SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD, SUMNER COUNTY, KANSAS
DE-FE0006821

W. Lynn Watney, Jason Rush, Joint PIs

Kansas Geological Survey

The University of Kansas

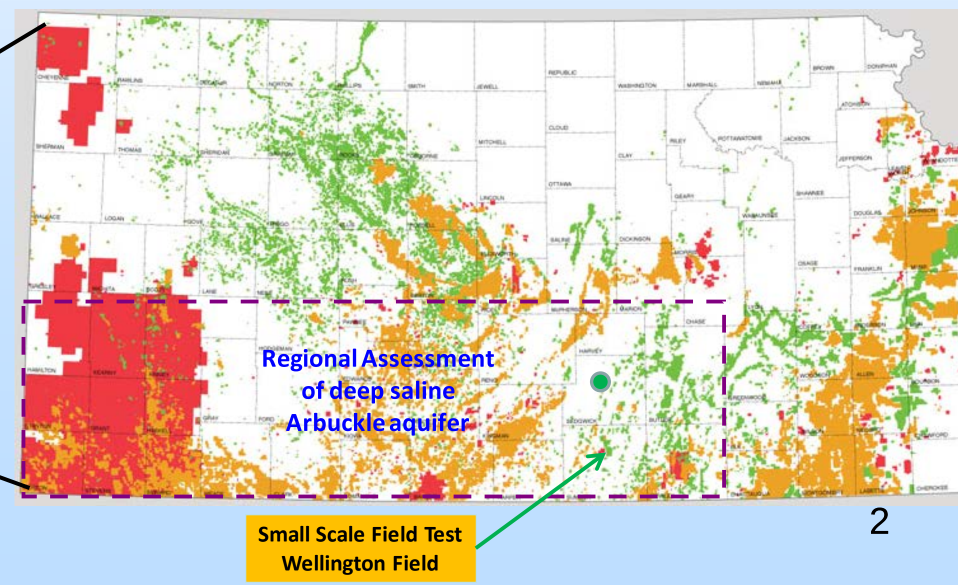
Lawrence, KS

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS
August 20-22, 2013

Brighton 1&2
Wednesday 8-21-13
1:10-1:35

Presentation Outline

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



Project Team

DOE-NETL Contract #FE0006821

KANSAS GEOLOGICAL SURVEY
The University of Kansas

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DEPARTMENT OF GEOLOGY
KANSAS STATE UNIVERSITY

Saugata Datta

THE UNIVERSITY OF KANSAS Department of Geology

Mike Taylor, Ross Black, George Tsoflias

Sandia Technologies, LLC

Dan Collins, David Freeman

Benefit to the Program

- **Program goals being addressed –**
  - Demonstrate that 99 percent of injected CO_2 remains in the injection zone
  - Conduct small field test to support characterization, site operations, monitoring, and closure practices for Class VI geosequestration Permit , Region 7 EPA, Kansas City
- **Project benefits of this small scale field test:**
  - Advance the science and practice of carbon sequestration in the Midcontinent
  - Evaluate reliable, cost effective 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

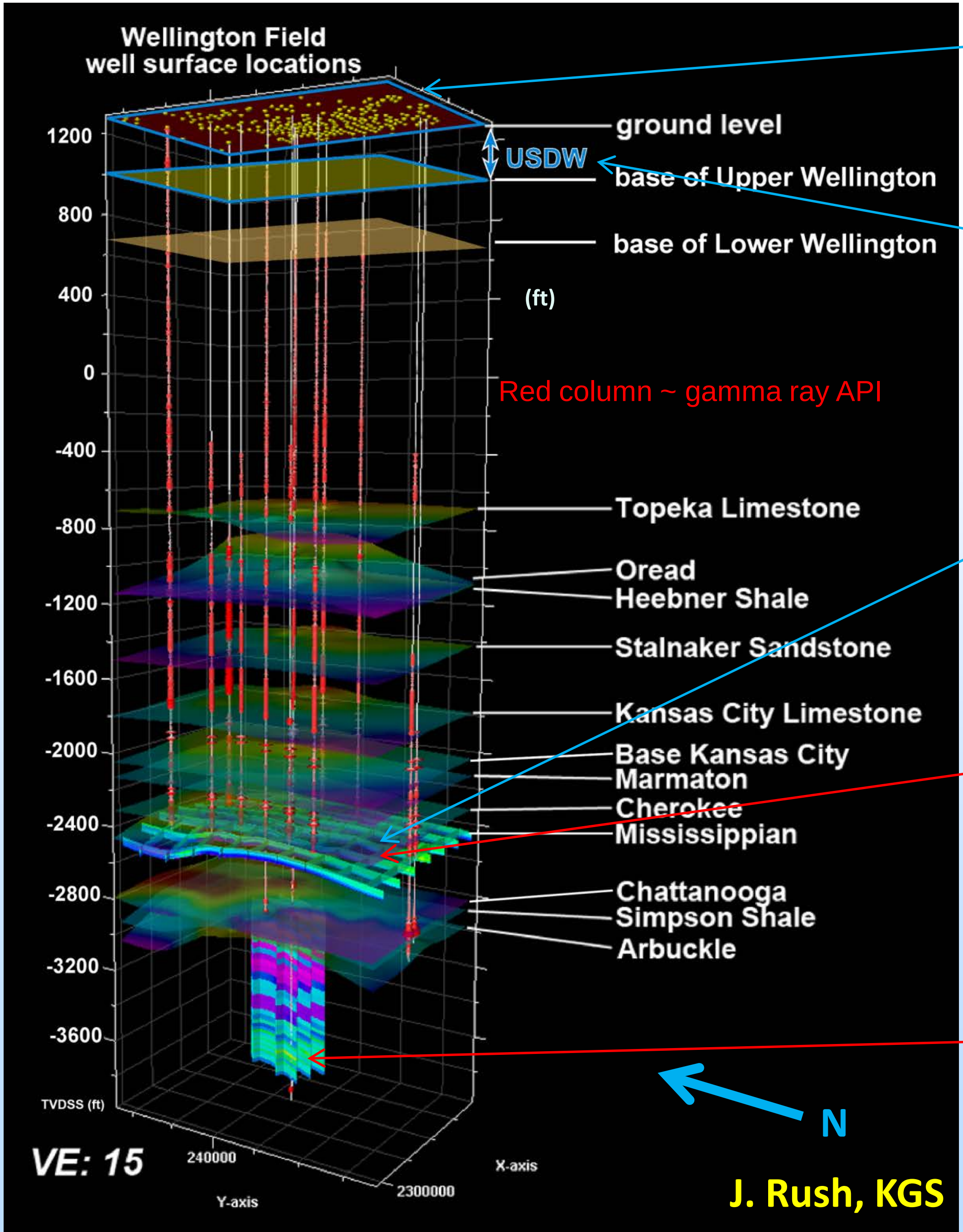
Project Overview: Goals and Objectives

1. Negotiate cost of CO2 with new source and commence field activities in Fall 2013.
2. Begin injection of 30,000 metric tons of CO_2 into Mississippian oil reservoir mid year 2014 using 5-spot pattern to demonstrate optimization for carbon sequestration.
3. Obtain Class VI permit by late 2014.
4. *Pending approval of Class VI injection application* -- Inject under supercritical conditions up to 40,000 metric tons of CO_2 into the underlying Arbuckle saline aquifer.
5. Demonstrate state-of-the-art MVA (monitoring, verification, and accounting) tools and techniques
6. Integrate MVA data and analysis with reservoir modeling studies to demonstrate and insure 99% CO_2 storage permanence.

