Evaluation of CO_2 Sequestration Potential in Ozark Plateau Aquifer System (OPAS) in Southern Kansas - Initial Studies*

Willard L. Watney[1], Saibal Bhattacharya[1], Paul Gerlach[2], Jason Rush[1], Tom Hansen[3], Larry Nicholson[4], John Doveton[1], Anna Smith[5], Dennis Hedke[7], Susan Nissen[8], Abdelmoneam Raef[6], Jianghai Xia[1], David Koger[9], Ralph Baker[10], and John Victorine[1]

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Abstract

The Paleozoic-age Ozark Plateau Aquifer System (OPAS) in southern Kansas is centrally located to multiple major point sources of CO_2 emissions and is considered a prime candidate for CO_2 sequestration. The OPAS consists of the thick (>800 ft) and deeply buried (>3,500 ft) Arbuckle Group saline aquifer and overlying Mississippian carbonate reservoirs, such as Wellington field (Sumner County), many of which are in various stages of depletion. The Arbuckle saline aquifer consists of siliceous dolomite with interbedded shales, and appears to be well suited for supercritical CO_2 sequestration because multiple regional caprocks isolate it from shallow freshwater aquifers. Demonstration of CO_2-EOR potential in depleted Mississippian fields should spur infrastructure development for commercial scale CO_2 sequestration in the OPAS.

This study focuses on 1) developing a regional (≈ 20,000 mi^2) geomodel for the Arbuckle saline aquifer, 2) constructing a local geomodel of the Mississippian reservoir and the underlying Arbuckle saline aquifer at Wellington field, 3) estimating the CO_2

sequestration capacity of the OPAS, and 4) evaluating CO_2-EOR potential of Wellington field. The regional Arbuckle geomodel was constructed utilizing wireline logs from 95 type wells and 1,400 key wells, five cores, DSTs, and gravity/magnetic and remote sensing data. The detailed Wellington geomodel integrates existing geologic and engineering data with newly acquired data: multi-component 3D seismic survey (10 mi^2), gravity/magnetic surveys, and core and wireline logs from two wells drilled to basement.

The regional Arbuckle geomodel has helped to understand factors, such as lateral continuity of Arbuckle strata including caprocks and shale beds, and relationship between underpressurization and hydraulic connectivity to the outcrop (northwestern flank of Ozark Uplift), critical to modeling sequestration capacity of the OPAS. Arbuckle flow units, indentified by depth-constrained cluster analysis of petrophysical data and mapped over a 9-Township area over a monoclinal structure, were used in simulation studies, with CO_2 injected in bottom Arbuckle flow unit, to demonstrate sequestration of significant tonnage of CO_2 by solution, residual gas saturation, and mineralization. Intermediate shaly layers in Arbuckle appear to prevent vertical migration of free-phase CO_2 to the lowermost caprock. Simultaneous brine injection from shallow Arbuckle flow-units increased residual gas trapping of CO_2.

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South-central Kansas CO_2 Project: Kansas Geological Survey, Web accessed 21 July 2011, http://www.kgs.ku.edu/PRS/Ozark/index.html

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Doe Contract #FE0002056

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

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Outline

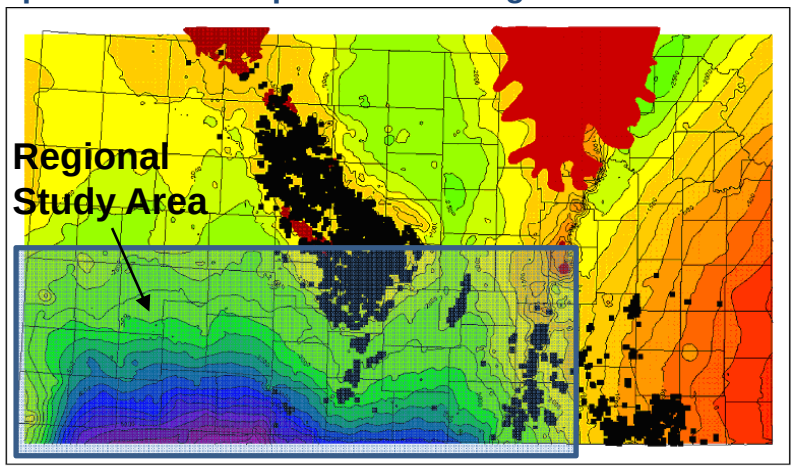
- **Project Overview**
- **Definition of Mississippian-Cambrian "*Ozark Plateau Aquifer System (OPAS)*"**
- **Regional distribution of Arbuckle saline aquifer and caprock**
  - ***Caprock continuity and integrity***
  - ***Storage***
    - ***Continuity of hydrostratigraphic flow units***
    - ***Evaluating open or closed hydrologic system***
- **Structure**
  - ***Defining fractures/faults/flexure***
  - ***Deep-seated structures***
- **Preliminary simulation of commercial scale CO_2 injection**
  - ***Footprint & stratigraphic constraint of commercial scale CO_2 plume***
- **Wellington Field**
  - ***Multicomponent 3D seismic***
  - ***Initial geomodels***
  - ***New injectivity & storage data (1st quarter 2011)***
    - ***1500 ft core, logs, drill stem tests, and well tests – KGS #1-32 & #1-28***
- **Summary**

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

Project Overview

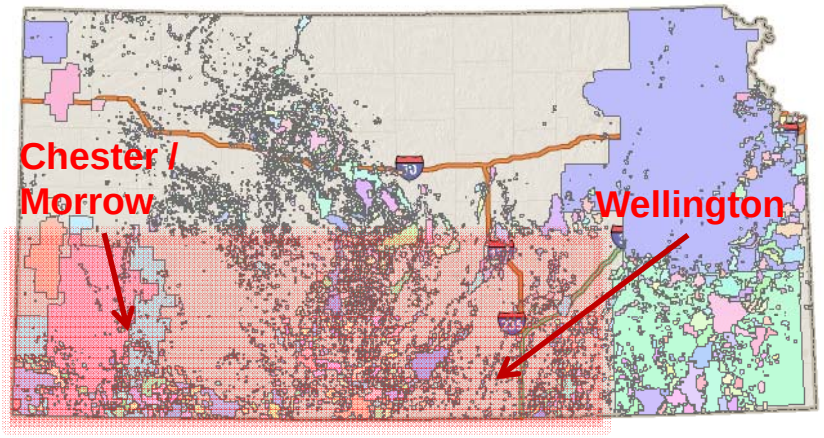
- Start Date - Dec 2009 (3 yr. study)
- Acquire data & build geomodels
  - *1. Wellington field (Sumner County, KS)*
    - *Depleted Mississippian oil field*
    - *Underlying Arbuckle saline aquifer*
  - *2. Chester/Morrow oil field in SW KS*
  - *3. Regional Arbuckle saline aquifer*

Top Arbuckle Group and Producing Wells in Arbuckle



- Conduct simulation studies for EOR & sequestration
- Arbuckle saline aquifer – 29 county area (southern Ks)
  - Identify potential sequestration sites
  - Conduct large scale simulations
  - Estimate sequestration capacity

All Oil and Gas Fields



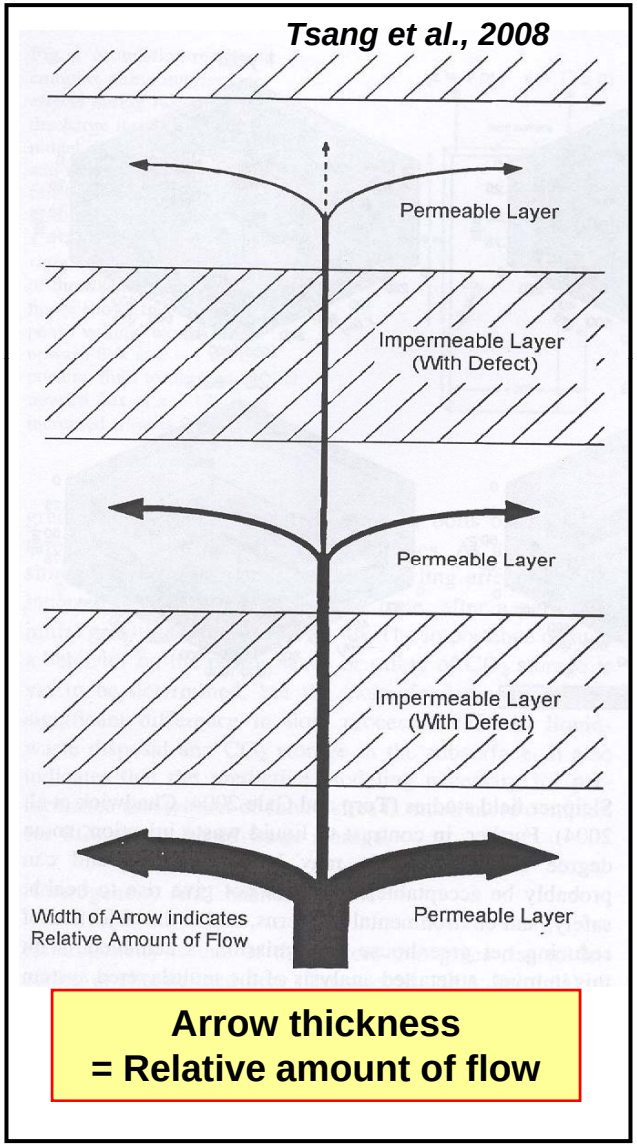
- Risk analysis related to CO_2 sequestration
  - Rock heterogeneities
  - Unplugged abandoned wells
- Technology transfer

