Oklahoma Geological Survey, Oklahoma Corporation Commission
Oklahoma map - Public Justice lawsuit on behalf of the Sierra Club dated 10/29/2015

Seismic and Waste Disposal Trends in Sothern Kansas



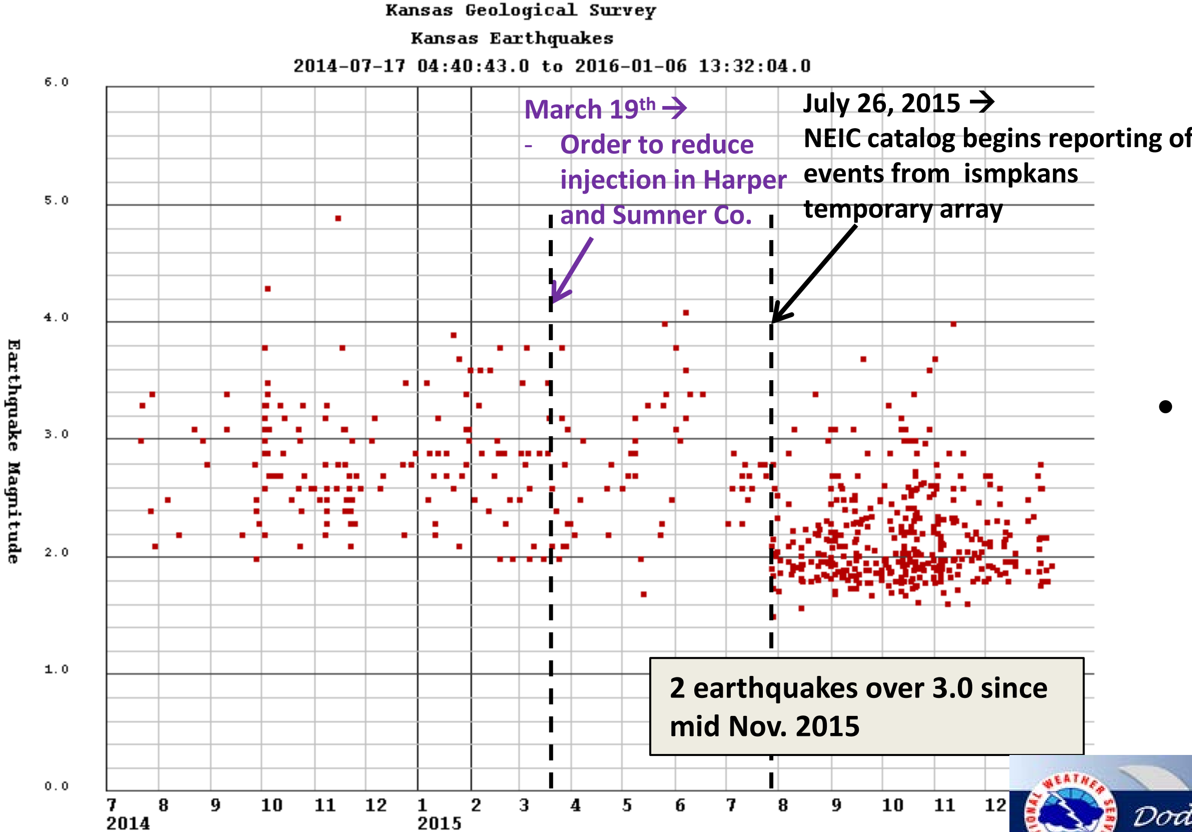




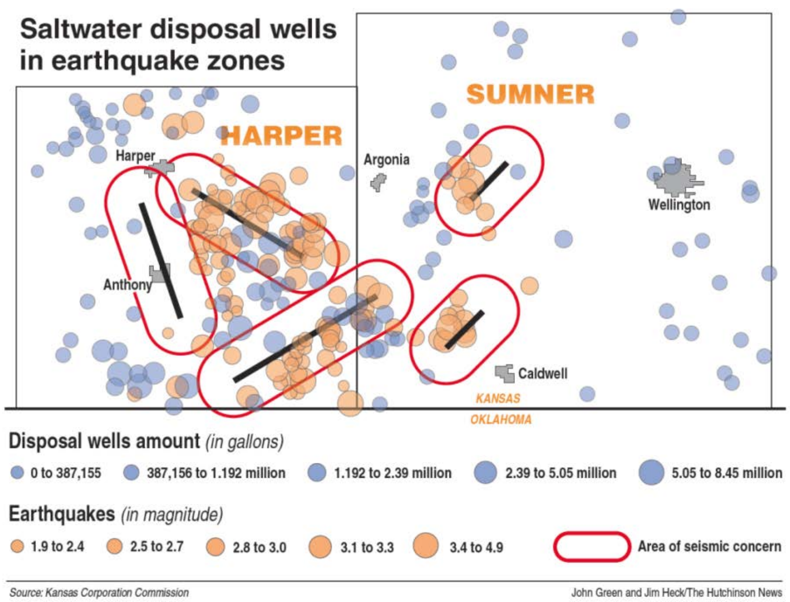
Slight reduction in seismic activity following state restriction order on injection volumes and other factors

