Carbon Dioxide Enhanced Oil Recovery and Sequestration Projects -- Wellington Field, Sumner County and Southwestern Kansas

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Kansas Geological Survey

1930 Constant Avenue

Lawrence, KS 66047

Geology Section Fall 2011 Seminar
Wichita, Kansas,
September 8, 2011

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Kansas
Department of Health and Environment

Overview – CO_2 Projects in Kansas

- 1. ***Southwest Kansas CO_2-EOR Initiative*** **-- Chester and Morrow Reservoirs & deep Arbuckle saline aquifer**

- **2. Capacity for CO_2 sequestration in regional, deep, saline Arbuckle aquifer in southern Kansas and by CO_2-EOR in Mississippian chert reservoir in Wellington Field, Sumner County**

- **3. <u>Small-scale</u> field test demonstrating CO_2 sequestration Wellington field, Sumner County, Kansas (<u>*pending*</u>)**

- **4. Horizontal well to test lateral heterogeneity in Arbuckle oil reservoir defined from seismic attributes, Bemis-Shutts oil field, Ellis County**

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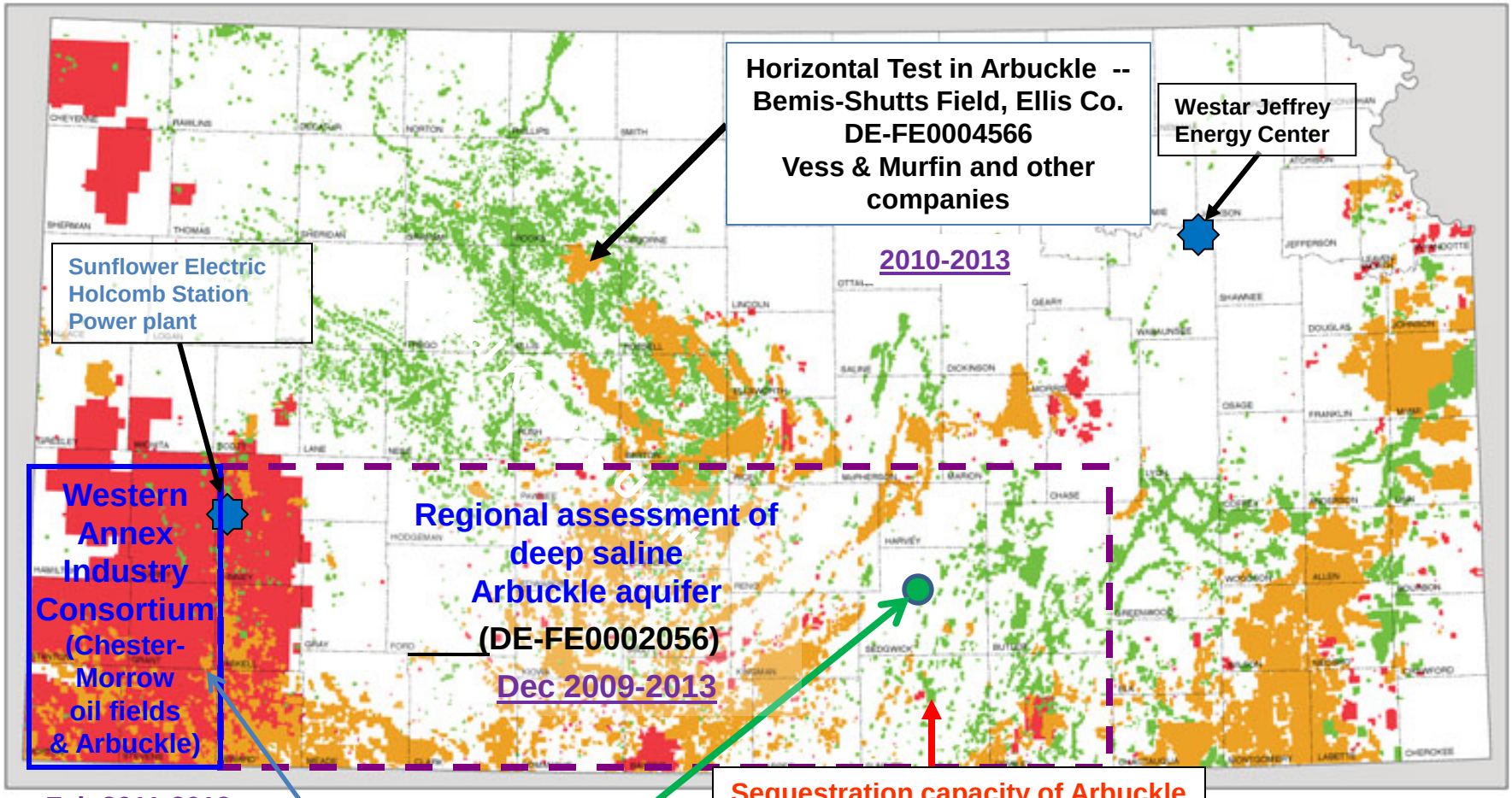
OIL AND GAS FIELDS OF KANSAS

2009



http://www.kgs.ku.edu/PRS/petro/ogSheetMap.html

Modeling CO_2 Sequestration Potential in Kansas

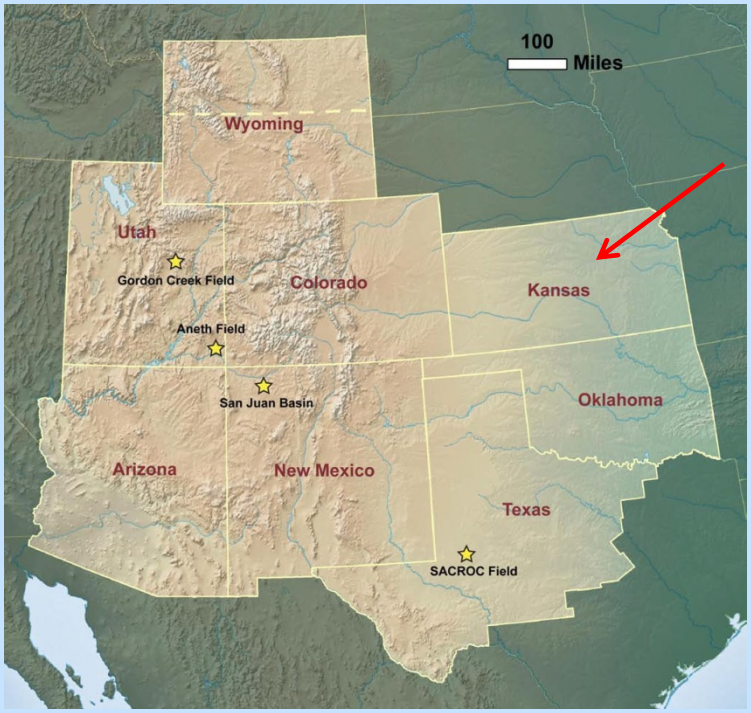
- **Regional distribution of Arbuckle saline aquifer and caprock**
  - *Caprock continuity and integrity*
  - *Storage*
    - *Continuity of hydrostratigraphic flow units*
    - *Evaluating open or closed hydrologic system*
    - *Capacity via volumetrics and compositional simulation*

- **Structure**
  - *Systematically characterize fractures/faults/flexures*
  - *Map deep-seated structures and assess nature and timing of reactivation*

- **Preliminary simulations of commercial scale CO_2 injection**
  - *Footprint & stratigraphic constraint of commercial scale CO_2 plume in saline aquifer*
  - *-- Improved efficiency and effectiveness of CO_2-EOR*

- **CO_2-EOR Potential**
  - *Wellington Field, Sumner County Kansas and Chester/Morrow sandstone reservoir (TBN) in SW Kansas*
  - *Multicomponent 3D seismic*
  - *Gravity/magnetics & remote sensing*
  - *3D geomodels*
  - *Reservoir simulation*

Kansas is part of the Southwest Regional Partnership on Carbon Sequestration (SWP)



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Industry Partners – *Western Annex*

SW Kansas CO_2 Sequestration Consortium

IHR
Improved Hydrocarbon Recovery LLC

HEDKE-SAENGER GEOSCIENCE, LTD

SUNFLOWER ENERGY LLC

+drilling and seismic contractors TBN

CIMAREX

GloriOil

Anadarko
Petroleum Corporation

Dawson-Markwell Exploration Co.

BEREXCO

CELEBRATING 20 YEARS
MERIT ENERGY COMPANY

Industrial and Electrical Power Sources of CO_2

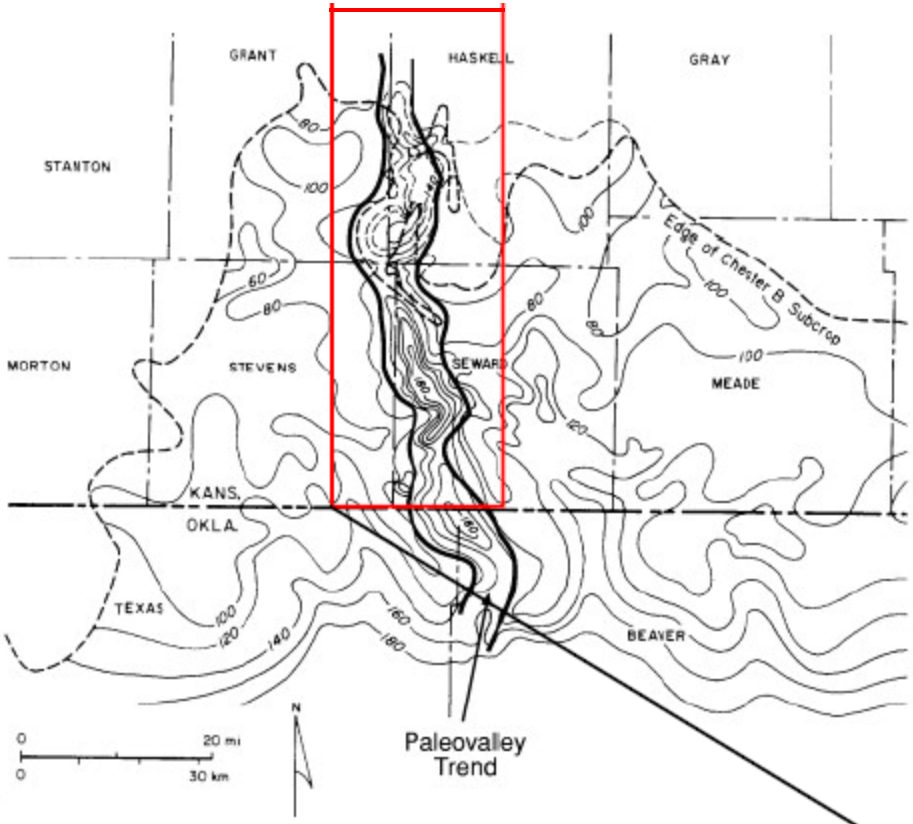
Conestoga Energy Partners, LLC
fueling the new frontier

SUNFLOWER ELECTRIC POWER CORPORATION
A Touchstone Energy® Cooperative
. . . energy done right

Abengoa Bioenergy : The Global Ethanol Company

Western Annex

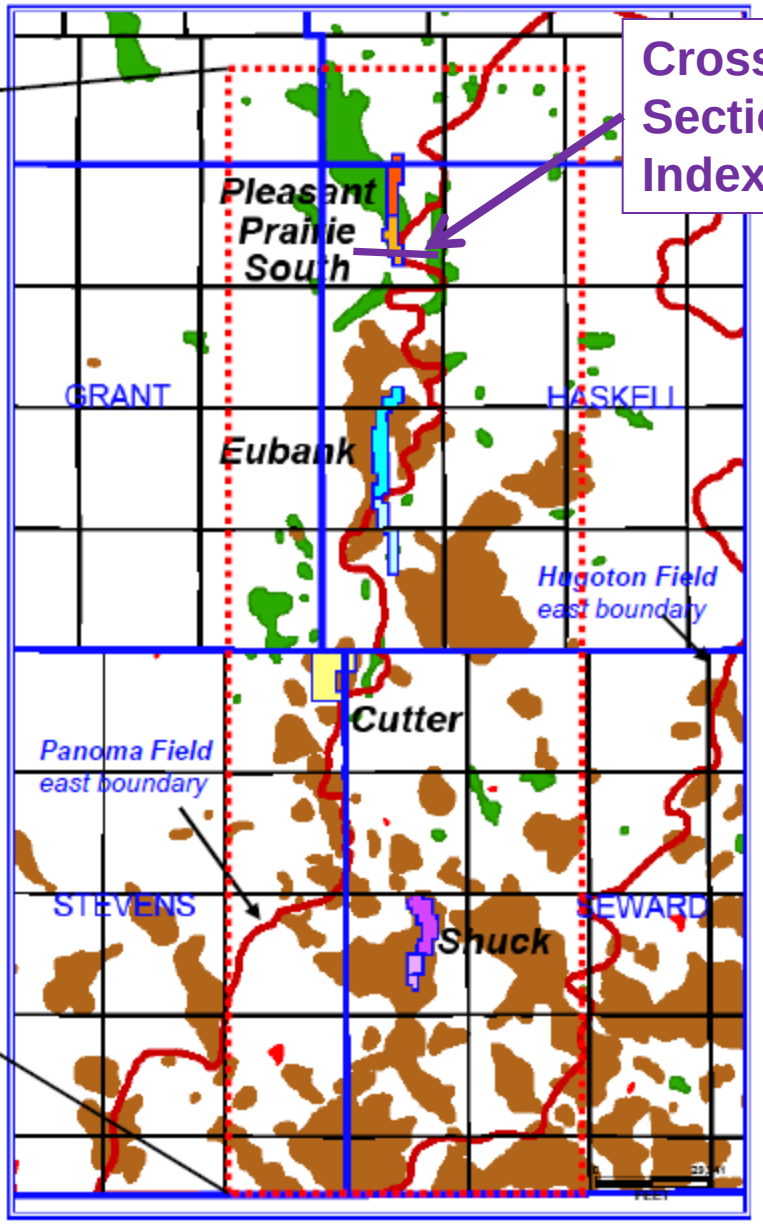
Evaluating CO2-EOR in Chester/Morrow Sandstone Oil Reservoirs and deep saline aquifer sequestration in underlying Arbuckle



(Above) Regional isopach of lowermost Chesterian incised valley fill (*Montgomery & Morrison, 2008*)

(Right) Four fields in study. Green – Oil; Brown – Oil and Gas. Grid is Township-scale (6 mi.).

20 MM bbls oil produced
~40 MM bbls oil remaining

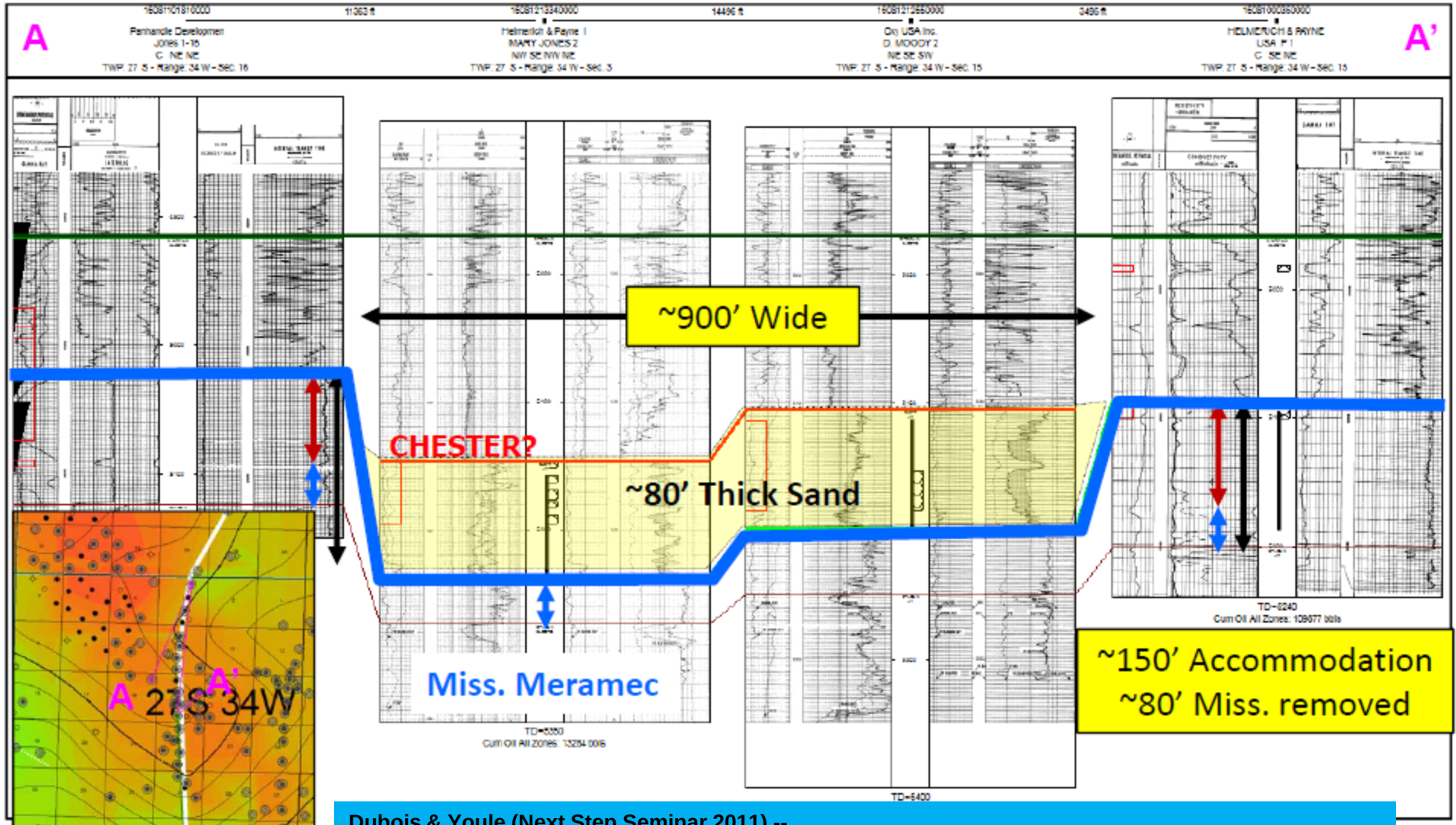


Dubois & Youle (Next Step Seminar 2011) -- http://www.kgs.ku.edu/PRS/Ozark/Reports/2011/SwKsCO2_KsNextStep_Dubois-Youle_0804-2011.pdf