Technical Status

- **Replacing CO_2 source** – Colwich ethanol plant near Wellington remains closed
- **Negotiations continuing** with 2 compressed CO_2 sources to maximize CO_2 for project , delivering at least 40,000 tonnes.
- **Begin field activities** as soon as CO_2 source is secured with Mississippian CO_2-EOR injection beginning in mid 2014.
- **File Class VI permit** for Arbuckle saline injection with EPA by in Fall 2013.
- **Saline injection** potentially begin by July 2015 immediately following test in the Mississippian oil reservoir.

CO2-EOR, saline injection , Class VI, MVA - Wellington Field



- InSAR, CGPS surface deformation/IRIS seismometers
- Measure soil gas flux

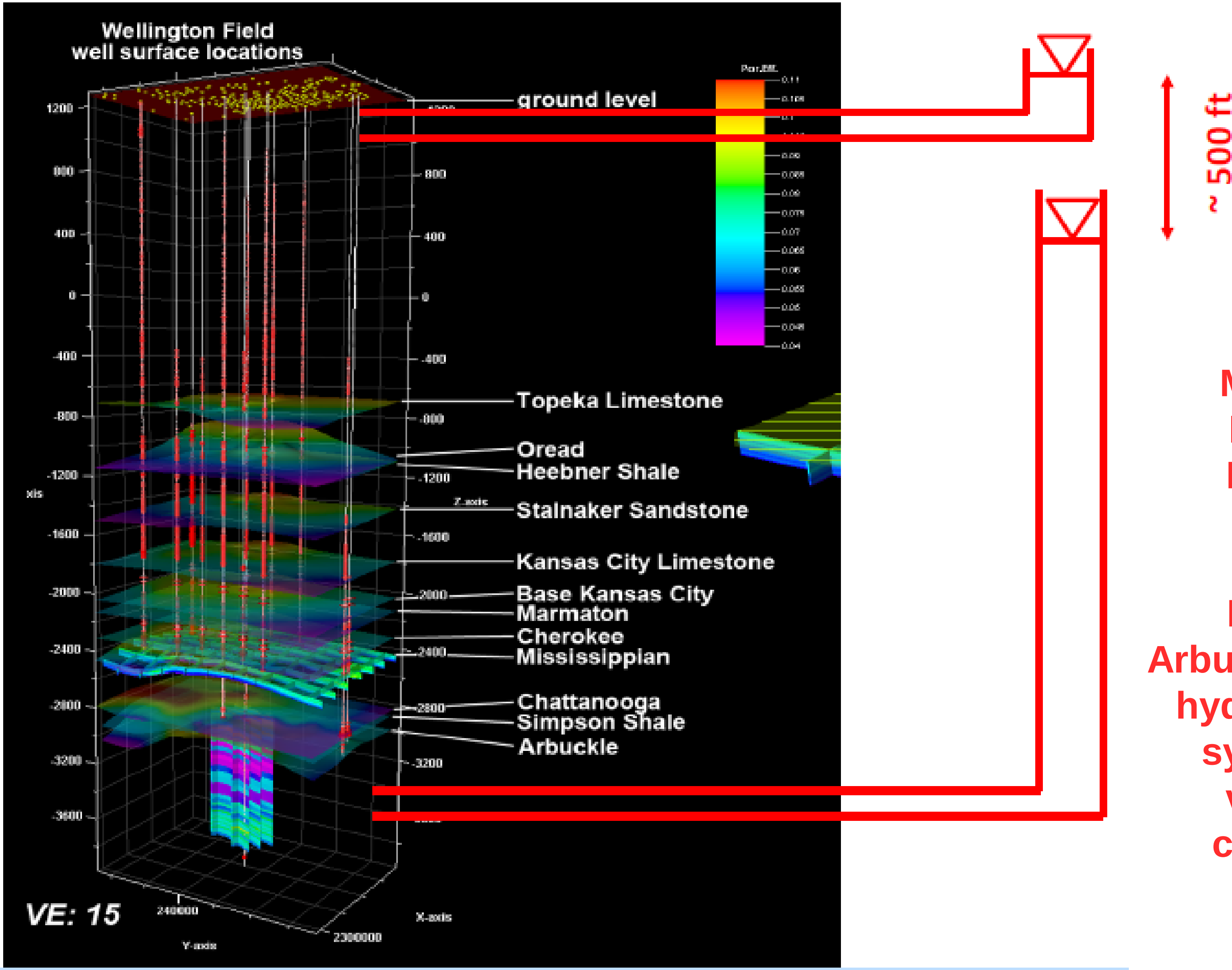
- Monitor for tracers, CO_2, aqueous geochemistry in shallow freshwater wells
- Monitor ~600 ft deep well below shallow evaporite cap rock

- Test for CO_2 and analyze 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 up to 40,000 tonnes of CO_2 with tracers into lower Arbuckle saline aquifer and seismically image and sample in situ CO_2 plume to validate geomodel and simulations - U-Tube, CASSM and cross hole seismic with DTS & acoustic fiber optics (long string fiber pending)

