SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS

Project Number DE-FE0006821

W. Lynn Watney
Kansas Geological Survey
Lawrence, KS

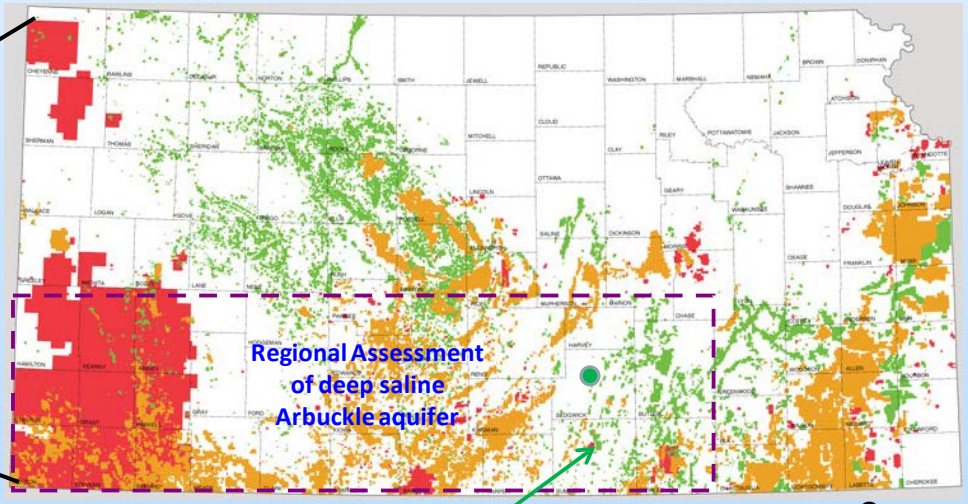
U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
August 21-23, 2012

Fountainview
Wednesday 8-21-12
1:10-1:35

KANSAS GEOLOGICAL SURVEY
The University of Kansas

Presentation Outline

- Benefits to the Program
- Project Overview
- Technical Status
- Accomplishments to Date
- Summary



Acknowledgements & Disclaimer

Acknowledgements

- *The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant DE-FE0002056 and DE-FE0006821, W.L. Watney and Jason Rush, Joint PIs. Project is managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners, Brian Dressel, Program Manager.*

Project Team

DOE-NETL Contract #FE0006821

KANSAS GEOLOGICAL SURVEY
The University of Kansas

L. Watney (Joint PI), J. Rush (Joint PI), J. Doveton, E. Holubnyak, M. Fazelalavi, R. Miller, D. Newell

TBirdie Consulting, Inc
4705 McCormick Street • Lawrence • KS 66047 • 785 843 1085 • 785 865 0678 (fax) • tbirdie@sunflower.com

T. Birdie

NETL

Brian Dressel, P.M.

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

Tom Daley, Barry Freifeld

BEREXCO

Dana Wreath, Adam Beren

DEPARTMENT OF GEOLOGY

KANSAS STATE UNIVERSITY

Saugata Datta

Chris Standlee, Danny Allison, Tim Frazer

KU THE UNIVERSITY OF KANSAS Department of Geology

Mike Taylor, Ross Black, George Tsoflias

Sandia Technologies, LLC

Dan Collins, David Freeman

Benefits to the Program

- **Program goals being addressed –**
  - Develop and test technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.
  - Conduct field tests to support site selection, characterization, site operations, and closure practices.
- **Project benefits of this small scale field test:**
  - Advance the science and practice of carbon sequestration in the Midcontinent
  - Evaluate best practices for MVA tailored to the geologic setting
  - Optimize methods for remediation and risk management
  - Provide technical information to local petroleum industry for implementation of CCUS
  - Enable additional projects and facilitate discussions on regulations and policy

Project Overview
Goals and Objectives

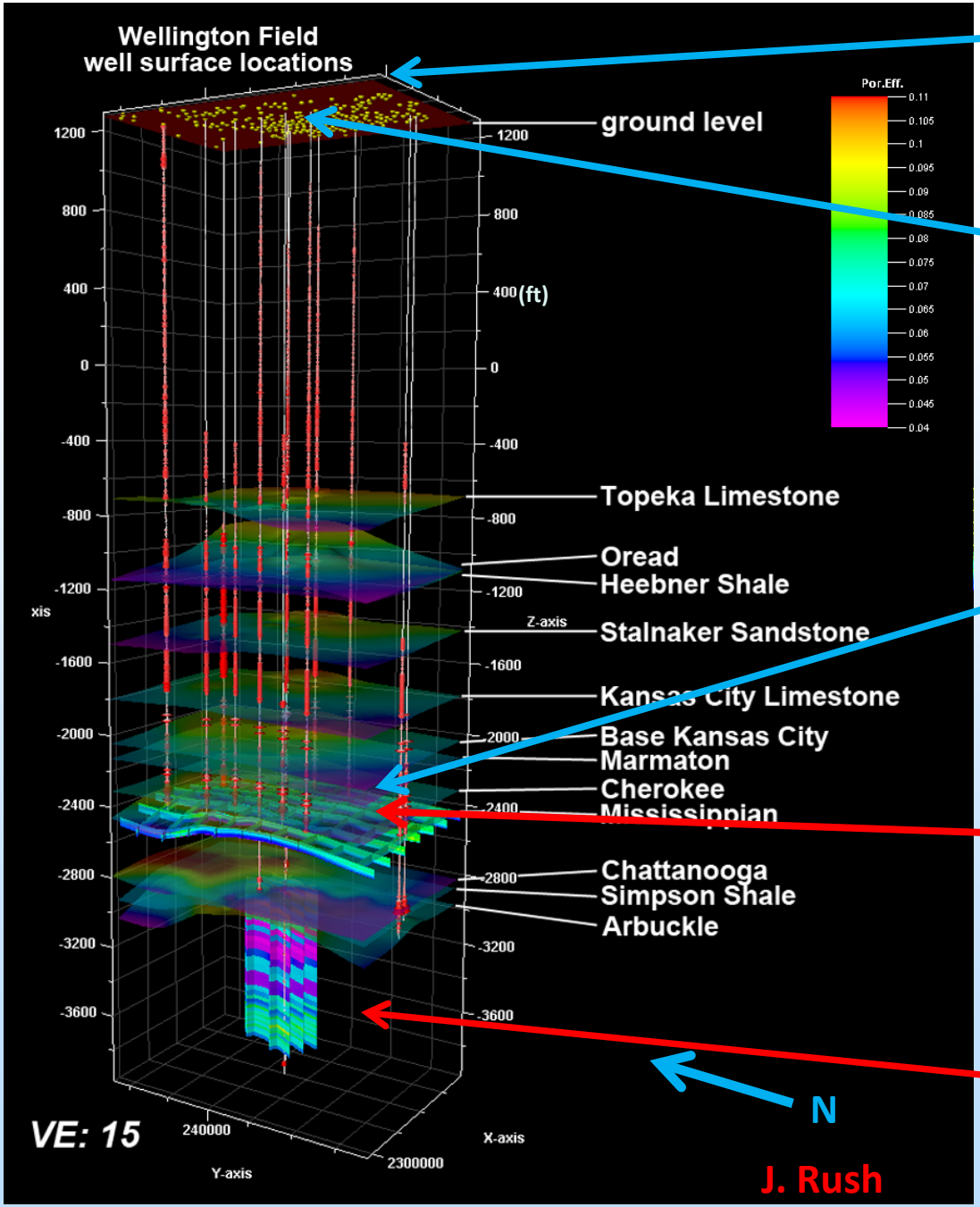
1. Install CO_2 capture facilities at the Abengoa Biofuels Colwich KS ethanol plant
2. Inject 30,000 metric tons of CO_2 into Mississippian oil reservoir
3. Demonstrate state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques
4. Develop a robust geomodel and conduct reservoir simulation studies
5. Integrate MVA data and analysis with reservoir modeling studies to demonstrate and insure 99% CO_2 storage permanence
6. *Pending approval of Class VI injection application* -- Inject under super-critical conditions approximately 40,000 metric tons of CO_2 into the Arbuckle saline aquifer

Technical Status

-- *Focus of Effort*

- ****GO/NO-GO DECISION POINT** to obtain Class VI injection permit**
  - Submit a successful application for Class VI permit to EPA
    - Provide precise answers, minimize assumptions, reduce uncertainty, provide financial assurance, argue for flexibility on closure, address seismicity
    - <u>September 2012 submittal</u>
- Petrel model and coupled geomechanical-flow modeling of Wellington for CO_2-EOR (CCUS) in 20 million barrel oil reservoir

Finalize static & dynamic model for Class VI



- InSAR/LiDAR CGPS surface deformation/IRIS seismometers
- Measure soil gas flux and chemistry through series of shallow probes.