VALLEY MORPHOLOGY: North End of Study Area

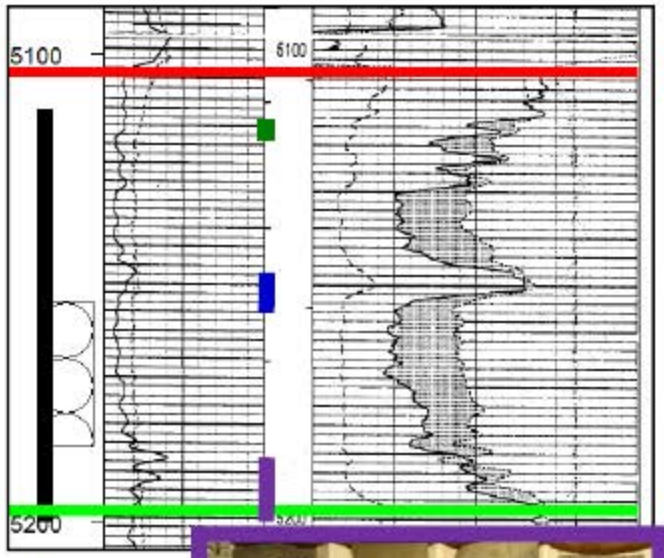
Pleasant Prairie South Field 4.36MBO

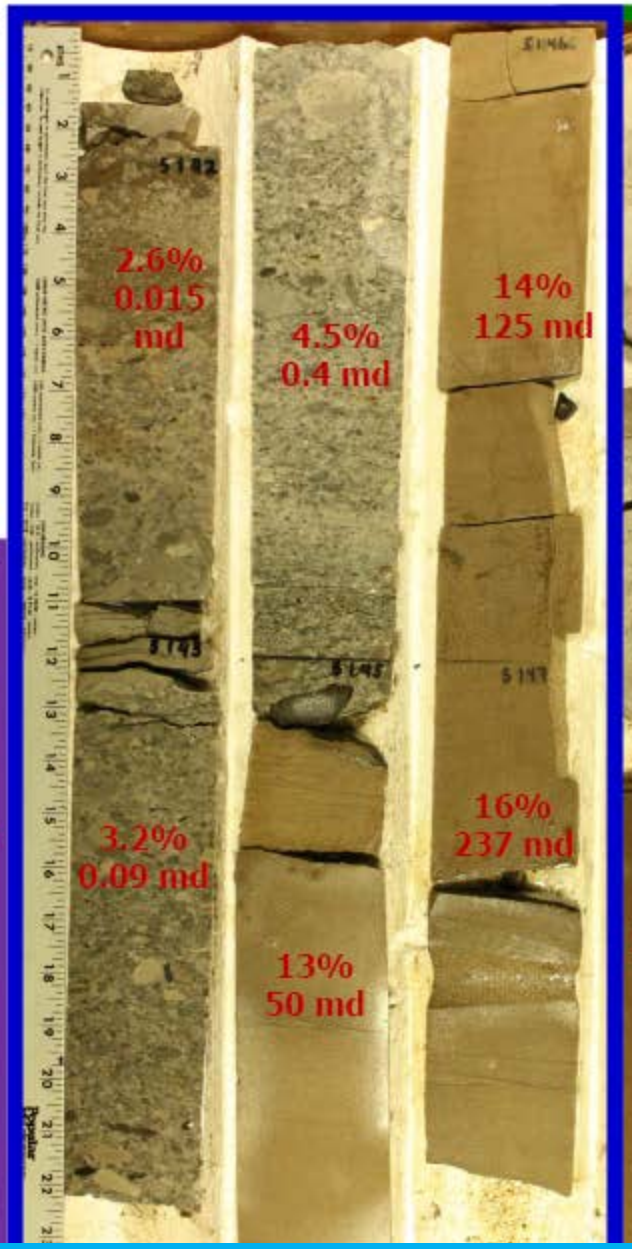
Valley Incised through the SE end of Pleasant Prairie anticline.

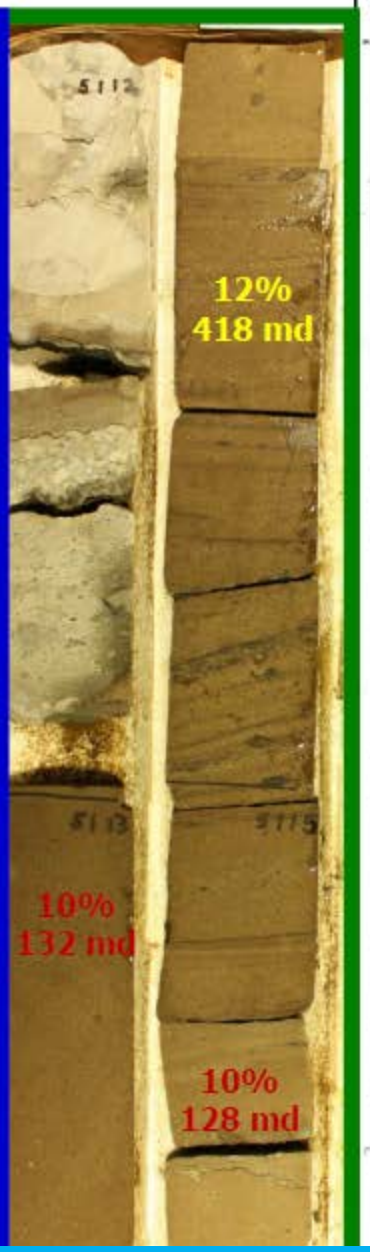


Dubois & Youle (Next Step Seminar 2011) --
http://www.kgs.ku.edu/PRS/Ozark/Reports/2011/SwKsCO2_KsNextStep_Dubois-Youle_0804-2011.pdf

Valley Fill Facies: Pleasant Prairie Pool Oxy Moody 2 15-27s-34w







Best Producting facies:

Mostly fgr to vfgr, tr md gr, low angle to trough X-bedded SS. Locally common shale pebbles and organic debris.

Dubois & Youle (Next Step Seminar 2011) --
http://www.kgs.ku.edu/PRS/Ozark/Reports/2011/SwKsCO2_KsNextStep_Dubois-Youle_0804-2011.pdf

"Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir (Wellington Field) to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System (*OPAS*), South-Central Kansas"

Original DOE-funded Project --
website: http://www.kgs.ku.edu/PRS/Ozark/index.html

- **Paleozoic-age Ozark Plateau Aquifer System (OPAS)**
  - Thick and deeply buried Arbuckle Aquifer
  - Overlying Mississippian carbonates contain large oil and gas reservoirs
  - Arbuckle -- thickness (600-1000 ft), supercritical P-T for CO_2 (>3500 ft), stratigraphic isolation from freshwater aquifers, and very limited oil and gas production.
  - Published estimates of CO_2 sequestration capacity in the Arbuckle Group in KS vary between 1.1 to 3.8 billion metric tonnes based on static CO_2 solubility in brine under in situ pressure and temperature

Partners

(Regional and Wellington)

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Devilbiss Coring Service

BEREXCO

PARAGON
GEOPHYSICAL SERVICES, INC

Basic Energy Services

noble energy

TRILOBITE TESTING, INC.

LOCKHART GEOPHYSICAL

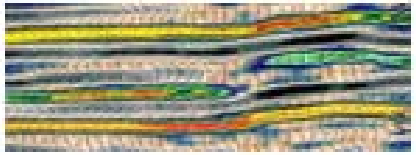
MUDCO

Weatherford LABORATORIES

ECHO GEOPHYSICAL CORPORATION
INTEGRITY · STABILITY · INNOVATION

HALLIBURTON

HEDKE-SAENGER GEOSCIENCE, LTD



Bittersweet Energy Inc.

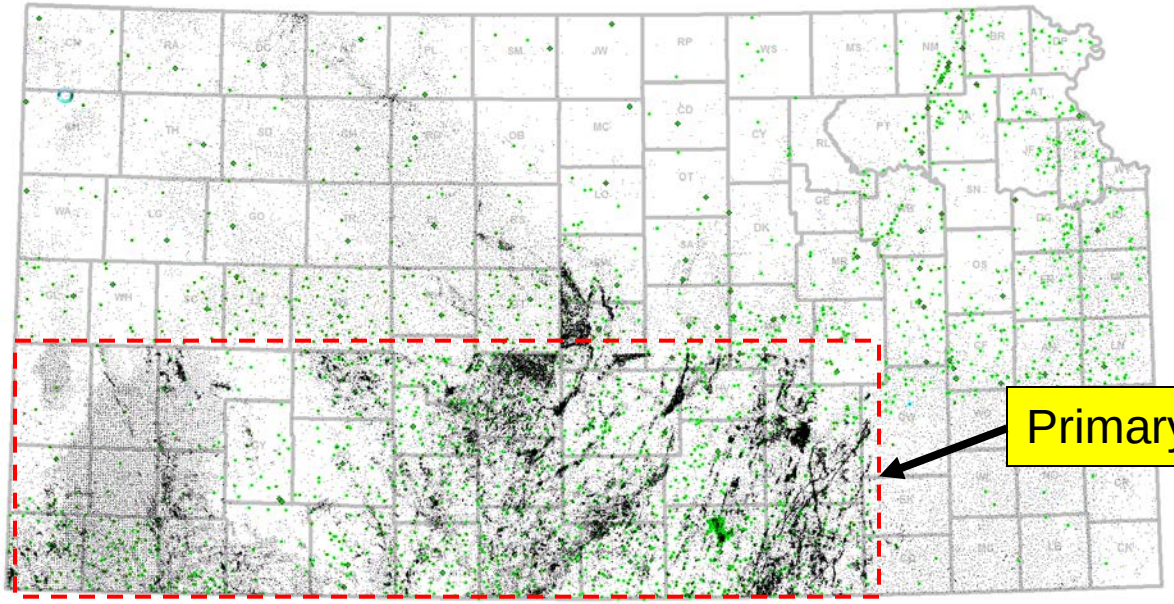
Charter Consulting
Integrated Geology & Geophysics

Petrotek

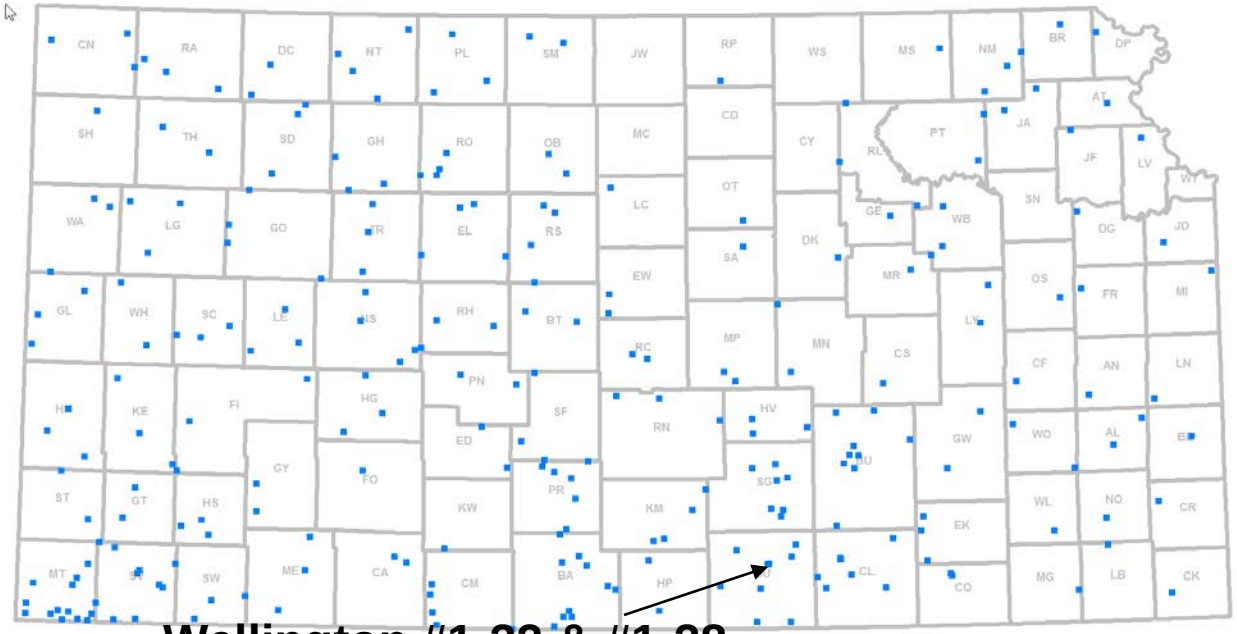
KOGER
REMOTE SENSING

LOGDIGI
A LEADING CONSULTING COMPANY

Regional Characterization of OPAS



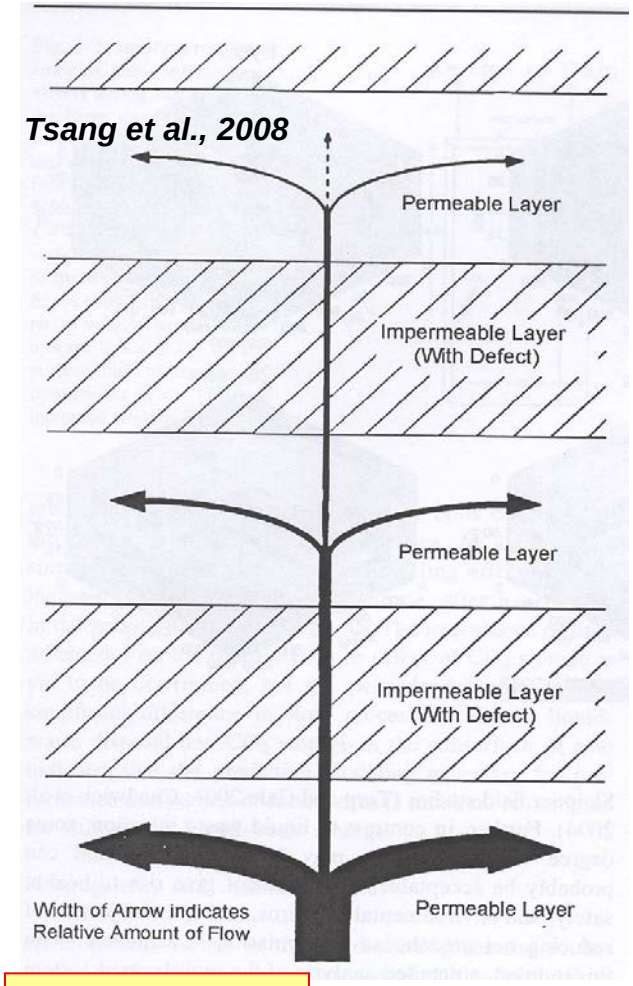
Total well database including those used for tops only (black), e-logs (green)