http://www.kgs.ku.edu/PRS/Ozark/index.html

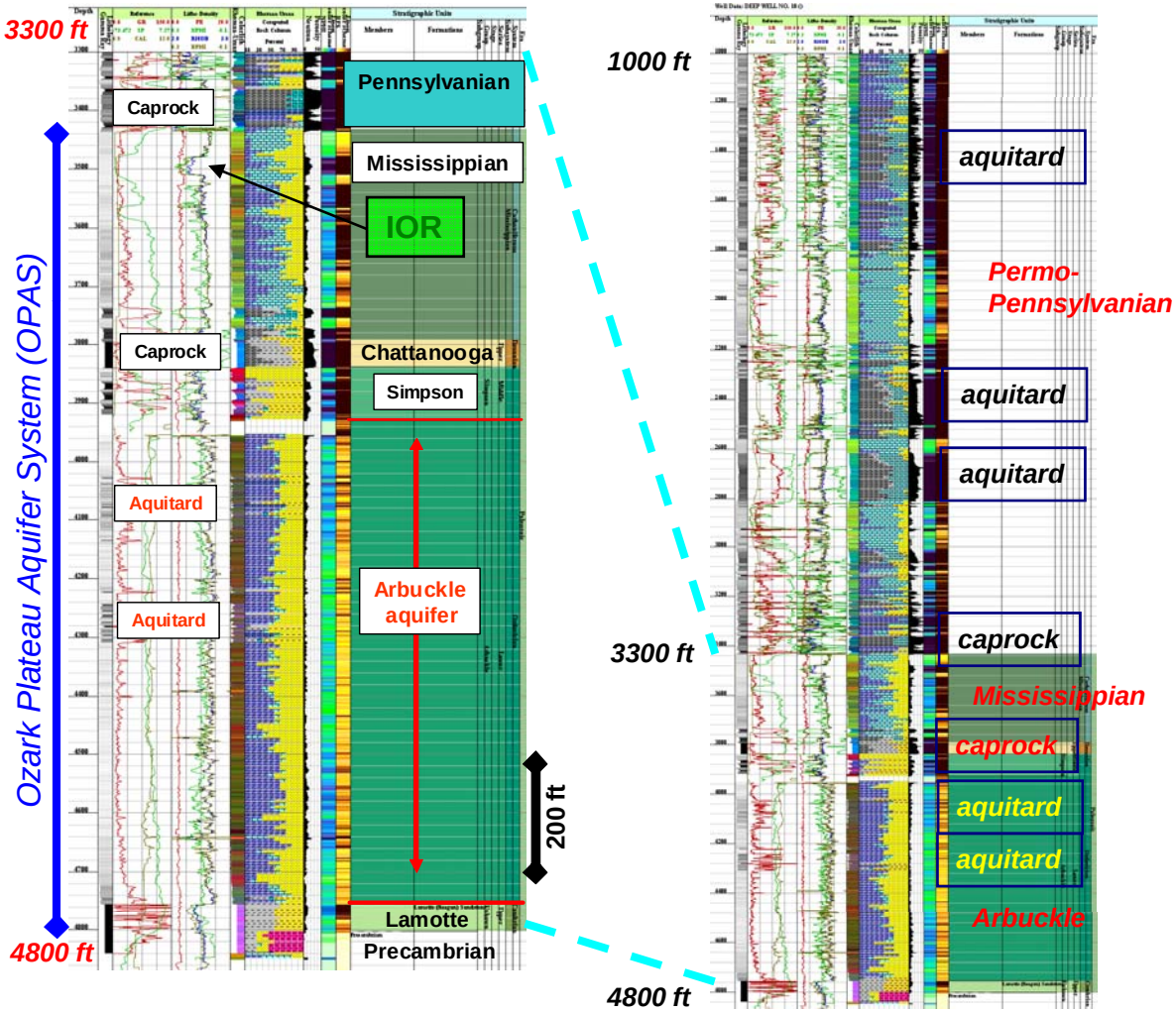
Hydrostratigraphy – *Ozark Plateau Aquifer System*

Mississippian to Cambrian Age Strata

Overlain by Multiple Caprocks & Aquitards



OxyChem Well #10 brine injection well – Sedgwick County, KS

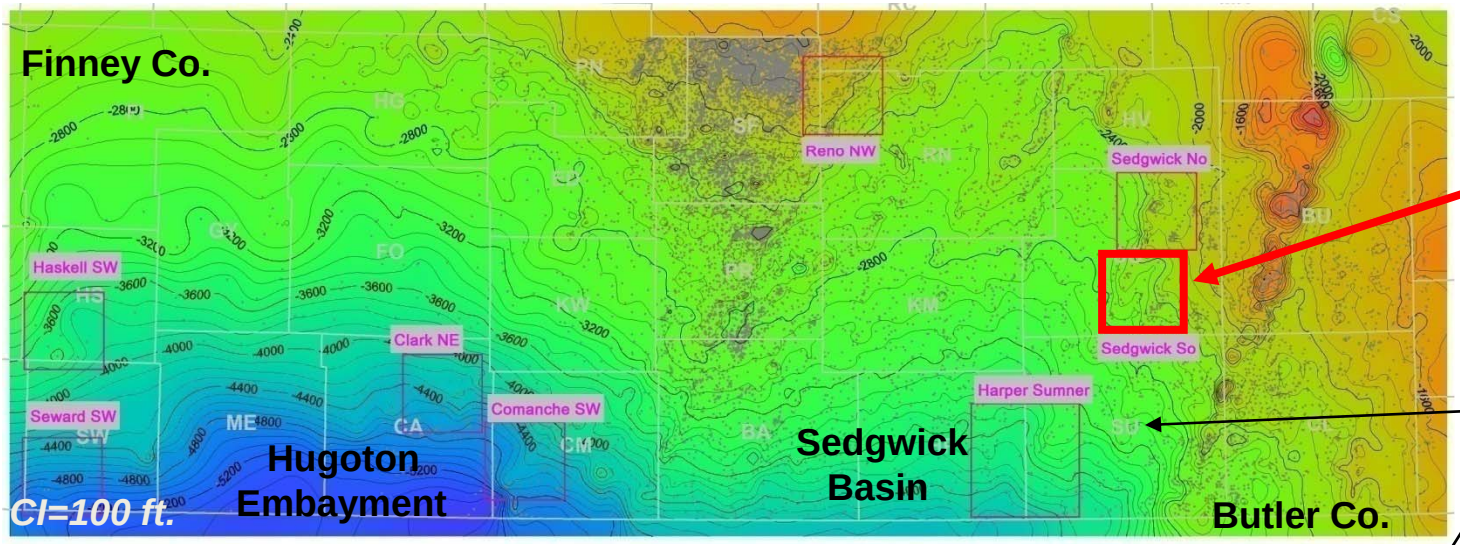


<u>Arbuckle Aquifer</u> includes Arbuckle Group & Bonneterre Dolomite

Primary deep saline aquifer

Regional Study – Mapping the Arbuckle

Structure top of Arbuckle Group

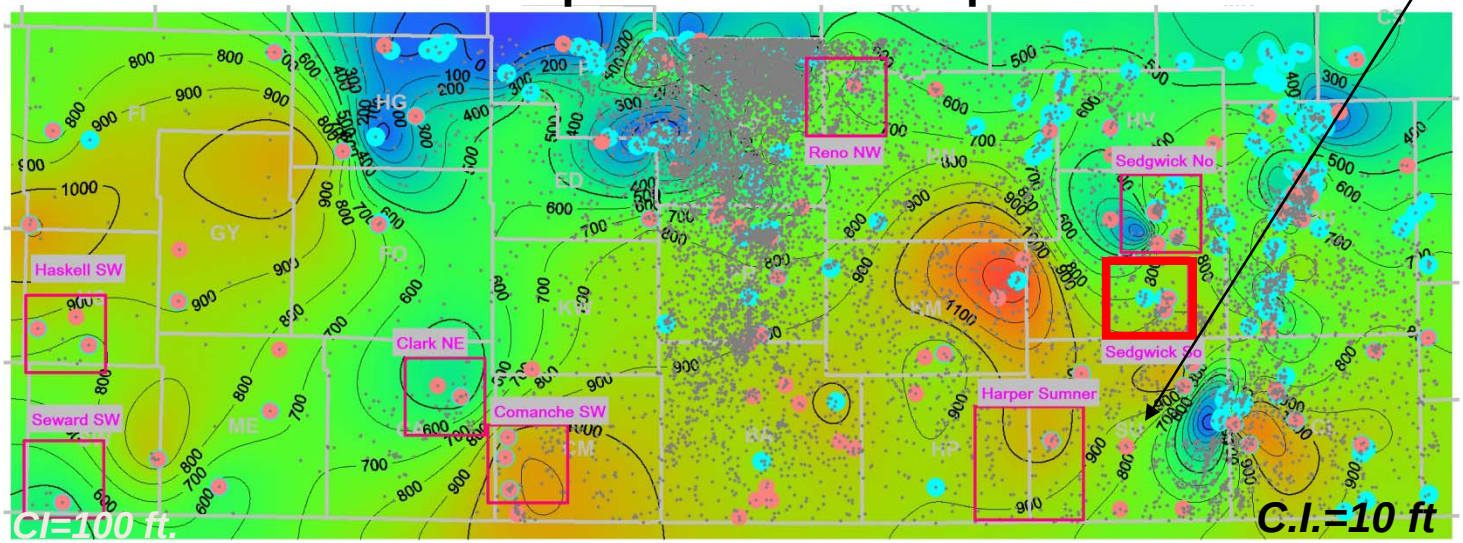


Initial Arbuckle modeling site southern Sedgwick County

Wellington Field

50 mi

Isopach Arbuckle Aquifer



AREAS OF INTEREST

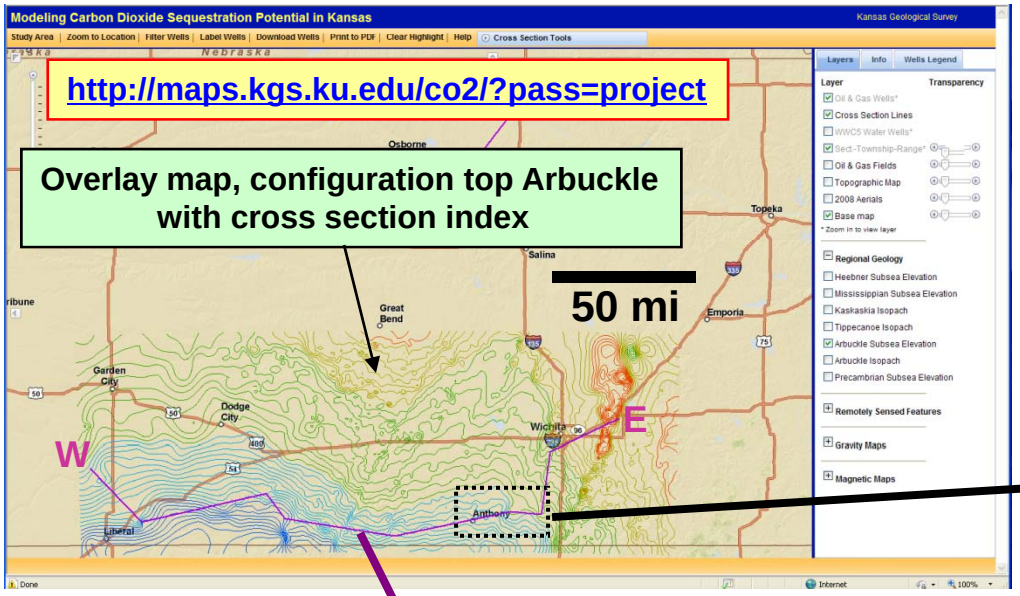
ARBK Penetrations

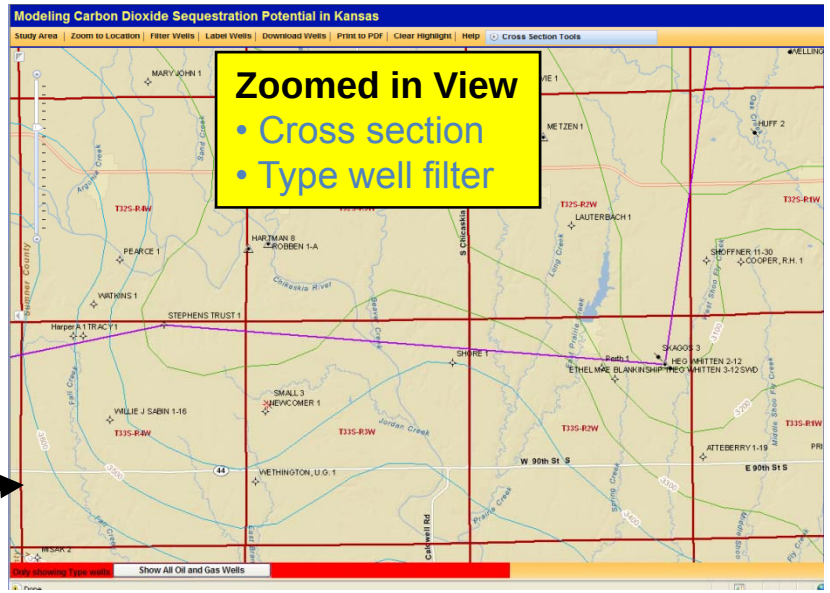
Super Type Well (91 wells)