- Monitor for tracers, CO_2, inorganics and organics in 12 shallow freshwater wells (in two nests of 6 wells)
- Monitor two deeper wells ~600 ft deep below shallow evaporite cap rock

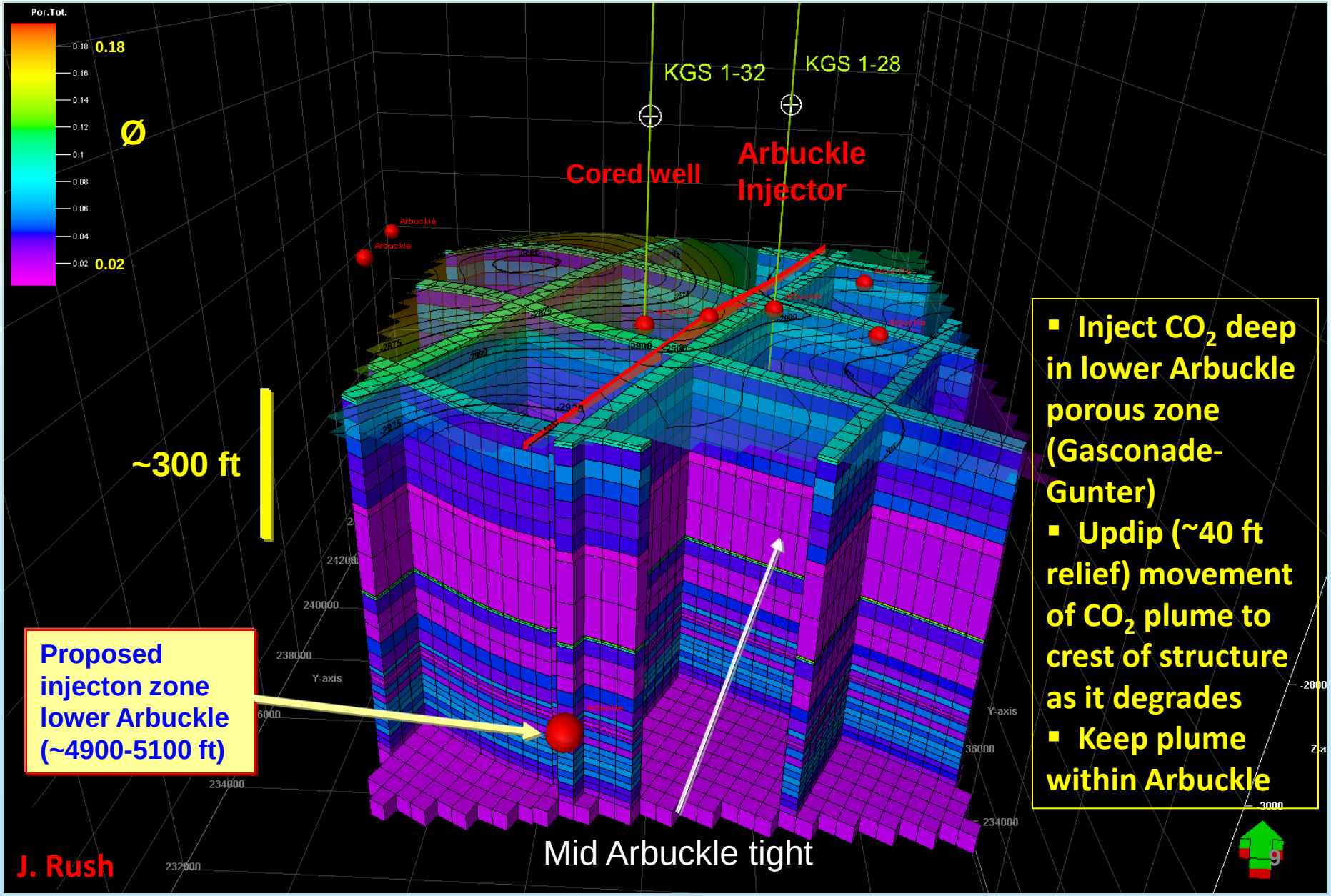
- Measure for tracers and CO_2 casing head gas and fluid samples from Mississippian wells (if positive, run 2D seismic)
(*Underpressured oil reservoir should trap any vertically migrating CO2*)

Inject 30,000 tonnes of CO_2 into Mississippian oil reservoir to demonstrate CO2-EOR and 99% assurance of storage with MVA

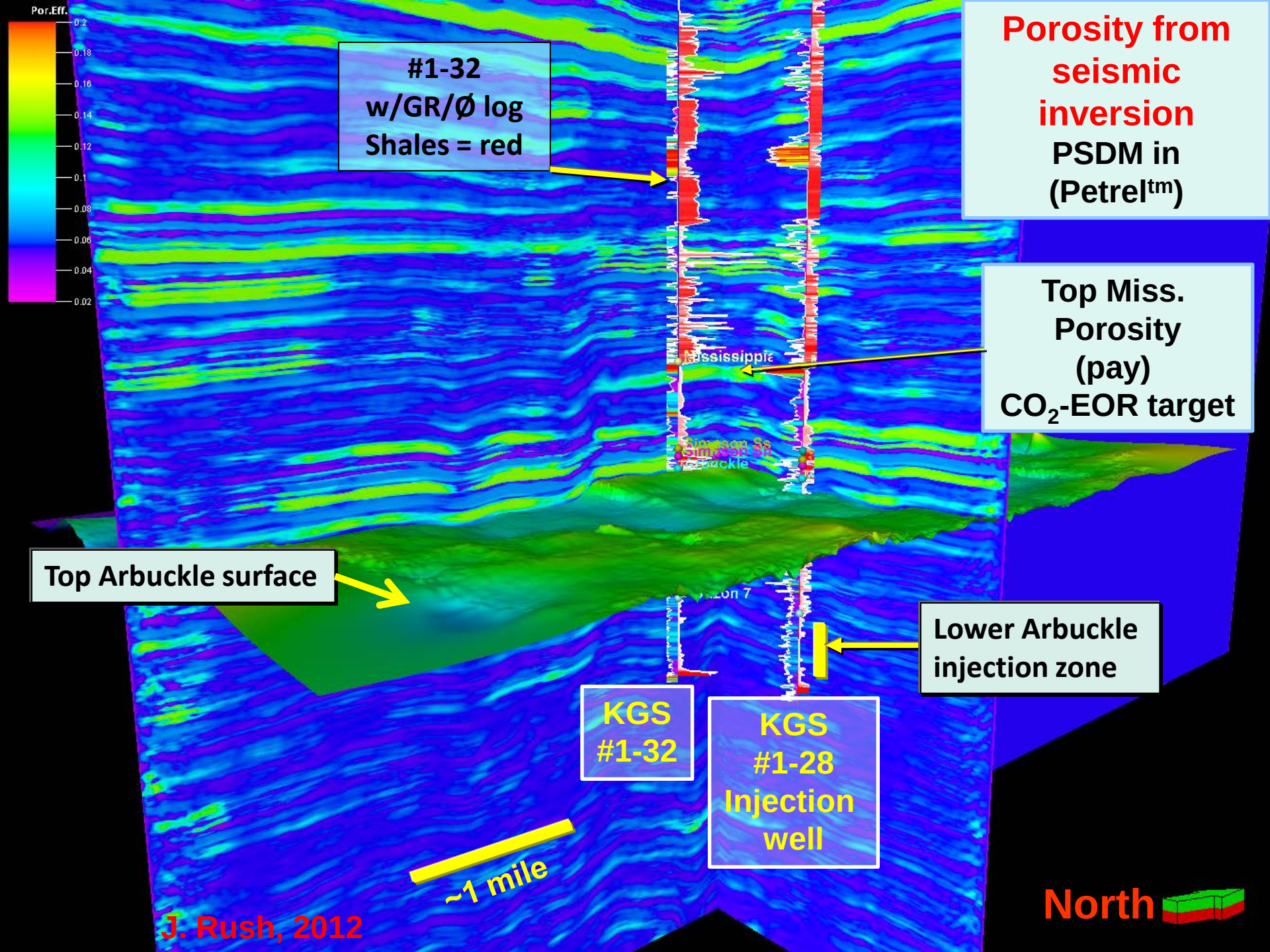
Pending Class VI permit and DOE funding -- Inject 40,000 tonnes of CO_2 with SF6 and krypton tracers into lower Arbuckle saline aquifer and seismically image and sample in situ CO_2 plume development to verify geomodel and simulations

Petrel^{tm} geomodel of Arbuckle

(porosity & structure)



- Inject CO_2 deep in lower Arbuckle porous zone (Gasconade-Gunter)
- Updip (~40 ft relief) movement of CO_2 plume to crest of structure as it degrades
- Keep plume within Arbuckle


Por.Eff.
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
#1-32
w/GR/Ø log
Shales = red
Porosity from seismic inversion
PSDM in (Petrel™)
Top Miss. Porosity (pay)
CO2-EOR target
Mississippi
Top Arbuckle surface
Lower Arbuckle injection zone
KGS #1-32
KGS #1-28 Injection well
~1 mile
North
J. Rush, 2012

Technical Status

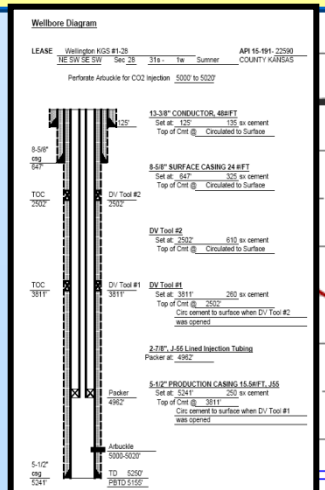
Class VI Geosequestration Injection Permit

- **Submittal of Class VI application**:
  - September 2012
- **Static and coupled dynamic modeling of saline aquifer** for 40 kton CO_2 injection (supported by DE-FE0002056)
- **Injection zone** –
  - Highly permeable lower Arbuckle (100s of md to ~1 D, ~200 ft thick)
  - Multiple flow units to decrease thickness of single phase buoyant supercritical CO_2 plume
- **Baffle and trapping of CO_2 plume** –
  - Plume likely accumulate under low pressure only below and within ~400 ft thick middle Arbuckle (lower Jeff-City Cotter & Roubidoux)
  - Pressure and plume behavior within lower Arbuckle (Gasconade to Gunter Ss.) – very low risk for caprock and movement into nearest deep wells
- **Primary caprock interval** – ~230 ft gross thickness including Lower Mississippian argillaceous siltstone, Chattanooga and Simpson shales
- **USDW and interaction with subsurface brines** –
  - Marginal surface aquifer, its potentiometric surface ~500 ft above that of saline aquifer
  - Multiple secondary caprock/seals – 1000's feet of shale, and 200 ft shallow evaporites

Boreholes penetrating the Arbuckle saline aquifer in Wellington Field

<u>Berexco, LLC has</u>:

- Purchased pore space
- Insured activity
- #1-28 well completion in compliance with EPA specs
- Disposal fee of CO2 as part of cost share