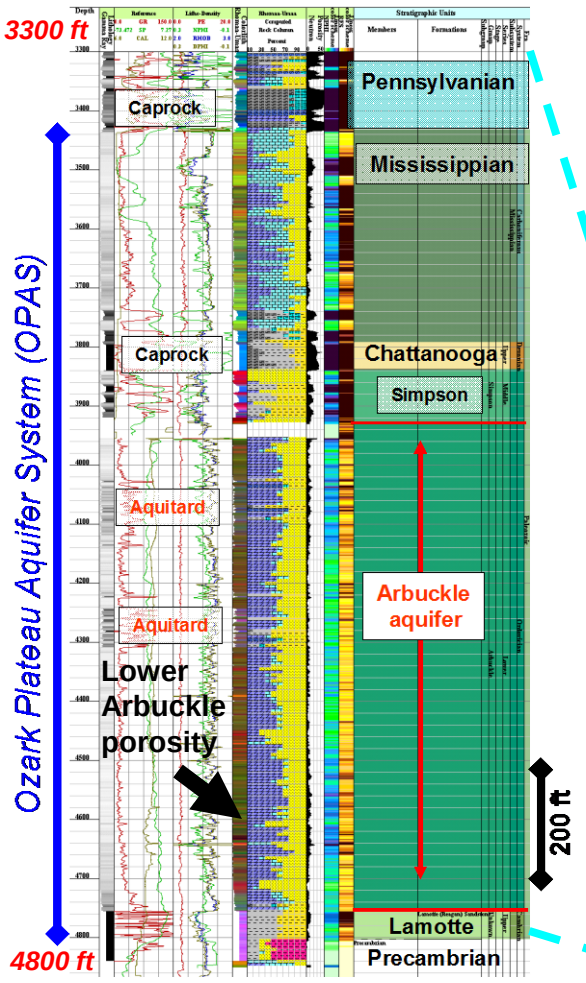


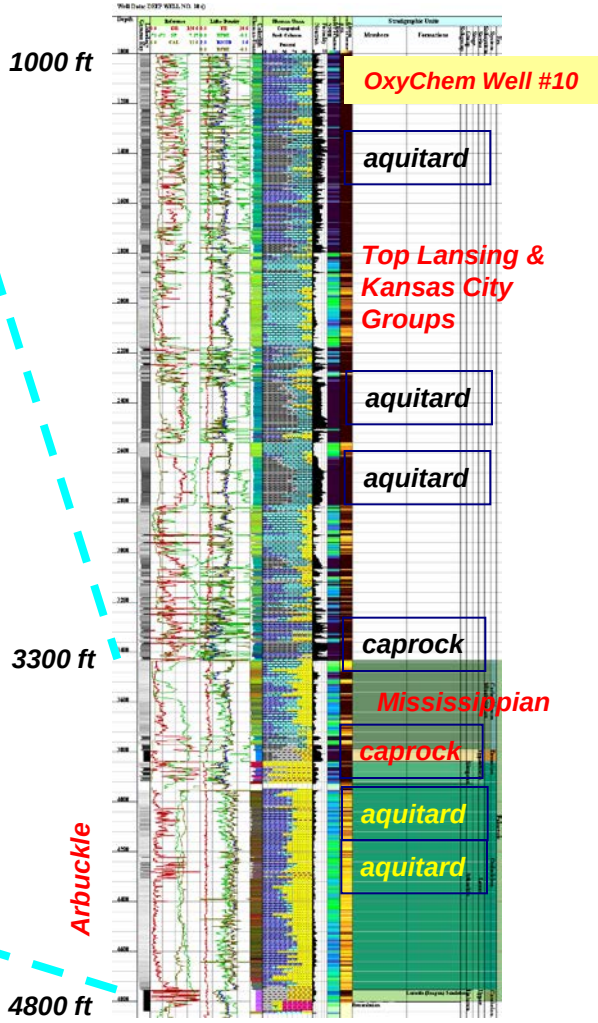
Status of supertype well (5-19-11) – wells with nearly complete penetration of Arbuckle with modern log suite – creating digital LAS files, strat type log linked by cross sections in collaboration with the Ks Geol. Society

Hydrostratigraphy – *Ozark Plateau Aquifer System*

Multiple Caprocks & Aquitards - Leakage Attenuation



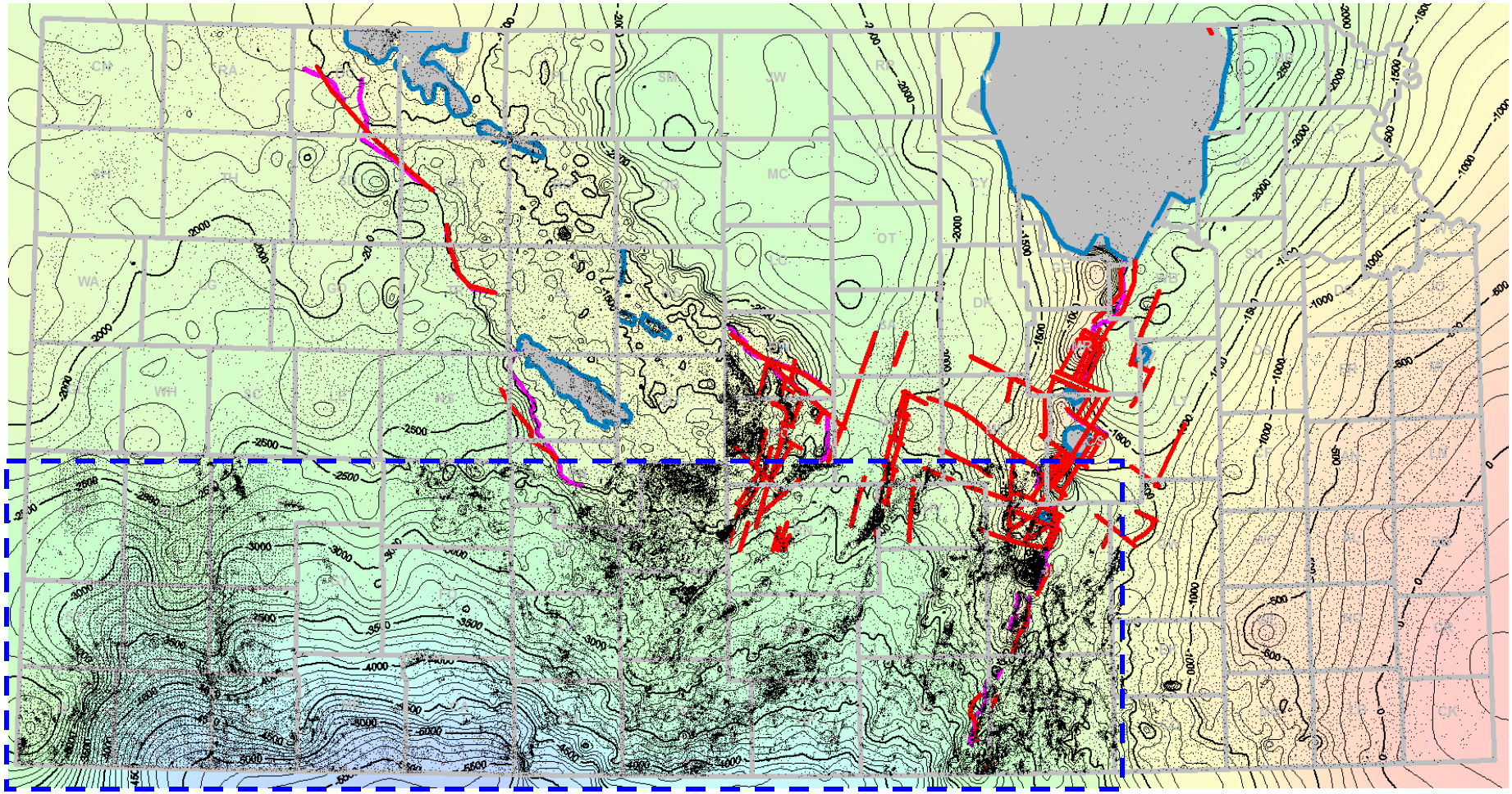




Arrow thickness = Relative amount of flow

CO_2 plume undergoes pressure reduction in scenario of a breach in the cap rock. Additional CO_2 gets trapped in the fine pores of aquitards.

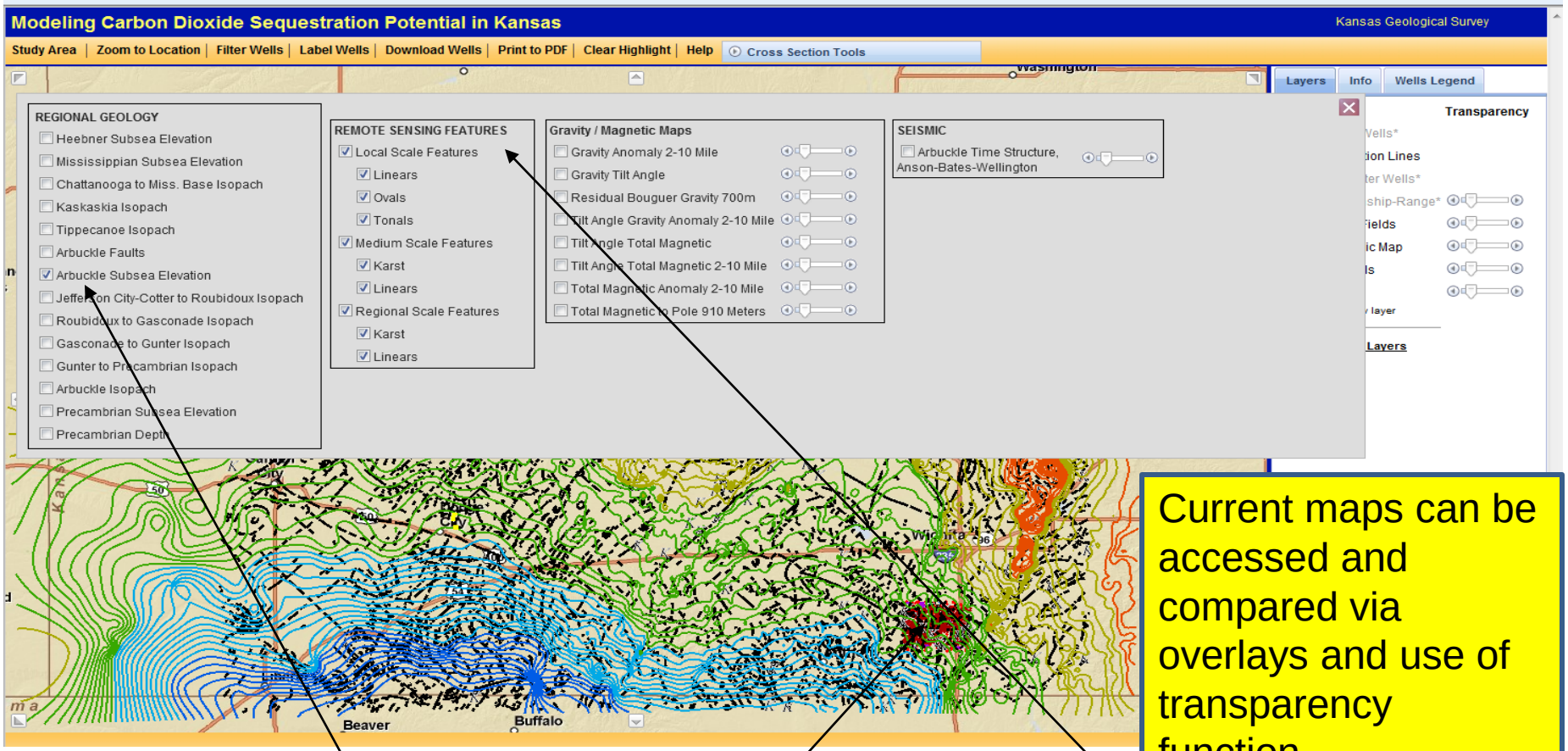
Top Arbuckle Group



- **Published faults are being compiled and new ones are under investigation**
- **Focus of <u>quantitatively</u> assessing CO2 sequestration capacity of Arbuckle saline aquifer is within dashed blue area**
- **Subsea contours; Contour interval = 100 ft.**

Interactive Project Mapper

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



Current maps can be accessed and compared via overlays and use of transparency function

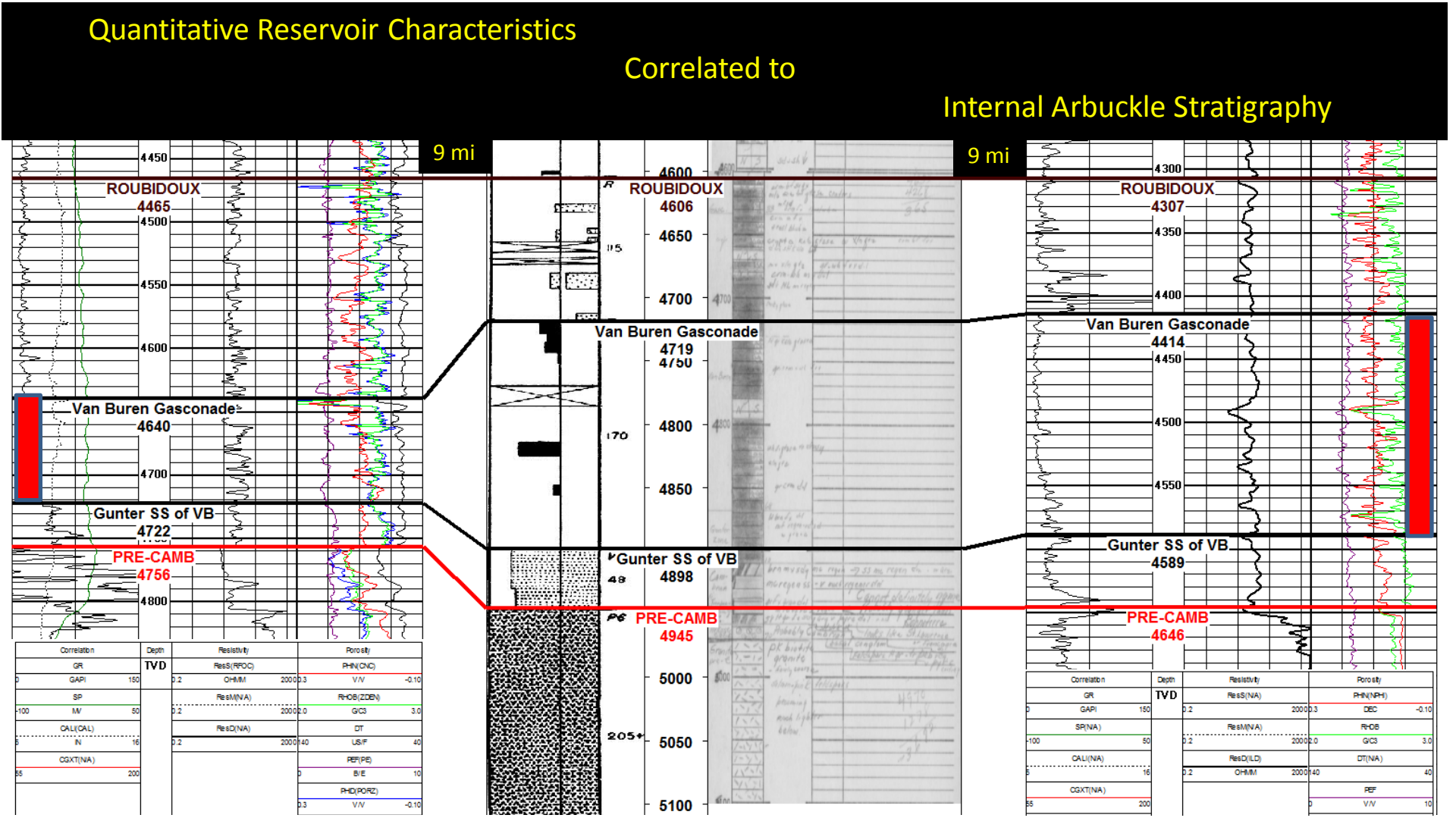
Wellington

Arbuckle subsea elevation
Contour interval = 100 ft.

surface lineaments

Bittersweet Energy LLC/Mike Killian (KGS)

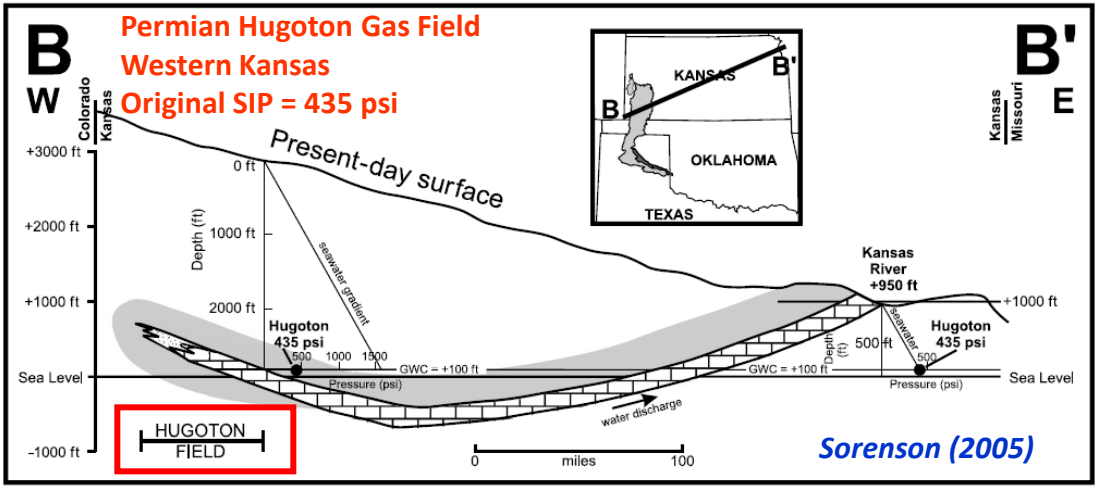
Quantitative Characterization of Arbuckle in southern Kansas



Example cross section of lower Arbuckle from top Roubidoux (datum) to basement including new and old well data (insoluble residue logs, georeports, and modern suite of logs managed as LAS files) – Gerlach et al.