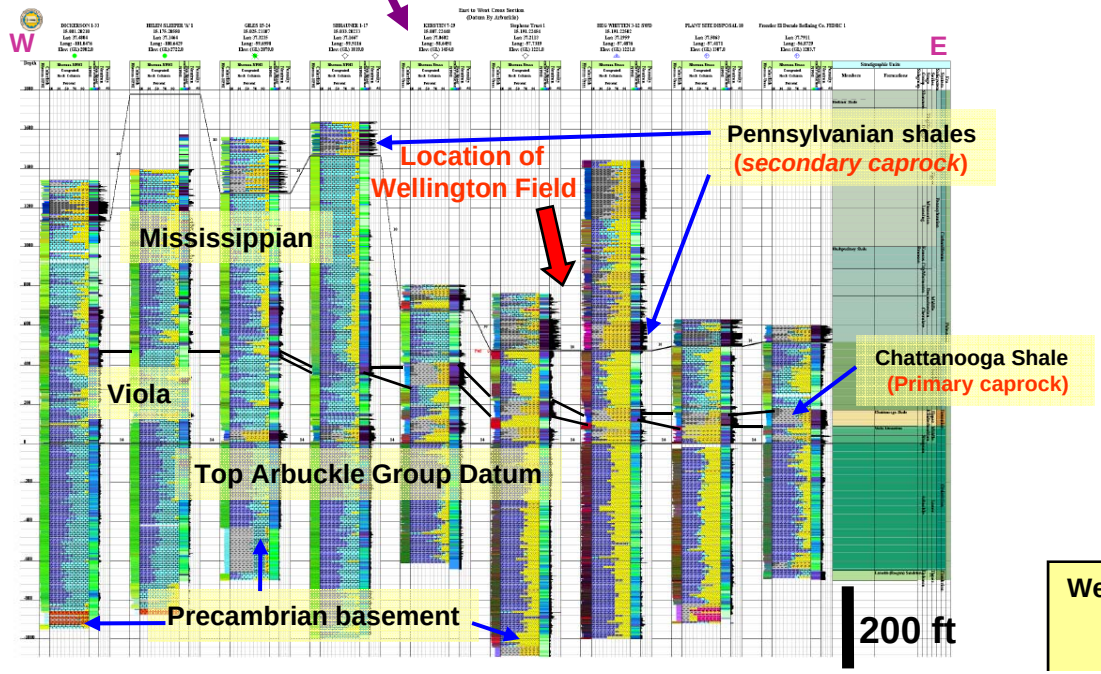
P-C Tests (292 wells)

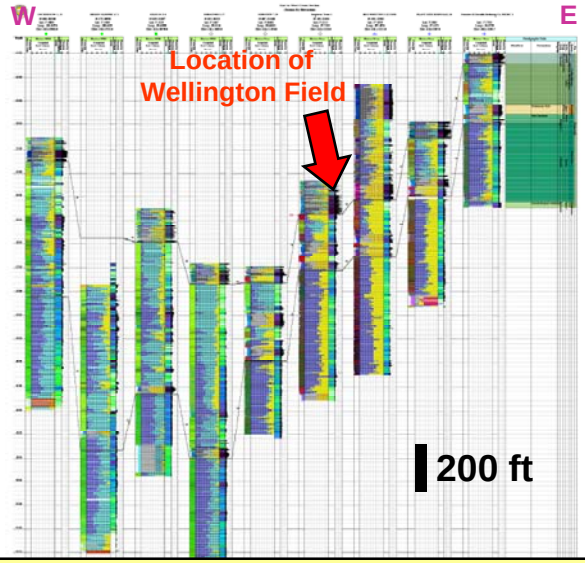
Regional Study – Continuity of Aquifer System and Caprocks

Interactive Web-based Project Mapper and Well Data Analysis Tools



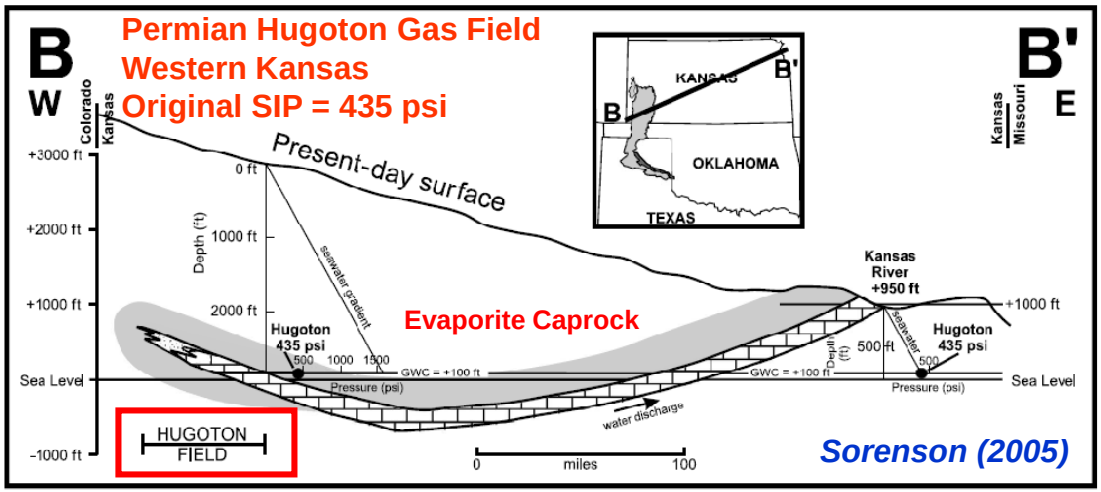






West-East Stratigraphic (left) & Structural (right) Cross Sections
- Log-derived lithology and porosity
- Mississippian to Precambrian interval

Arbuckle Saline Aquifer
Hydraulically Connected to Outcrop – *Open System*



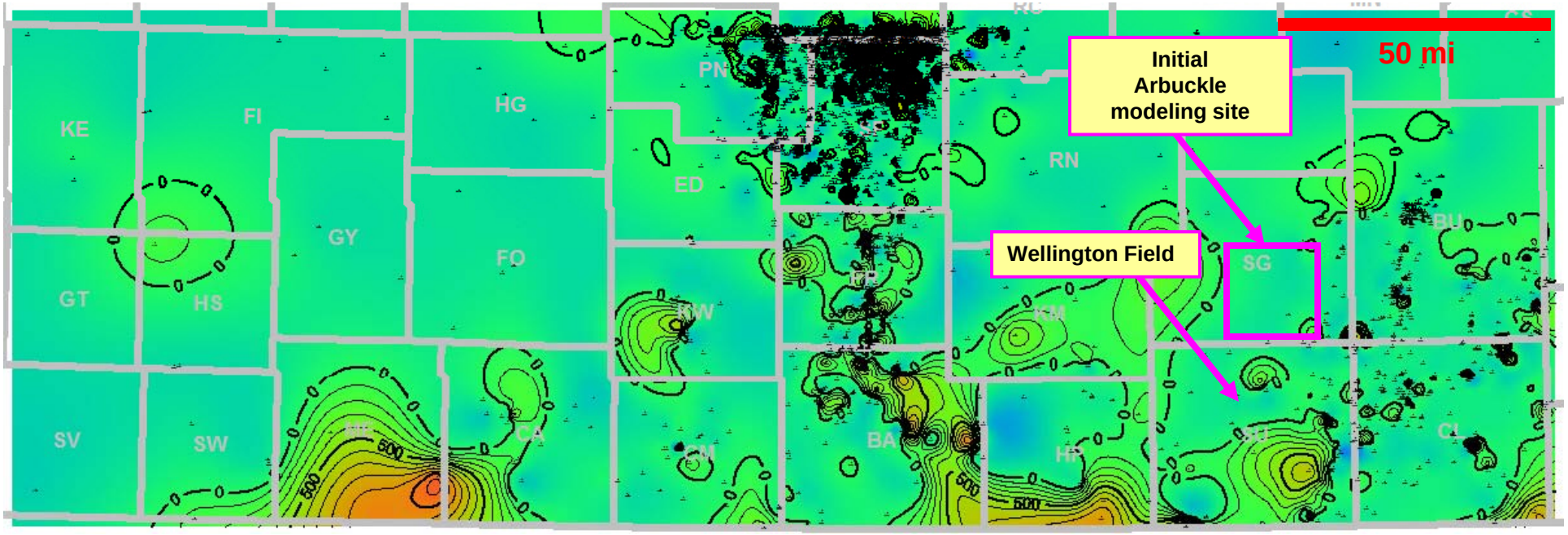
Arbuckle exposure at base of Missouri River, north-central Missouri – Elevation 450 ft

& ~200 mi northeast

Assume hydrostatic gradient = 0.435 psi/ft

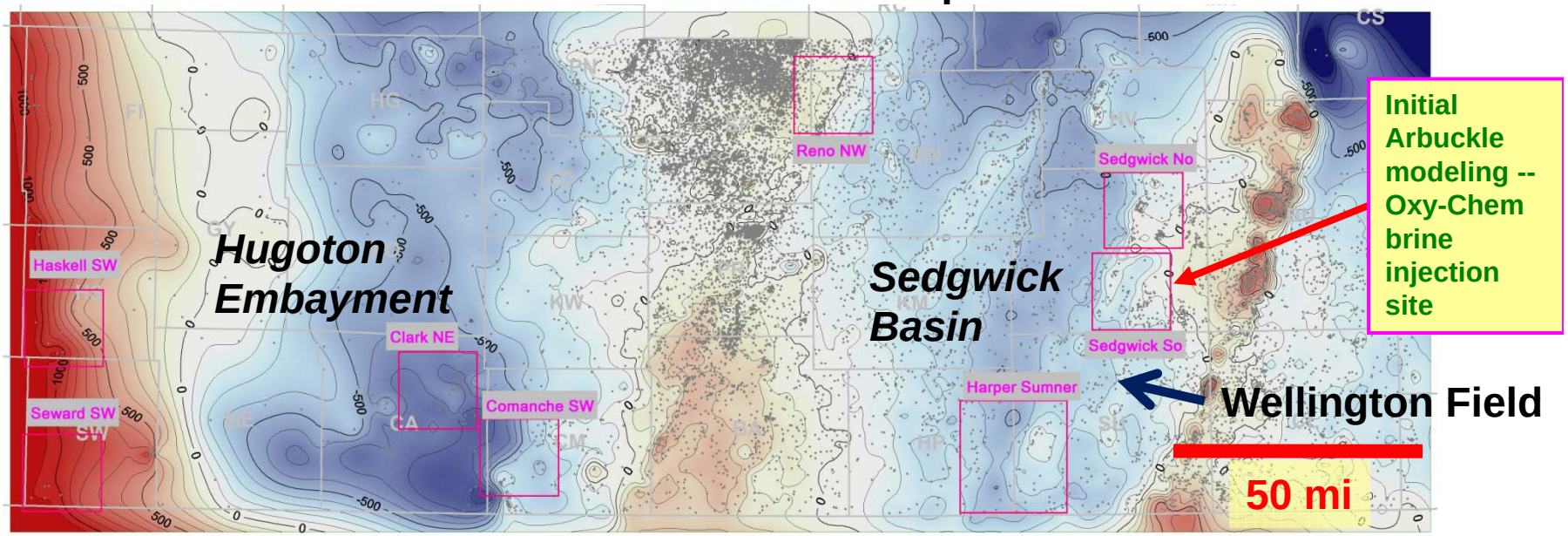
Index map

Map of the difference between estimated hydraulic head at base of Arbuckle test interval and measured shut-in pressure