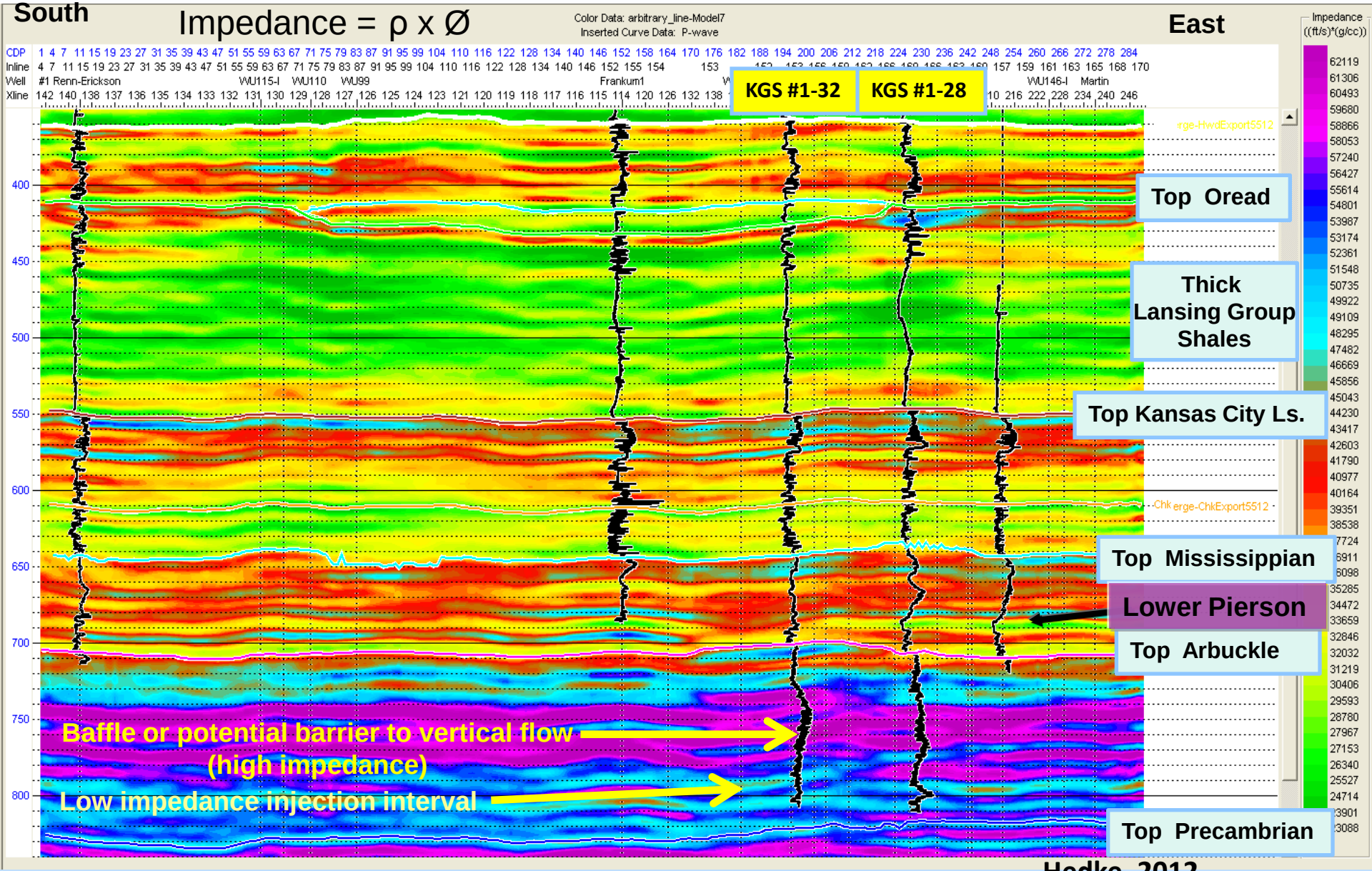


- Proposed monitoring borehole (#2-28) within 600 ft of the existing #1-28 CO_2 injector into Arbuckle
- Yellow dot – modeled maximum size of CO_2 plume, ~600 ft radius
- Orange circle – extent of pressure field, 1800 radius, 125 psi

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

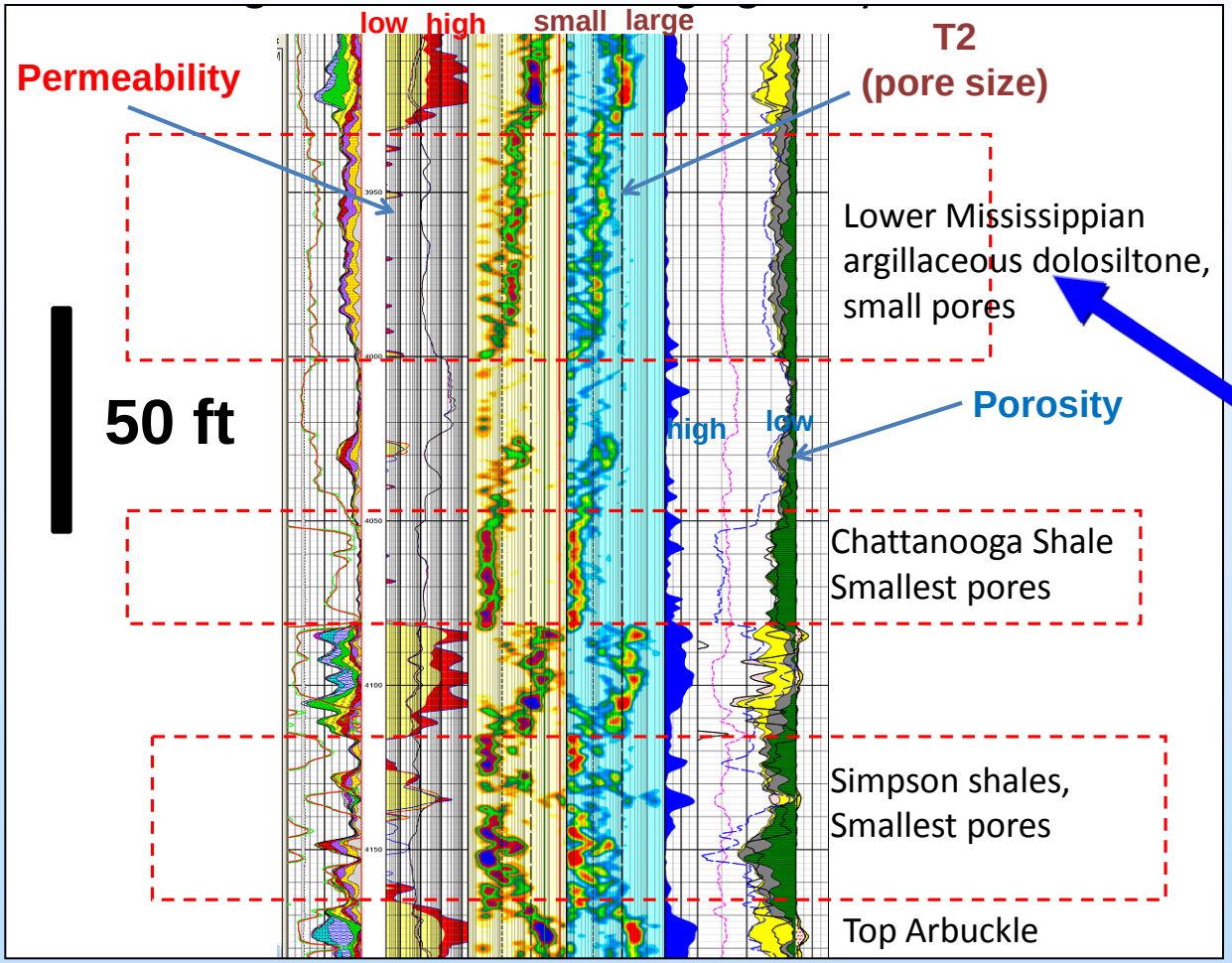
Arbitrary seismic impedance profile

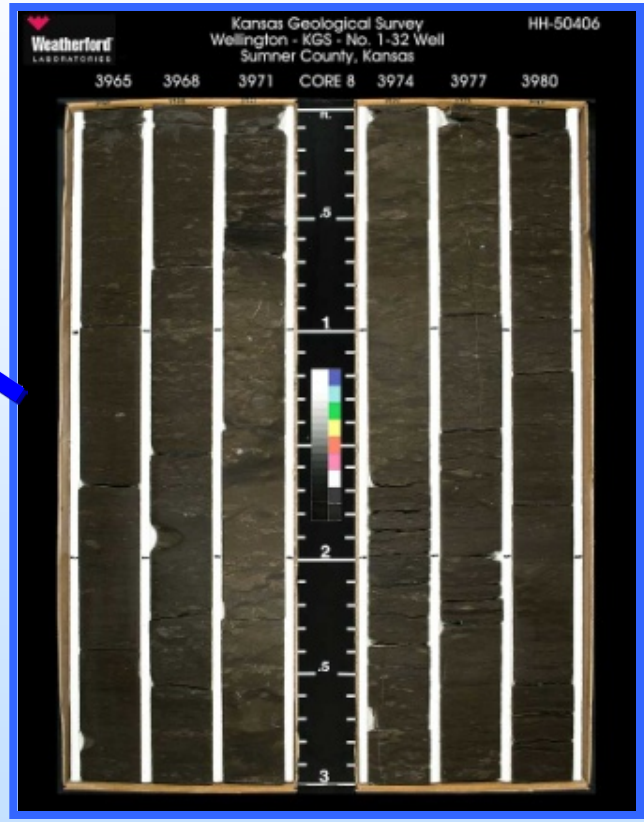
distinct caprock, mid-Arbuckle tight, lower Arbuckle injection zone



Hedke, 2012

230 ft gross thickness interval of primary caprock in KGS #1-28 (injection well) – illustrated by nuclear magnetic resonance log