Arbuckle saline aquifer is an open system

Arbuckle Saline Aquifer Connected to Outcrop

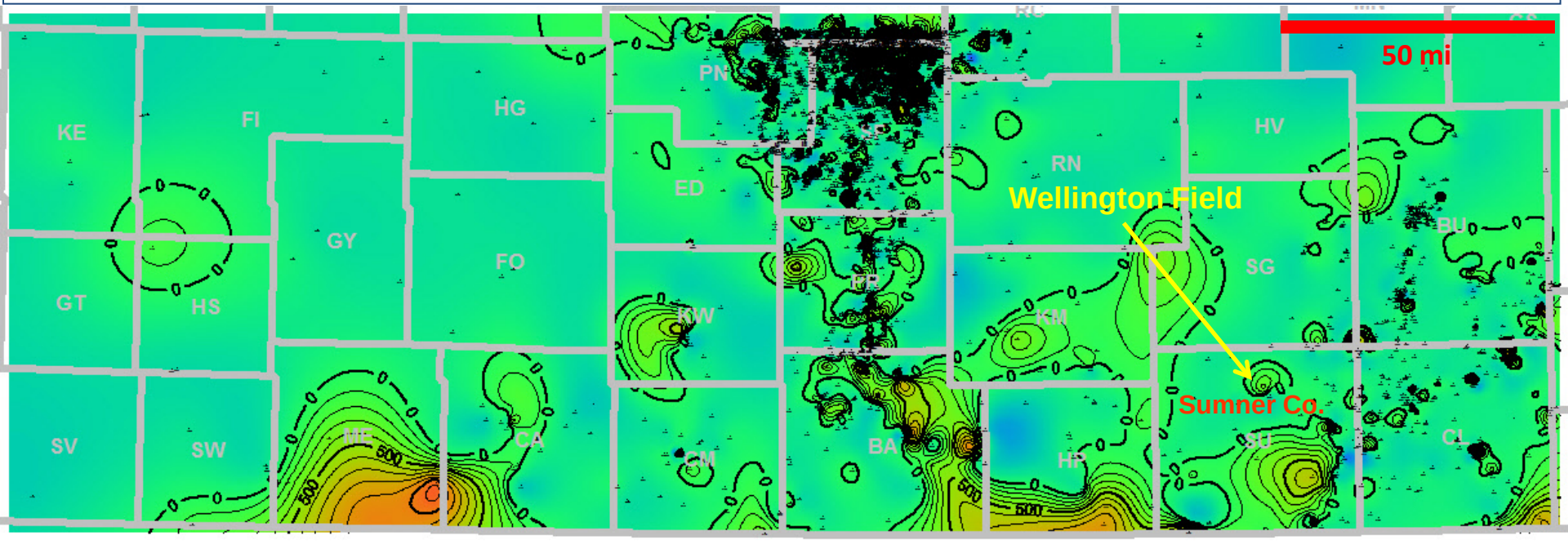


Arbuckle exposure at base of Missouri River, north-central Missouri –

Elevation 450 ft; surface exposures located ~200 mi northeast

Assume hydrostatic gradient = 0.435 psi/ft

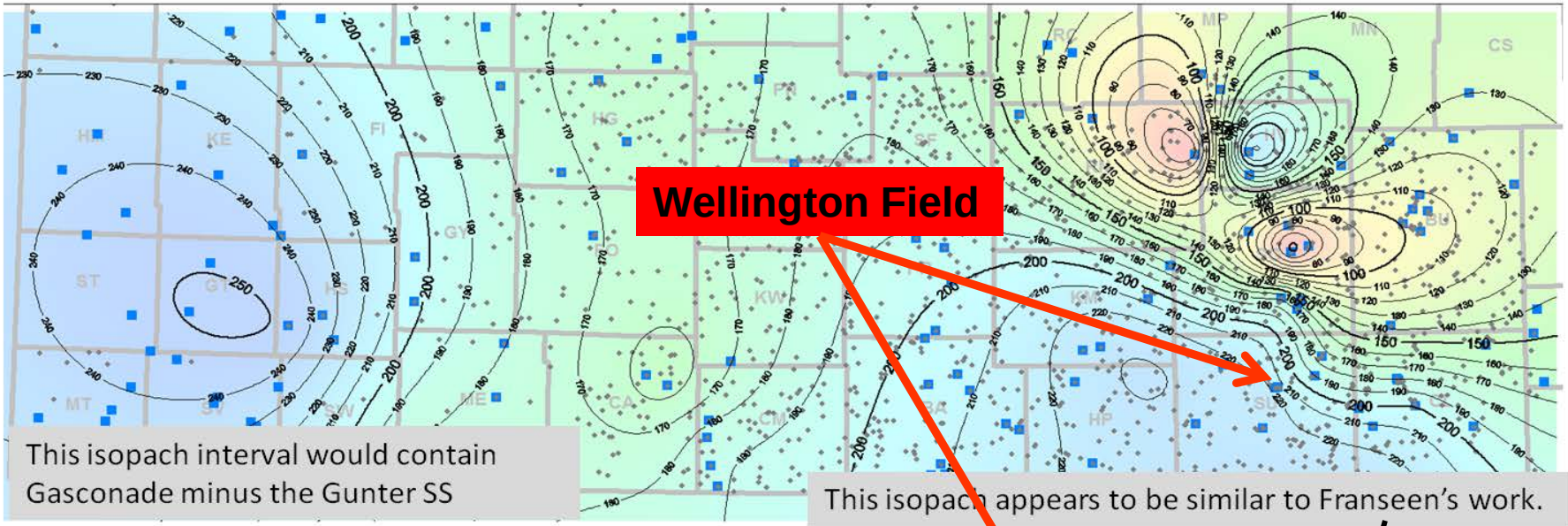
Map of the difference between estimated hydraulic head at base of Arbuckle test interval and measured shut-in pressure



Lower porous zone in Arbuckle

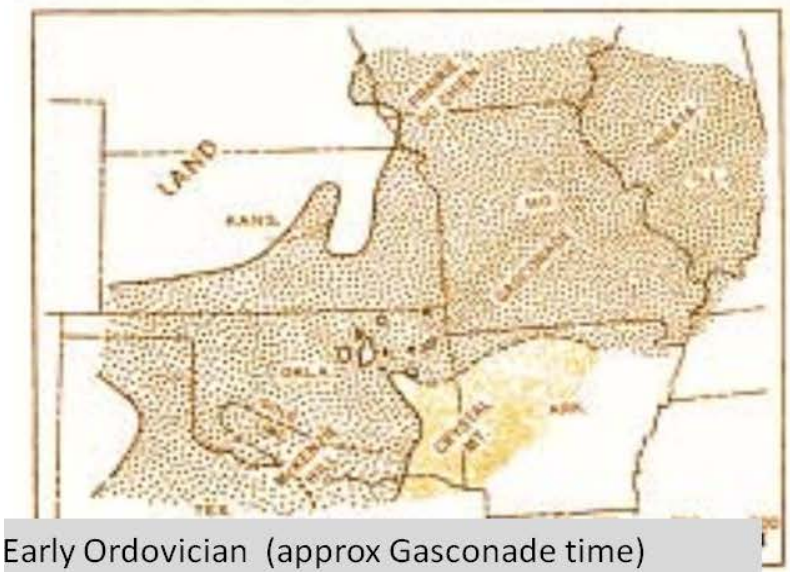
Gerlach et al.

ISOPACH GASCONADE to GUNTER SS

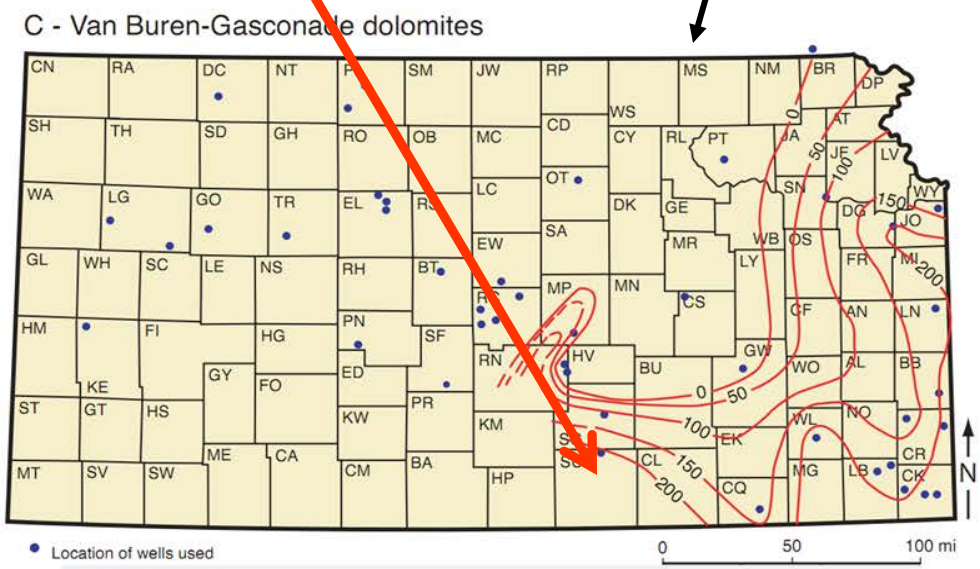


This isopach interval would contain Gasconade minus the Gunter SS

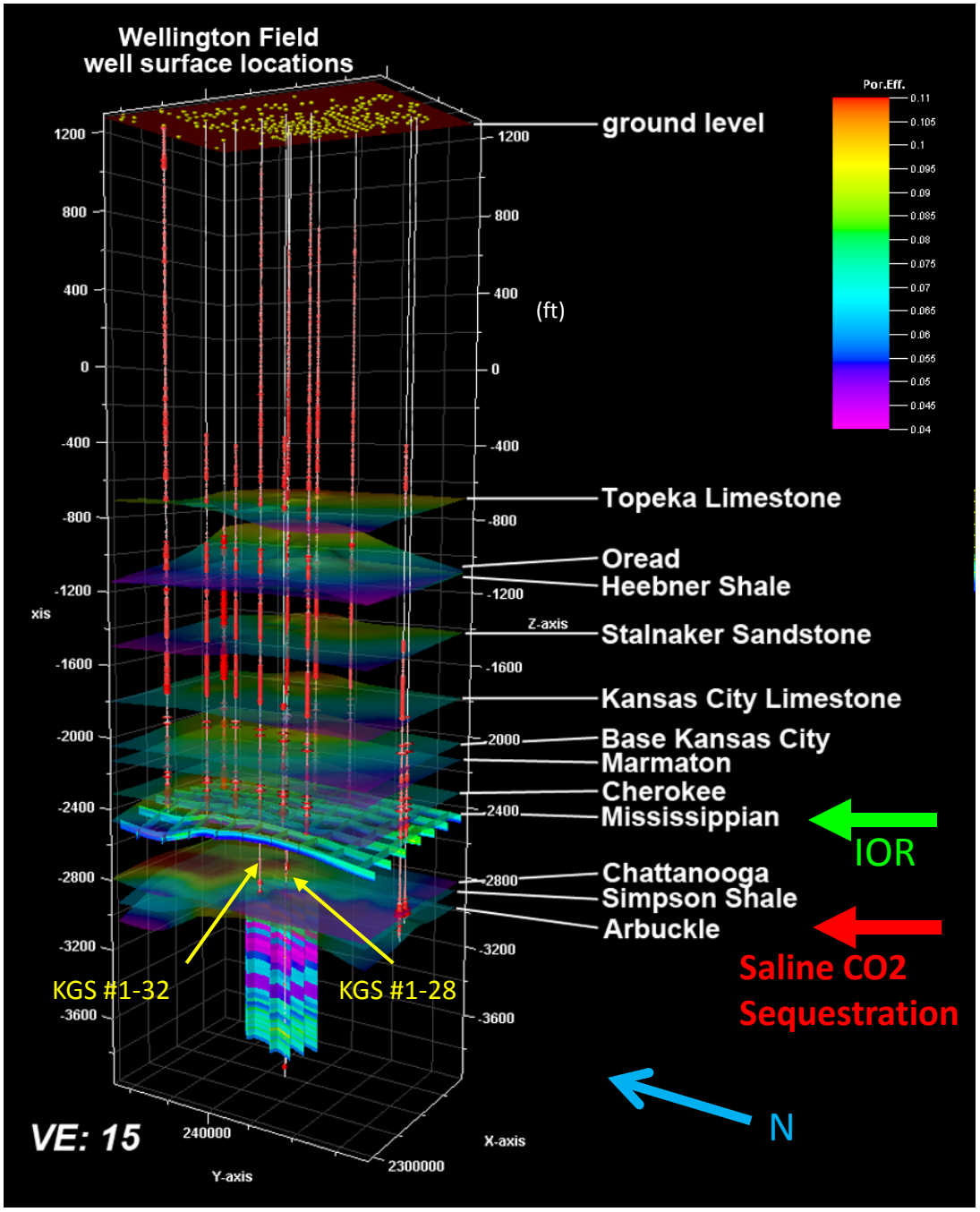
This isopach appears to be similar to Franseen's work.



Early Ordovician (approx Gasconade time) Paleogeography, Chenoweth, 68



Van Buren Gasconade Isopach, Franseen et al., 2004



Wellington Field

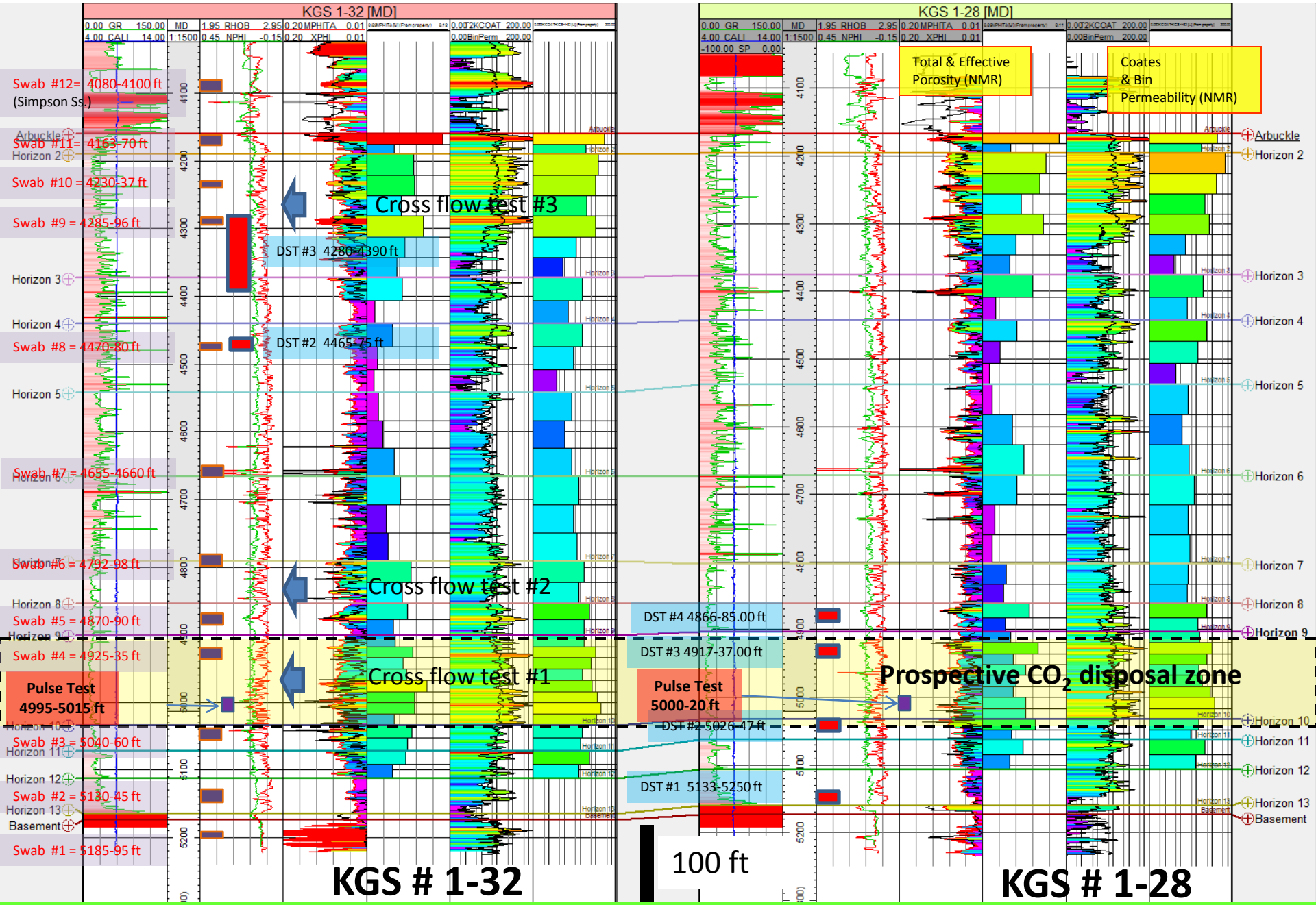
1) Mississippian tripolitic chert/dolomite reservoir
2) Arbuckle saline aquifer
3) Intervening caprocks

- 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

Small scale field test (70k tonnes CO2) contract being negotiated with DOE

- MVA deployment and testing -- LiDAR/InSAR, shallow GW monitoring
- Mississippian reservoir - pressure, geochemistry, strategic 2D seismic
- Arbuckle - in situ cross hole tomography, U-tube plume sampling, CASM (continuous seismic imaging), repeat 3D seismic

Step rate test completed and preliminary perforate & swab intervals in Arbuckle and Simpson Groups



Cross section (east to west) between KGS #1-28 and #1-32 in Wellington Field and upscaled hydrostratigraphic units in Arbuckle Group

ZONAL FRACTURES AND AUTOCLASTIC BRECCIAS IN THE POROUS INTERVALS OF THE ARBUCKLE

4593 ft

4556.2 ftt

4609 ft.