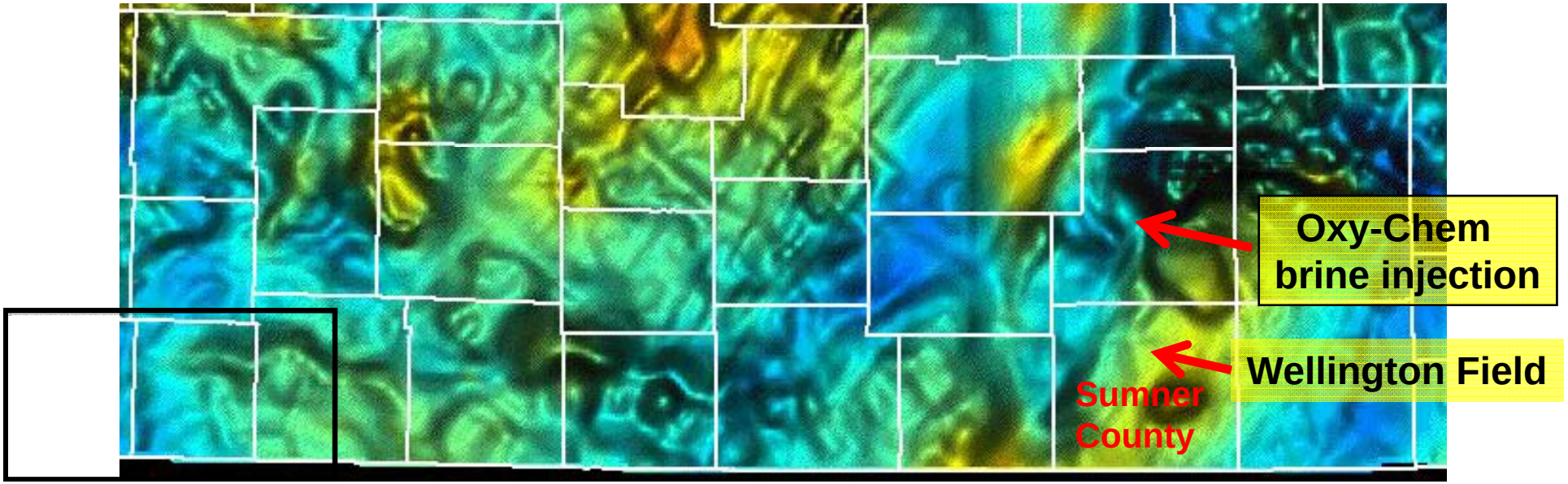


Regional Structure

3rd Order Structural Residual - Top Arbuckle

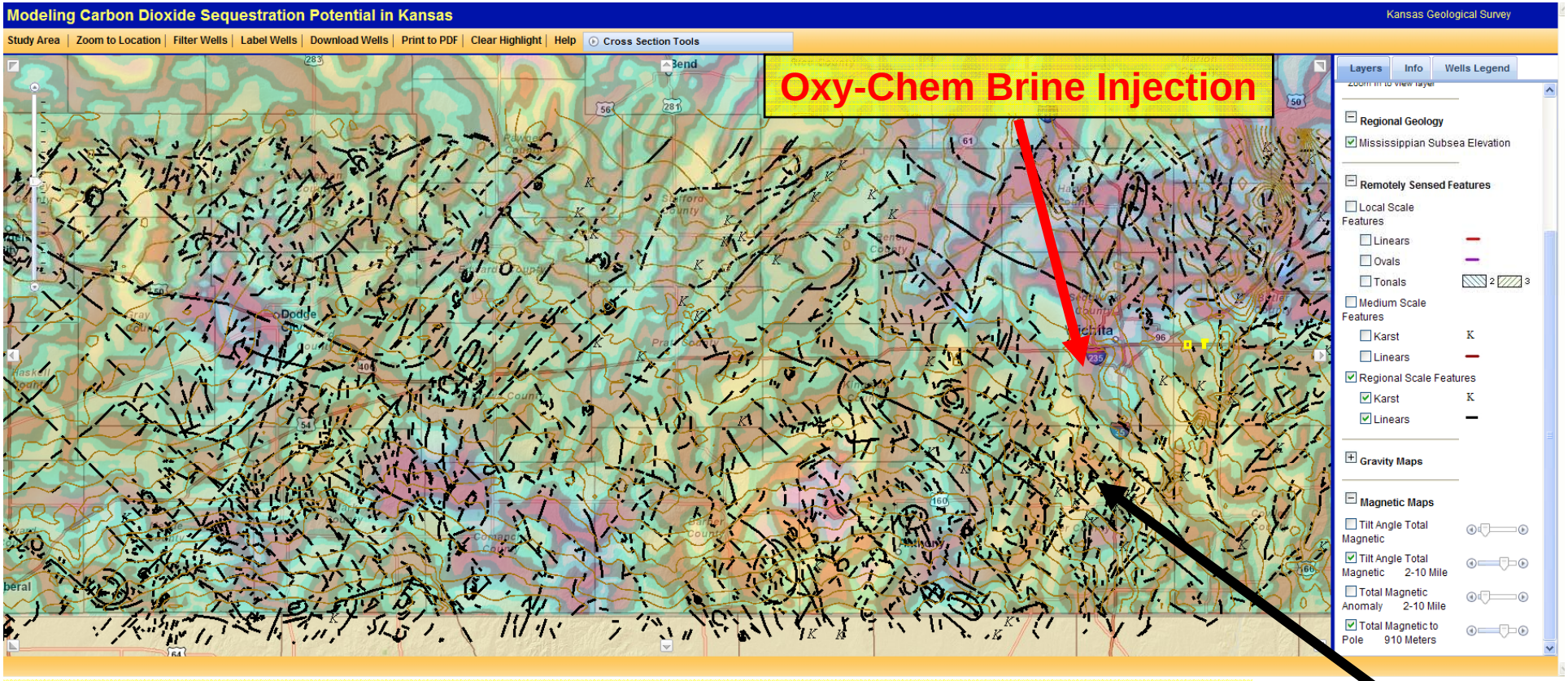


Color Based on Gravity, "Relief" Based On Total Magnetic Field



Regional Structure – Deep-Seated Faults & Shallow Expression

Re-Processed Gravity & Magnetics + Subsurface structural mapping + local 3D seismic + Landsat-Derived Remote Sensing Analysis --- Integrated view via *Interactive Web-based Project Map*



Southern Kansas – project area

Tilt-angle magnetic (thick black/red/blue lines) + Total magnetic field intensity (color tones) + Surface lineaments (thin black line segments) + Structure contours top Mississippian

Wellington Field

50 mi

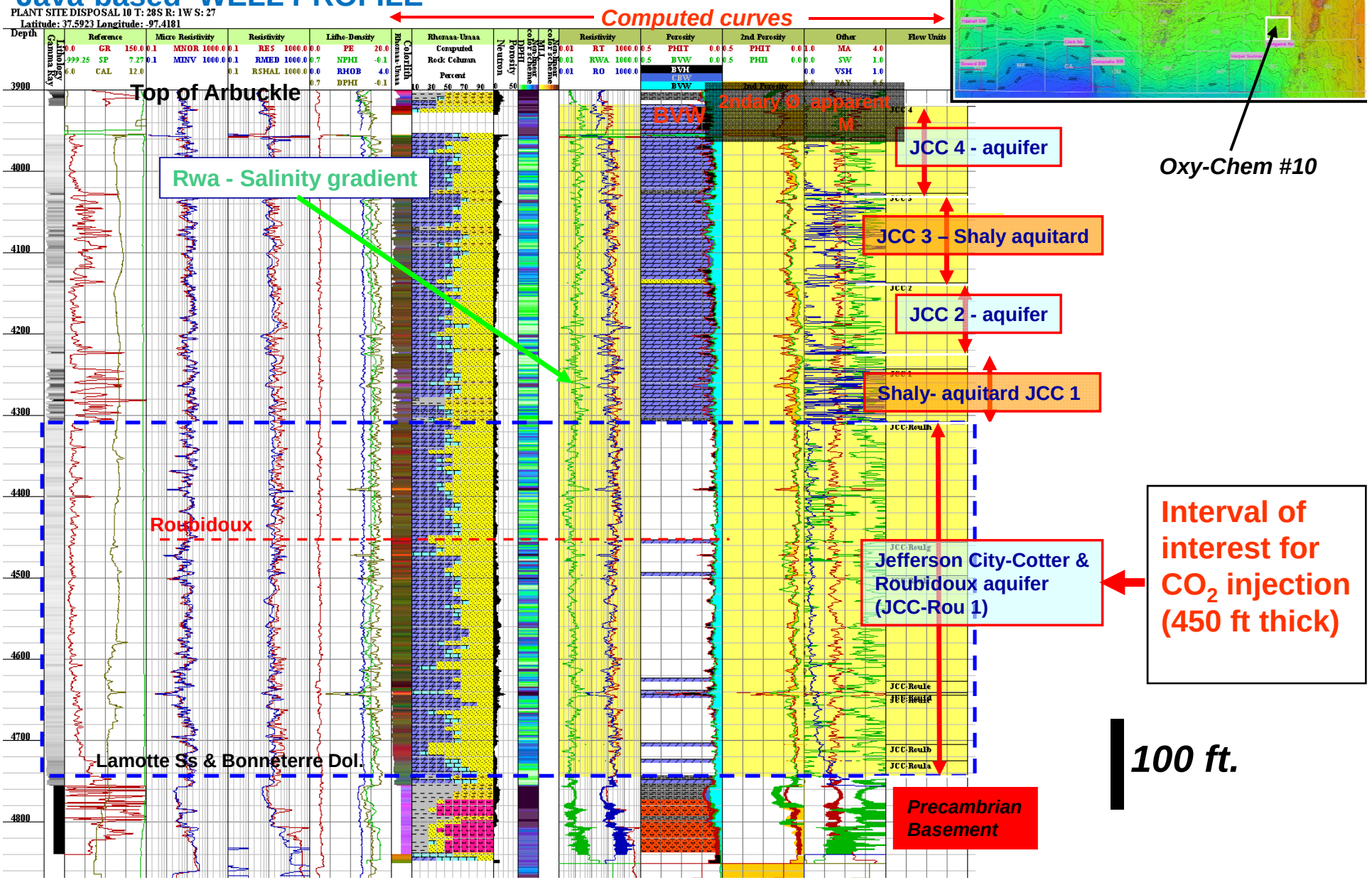
http://maps.kgs.ku.edu/co2/?pass=project