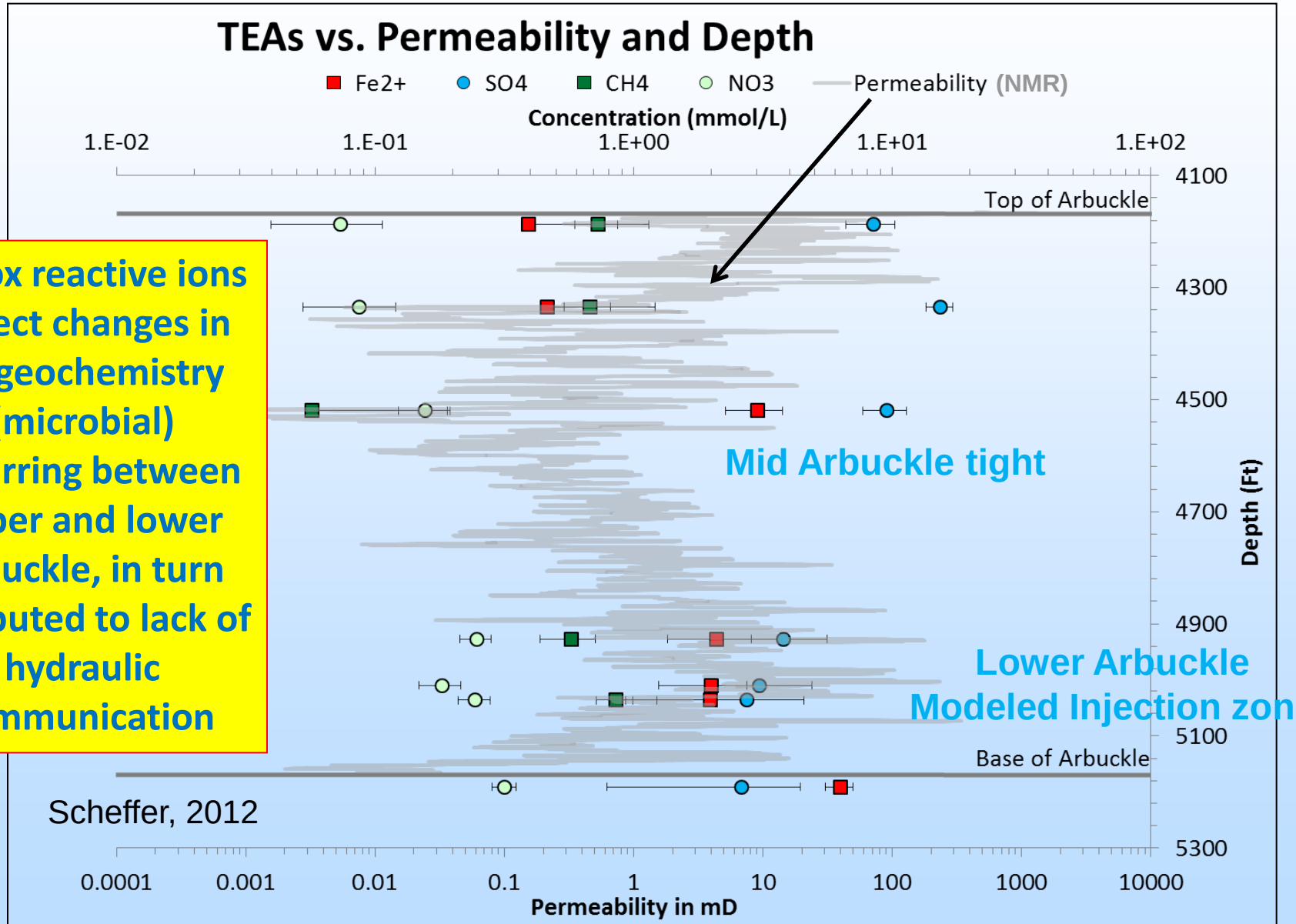
Caprock evidence:

- Micro-nano darcy perm
- Quiet fracture wise
- Organic matter 1%

KANSAS GEOLOGICAL SURVEY
The University of Kansas

Permeability profile of Arbuckle in cored well - #1-32

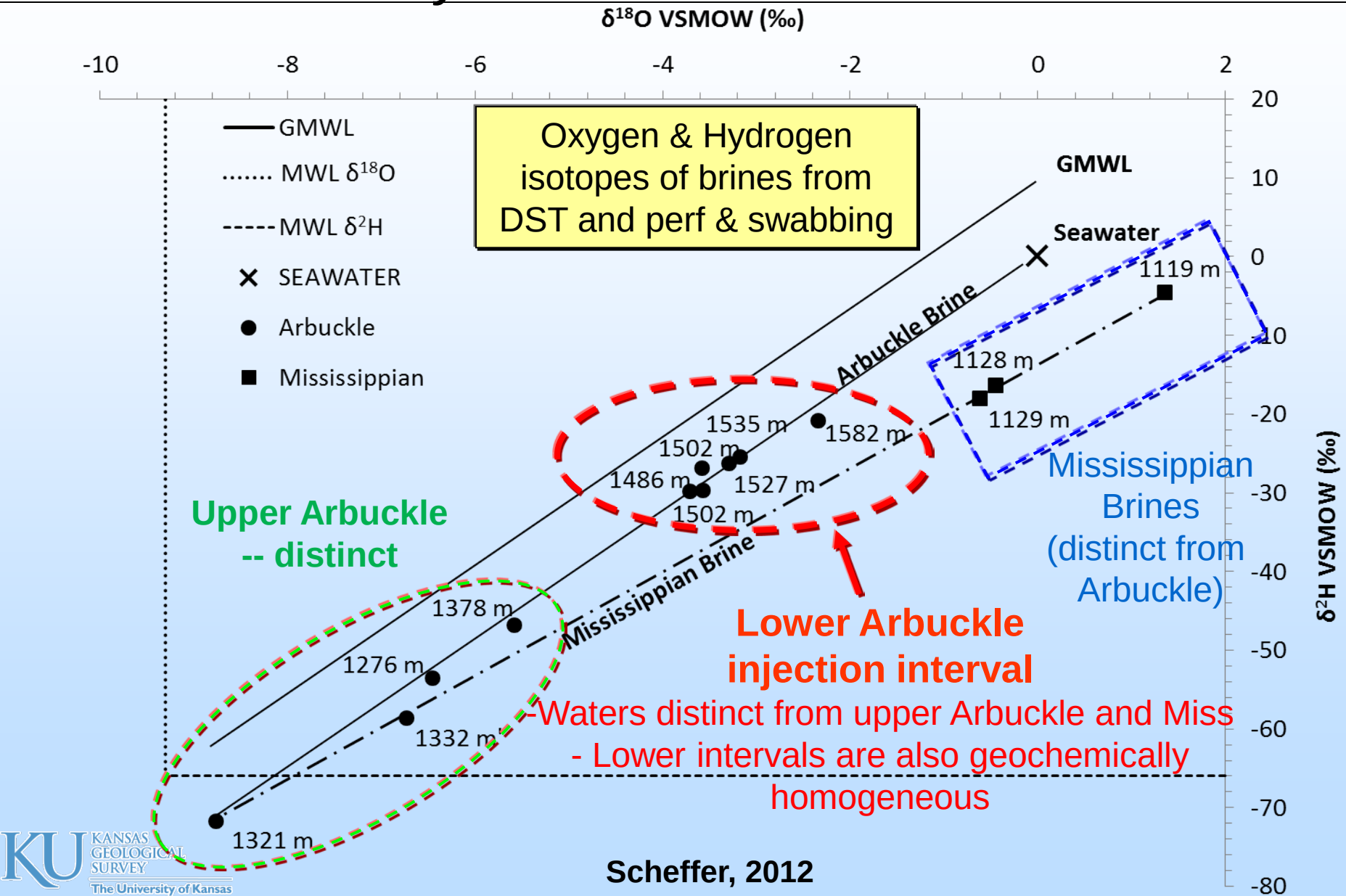
with concentrations of redox reactive ions (Fe^{2+}, SO_4^{2-}, CH_4, NO_3^-) from KGS #1-32 & #1-28



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

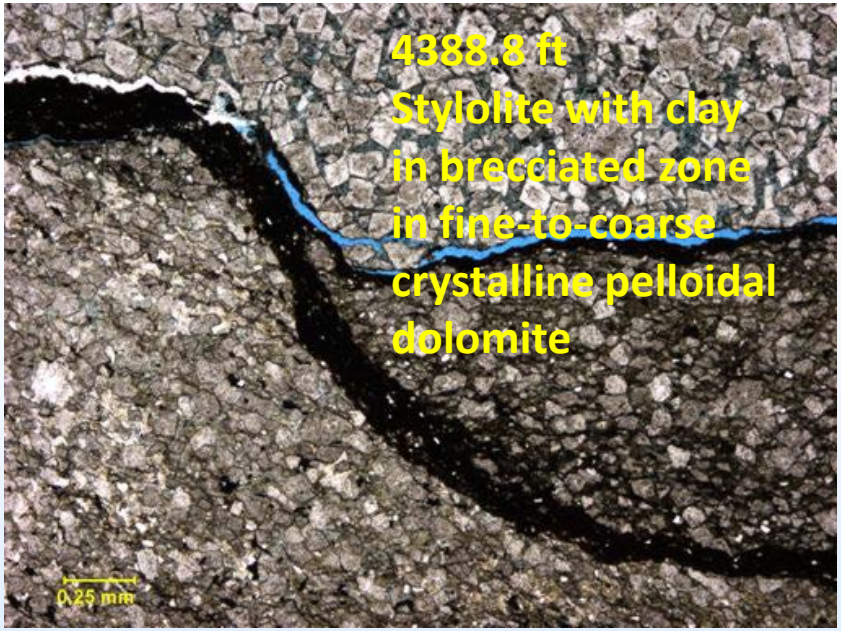
Scheffer, 2012

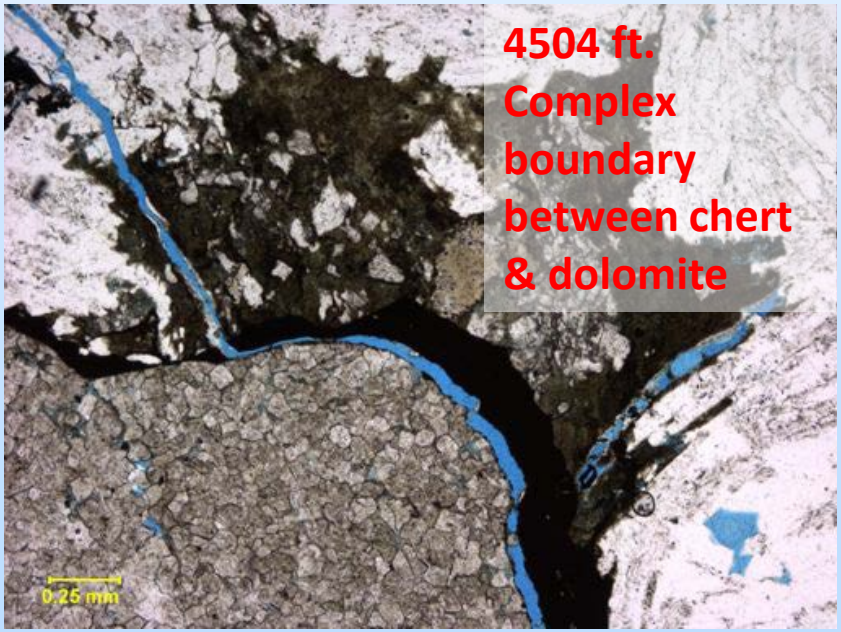
Lower and upper Arbuckle are not in hydraulic communication