Small Scale Field Test Demonstrating CO2 sequestration in Arbuckle Saline Aquifer and by CO2-EOR at Wellington field, Sumner County, Kansas

KANSAS GEOLOGICAL SURVEY
The University of Kansas

Funding Opportunity Number: DE-FOA-0000441
CFDA Number: 81.089 Fossil Energy Research and Development
$11,484,490 requested from DOE
$3.235 million cost share

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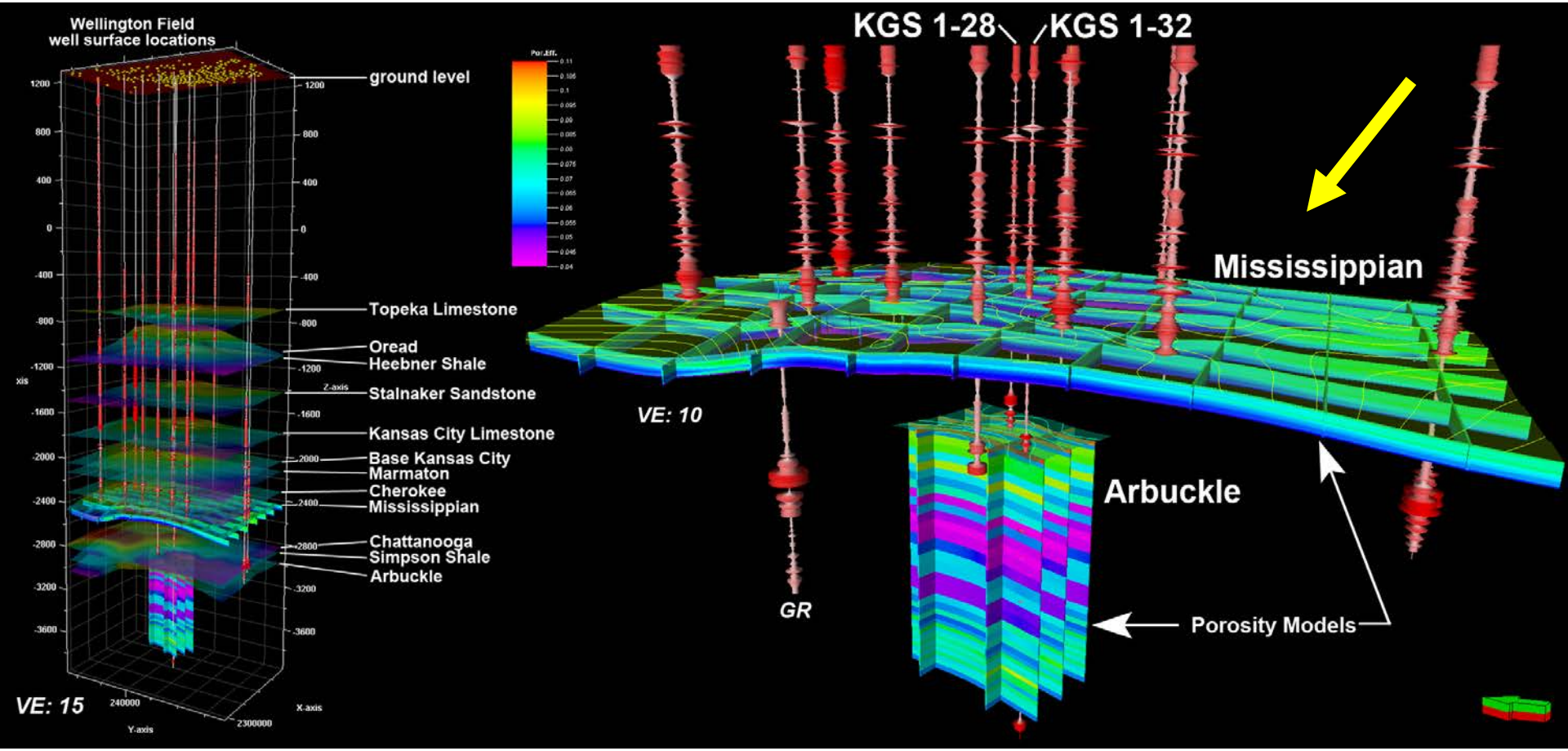
Abengoa Bioenergy : The Global Ethanol Company

KU THE UNIVERSITY OF KANSAS Department of Geology

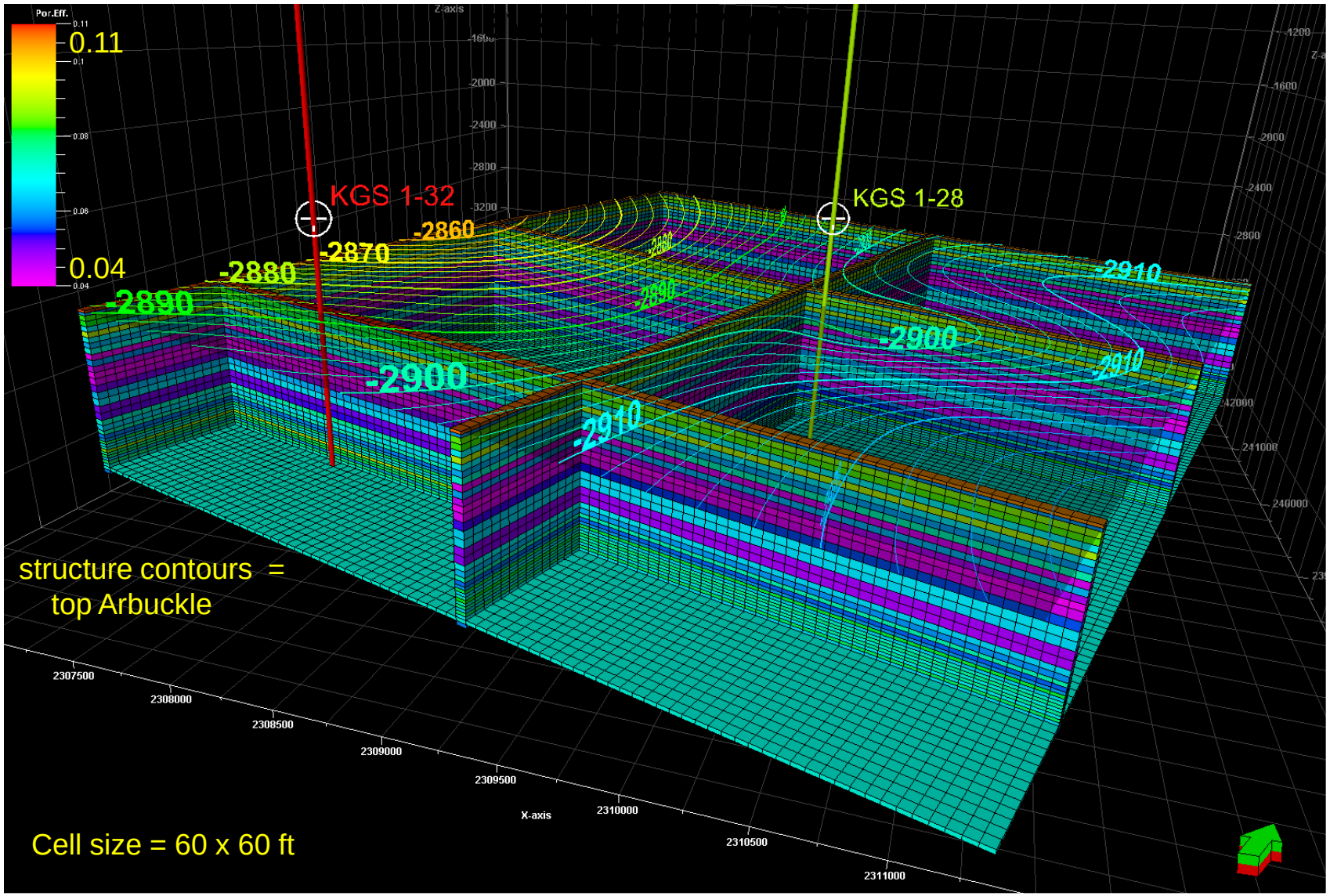
Sandia Technologies, LLC

Wellington Field

Mississippian tripolite/chert reservoir (underpressured), lower Mississippian & Simpson sealing strata, & Arbuckle aquifer



Upscaled average porosity (effective Φ from NMR) for Arbuckle Group in vicinity of KGS #1-32 & #1-28

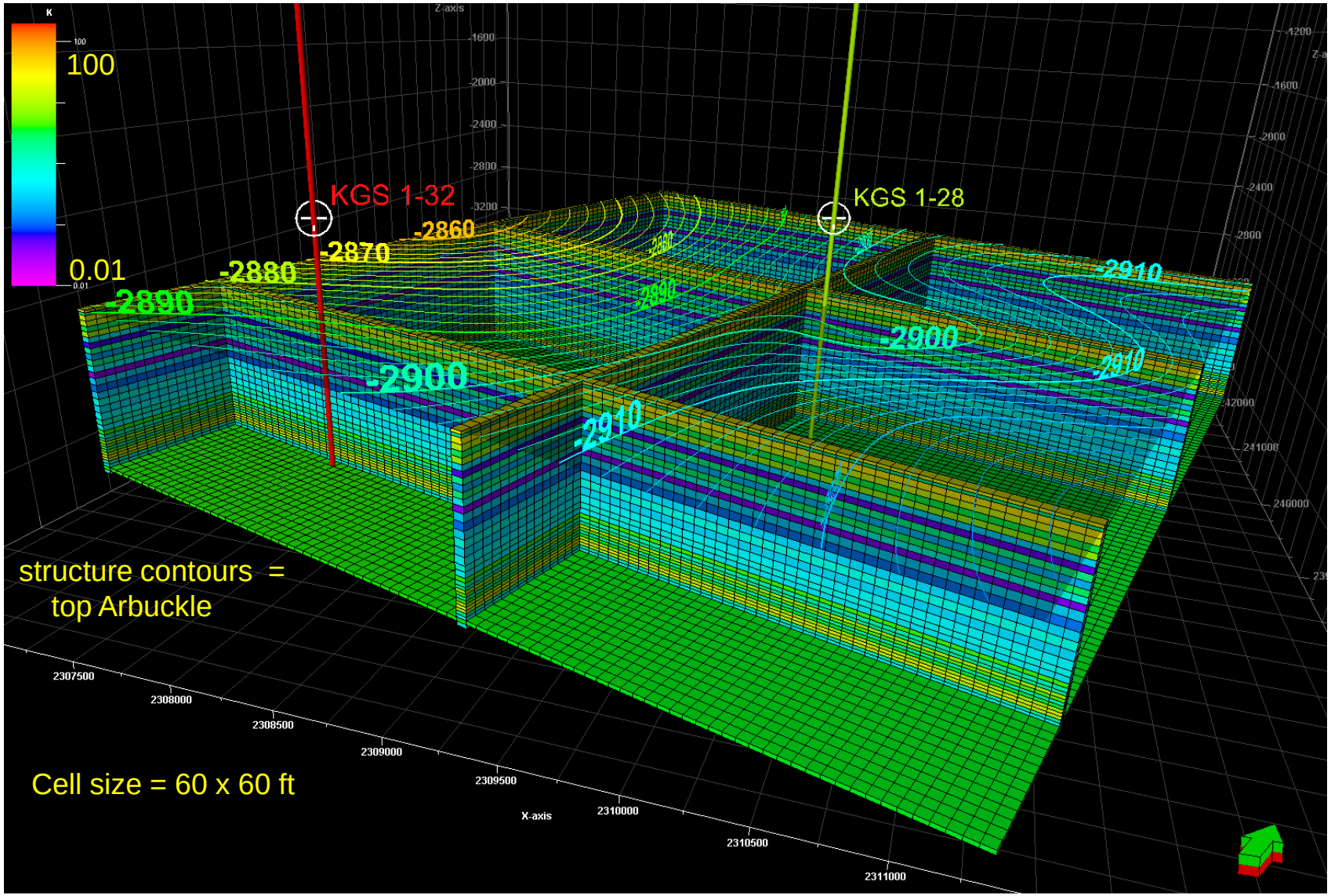


Permeability Geomodel of Arbuckle Group

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



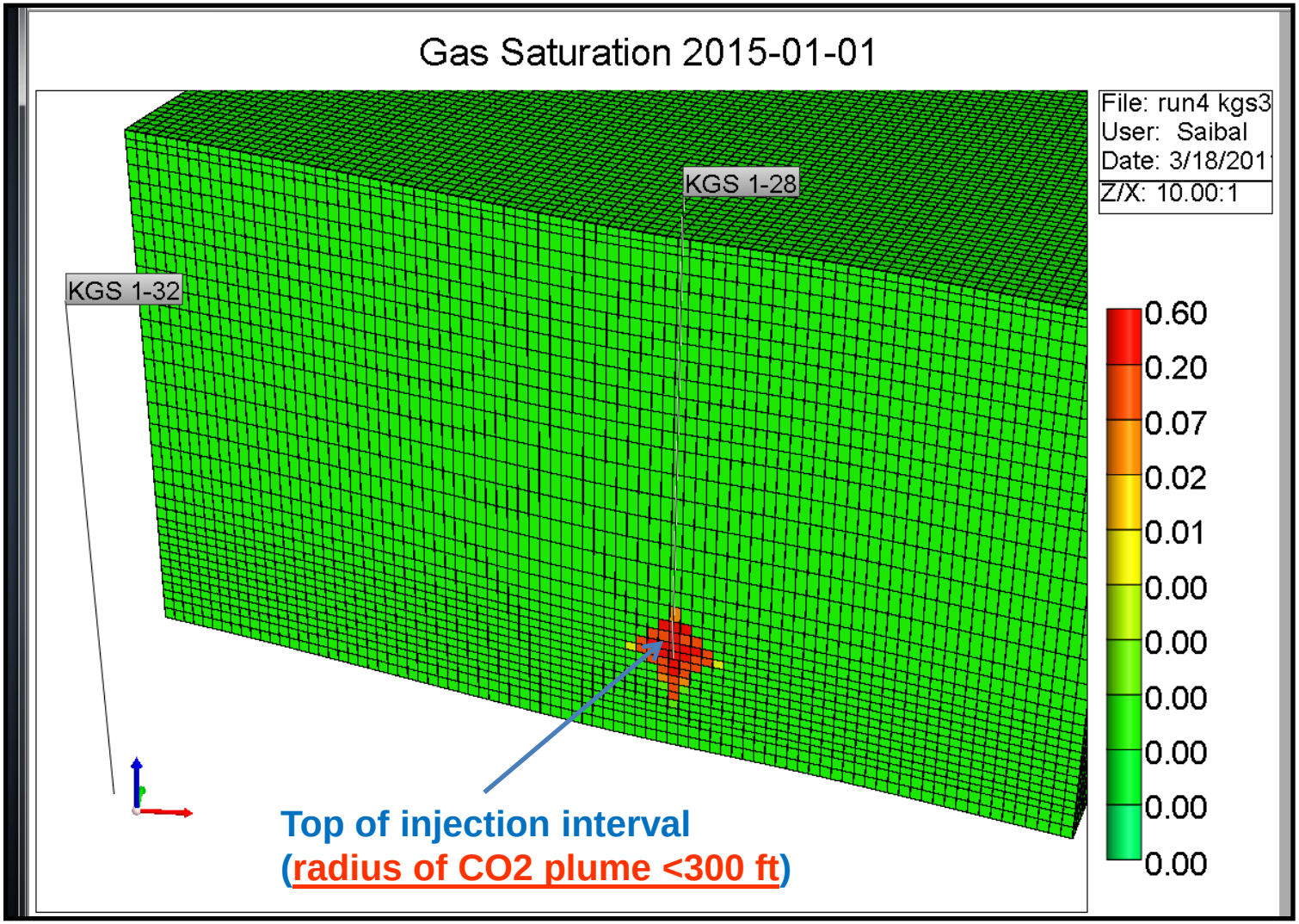
Simulated *hypothetical* injection

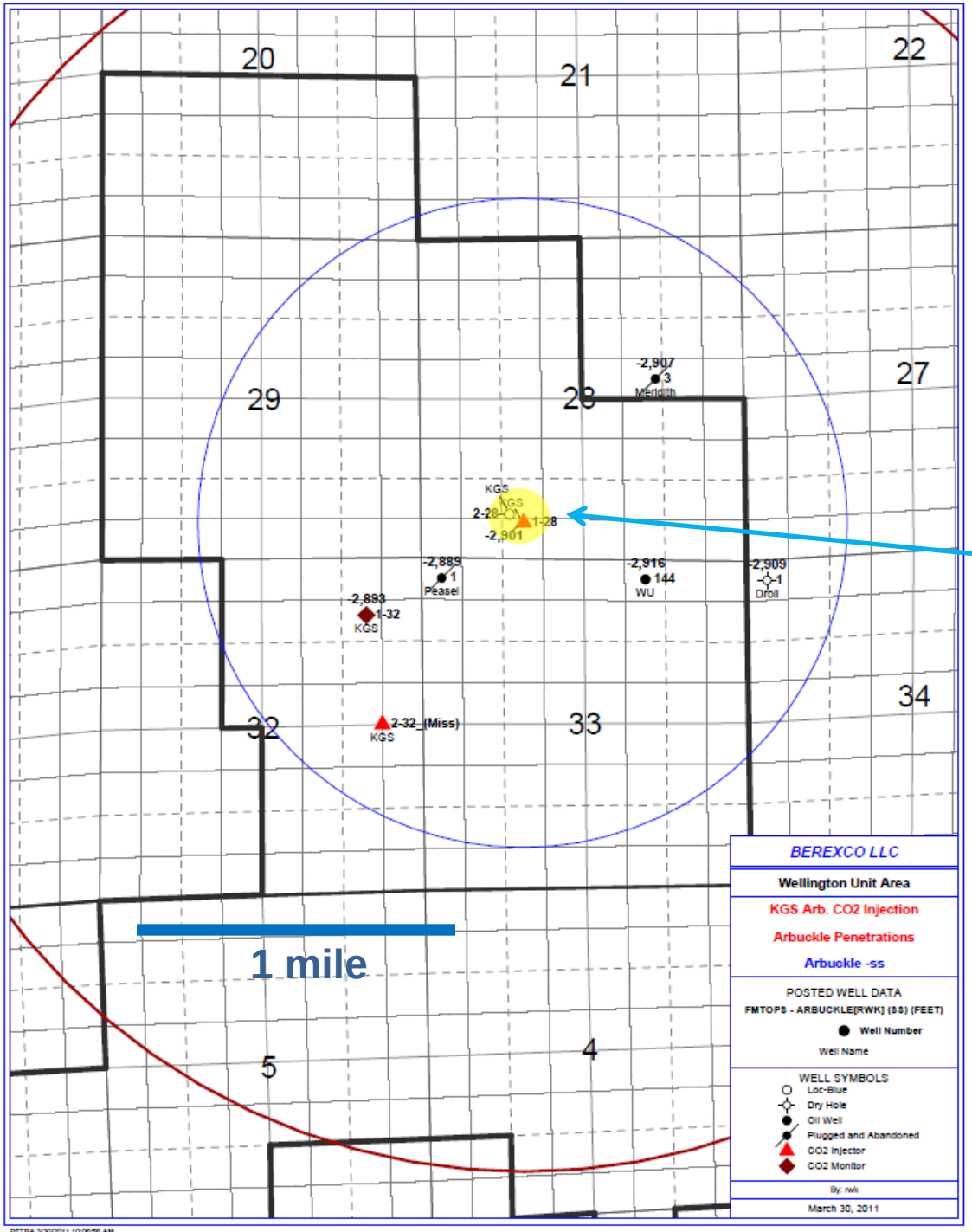
started on Jan 1, 2011 (for 9 months)