Head Difference Between Arbuckle and USDW



Maximum Injection Pressure = 325 ft

Regional Arbuckle an open hydrogeologic system, not vertically connected

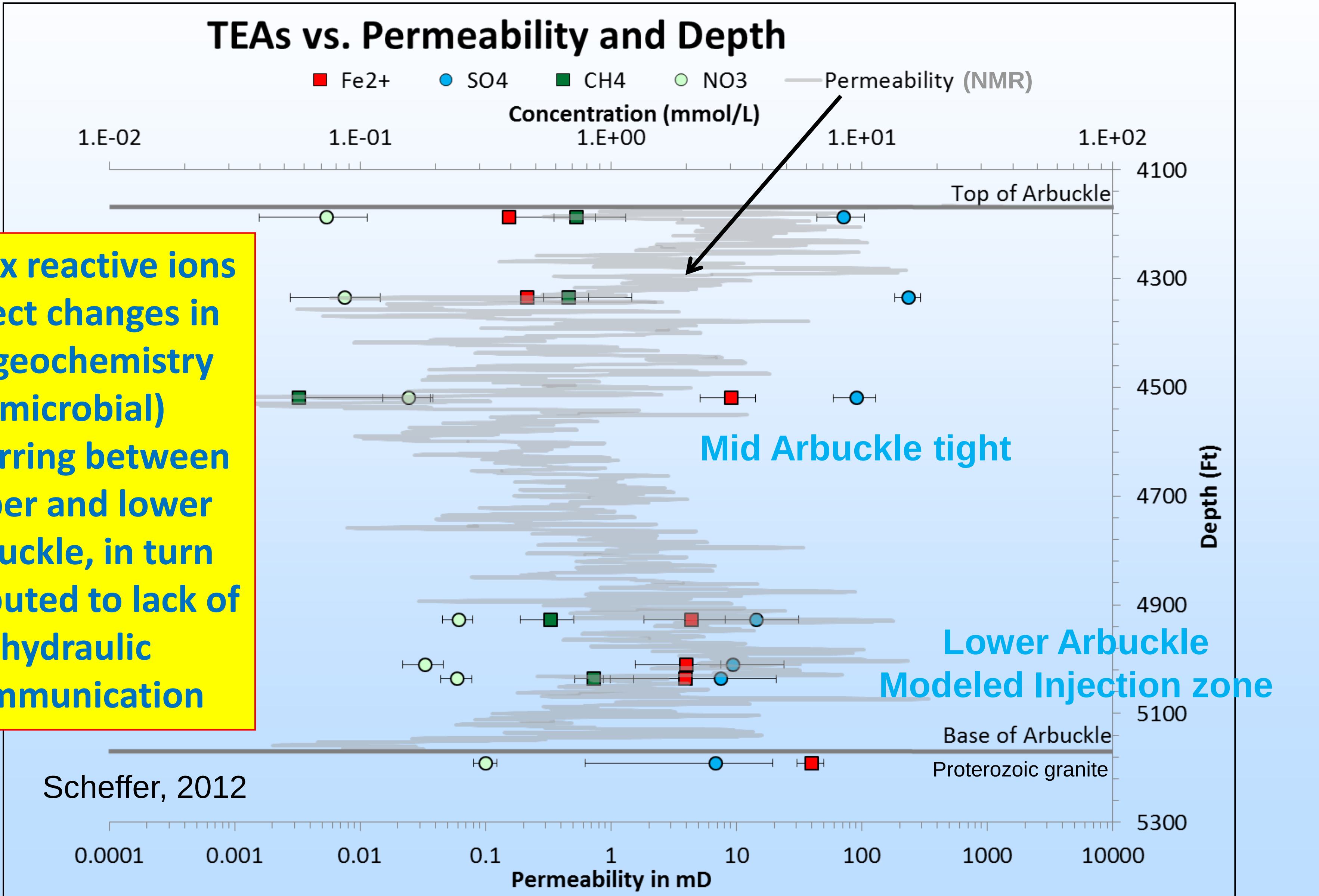
Technical Status

Class VI Geosequestration Injection Permit

- **Submittal of Class VI application**:
  - Late Fall 2013
- **Static and coupled dynamic modeling of saline aquifer** for up to 40 kton CO_2 injection
- **Injection zone** –
  - Highly permeable 150+ ft thick lower Lower Ordovician Arbuckle (Gasconade Dolomite, 100s of md to >1 D)
  - Multiple flow units decreasing thickness of buoyant supercritical CO_2 plume
- **Baffle and trapping of CO_2 plume (final model)** –
  - Multilayer plume under a ~400 ft thick shaly, low perm middle Arbuckle (lower Jefferson City-Cotter & Roubidoux formations)
  - Low pressure (<325 psi) and multi-layer plume (1800 ft radius) within lower Arbuckle (Gasconade) presents very low risk for caprock
- **Primary caprock interval** – ~230 ft gross thickness including Lower Mississippian argillaceous, organic dolosiltstone (Pierson/St. Joe Limestone), Chattanooga Shale and shales in the Simpson Group
- **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

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

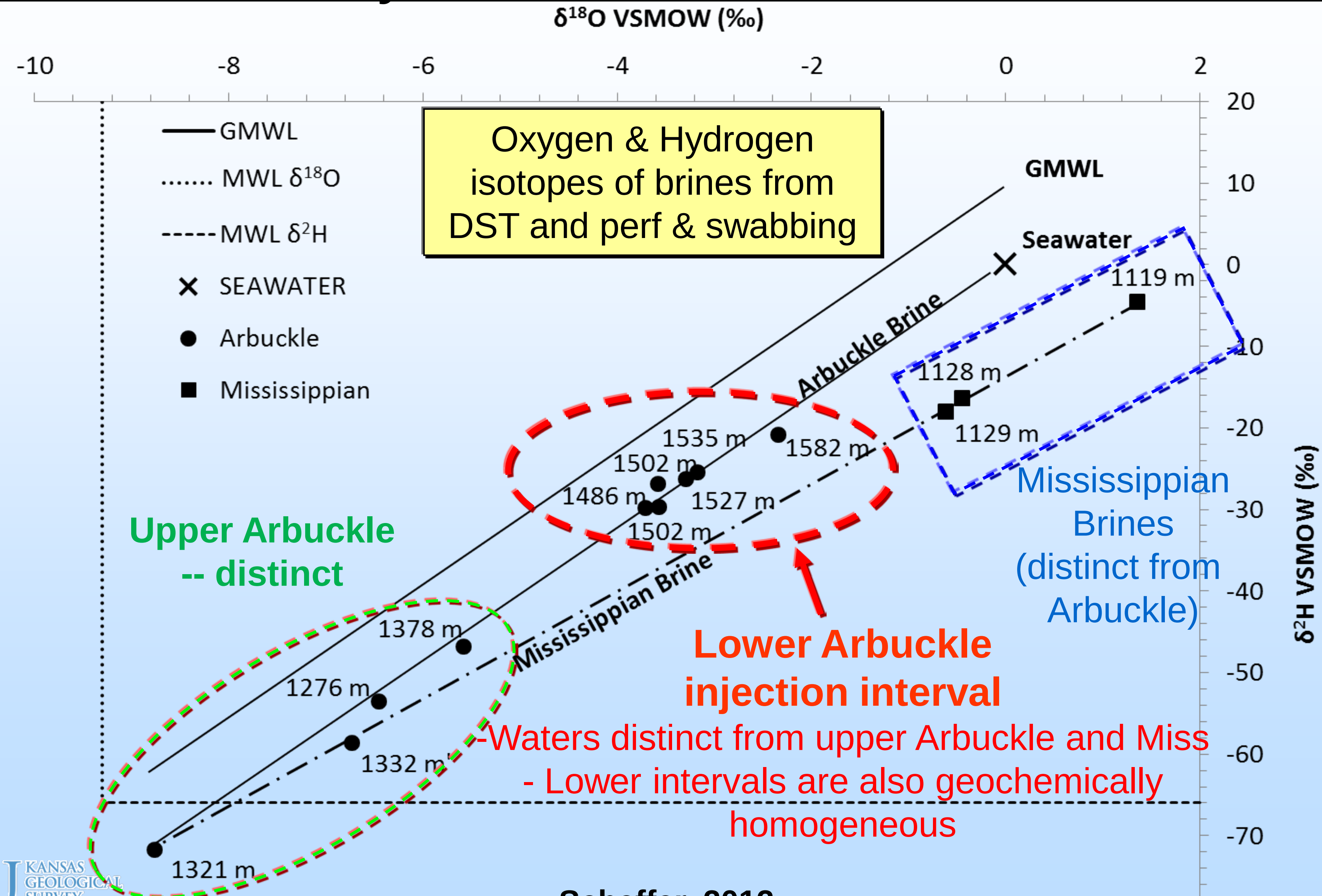
with concentrations of redox reactive ions (Fe^{2+}, SO_4^{2-}, CH_4, NO_3^-) from KGS #1-32 & #1-28