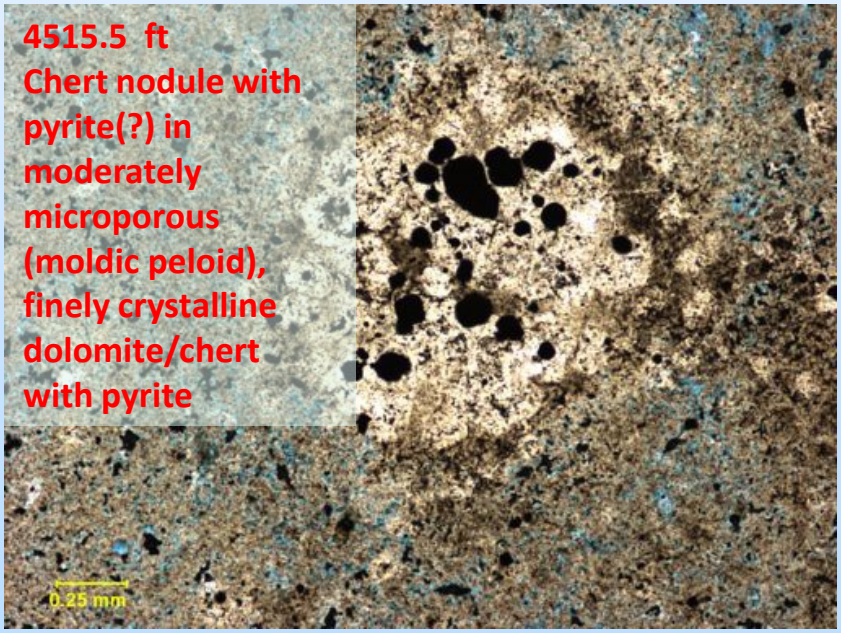


Rock fabrics in “baffle” interval of middle Arbuckle -- *Thin section photomicrographs*

Anticipated reaction of CO_2 with - 1) argillaceous and sulfide/oxide material in the fracture pores, 2) reaction rims and microporosity in chert & dolomite and increased surface area along pore systems



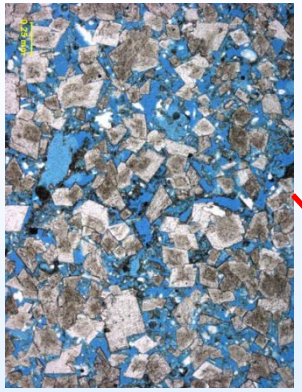


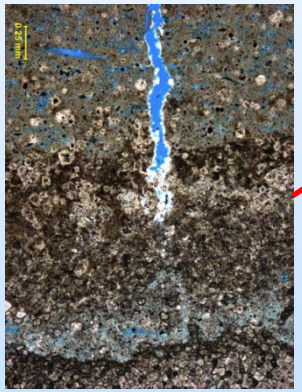


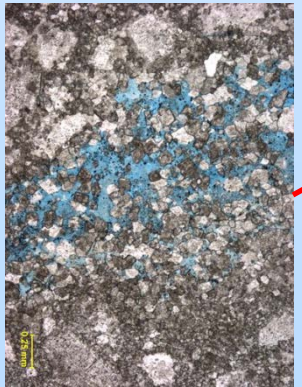
Barker et al. (2012)