Grid cells 60’ by 60’

Total CO_2 injected into Arbuckle ~ 40,000 tons

Injection layers – L25 to L30, each ~20 ft thick, 120 ft total





Map showing boreholes that penetrate the Arbuckle saline aquifer in Wellington Field

- Proposed monitoring borehole (#2-28) within 300 ft of the existing #1-28 borehole to be converted into CO_2 injector for small scale field test

- Yellow dot shows estimated size of CO_2 plume after injection of 40,000 tonnes in 120 ft interval of lower Arbuckle based on preliminary simulation results

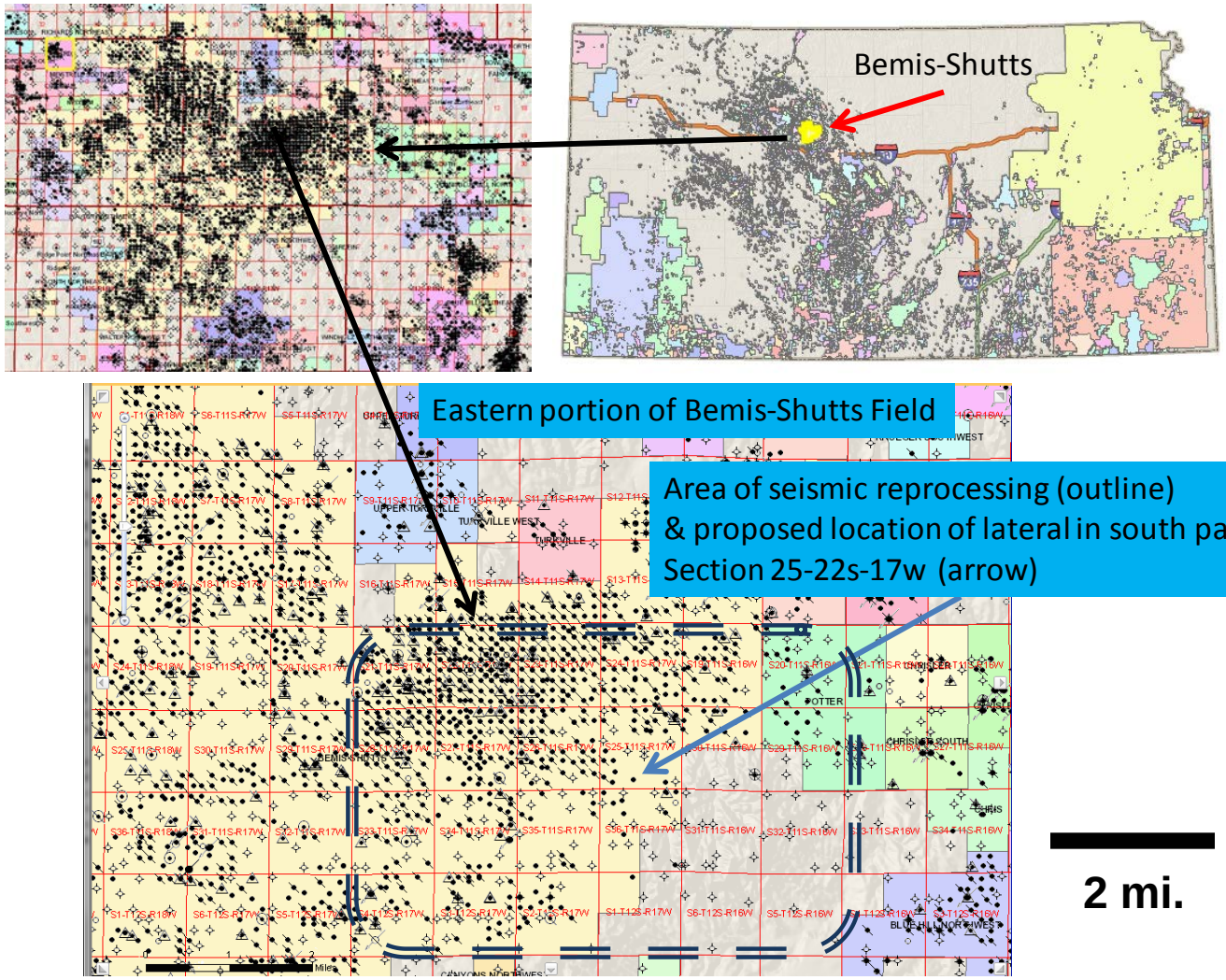
Bemis-Shutts Field
Ellis County, Kansas

Vess Oil Corporation

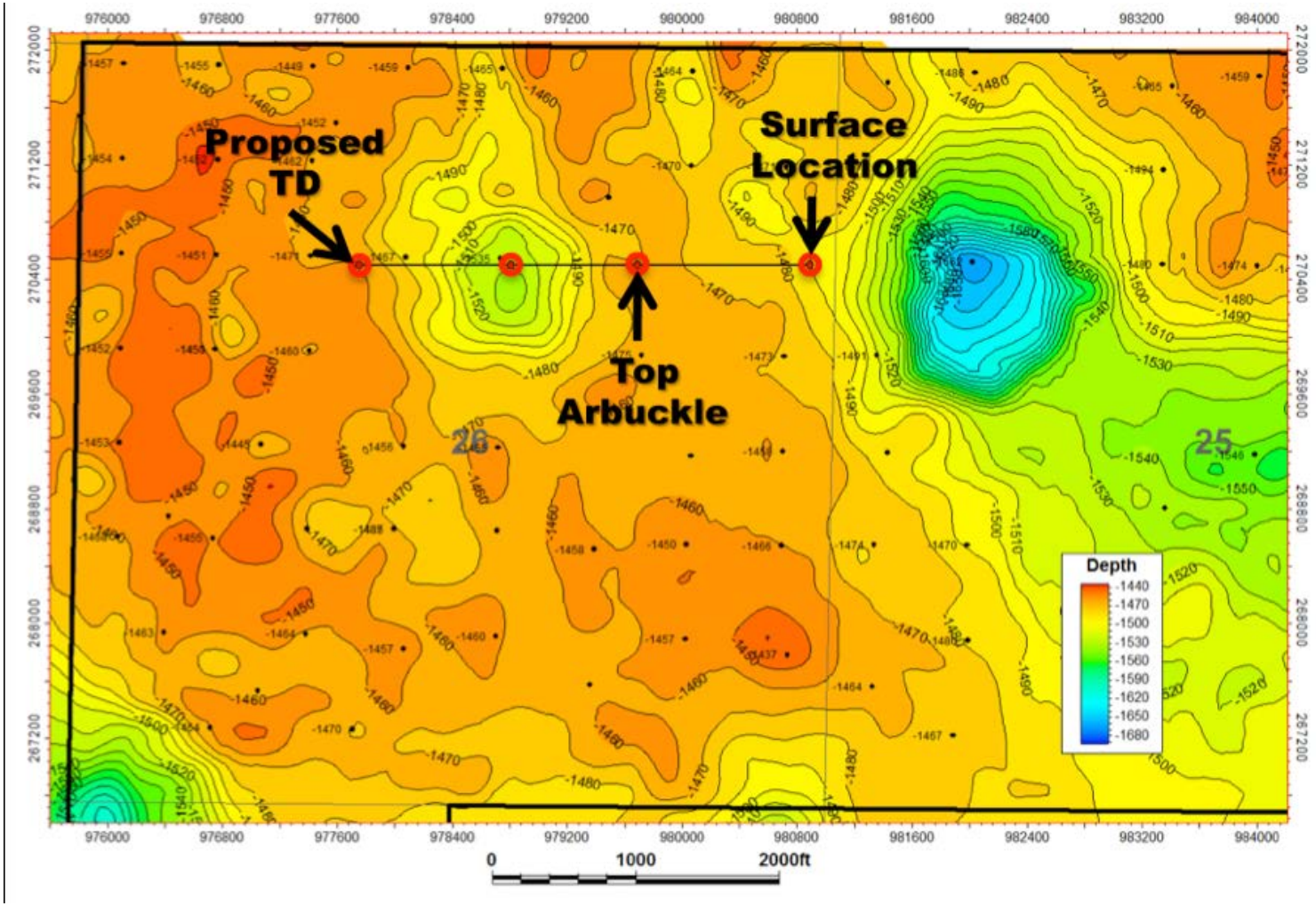
- "*Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage pathways in the Arbuckle saline aquifer: Reducing uncertainty in CO_2 storage and permanence.*"
  - Collaborative study of the Kansas Geological Survey with its industry partners **Vess Oil Corporation** and **Murfin Drilling Company**
  - Funded by the U.S. Department of Energy under grant DE-FE0004566 and cost-sharing by its industry partners
  - Seismic data has been donated to the project by MV Partners, Vess, Noble Energy, Berexco, Lario, Damar, Jolen, and Diehl
  - Other participants include Hedke-Saenger Geoscience, Ltd., Susan Nissan Geophysical Consulting, Geotextures, Tres Management Services, and Saugata Datta, K-State along with staff members in the Energy Research Section of the Kansas Geological Survey

Bemis-Shutts Field, Ellis County, Ks.

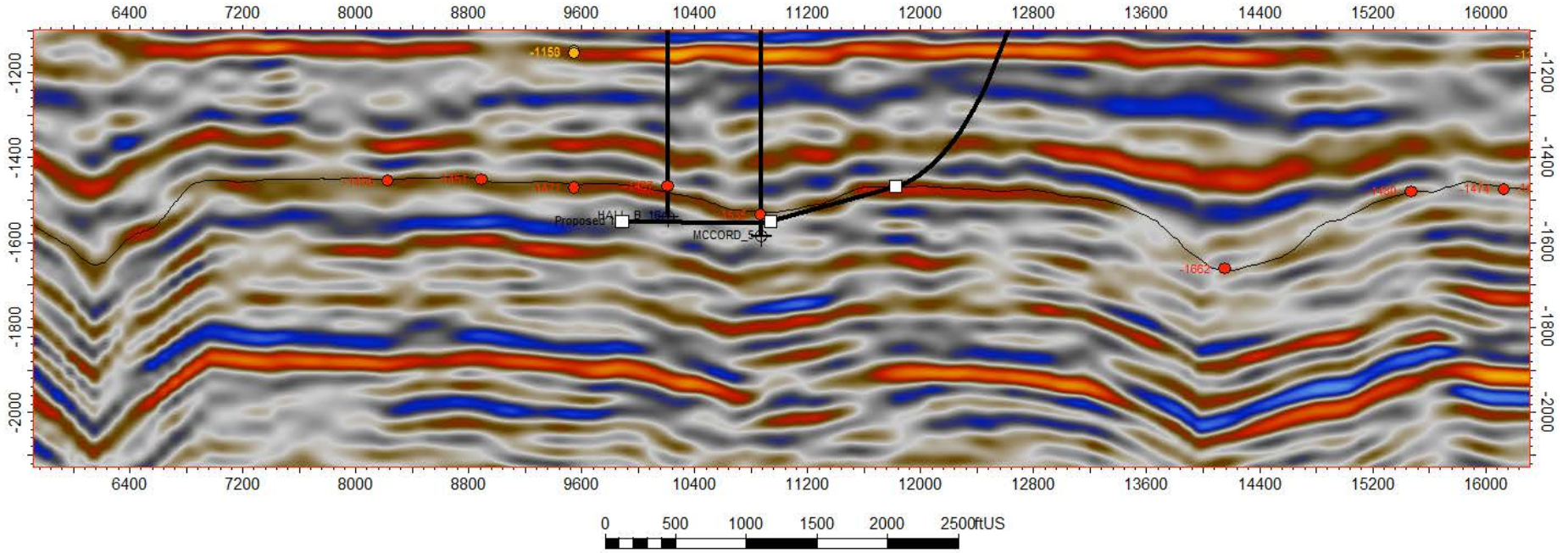
Seismic reprocessing including volumetric curvature and pre-stack depth migration. Seismic and well data used to locate site for horizontal well in this large, mature oil field



Map showing test borehole targets in relation to paleokarst feature



Cross line 182 showing planned test boring trajectory. Offsetting well control, paleokarst dimensions, and structure are ideal for meeting project objectives (i.e., ~1500-ft paleokarst feature)



Kansas State Plane Northern Zone (NAD 83)

Target	X	Y	Depth (TVDSS)
1 (surface location)	980890	270500	1800
2 (top Arbuckle)	979690	270500	-1467
3 (intermediate target)	978810	270500	-1550
4 (TD)	977755	270500	-1550

Summary of Findings

KANSAS GEOLOGICAL SURVEY
The University of Kansas

- **Injectivity and Storage in Arbuckle**
  - Discontinuous fracturing compliment matrix porosity
  - Karst overprinting
  - Lithofacies control porosity & permeability in widespread, correlatable stratal packages
  - Arbuckle is an open hydrologic system

- **Structure**
  - Deep-seated, basement structures/faulting abundant in Midcontinent craton
  - Characterizing flexures & fractures from new processing of gravity-magnetics, structure mapping, multicomponent (converted shear wave) 3D seismic, and lineament analysis from remote sensing
  - Developing a mechanical stratigraphy to better characterize and model (predict) fractures and faults affecting reservoir, aquifer, and caprocks

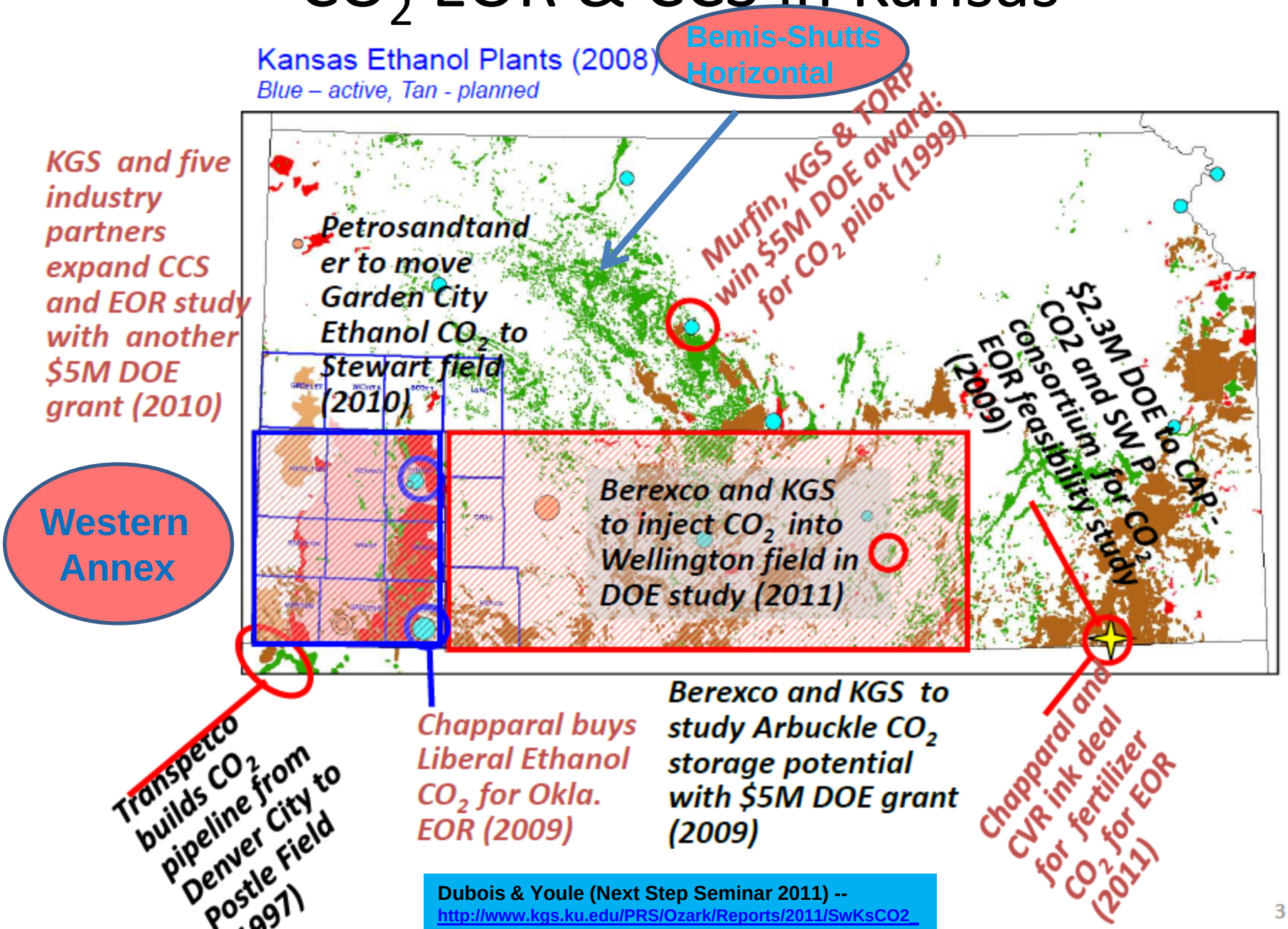
- **Simulation of commercial scale CO_2 injection**
  - Estimated footprint for 10 MM tonnes CO_2 injection with plume size < 2 mi radius
  - Preliminary simulation of CO2 injection for small scale field test at Wellington Field, 40,000 tonnes with plume size <300 ft radius
  - Internal aquitards in Arbuckle being evaluated as possible baffles and barriers to vertical migration of CO_2 plume
  - Preliminary results of pulse test in lower Arbuckle at Wellington Field that at 20 ft flow unit is laterally connected at distance of 3000 feet