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



Scheffer, 2012

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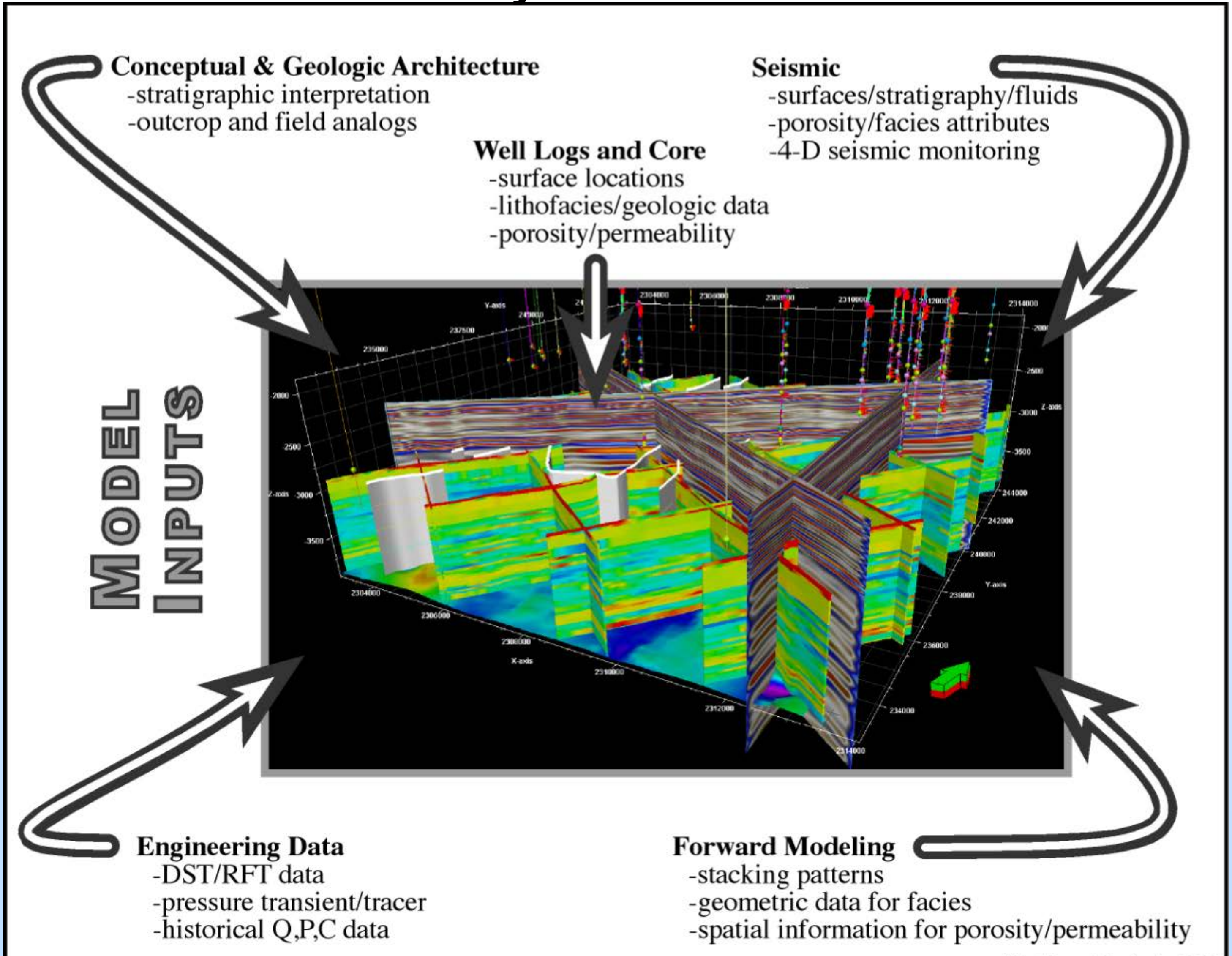
Ideal Input for Static and Dynamic Modeling with Characterization Being Accomplished Under Concurrently Funded DE-FE0002056



modified from Deutsch, 2002

Aquifer Characterization
Arbuckle Saline Aquifer

- Dominantly cherty dolomite

- **Permeable** - Upper 70 m: very porous medium pelleted dolomitic pack-stones and grain-stones

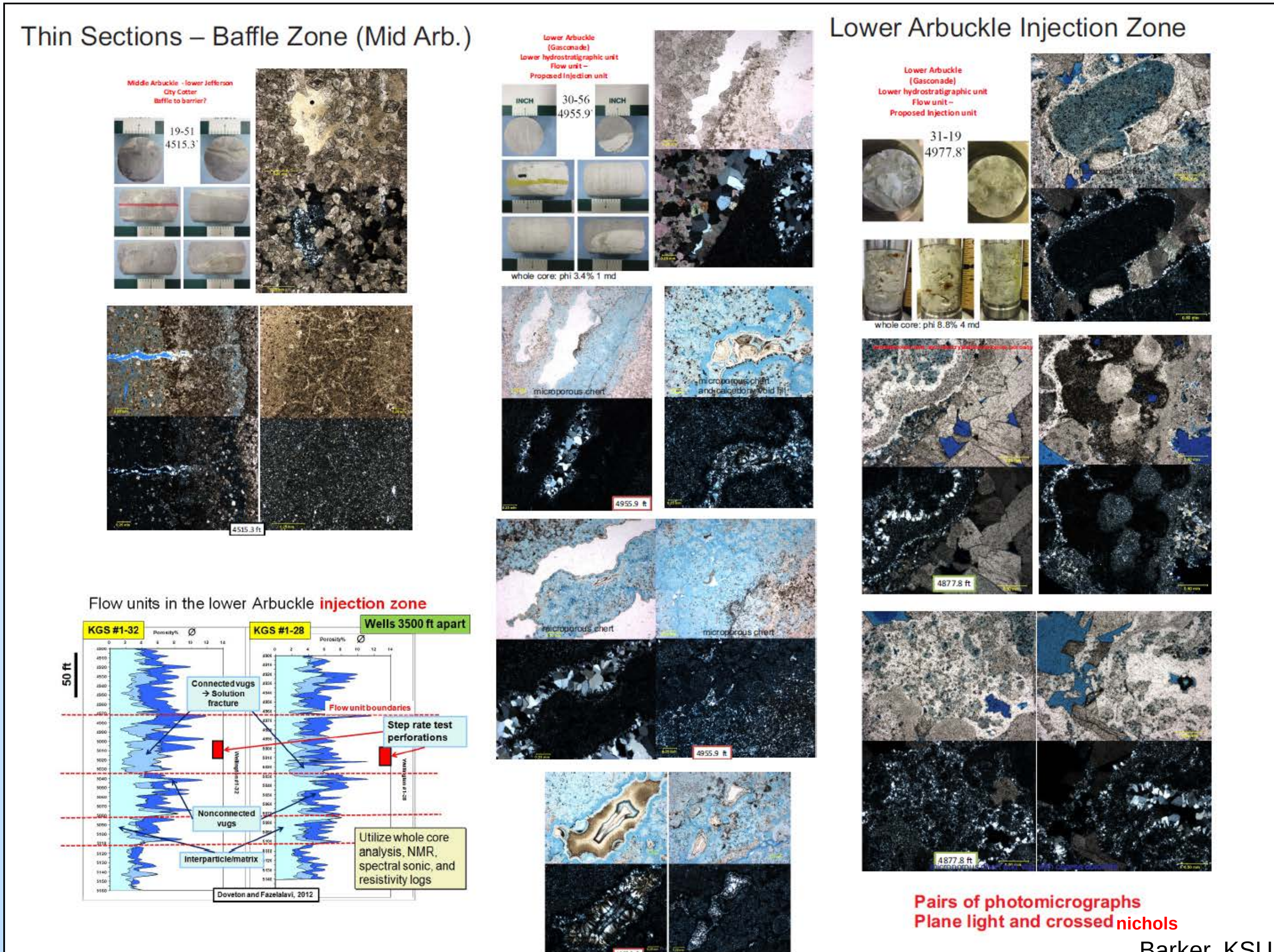
- **Baffle** - Middle 110 m: tight, dense, micritic dolomite