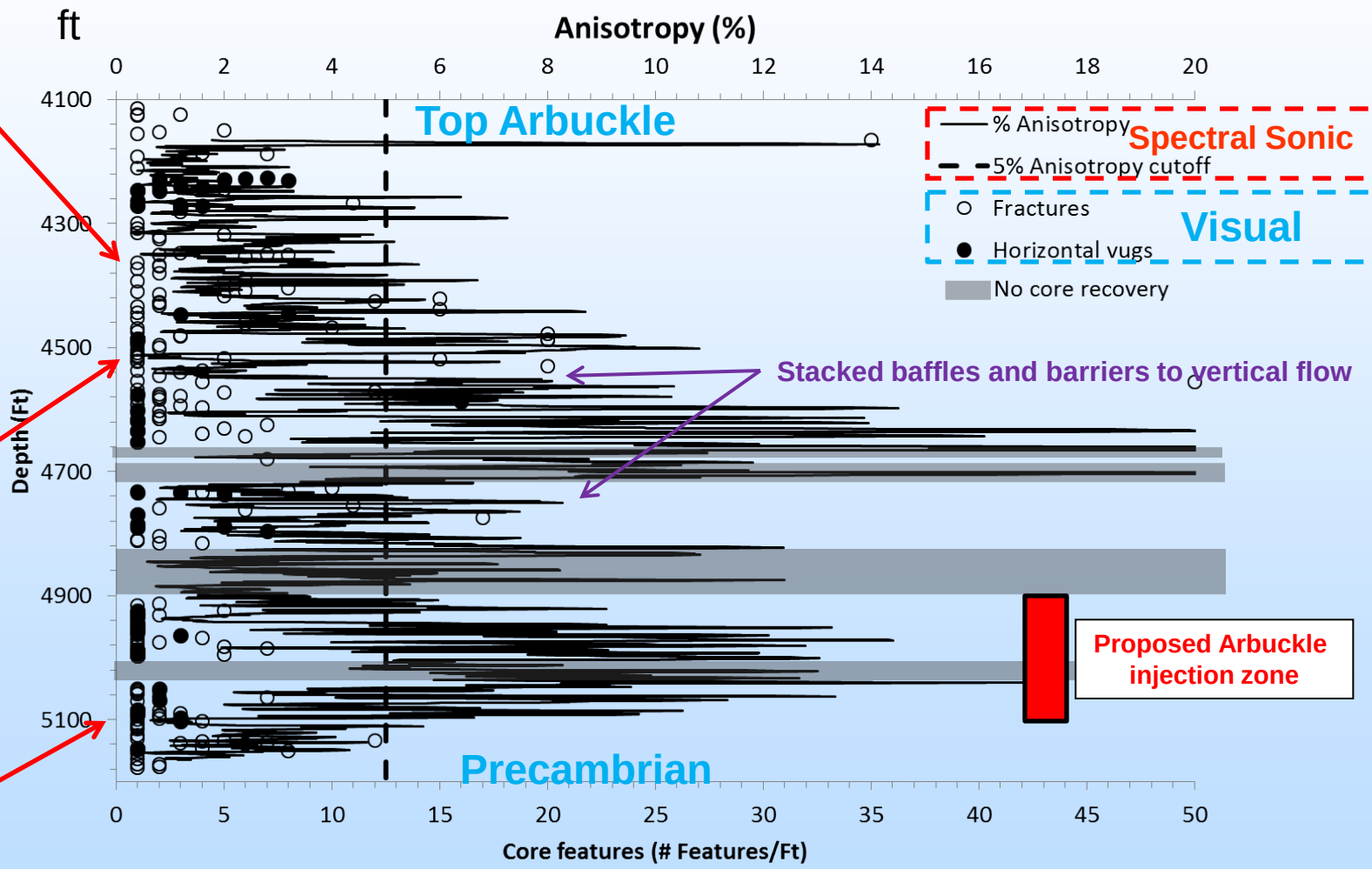
Zonal fracturing in Arbuckle

Spectral acoustic log, core, microresistivity imaging







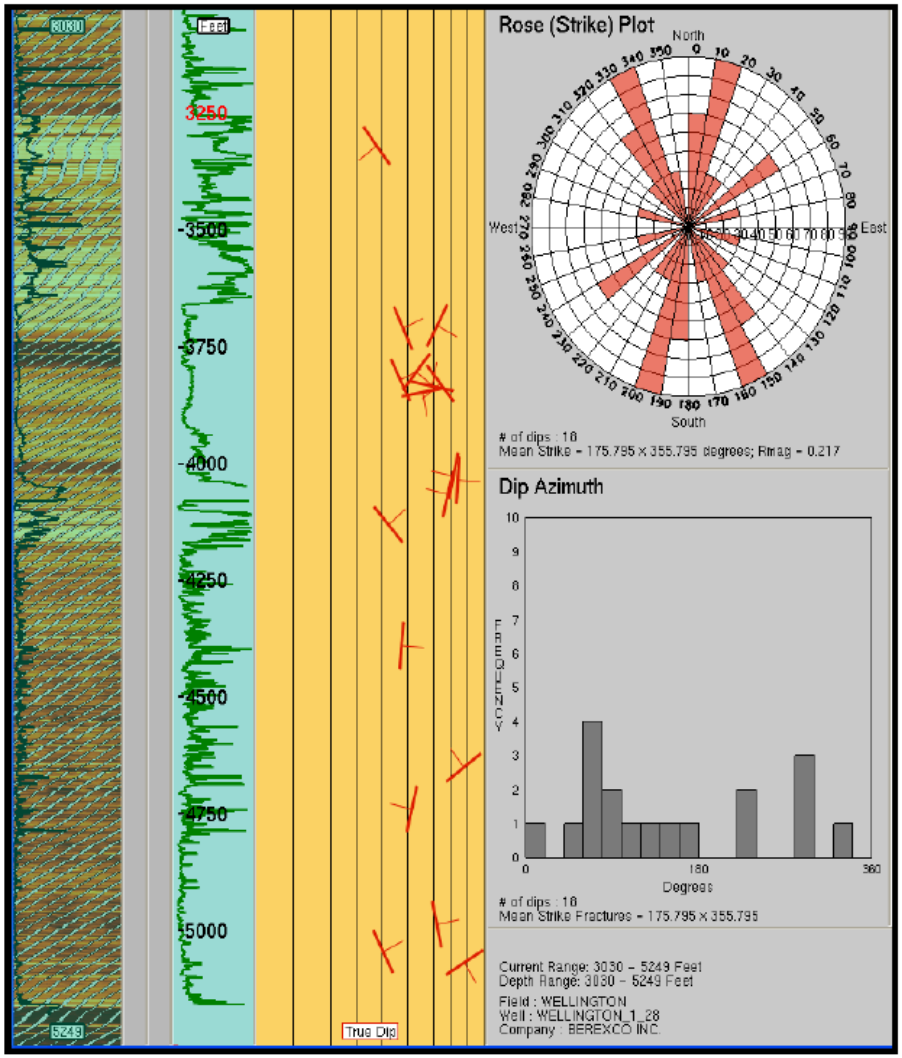


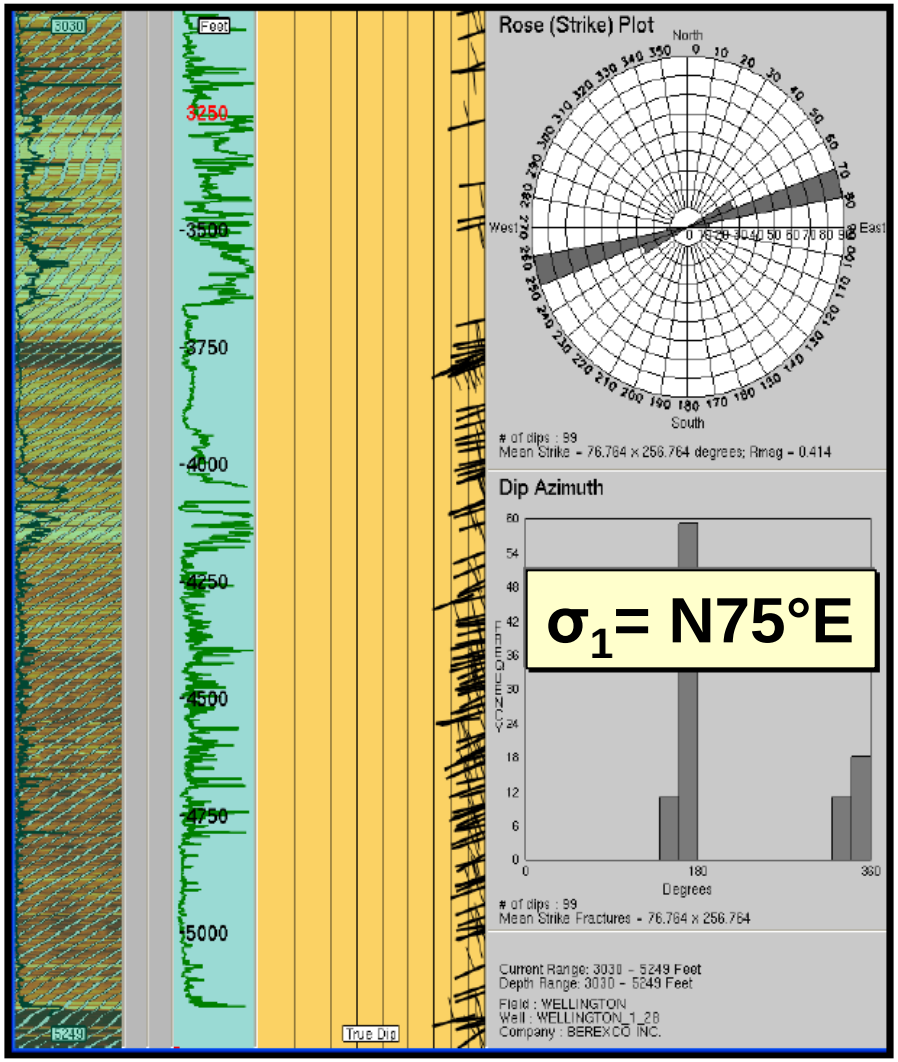
KU KANSAS GEOLOGICAL SURVEY The University of Kansas

Scheffer, 2012; Lorenz and Cooper, 2011

Fracture Statistics: 5249'-3030'

Wellington KGS #1-28



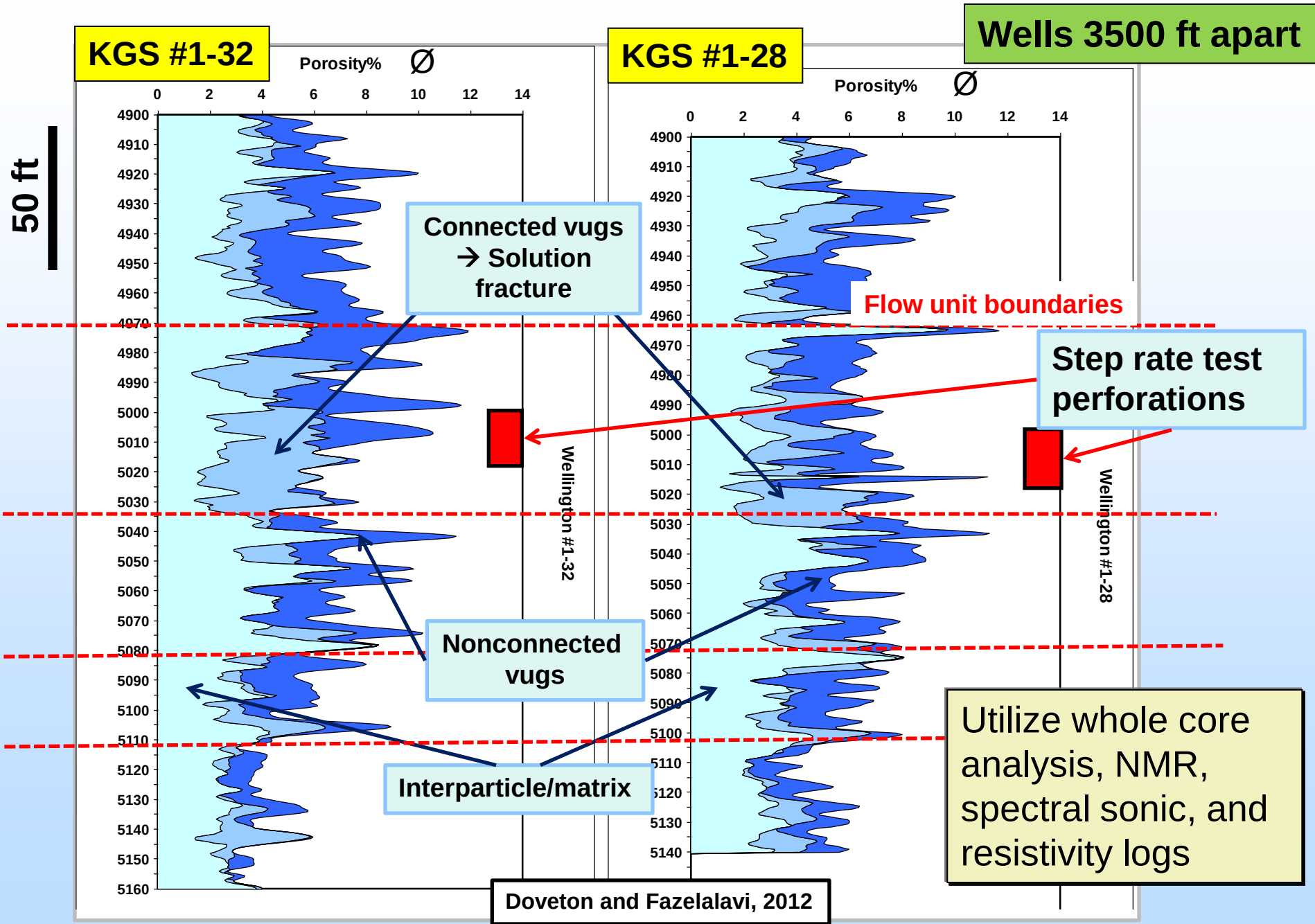


There are 18 natural mineralized "closed" fractures in this pass with two orientations, the first is NNE x SSW and the other is NNW x SSE.

There are 99 drilling induced fractures in this pass, oriented 76°/256°, indicating the maximum stress direction.