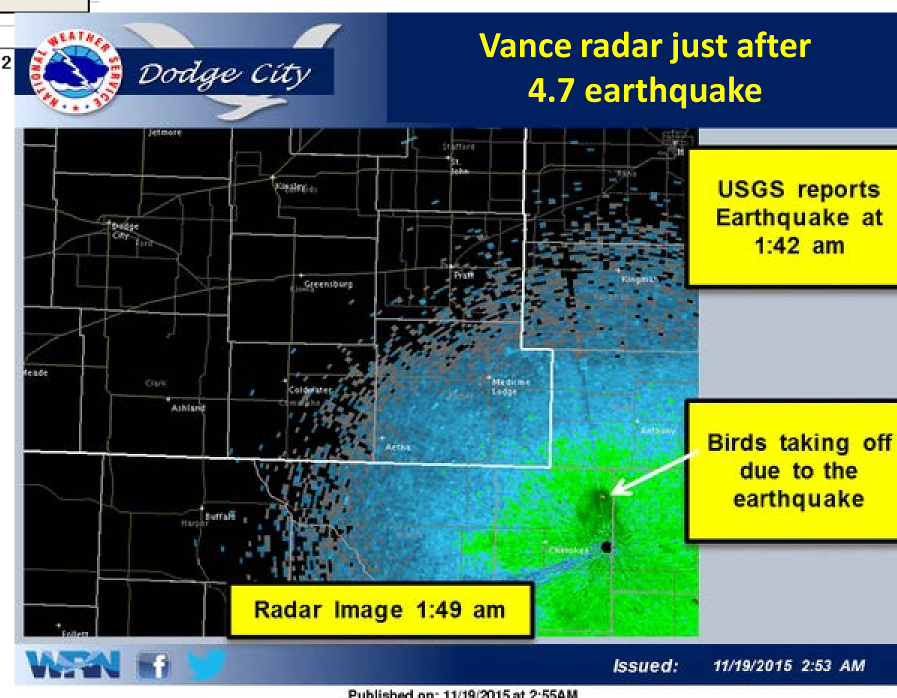
Kansas Earthquakes as Reported by NEIC

- First report on July 26, 2015 of new USGS temporary array “ismpkans” in Harper & Sumner counties