Acknowledgements & Disclaimer

Acknowledgements

- *The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number DE-FE0002056 (Wellington), W.L. Watney, PI and Grant Number DE-FE0004556 (Bemis-Shutts) Jason Rush, PI. Projects are managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners.*

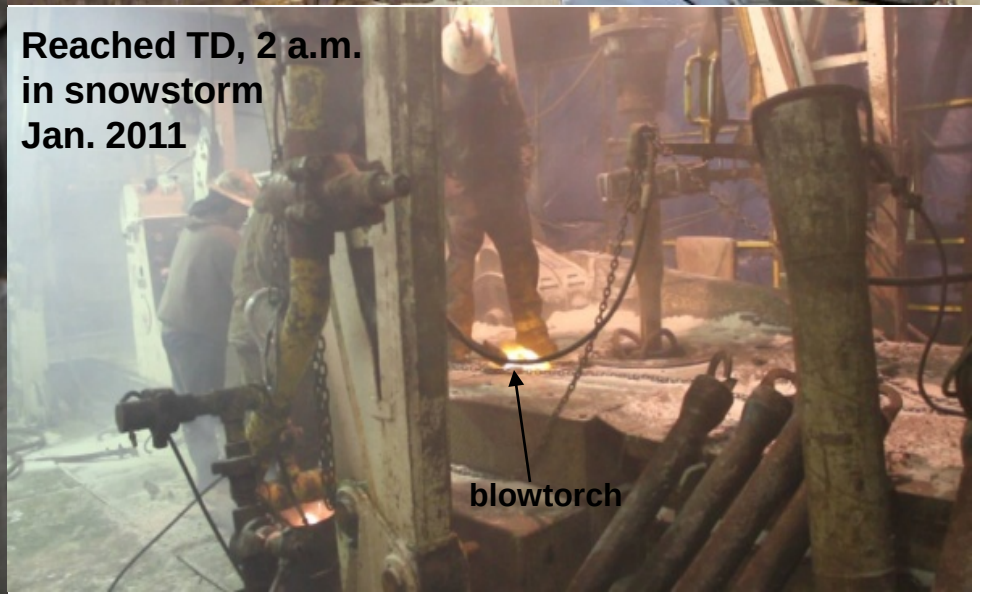
CO_2 EOR & CCS in Kansas



Dubois & Youle (Next Step Seminar 2011) -- http://www.kgs.ku.edu/PRS/Ozark/Reports/2011/SwKsCO2_KsNextStep_Dubois-Youle_0804-2011.pdf

Basement Faulting in #1-32

“Tombstone” Granite



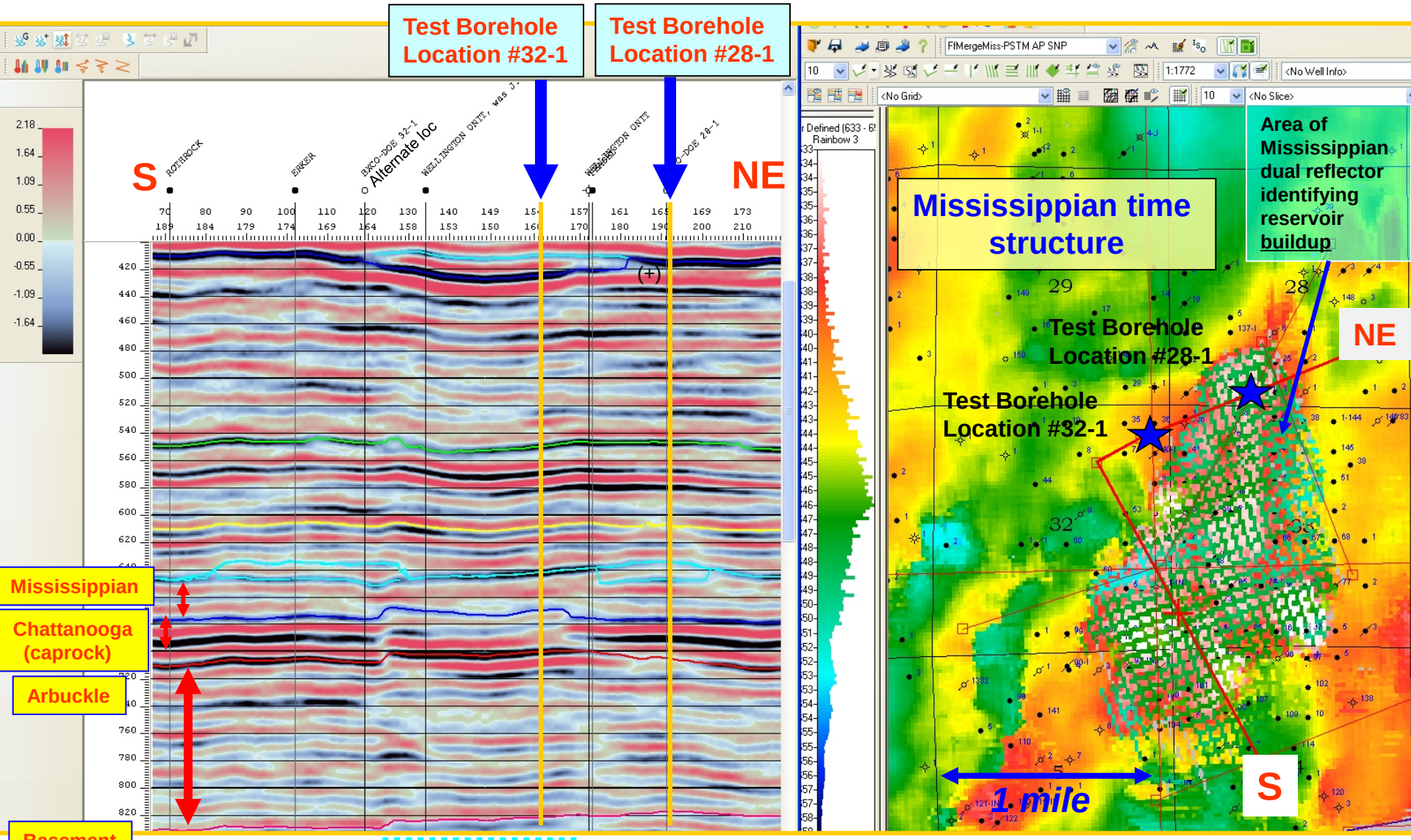
Bemis-Shutts Field
Project Objectives

- The project is evaluating the effectiveness of a new seismic tool to identify the presence, extent, and impact of paleokarst heterogeneity on CO_2 sequestration.
- The selection of the test site in Bemis-Shutts Field also has significant implications for oil production from this field and on the Central Kansas Uplift.
- This proposed project will also provide a valuable data set to complement the DOE-funded regional assessment of Arbuckle CO_2 sequestration potential focused on south-central KS (DE-FE0002056).

Wellington Field

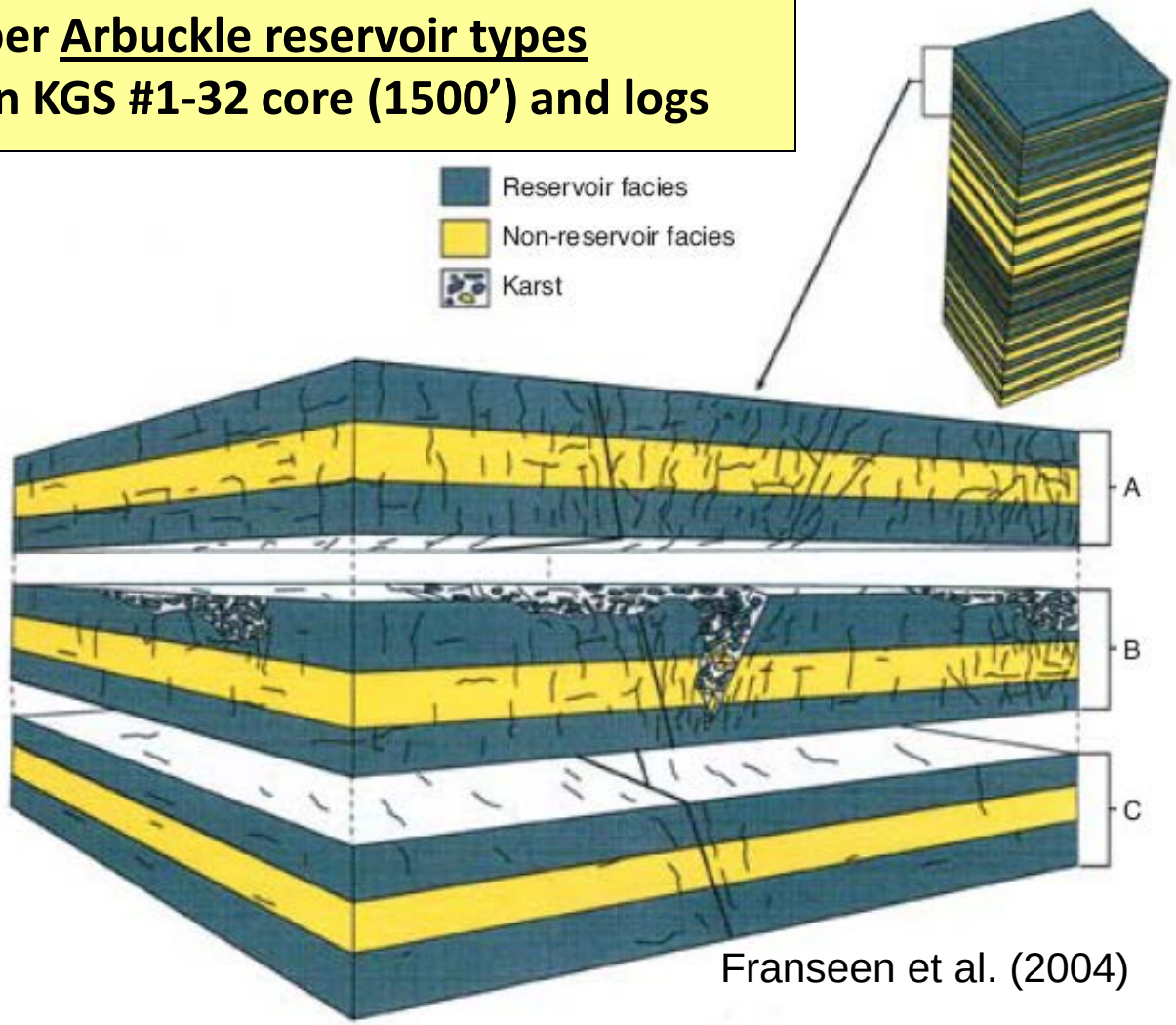
3D Seismic & New Basement Boreholes

Arbitrary seismic profile to compare borehole locations



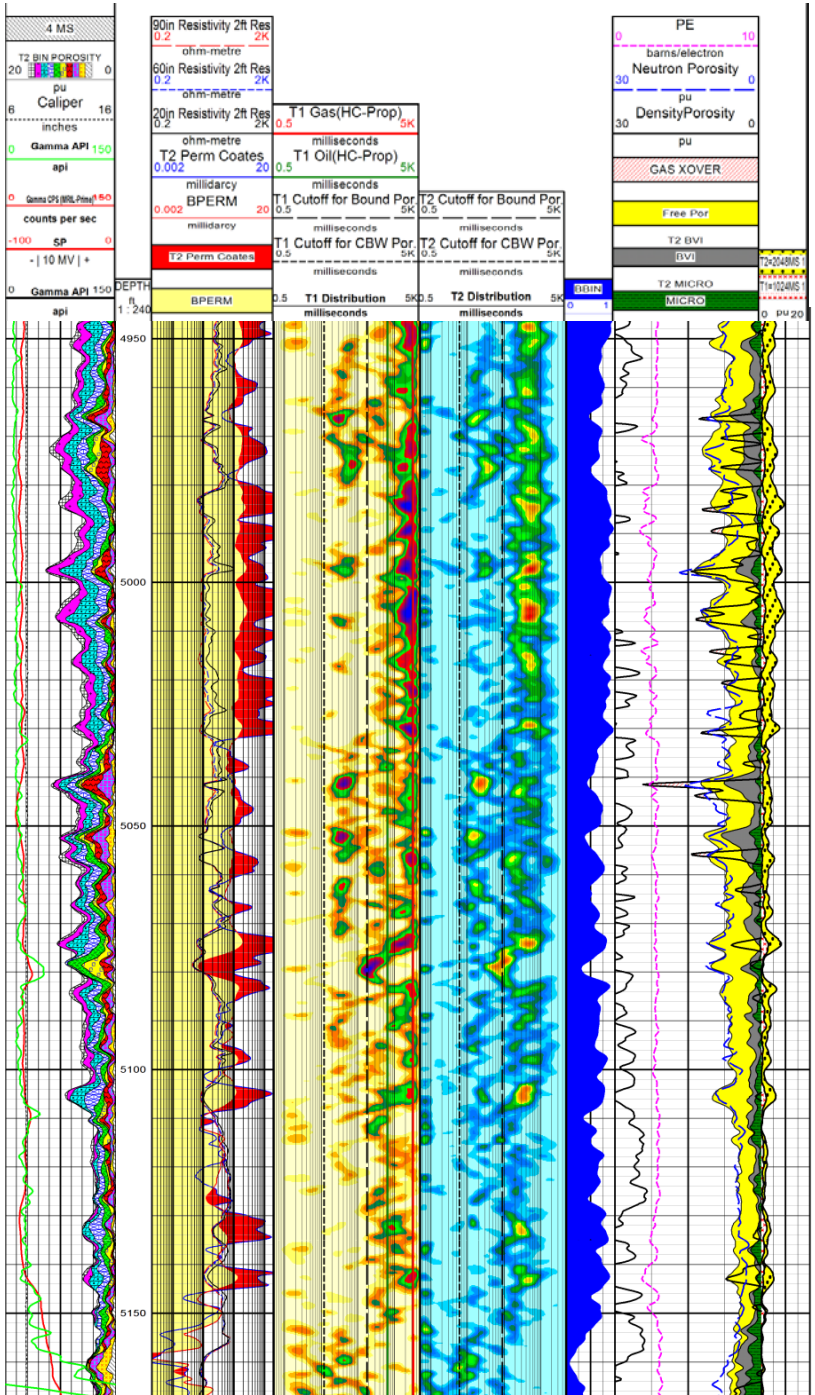
1000 ft Arbuckle at Wellington Field is complexly stacked lithofacies in persistent stratal packages

End-member <u>Arbuckle reservoir types</u> observed in KGS #1-32 core (1500') and logs



Franseen et al. (2004)

Discontinuous fracturing, karst overprinting, lithofacies control porosity & permeability in <u>persistent stratal packages</u>



NMR log showing locations of pulse test & swabbing intervals in <u>lowermost Arbuckle</u> of well #1-32