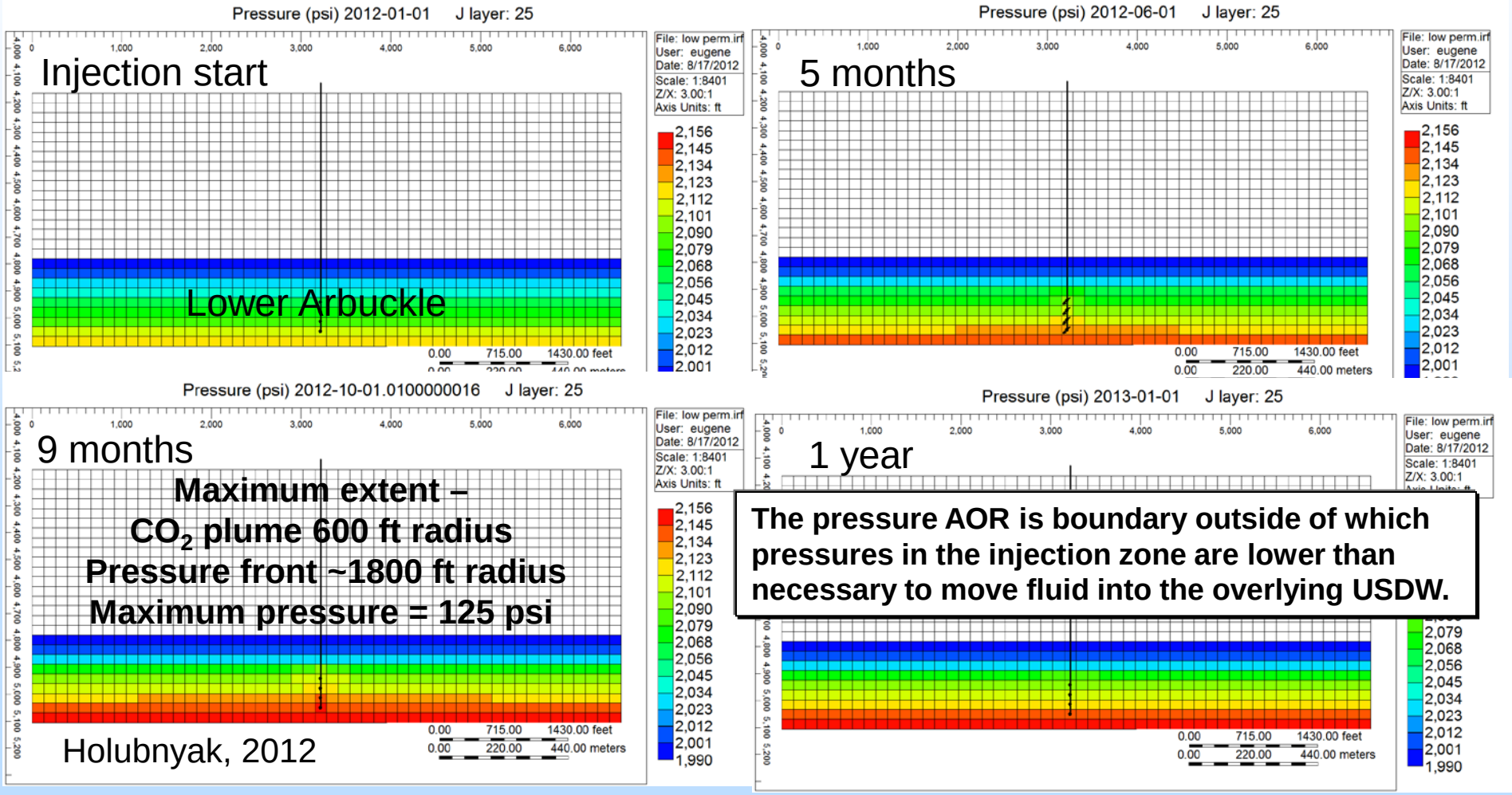
HALLIBURTON

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



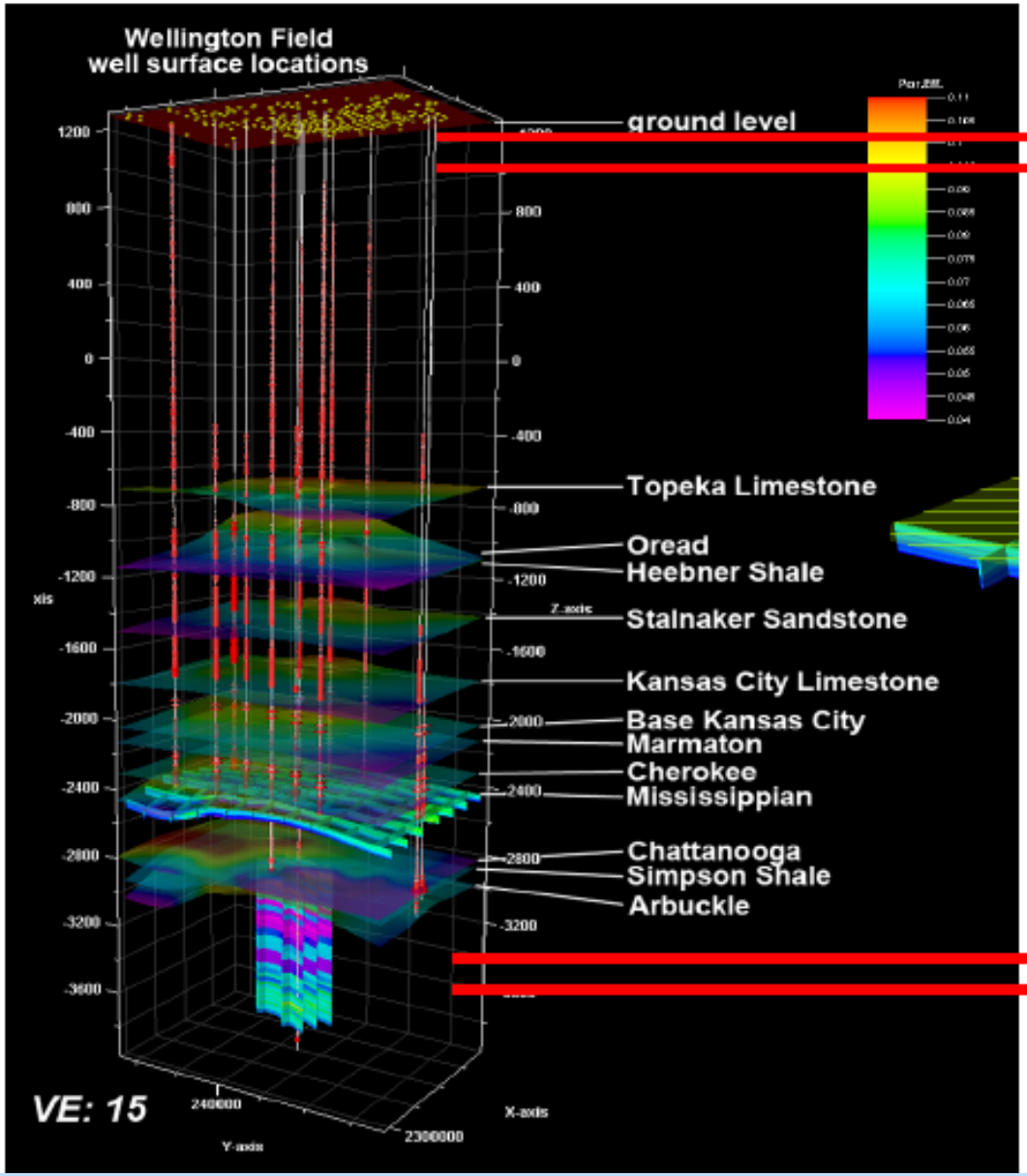
Simulated Pressure Profile around KGS #1-28

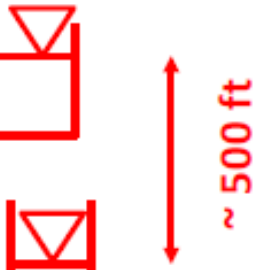
9 Months, 40 kt CO_2 injection scenario
– Low permeability case, (100-500 md), dual Ø
Elevated pressure limited to lower Arbuckle injection zone



The pressure AOR is boundary outside of which pressures in the injection zone are lower than necessary to move fluid into the overlying USDW.

Head Difference Between Arbuckle and USDW



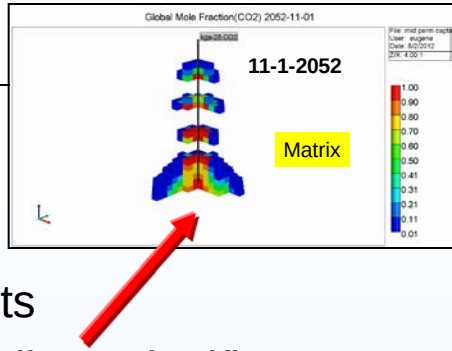


- **No natural connection between USDW and underlying Paleozoic strata**
- **Potentiometric surface of Arbuckle ~500 ft below USDW**
- **Maximum injection pressure = 125 psi within 1st month of injection**
- **Pressure front 1800 ft radius from injector**
- **Pressure well below parting or fracture pressure of caprock**
- **Regional study has established that Arbuckle is an open system**

Accomplishments to Date

- Robust characterization for injection and caprocks nearly complete
- Near completion of application for Class VI Injection Permit
- Latest modeling results for Class VI application
  - Excellent transmissibility in lower Arbuckle saline aquifer even if the lowest estimate for permeability is considered *(step rate test, DST, NMR, core, all backup assessment, seismic supports)*
  - More then adequate space for CO_2 storage in lower Arbuckle saline aquifer, commercial scale?
  - Modeling predicts that most (up to 99% max) of the injected CO_2 will be dissolved in brine
  - Viable option to decrease the injection time – very conservative small-scale field test
  - Developed highly constrained analysis to complete the Class VI that has instilled confidence of the multidisciplinary team in its viability
  - Small scale test is next step to validate model, demonstrate MVA technologies, as next step to cost-effective commercial scale sequestration

Summary



Key Findings

– Suitable injection zones, caprock, and isolation from USDW
  - Arbuckle highly stratified three distinct hydrostratigraphic units
  - Even if mid-Arbuckle zone is considered as a permeable medium, significant amount of the CO_2 is predicted to be trapped in or near the injection zone due to decreased velocity of CO_2 travel through less permeable medium -- residual and solubility trapping
  - Pressure increase (125 psi) is insignificant and caprock/shales will not experience dangerous stress levels.

Lessons Learned

– Water geochemistry and biogeochemistry have proved extremely useful in evaluating interaction of hydrostratigraphic units

– Establishing magnitude and distribution of permeability in complex carbonate aquifer system requires multiple independent means to assess.