Initial Simulation Study – Dimensions of Commercial-Scale CO_2 Plume

Arbuckle flow unit (*hydrostratigraphic unit*) characterization

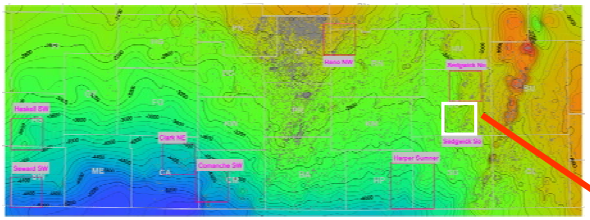
Depth-constrained cluster analysis of petrophysical logs

Java-based WELL PROFILE



Initial Simulation Study to Estimate Size of Commercial CO_2 Sequestration (10 million tonnes CO_2, Supercritical)

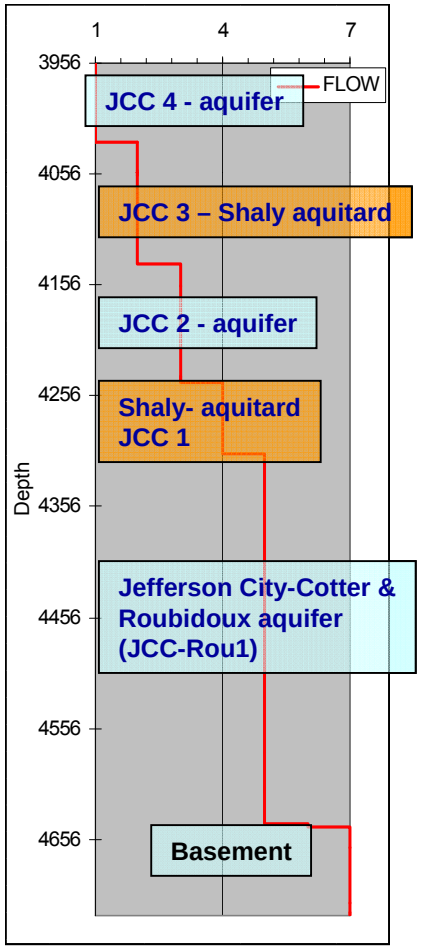
9 Township Model – centered around Oxy-Chem #10 brine injection facility

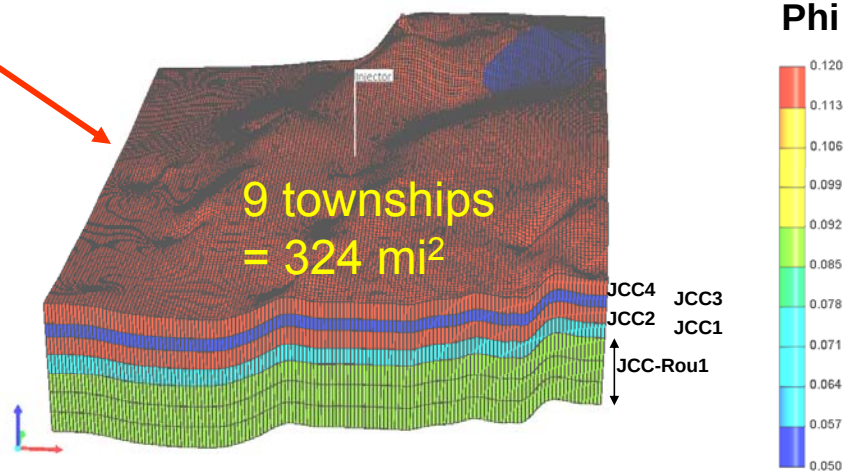


Grids: 330’ by 330’

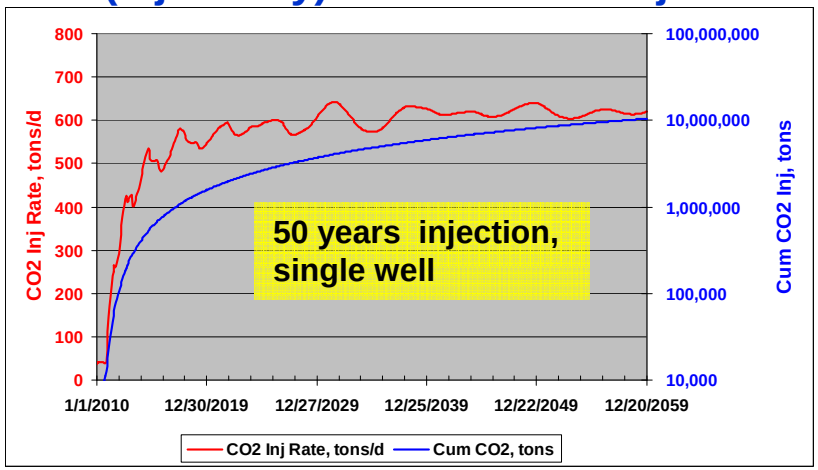
Injection pressure < fracture pressure (3000 psi)

Injection from 2010 to 2060. Run till 2200





Rate (injectivity) & cumulaitve injection

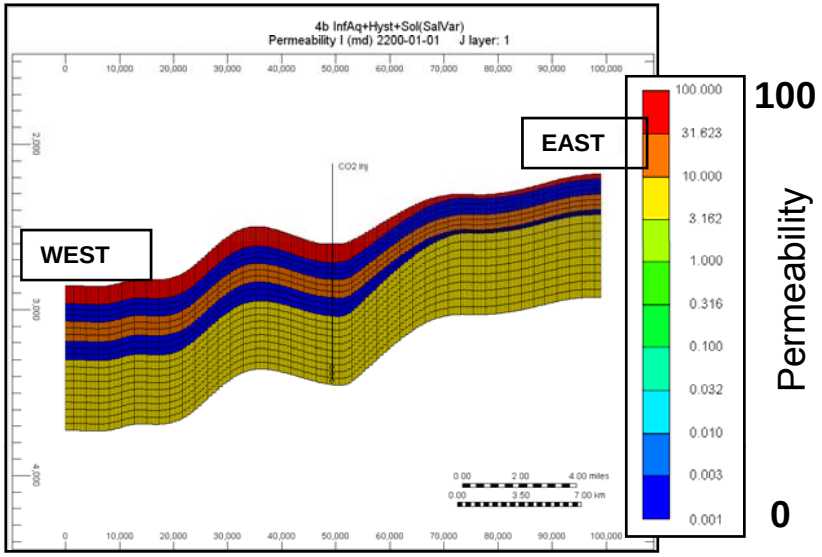


Initial Simulation Study

2D Model around Oxy-Chem #10 – 20 Layer Model Inputs

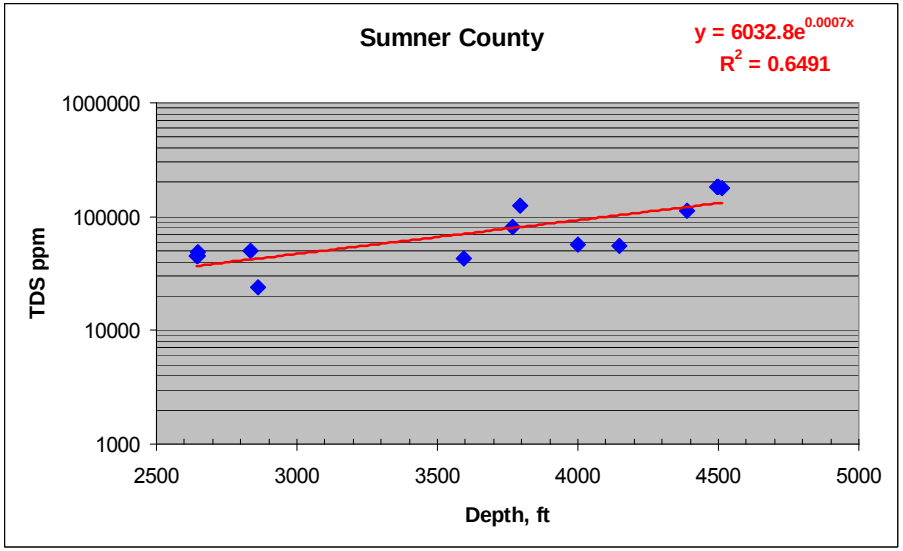
Estimated Permeability

Oxy-Chem core and petrofacies correlation to ~300 core analysis archived from Arbuckle reservoirs – Byrnes et al 2003



Oxy-Chem #10				Sumner CO			
Flow units	Layers	Avg Depth	Pr - Hyd Head	Frac Pr	ppm	Phi	K, md
1	1	2658.5	1245	3009	100079	0.12	100
2	2	2732	1277	3065	105363	0.05	0.001
2	3	2765.5	1292	3090	107863	0.05	0.001
2	4	2799	1307	3115	110422	0.05	0.001
3	5	2834.5	1322	3141	113201	0.12	20
3	6	2871	1338	3169	116130	0.12	20
3	7	2907.5	1354	3196	119135	0.12	20
4	8	2944.5	1370	3224	122261	0.06	0.001
4	9	2981.5	1386	3252	125469	0.06	0.001
4	10	3019	1402	3280	128806	0.06	0.001
5	11	3058.5	1419	3309	132418	0.09	10
5	12	3099.5	1437	3340	136273	0.09	10
5	13	3140.5	1455	3371	140241	0.09	10
5	14	3181.5	1473	3402	144324	0.09	10
5	15	3222.5	1491	3432	148526	0.09	10
5	16	3263.5	1509	3463	152851	0.09	10
5	17	3304	1526	3494	157246	0.09	10
5	18	3344.5	1544	3524	161768	0.09	10
5	19	3385.5	1562	3555	166478	0.09	10
5	20	3426.5	1580	3585	171325	0.09	10