- **Permeable** - Lower 110 m: thin dolomitic strataform breccias created by dissolution of evaporites, packstones and grainstones with discontinuous solution enhanced fractures

Aquifer Characterization

Mid Arbuckle baffle = tight rock

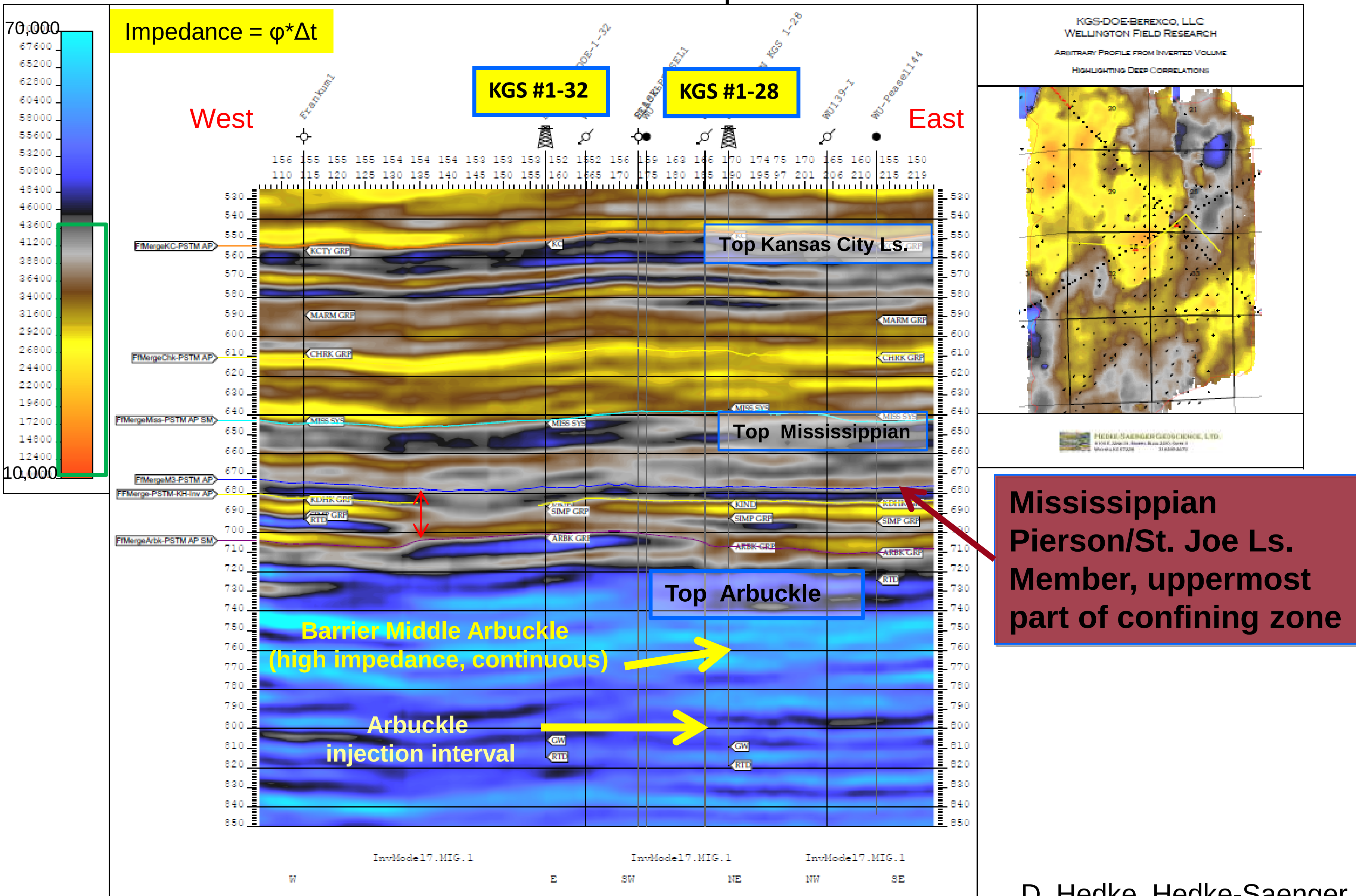
Lower Arbuckle Injection interval = include abundant micropores (microporous chert)



Primary Confining Zone Continuous in the Wellington Area

(Lower Mississippian Pierson fm.+Chattanooga Sh+Simpson Group)