Future Plans

– Submit application for Class VI injection permit in September 2012

– New Petrel model for coupled geomechanical-flow modeling

– Commence field operations when ethanol plant resumes operations

Appendix

ORGANIZATION CHART

Kansas Geological Survey

Name	Project Job Title	Primary Responsibility
Lynn Watney	Project Leader, Joint Principal Investigator	Geology, information synthesis, point of contact
Tiraz Birdie	Consulting Engineer	Reservoir engineer, dynamic modeling, synthesis
Jason Rush	Joint Principal Investigator	Geology, static modeling, data integration, synthesis
John Doveton	Co-Principal Investigator	Log petrophysics, geostatistics
Dave Newell	Co-Principal Investigator	Fluid geochemistry
Rick Miller	Geophysicist	2D seismic aquire & interpretation
		LiDAR support, water well drilling/completion
TBN	Geology Technician	Assemble and analyze data, report writing
TBN	Engineering Technician	Assemble and analyze data, report writing

KU Department of Geology

Michael Taylor	Co-Principal Investigator	Structural Geology, analysis of InSAR and LiDAR
TBN	Graduate Research Assistant	Structural Geology, analysis of InSAR and LiDAR

Kansas State Unversity

Saugata Datta	Principal Investigator	Aqueous geochemistry
TBN	Graduate Research Assistant	
TBN	3- Undergraduate Research Assistants	

Lawrence Berkeley National Laboratory

Tom Daley	Co-Principal Investigator	Geophysicist, analysis of crosshole and CASSM data
Jennifer Lewicki	Co-Principal Investigator	Hydrogeology, analysis of soil gas measuremnts
Barry Freifeld	Co-Principal Investigator	Mechanical Engineer, analysis of U-Tube sampler

Sandia Technologies, Houston

Dan Collins	Geologist	Manage CASSM and U-Tube operation
David Freeman	Field Engineer	Manage field install of CASSM and U-Tube

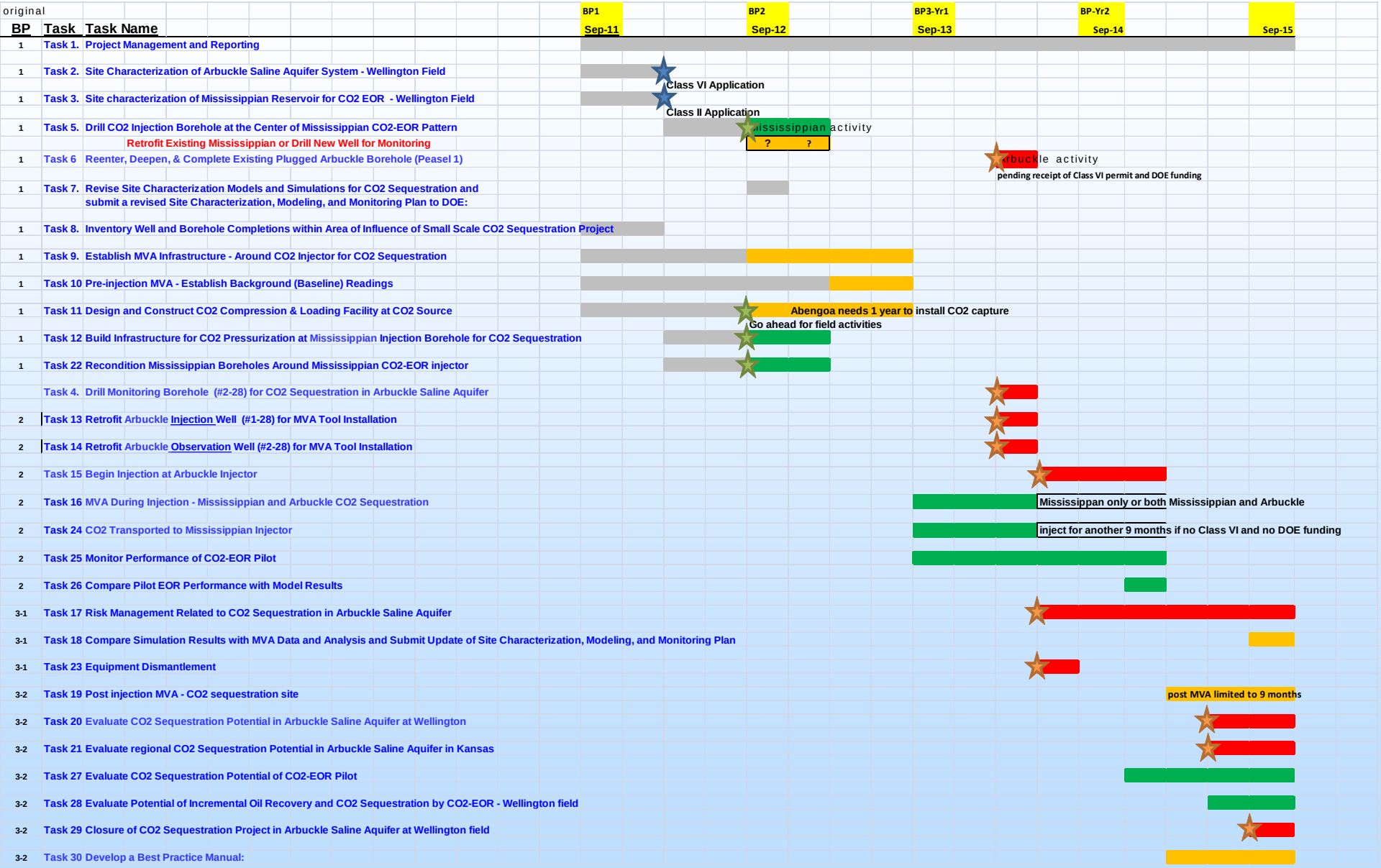
Berexco, LLC

Dana Wreath	VP Berexco	Engineering, Manager of Wellington Field
Randy Kouedele	Reservoir engineer	Enginering
Staff of Wellington Field		field operations
Beredco Drilling team		Mississippian and Arbuckle drilling operations

Abengoa Bioenergy Corp. - Colwich, KS

Christopher Standlee, Danny Alllison		CO2 supply – Colwich Ethanol Facility

Gantt Chart


original
BP
Task
Task Name
BP1
Sep-11
BP2
Sep-12
BP3-Yr1
Sep-13
BP-Yr2
Sep-14
Sep-15
1 Task 1. Project Management and Reporting
1 Task 2. Site Characterization of Arbuckle Saline Aquifer System - Wellington Field
Class VI Application
1 Task 3. Site characterization of Mississippian Reservoir for CO2 EOR - Wellington Field
Class II Application
1 Task 5. Drill CO2 Injection Borehole at the Center of Mississippian CO2-EOR Pattern
Mississippian activity
? ?
Retrofit Existing Mississippian or Drill New Well for Monitoring
1 Task 6 Reenter, Deepen, & Complete Existing Plugged Arbuckle Borehole (Peasel 1)
Arbuckle activity
pending receipt of Class VI permit and DOE funding
1 Task 7. Revise Site Characterization Models and Simulations for CO2 Sequestration and submit a revised Site Characterization, Modeling, and Monitoring Plan to DOE:
1 Task 8. Inventory Well and Borehole Completions within Area of Influence of Small Scale CO2 Sequestration Project
1 Task 9. Establish MVA Infrastructure - Around CO2 Injector for CO2 Sequestration
1 Task 10 Pre-injection MVA - Establish Background (Baseline) Readings
1 Task 11 Design and Construct CO2 Compression & Loading Facility at CO2 Source
Abengoa needs 1 year to install CO2 capture
Go ahead for field activities
1 Task 12 Build Infrastructure for CO2 Pressurization at Mississippian Injection Borehole for CO2 Sequestration
1 Task 22 Recondition Mississippian Boreholes Around Mississippian CO2-EOR injector
Task 4. Drill Monitoring Borehole (#2-28) for CO2 Sequestration in Arbuckle Saline Aquifer
2 Task 13 Retrofit Arbuckle Injection Well (#1-28) for MVA Tool Installation
2 Task 14 Retrofit Arbuckle Observation Well (#2-28) for MVA Tool Installation
2 Task 15 Begin Injection at Arbuckle Injector
2 Task 16 MVA During Injection - Mississippian and Arbuckle CO2 Sequestration
Mississippan only or both Mississippian and Arbuckle
2 Task 24 CO2 Transported to Mississippian Injector
inject for another 9 months if no Class VI and no DOE funding
2 Task 25 Monitor Performance of CO2-EOR Pilot
2 Task 26 Compare Pilot EOR Performance with Model Results
3-1 Task 17 Risk Management Related to CO2 Sequestration in Arbuckle Saline Aquifer
3-1 Task 18 Compare Simulation Results with MVA Data and Analysis and Submit Update of Site Characterization, Modeling, and Monitoring Plan
3-1 Task 23 Equipment Dismantlement
3-2 Task 19 Post injection MVA - CO2 sequestration site
post MVA limited to 9 months
3-2 Task 20 Evaluate CO2 Sequestration Potential in Arbuckle Saline Aquifer at Wellington
3-2 Task 21 Evaluate regional CO2 Sequestration Potential in Arbuckle Saline Aquifer in Kansas
3-2 Task 27 Evaluate CO2 Sequestration Potential of CO2-EOR Pilot
3-2 Task 28 Evaluate Potential of Incremental Oil Recovery and CO2 Sequestration by CO2-EOR - Wellington field
3-2 Task 29 Closure of CO2 Sequestration Project in Arbuckle Saline Aquifer at Wellington field
3-2 Task 30 Develop a Best Practice Manual:

Bibliography

Watney, W.L. et al., 2011, Small Scale Field Test Demonstrating CO2 sequestration in Arbuckle Saline Aquifer and by CO2-EOR at Wellington field, Sumner County, Kansas --Presentation to KCC-KDHE-EPA, Wichita

Barker, R., Watney, L., Bhattacharya, S., Strazisar, B., Kelly, L., Ford, S., Datta, S., 2011, Analytical description of the mineralogy and geochemistry of the Arbuckle deep saline aquifer in south central Kansas and implications for CO2 sequestration, T125. Assessing Potential Impacts of Geological Carbon Sequestration on Groundwater Quality: Geochemical and Hydrological Approaches, Annual GSA, Minneapolis.

Barker, R., Watney, L., Bhattacharyya, S., Strazisar, B., Kelly, L., Ford, S., Datta, S., 2011, Geochemical and mineralogical characterization of the Arbuckle aquifer with laboratory flow cell experiments under supercritical conditions: Implications for CO2 sequestration: AGU, GC30: Carbon Sequestration 3. Mineral Carbonation Under Low Temperature Conditions, San Francisco.

W. Lynn Watney, Jason Rush, 2011, GC44A-02. Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoirs to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas, AUG Fall Meeting, San Francisco.

Watney, W.L., 2012, Business Implications of A Class VI Permit – The Long View? -- A Kansas Perspective, PUTTING THE BUSINESS ELEMENTS TOGETHER FOR CO2 EOR USING CAPTURED CARBON, April 4-5, 2012 - Golden, Colorado, sponsored by Permian Basin CCUS Center and Colorado PTTC.

Scheffer, A.A., Gulliver, D., Roberts, J.A., Fowle, D., Watney, W.L., Doveton, J., Stotler, R., Whittemore, D., ms. in review, Geochemical, Microbiological, and Permeability Characteristics Indicating Vertical Zonation of the Arbuckle Saline Aquifer, a potential CO2 storage reservoir.