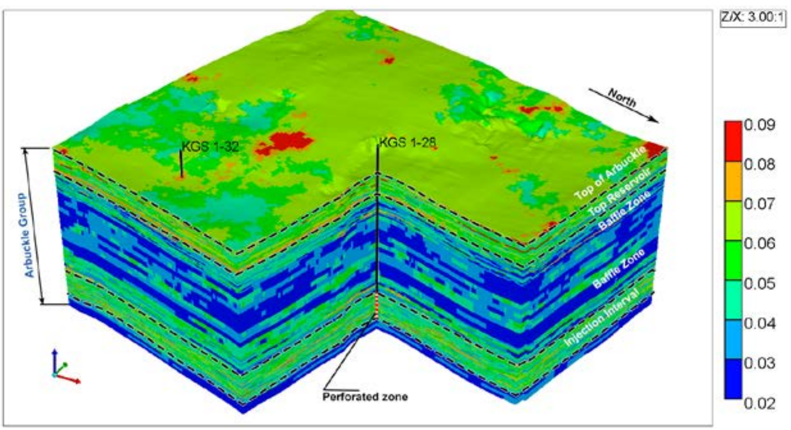
November 19, 2015



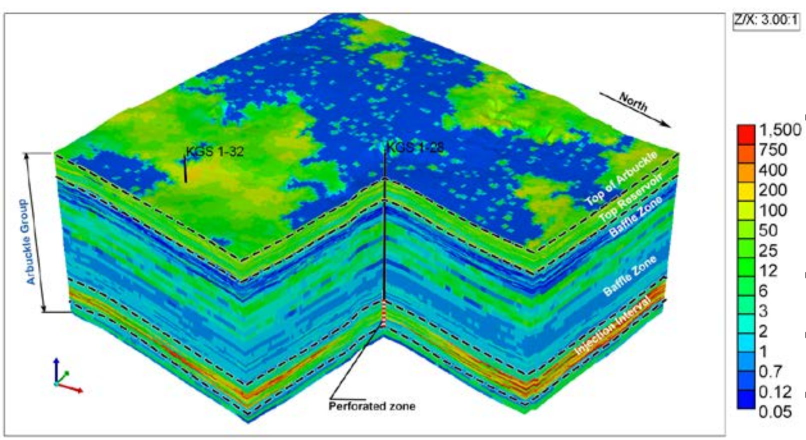


Common Analogs?

Arbuckle Porosity Model



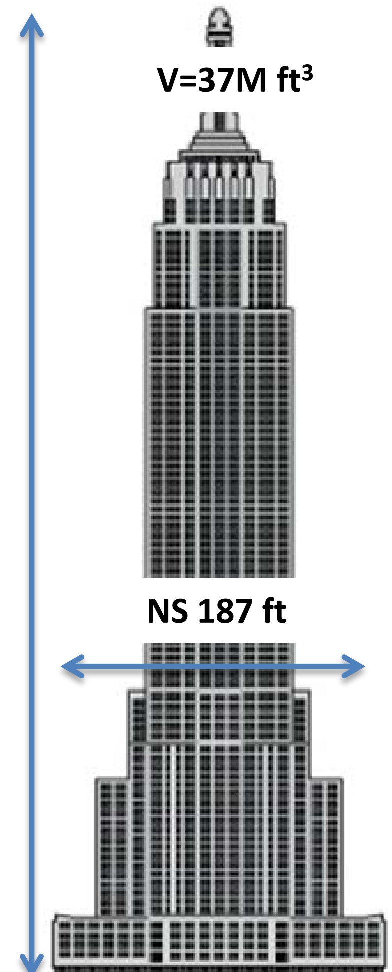
Arbuckle Permeability Model



- What is the capacity?
- Empty Volume = 37M ft^3 = 6.6M bbls
- If Ø = 5-7 %
- Volume$_Ø$ = ~450K bbls
- If efficiency = 50 %
- Volume$_e$ = ~ 225K bbls
- High volume wells used to deliver up to 30K bbls/day
- Therefore

  It would take up to 7-15 days to fill up this volume (<u>without considering existing water</u>)
- It would take 111-222 “ES units” to accommodate 50M bbls injected in 2014
- Translates into 3.9-7.8M ft^2
- Harper Co. Area = 22.4B ft^2
- “Plunging” system?