West-East Seismic Impedance PSTM

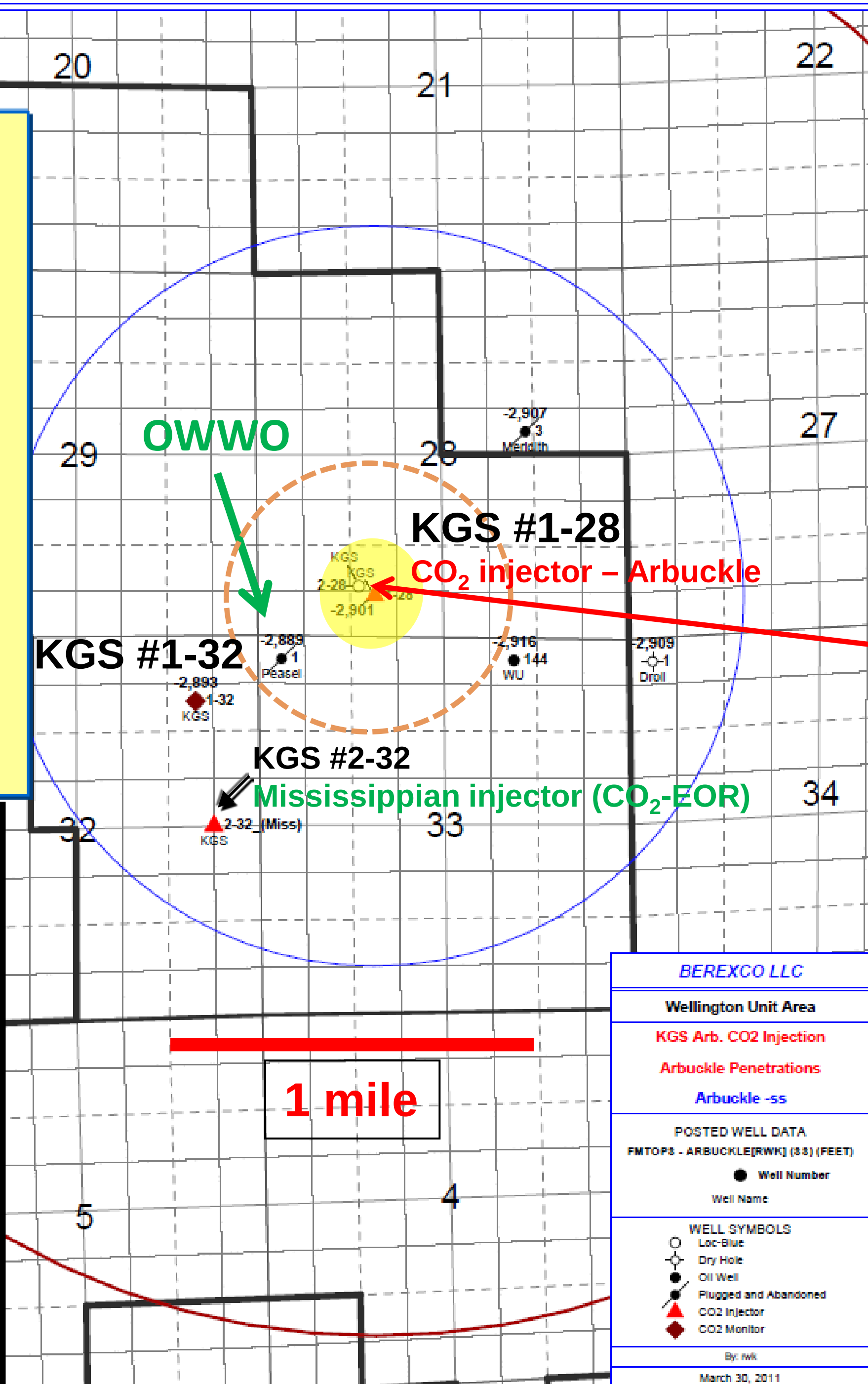


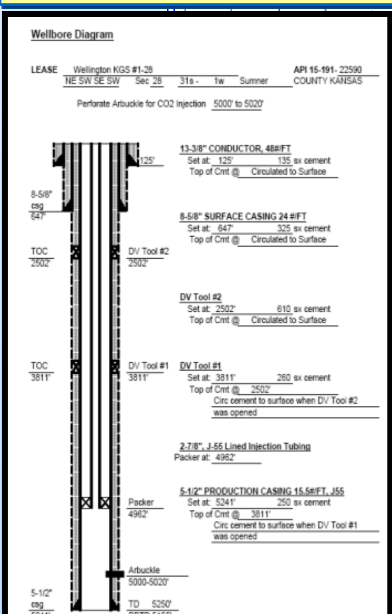
D. Hedke, Hedke-Saenger

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, ~1400 ft radius
- Orange circle – extent of pressure field, 2500 radius, 325 psi max (0.485 psi/ft)

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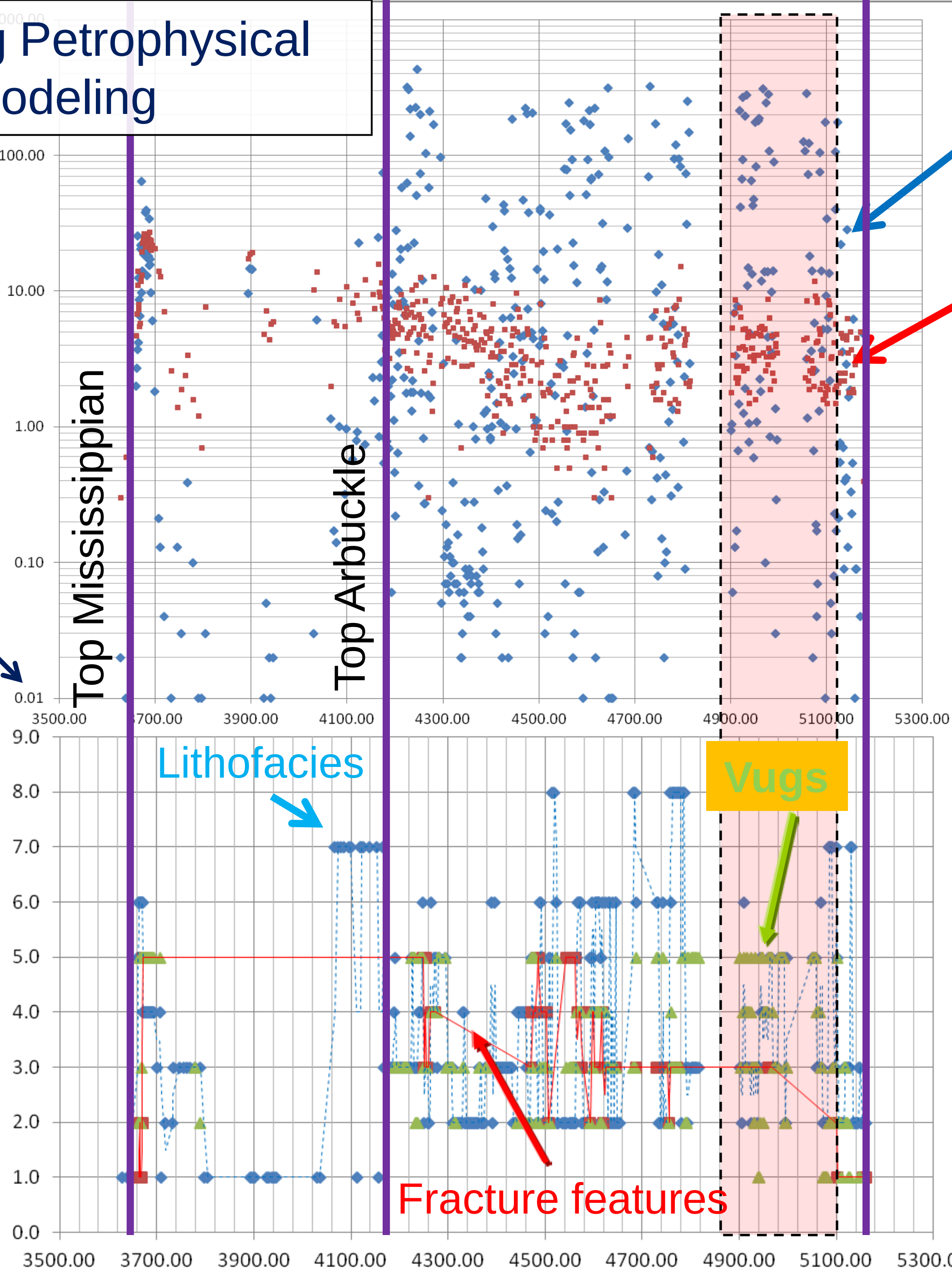
Core/Log Petrophysical Modeling