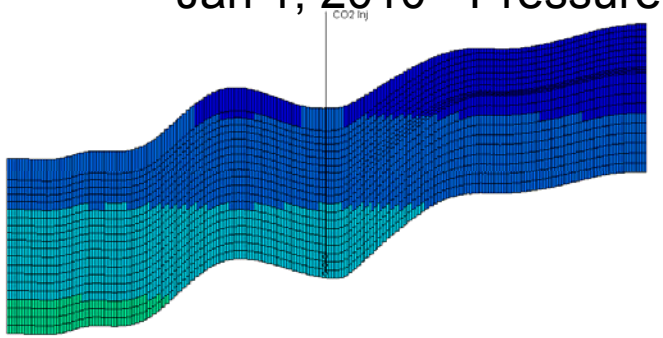
Salinity vs. Depth



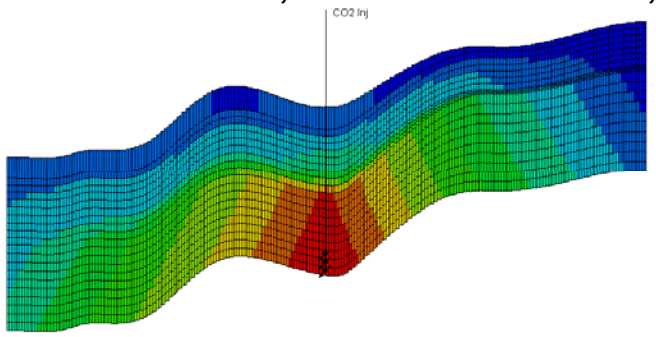
Initial Simulation Study

2D Model around Oxy-Chem #10 – 20 Layer Model Results

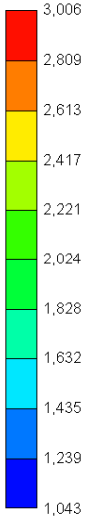
Jan 1, 2010 - Pressure, psi



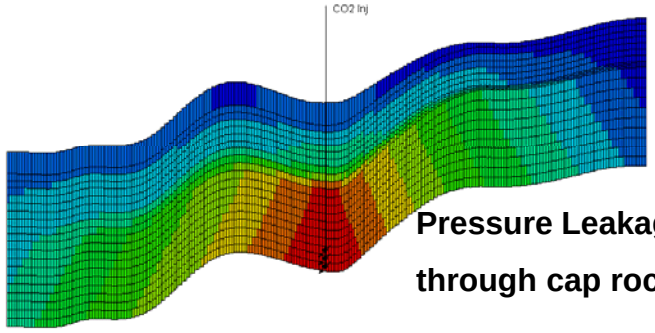
Jan 1, 2035 - Pressure,



Psi

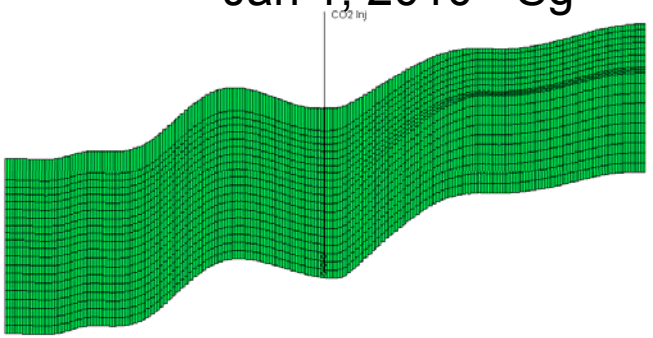


Jan 1, 2060 - Pressure,

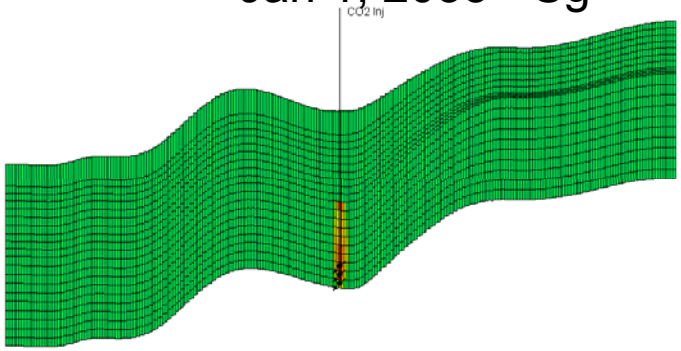


Pressure Leakage (brine) through cap rock

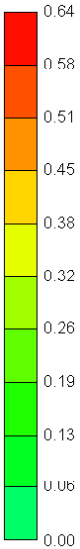
Jan 1, 2010 - Sg



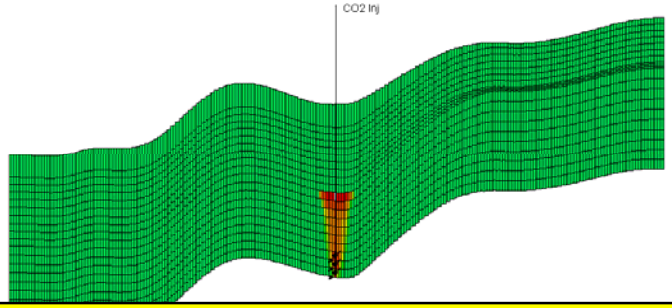
Jan 1, 2035 - Sg



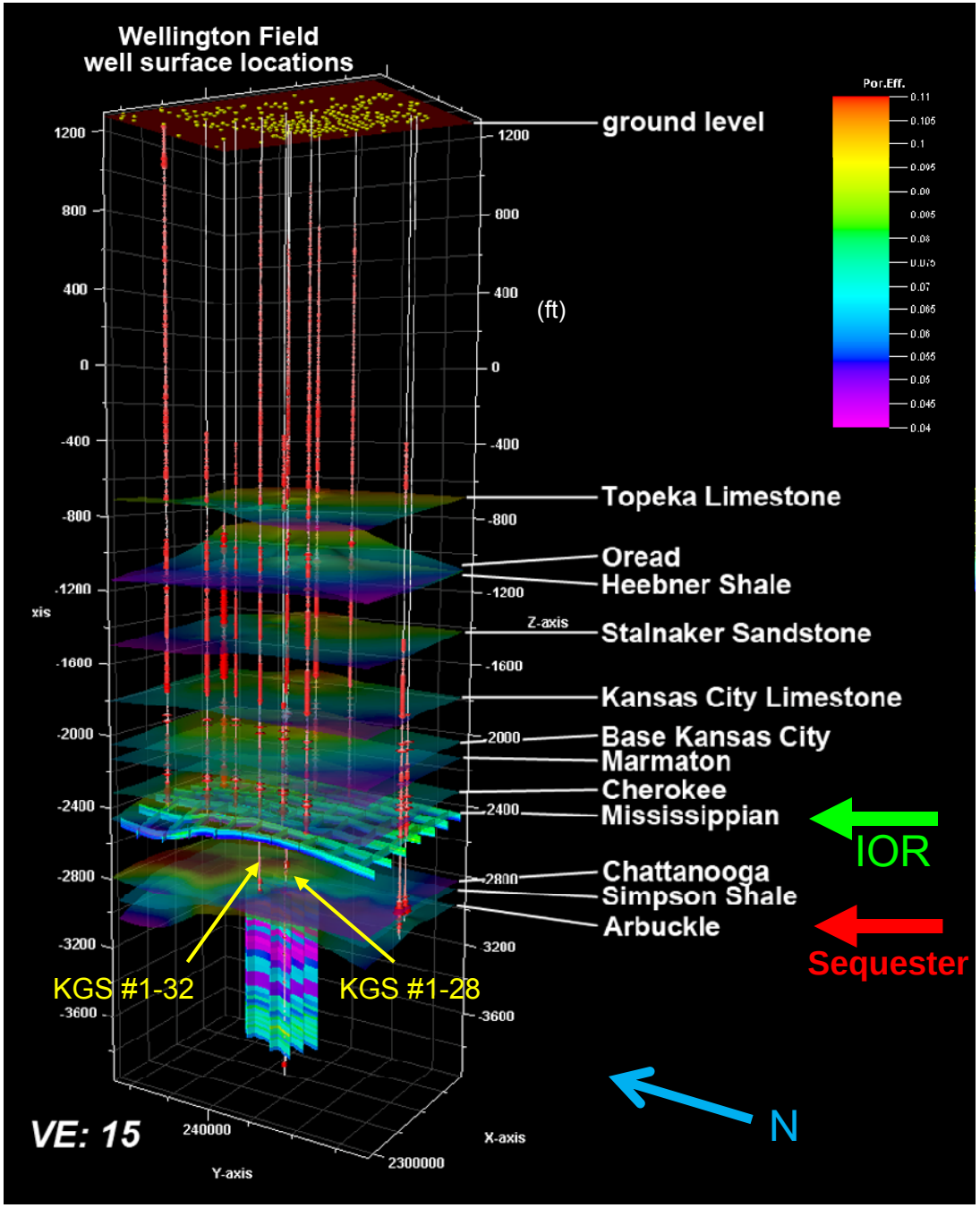
Sg



Jan 1, 2060 - Sg



Est. plume footprint <2 mi radius for 10 million tonnes CO_2



Wellington Field

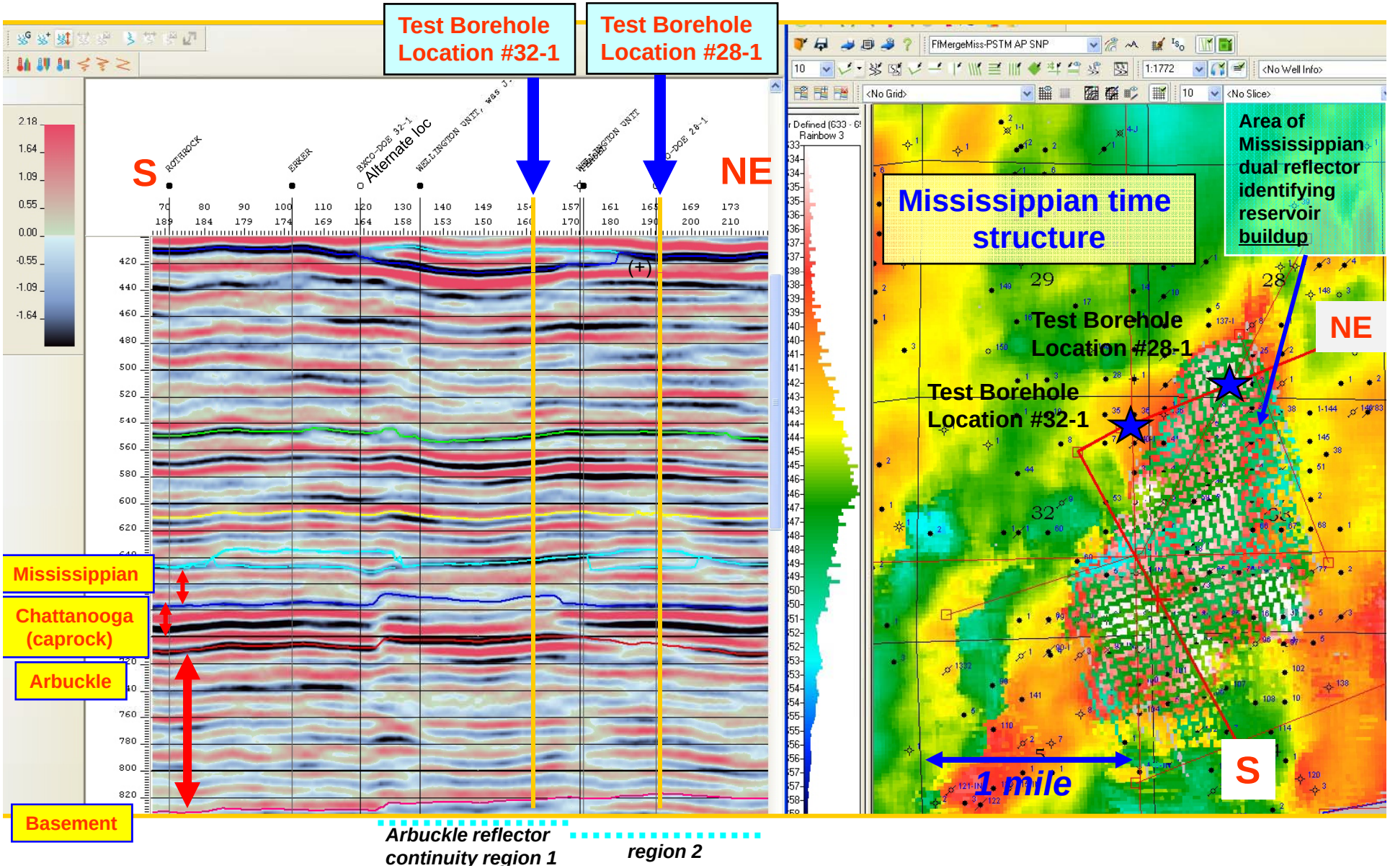
1) *Mississippian tripolitic chert/dolomite reservoir*
2) *Arbuckle saline aquifer*
3) *Intervening caprocks*