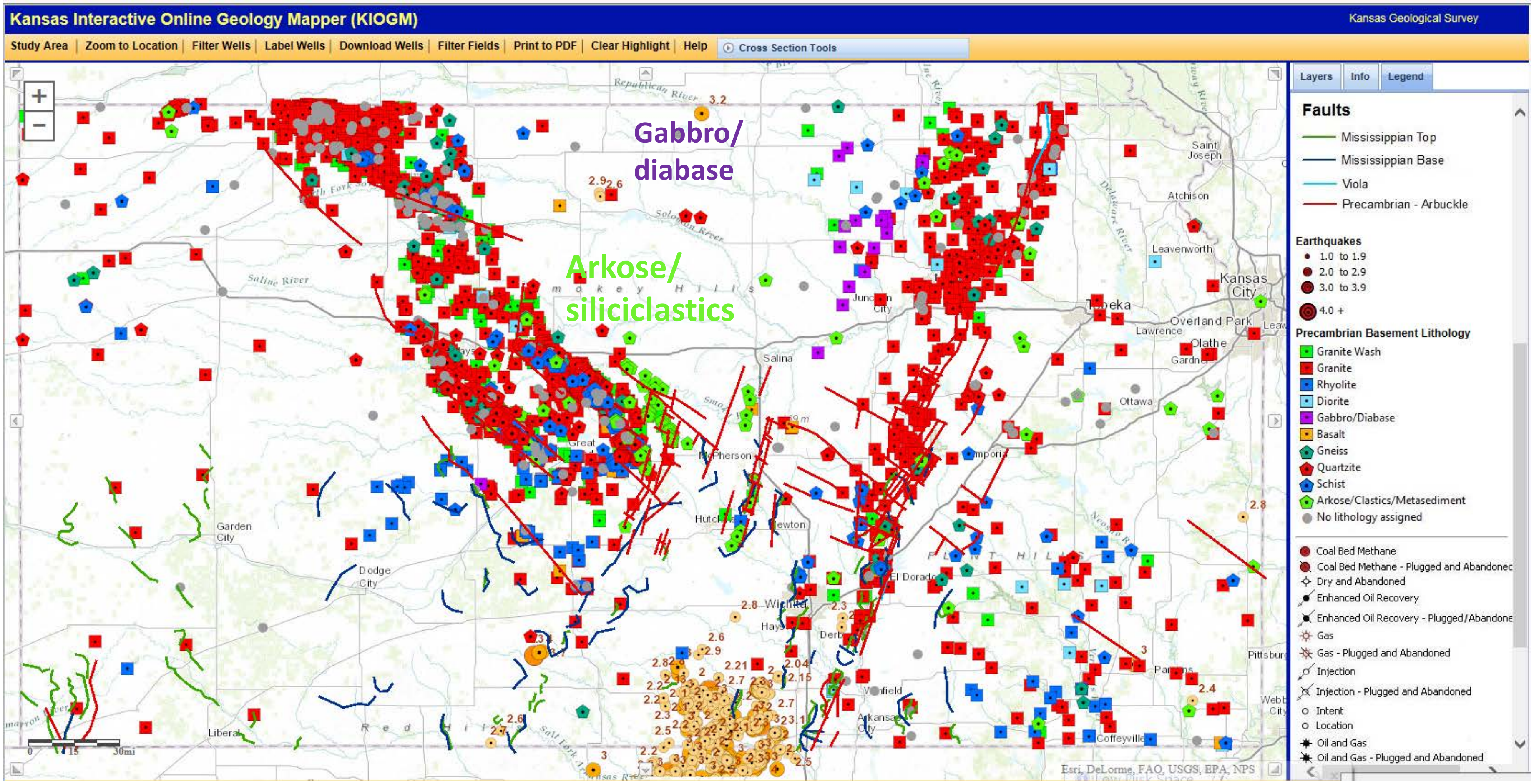
Empire State Building



blog.recursiveprocess.com

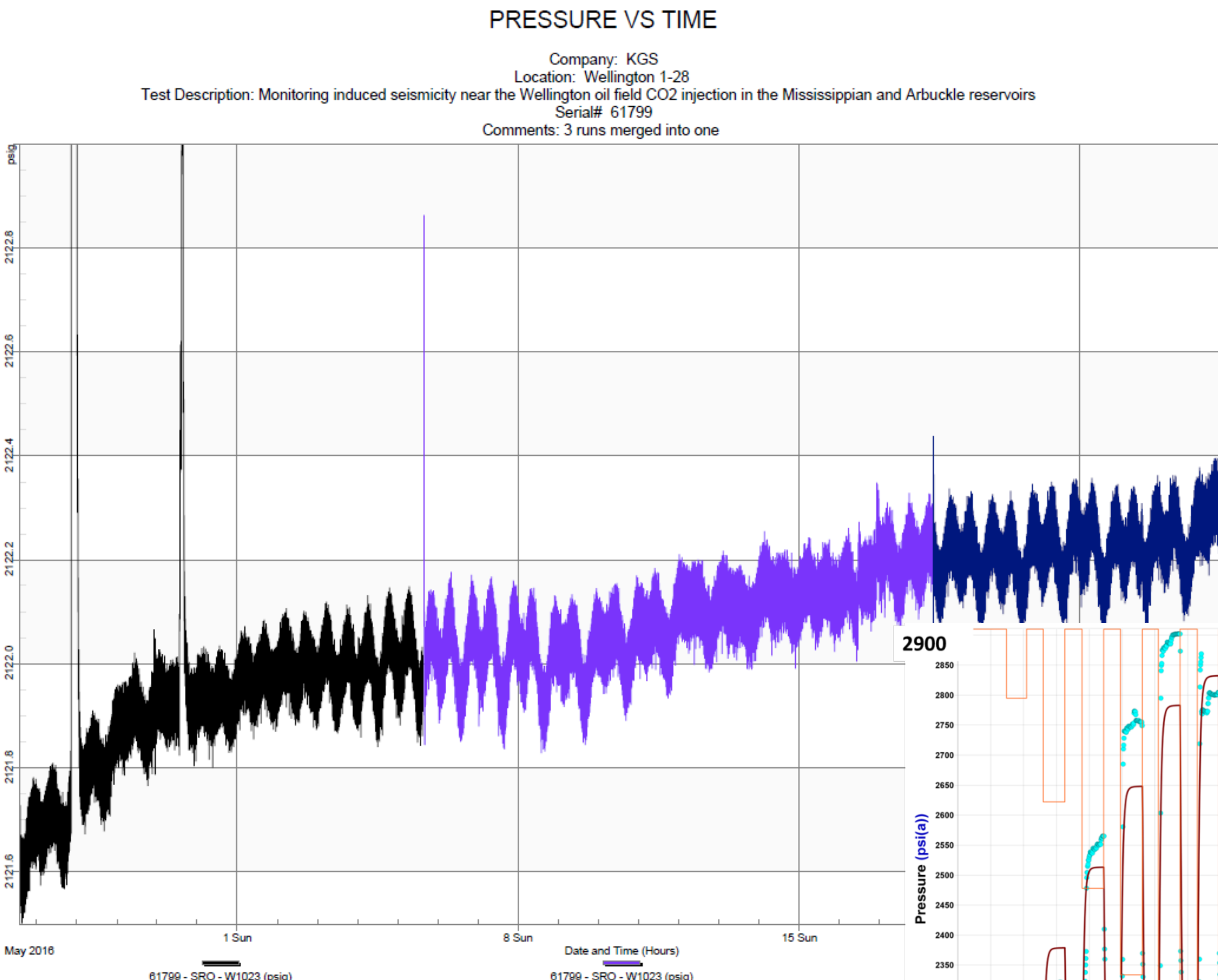
Basement geology from sample rock types in the area of the induced seismicity