Minimum k reported as <0.01 md, but accuracy of measurement down to 0.005 md (Weatherford)



Kmax
Ranges from 0.01 to 425 md (whole core)

Porosity –
predominately between 1-10%

Kmax
POR

Shale = 1
Mudstone = 2
Packstone= 3
Grainstone = 4
Incipient breccia = 5
Breccia =6
Sandstone = 7
Microbialite = 8

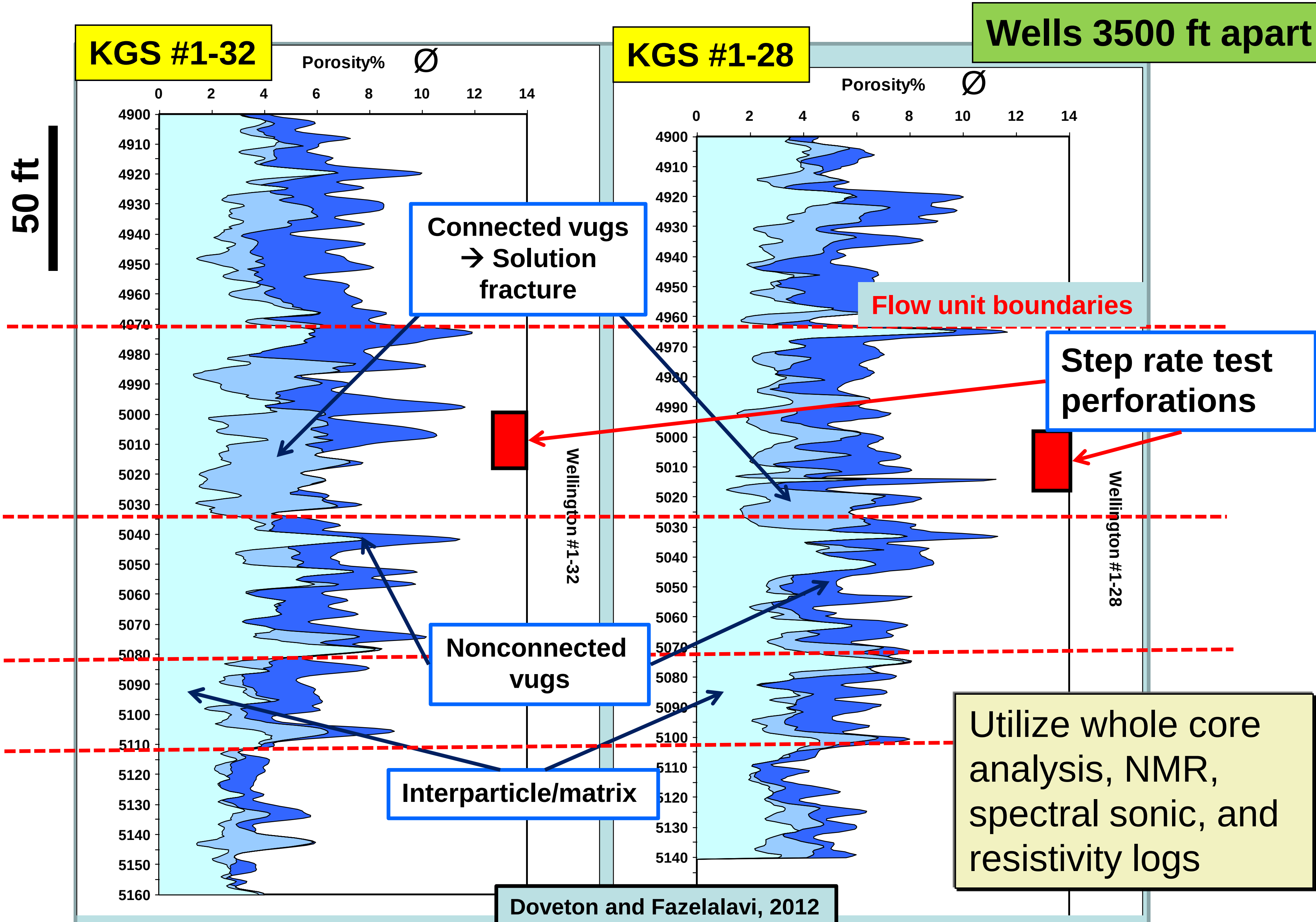
fractures (1-5, highest; 0, none)

Vugs (small to large, 1-5)

Lithofacies
Fractures
Vugs
2 per. Mov. Avg. (Lithofacies)
2 per. Mov. Avg. (Fractures)

KGS #1-32 whole core analysis *compared to core derived lithofacies* ***N = 480***

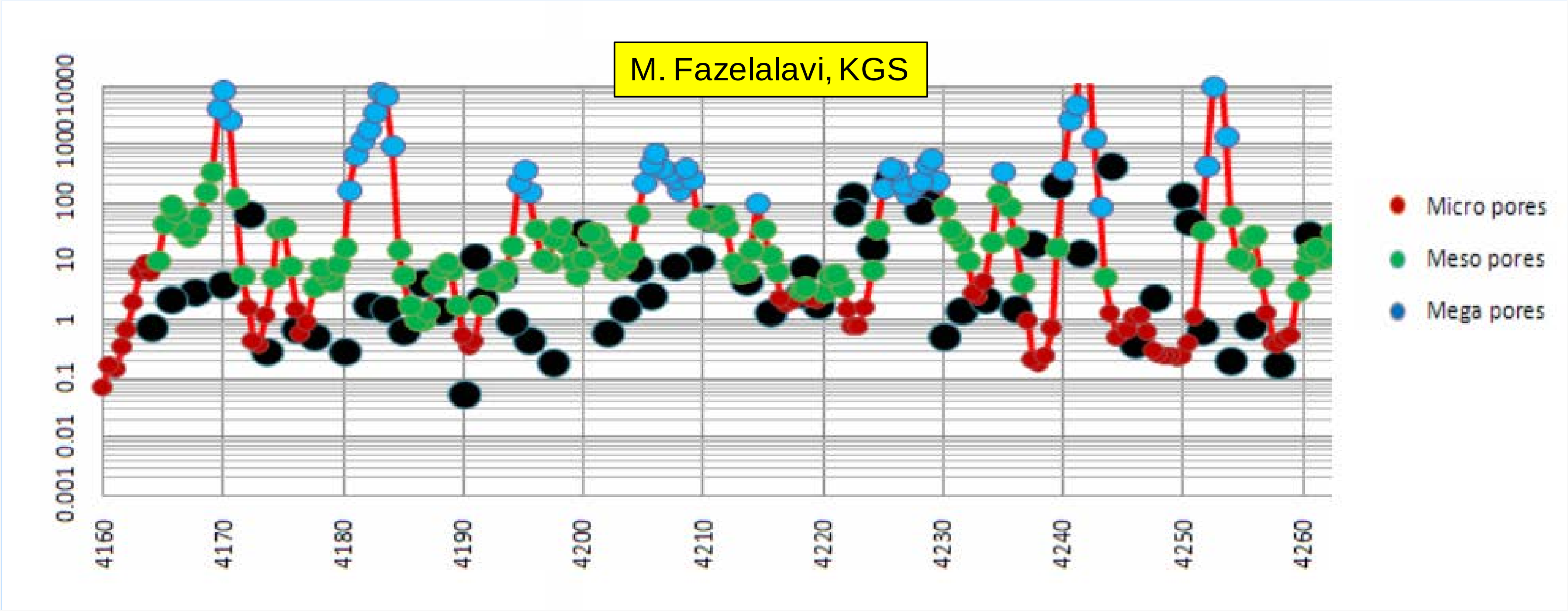
Flow units in the lower Arbuckle injection zone