- **New core and logs from KGS #1-32 and logs from #1-28 obtained in Jan-Feb. 2011**
- **Using to assess --**
  - **Integrity of caprocks**
  - **Porosity types, injectivity, and storage**
  - **Model potential for C02-EOR in Mississippian saline aquifer sequestration in Arbuckle**

Wellington Field

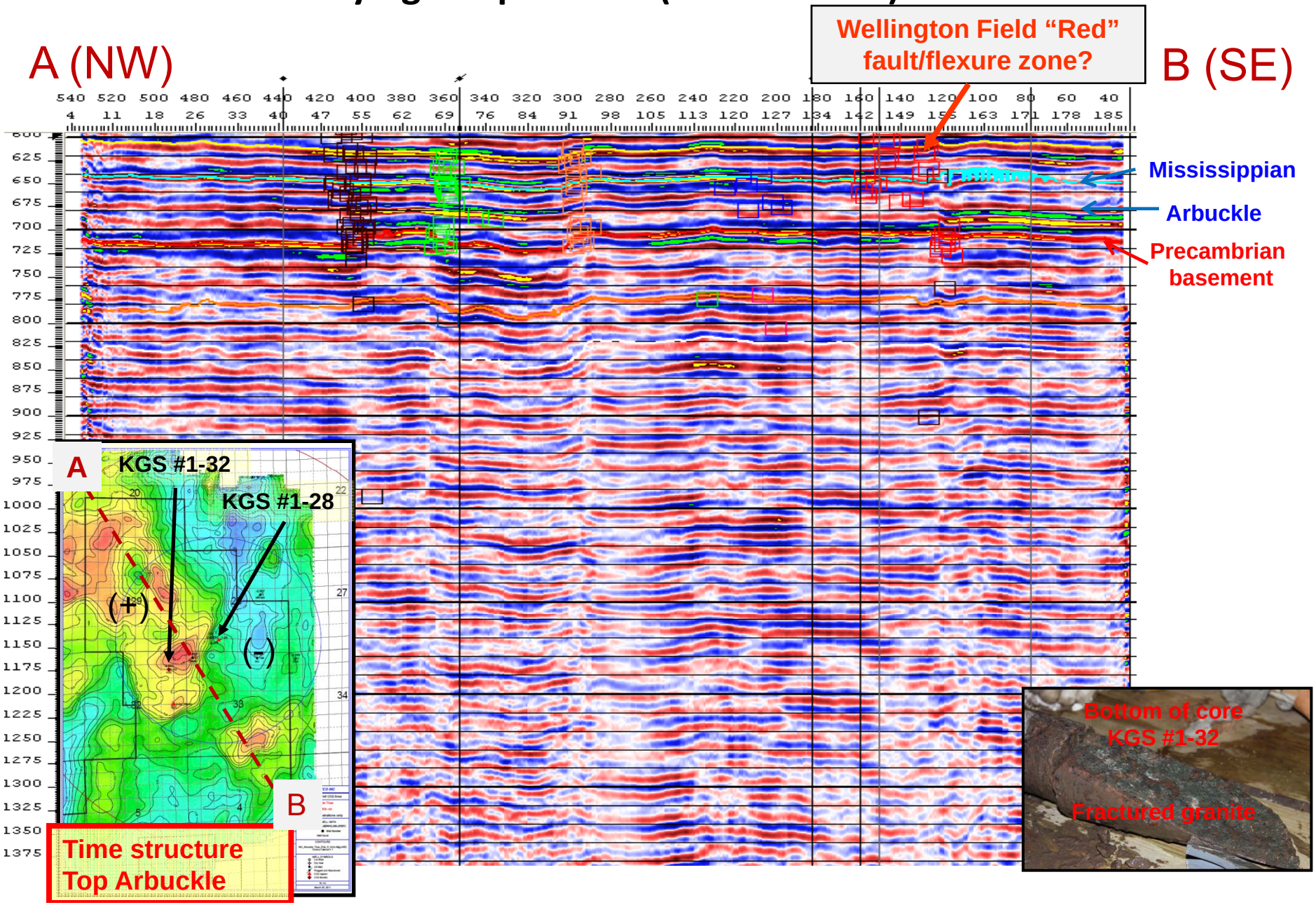
3D Seismic P-Wave Processing, Initial Interpretations, & Borehole Locations

Arbitrary seismic profile to compare borehole locations



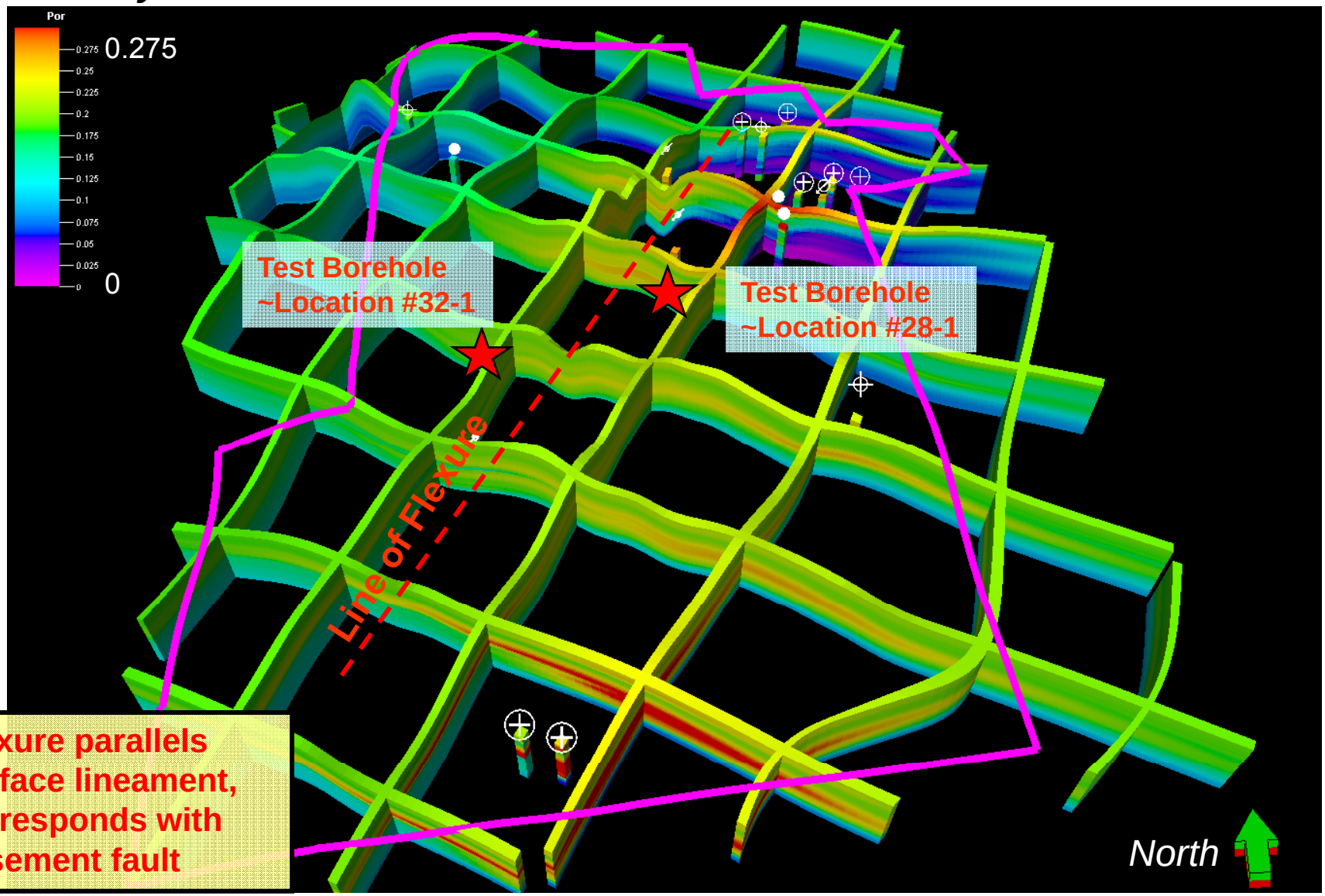
Faults & Flexure in Phanerozoic Strata

Overlying Deep-Seated (Precambrian) Faults



Wellington Field

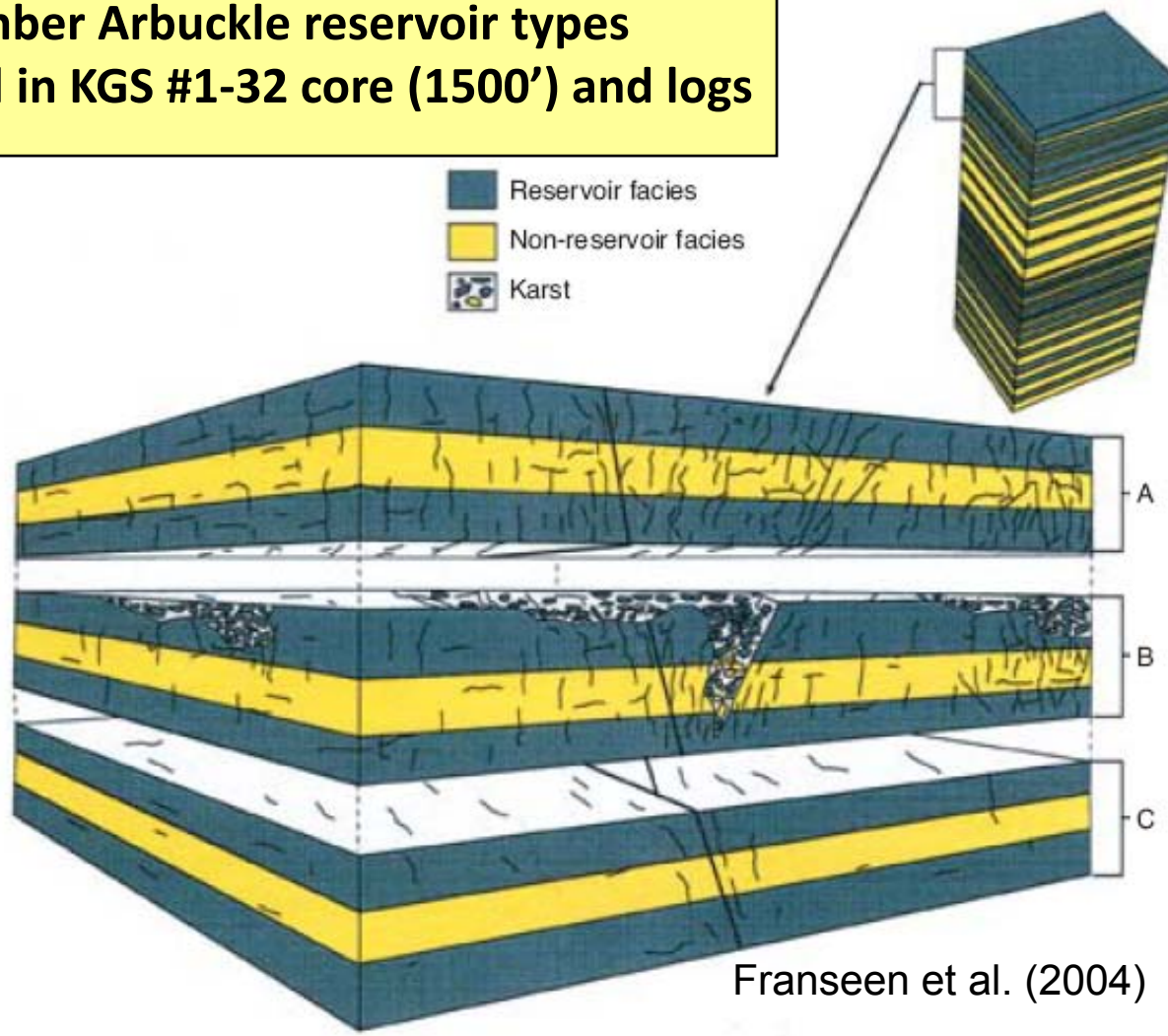
Porosity Fence Diagram
Mississippian Tripolitic Chert Oil Reservoir