→ thick arkosic sediment fill indicative of the Midcontinent Rift System (MRS)

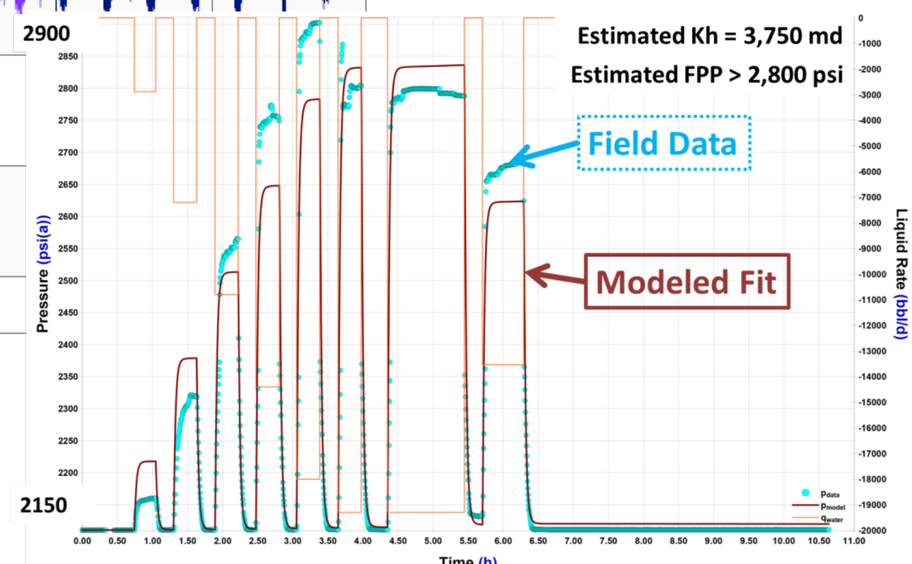


M. Killian, KGS

Downhole Pressure Monitoring



- ~ 30 psi increase since 2011
- 16 psi pressure spikes



Summary

- Does the risk of induced seismicity affect storage capacity?
  - Yes, absolutely
- Is the risk of induced seismicity a CCS killer?
  - IMHO, No; however…
- Arbuckle/basement interface?
- More characterization
- Monitoring strategies
  - Seismicity monitoring
  - Engineering solutions (pressure monitoring, well testing, etc.)
- Injection management strategies

Acknowledgements & Disclaimer

Acknowledgements

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Acknowledgements

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- Dana Wreath, Berexco, LLC for access and participation in drilling and testing at Wellington and Cutter fields and small scale field test at Wellington
- Rick Miller and Shelby Petrie, Wellington seismometer array, high resolution seismic
- Justin Rubinstein, USGS
- Induced Seismicity Task Force -- Rex Buchanan and Rolfe Mandel