Pulse Test 4995-15 ft

5049.7; 4997.7; NO Core RECOVERY

Swab #3 = 5040-45 ft

Corresponding to DST #2 in #1-28

5049.7; 4997.7; NO Core RECOVERY

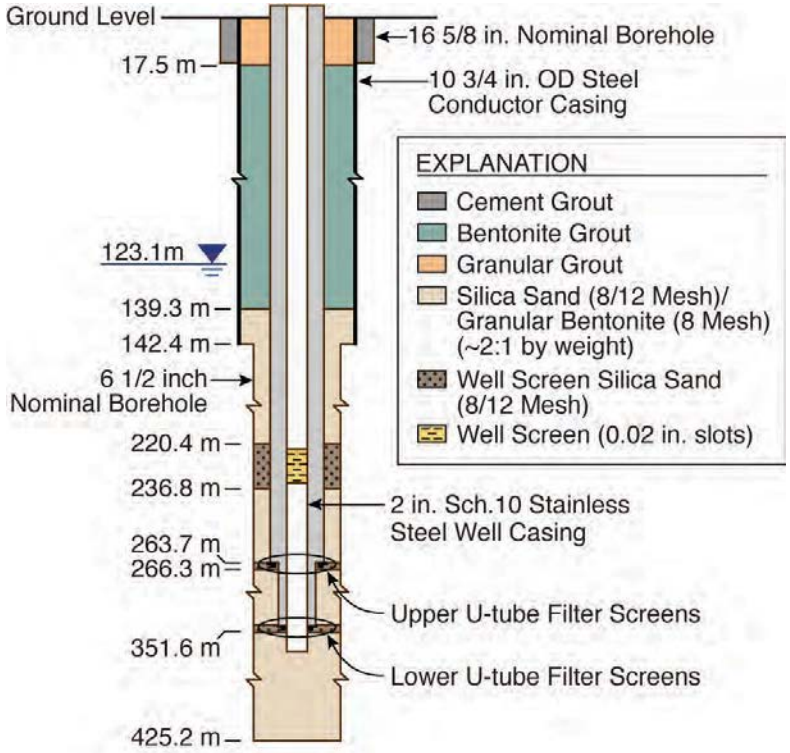
Swab #2 = 5130-45 ft

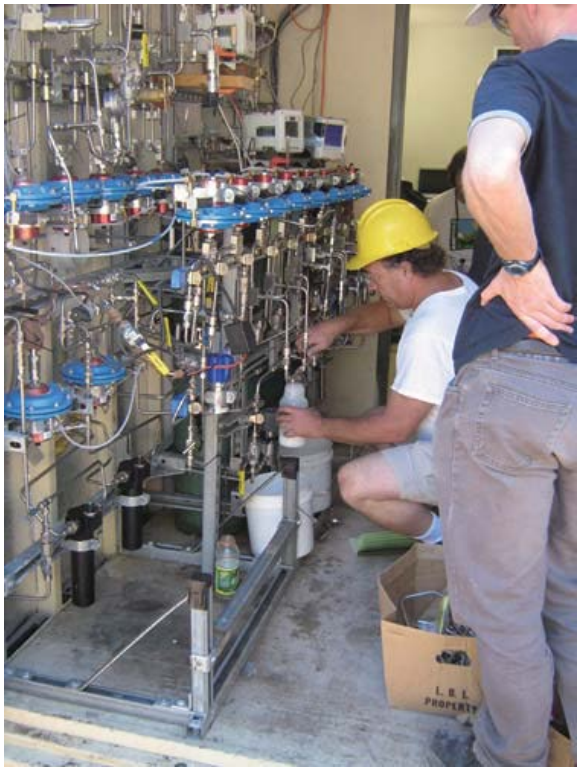
Corresponding to DST #1 in #1-28

5143.4; 5128; 5Y 4/1; olive gray; <u>sandstone with micritic dolomite matrix; frosted grains</u>; medium grade; rounded; increasing amounts of dolomite mud towards the top; bivalves; bioturbated; sm-scale mottling; scattered black lithoclasts; <u>patchy vugs filled with pink dolomite; porous towards the bottom couple feet</u>; gradational contact

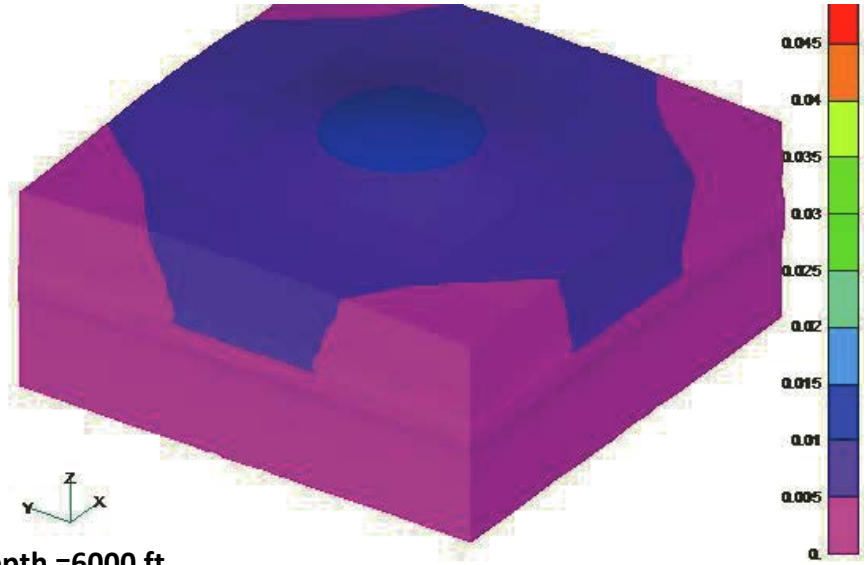
U-Tube In Situ Sampling of CO2 Plume

- Handling of multiphase fluid collected at high frequency



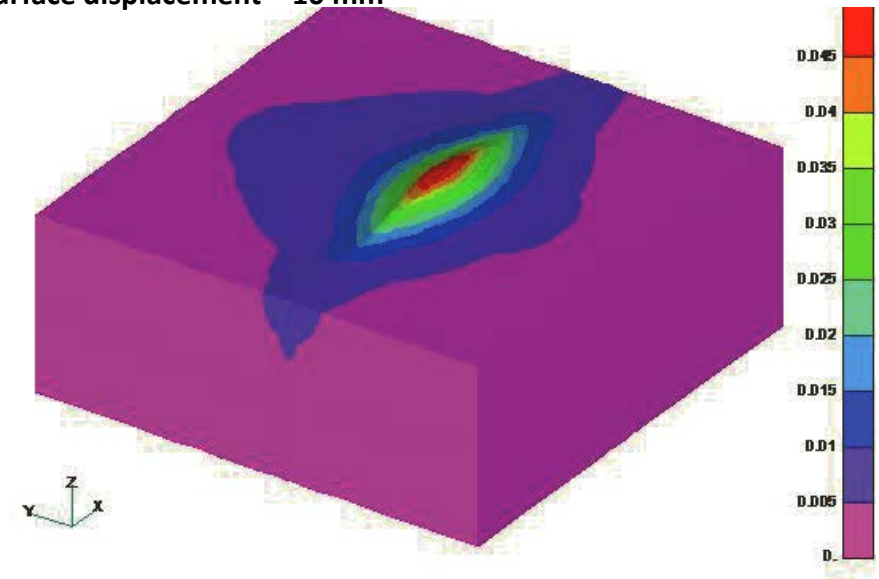


LiDAR and InSAR



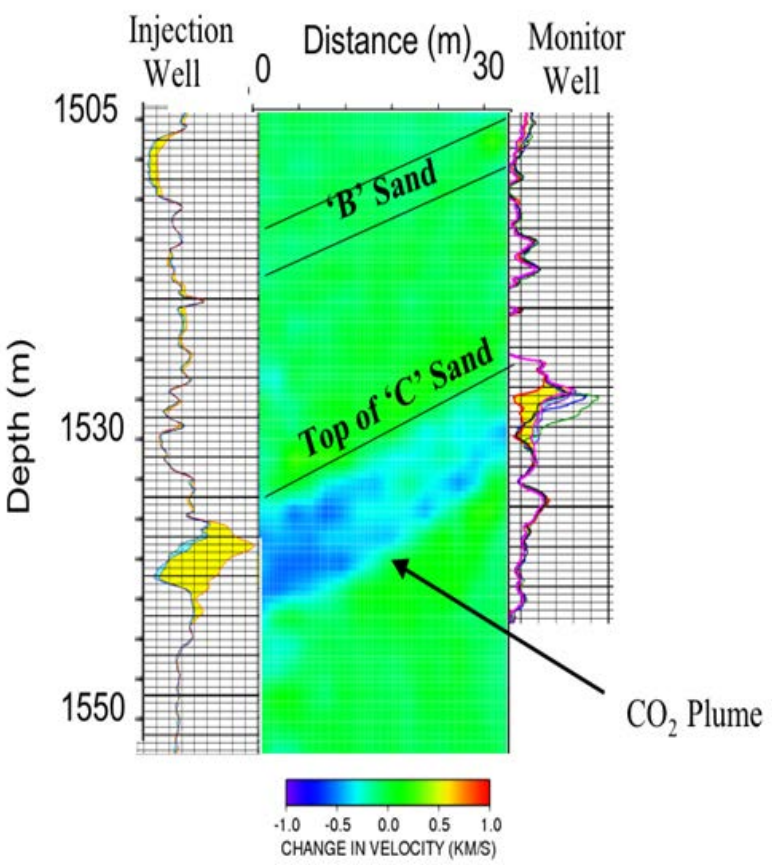
Simulated vertical displacement (in meter) after 3 years of CO2 injection (top) without and (below) with a permeable fault intersecting the caprock.

- **Injection depth =6000 ft**
- **Injection interval = 60 ft thick**
- **Max pressure ~10 Pa above ambient**
- **Injection rate = 1 MM tons per year**
- **Observed surface displacement = 10 mm**

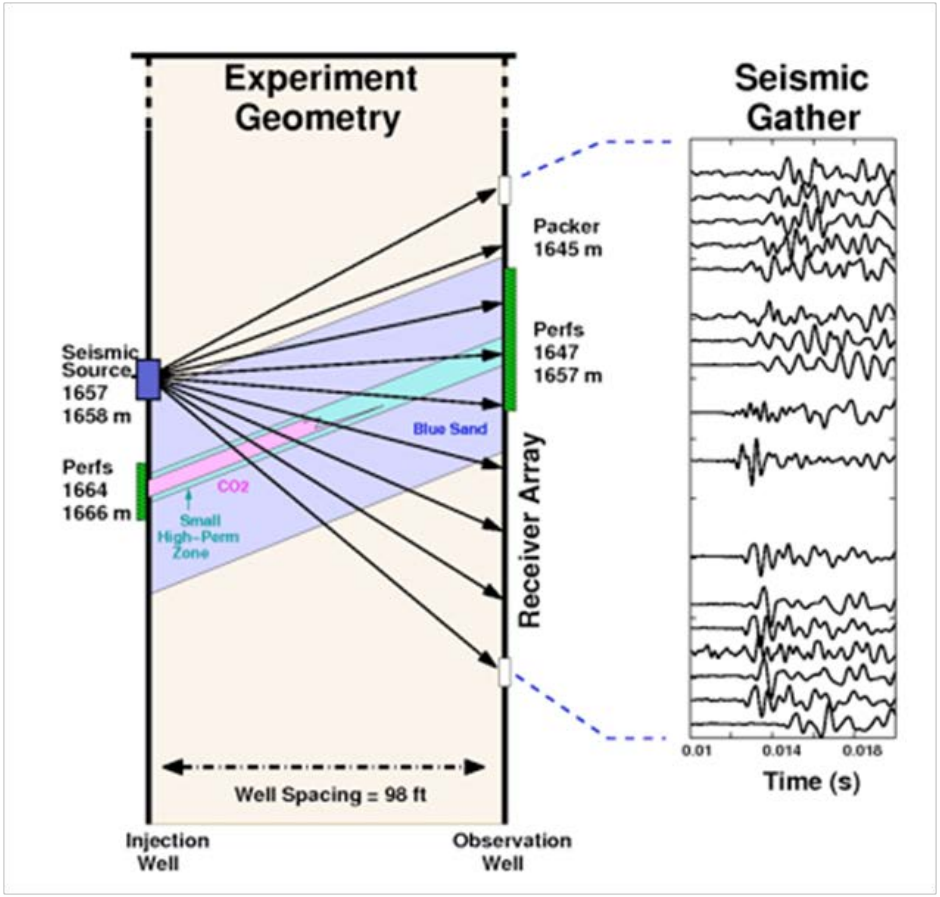


Coupled reservoir-geomechanical analysis of CO2 injection at
In Salah, Algeria
Rutqvista, Vascoa, Myera
(2009)

Seismic Tomography & CASSM
In situ CO2 plume movement to validate simulation



Detailed view of the injector region of the P-wave tomogram along with repeating logging for between monitoring and injector well.



Schematic representation of CASSM survey (left) as deployed for the Frio-II experiment, along with example seismic gather (right). Daley et al. (2008)

Overview – CO_2 Projects in Kansas

- 1. **Southwest Kansas CO2-EOR Initiative Chester and Morrow Reservoirs -Western Annex to Regional CO_2 Sequestration Project**
  - *CO_2 EOR technical feasibility study –Chester IVF and Morrow*
  - *Five industry partners (operators of fields)*
  - *Part of larger KGS-industry CCS and EOR study*
  - *Will not inject CO_2 –paper study only*
  - *Get fields in study "CO_2-ready"*
- **2. Evaluating CO_2 sequestration capacity of the deep saline Arbuckle aquifer and CO_2-EOR potential in the Mississippian (Osage) chert/dolomite reservoir – regionally and Wellington Field, Sumner County, Kansas**
  - *Two basement tests drilled in January-February 2011, including a 1638 ft core from the Pennsylvanian Cherokee Group through the 1000 ft Arbuckle Group.*
  - *Original grant from DOE/NETL -- FE0002056 supported by cost-sharing partners, including **Berexco et al.***

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Overview – CO_2 Projects in Kansas

- **3. Small-scale field test demonstrating CO_2 sequestration in Arbuckle saline aquifer and by CO_2-EOR at Wellington field, Sumner County, Kansas**
  - *Current budget negotiations through end of September, scheduled for October 2011 start* -- Funding Opportunity Number: DE-FOA-000441
  - *Small volume injection into Arbuckle saline aquifer and Mississippian (Osage) chert oil reservoir at Wellington Field not scheduled until mid 2013*
  - *CO_2 injection in saline aquifer accompanied by best practice monitoring methods*
- **4. Bemis-Shutts, Ellis County, KS –Horizontal well scheduled for November 2011 in the Arbuckle reservoir**
  - *Evaluate effectiveness of seismic attributes, namely volumetric curvature, to identify the presence, extent, and impact of paleokarst heterogeneity on CO_2 saline aquifer sequestration and oil production.*
  - *Funded by the U.S. Department of Energy under grant DE-FE0004566 and cost-sharing by its **industry partners -Vess, Murfin***
  - *Drill horizontal well in October-November 2011 framework*

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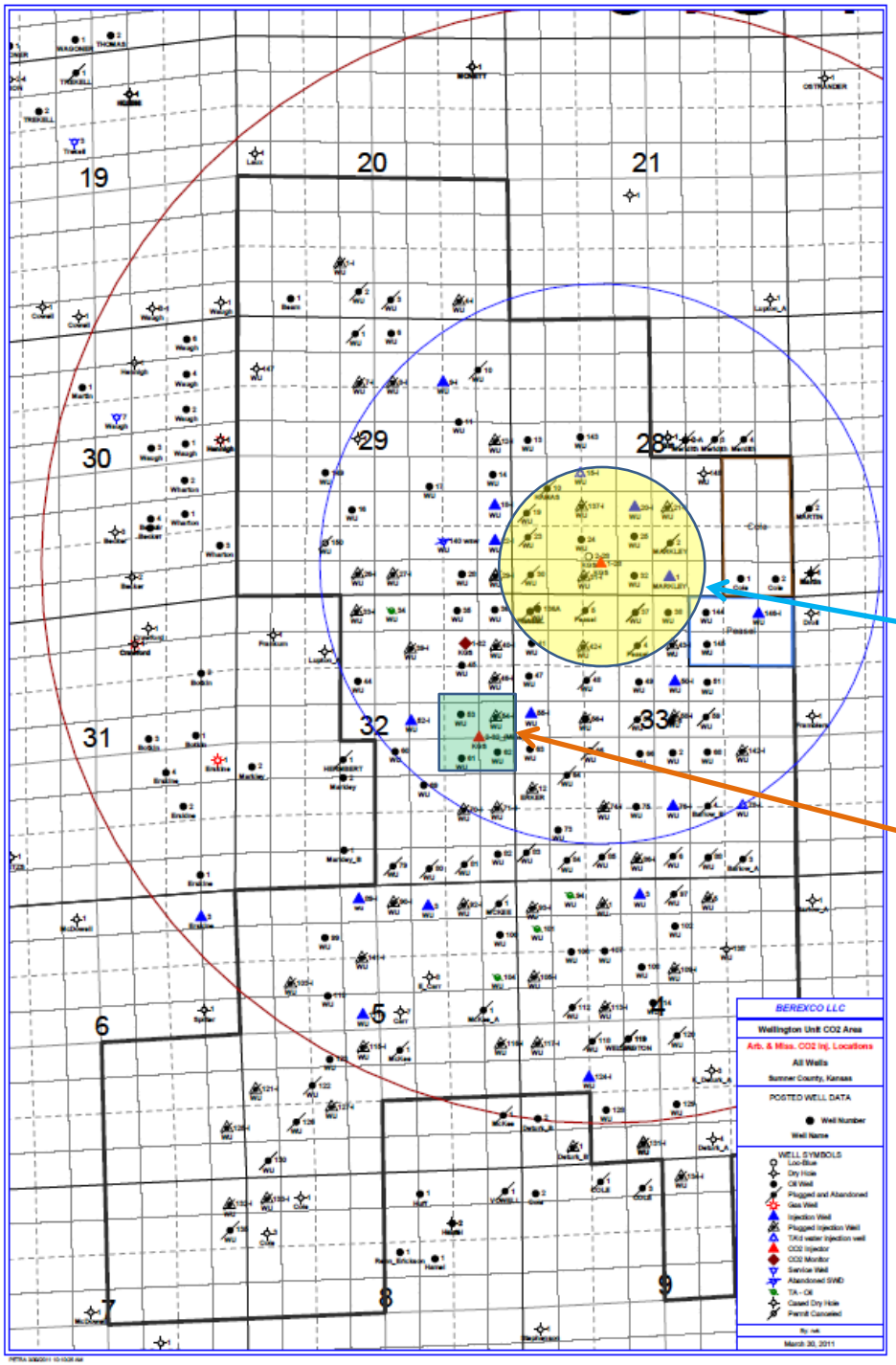

Map showing boreholes that penetrate the Mississippian oil reservoir in Wellington Field

- Location of Mississippian boreholes to be monitored during and after CO_2 injection into the Arbuckle

- Location of Mississippian injection borehole and 5-spot pattern of producing boreholes

1 mile