Flexure parallels surface lineament, corresponds with basement fault

New Injectivity and Storage Data in Wellington Field

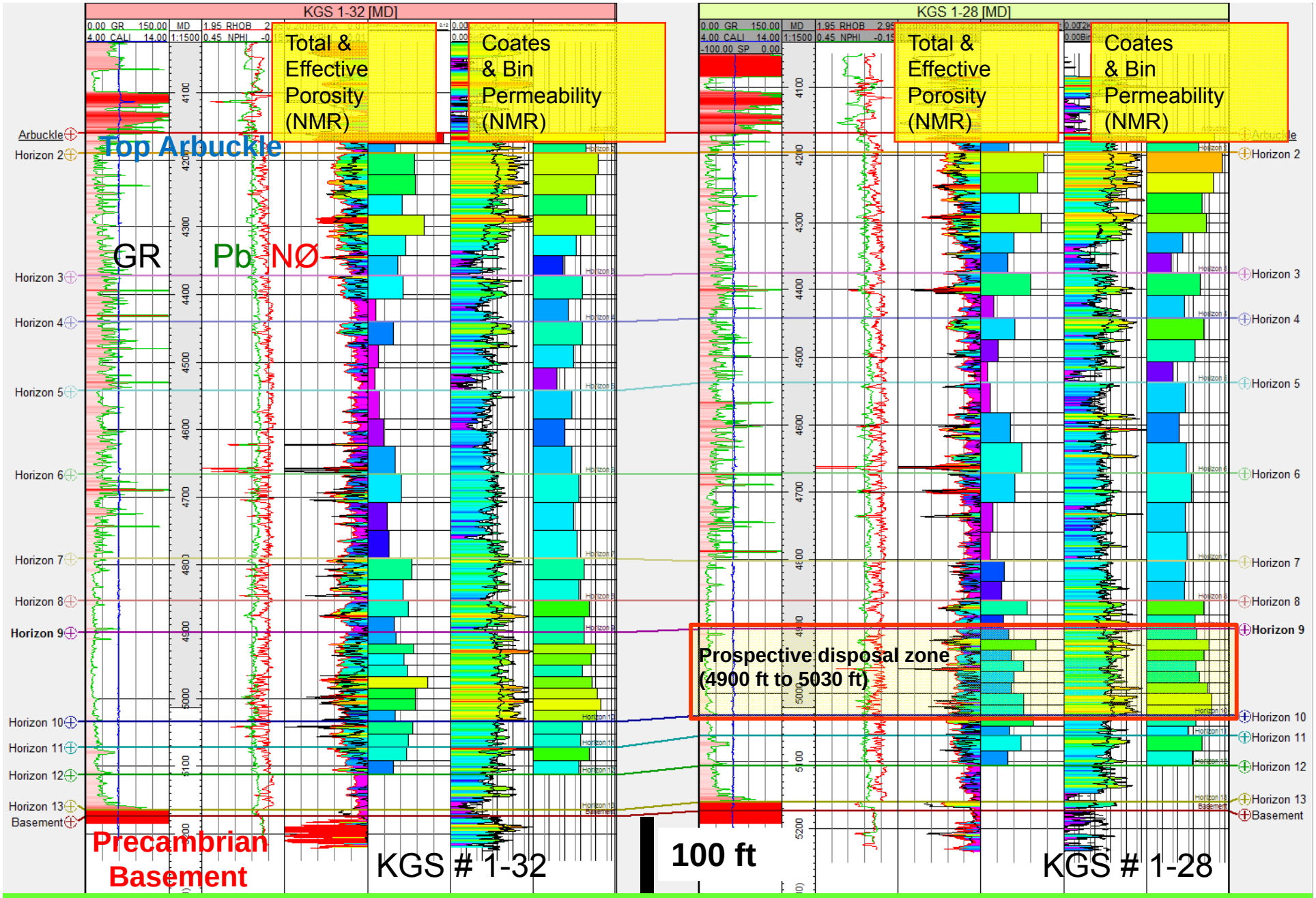
End-member Arbuckle reservoir types observed in KGS #1-32 core (1500’) and logs



Franseen et al. (2004)

Discontinuous fracturing, karst overprinting, lithofacies control porosity & permeability in persistent stratal packages

Role of Matrix Contribution to Porosity & Permeability in the Arbuckle Aquifer



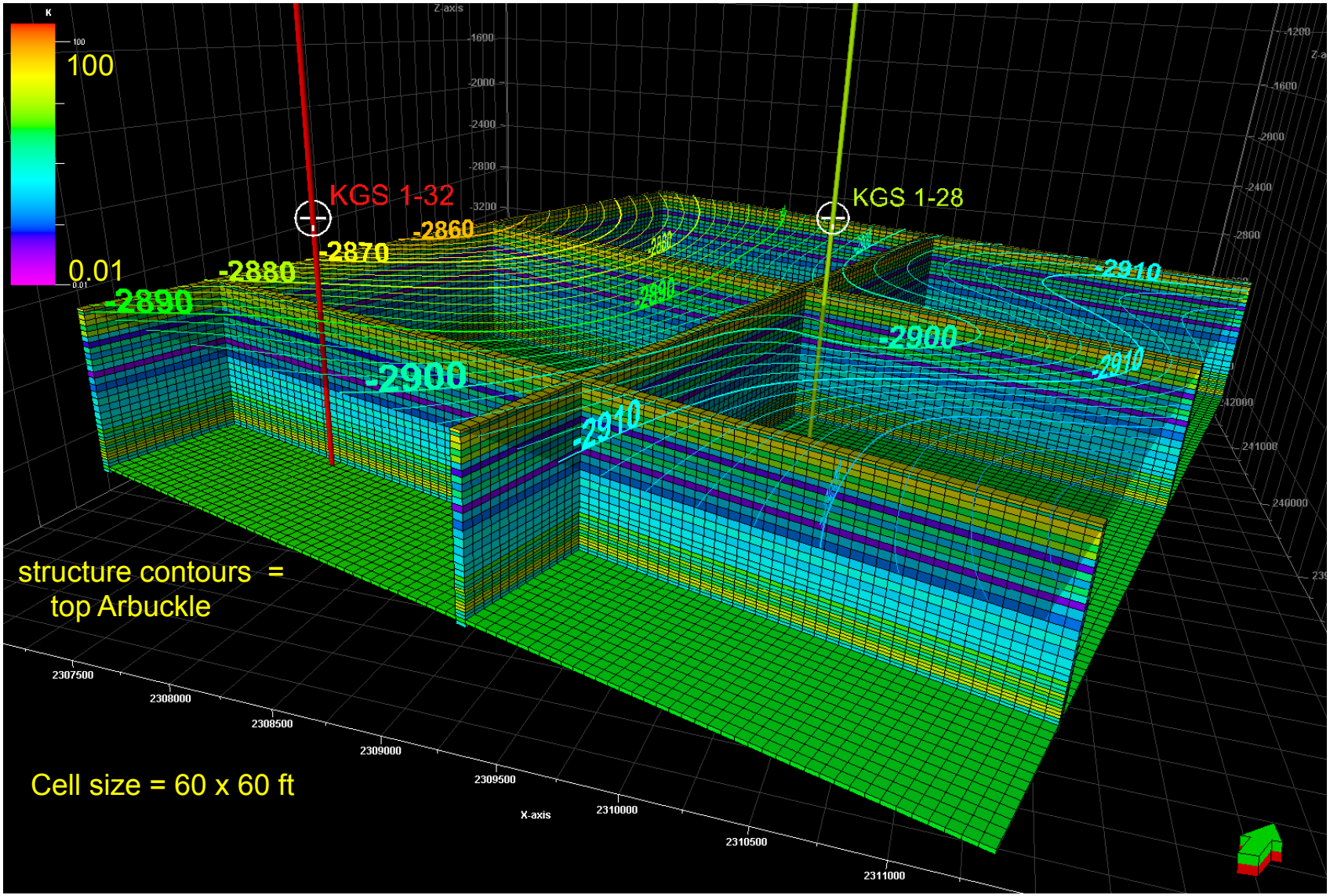
Log data and upscaled hydrostratigraphic units in Arbuckle Group in KGS #1-32 (left) and #1-28 (right)

Permeability Geomodel of Arbuckle Group

in vicinity of KGS #1-32 & #1-28

Upscaled Using geometric Mean of k (Coates NMR), Porosity Used for Trend

-- Contribution of fracture Φ & k yet to done



Summary

- **Injectivity and Storage**
  - Discontinuous fracturing
  - Karst overprinting
  - Lithofacies control porosity & permeability in persistent stratal packages
  - Arbuckle is an open hydrologic system

- **Structure**
  - Deep-seated, basement structures/faulting abundant in Midcontinent craton
  - Evidence of flexure & fractures from gravity-magnetics, structure mapping, multicomponent 3D seismic, and inferred from remote sensing
  - Studies underway to resolving structural controls on reservoir, aquifer, and caprock integrity

- **Simulation of commercial scale CO_2 injection**
  - Estimated footprint for 10 MM tonnes CO_2 injection < 2 mi radius
  - Internal aquitards in Arbuckle may act as baffles and barriers to vertical migration of CO_2 plume

- **New injectivity, storage, and caprock data for Wellington**
  - Core, logs, drill stem tests, and well tests being used to refine geomodel and simulations of the Arbuckle and obtain properties of main caprocks

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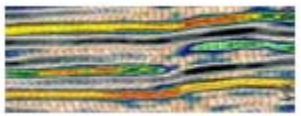

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