Utilize whole core analysis, NMR, spectral sonic, and resistivity logs

Improved permeability estimation in Wellington KGS #1-32 and correlation to Wellington KGS #1-28

- micro, meso, and mega groups defined
- core FZI and irreducible water saturation (from MRIL log)
- permeability computed from FZI value (Fazelalavi method)

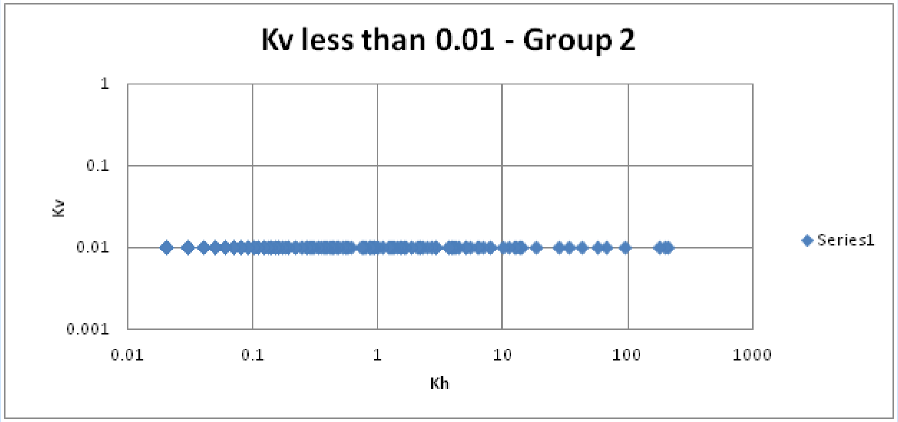


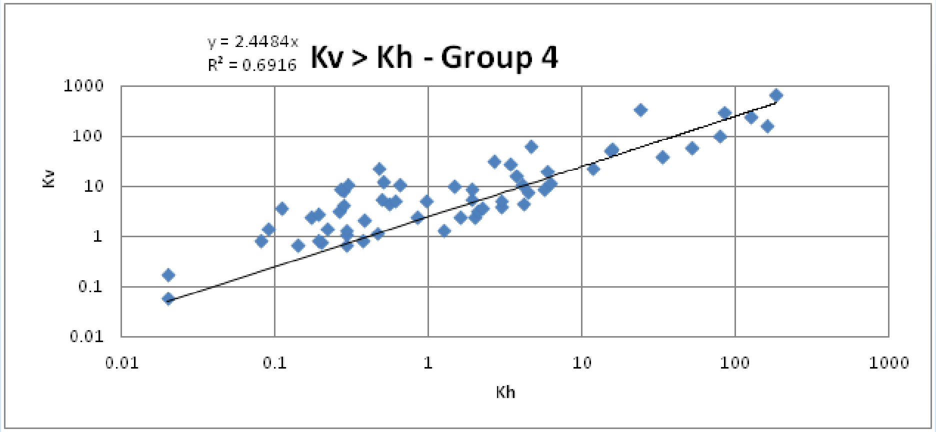
Black points = core measured permeability

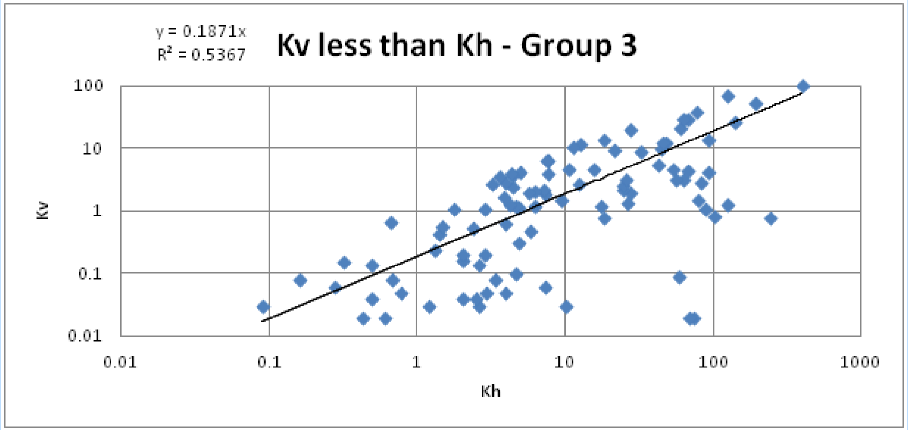
Correlations Between Kv and Kh from Whole Core Analysis & 5 Petrofacies Groups Derived fromTechlog

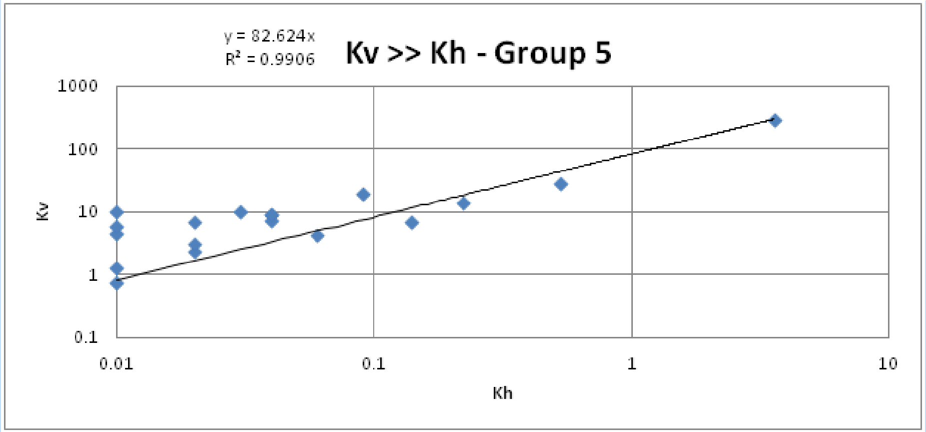
Group 1
There are 15 whole core samples in this group; both vertical and horizontal permeability are less 0.01 mD.

M. Fazelalavi, KGS









LAYOUT

Well(s): **WELLINGTON KGS #1-32, WELLINGTON KGS #1-28**

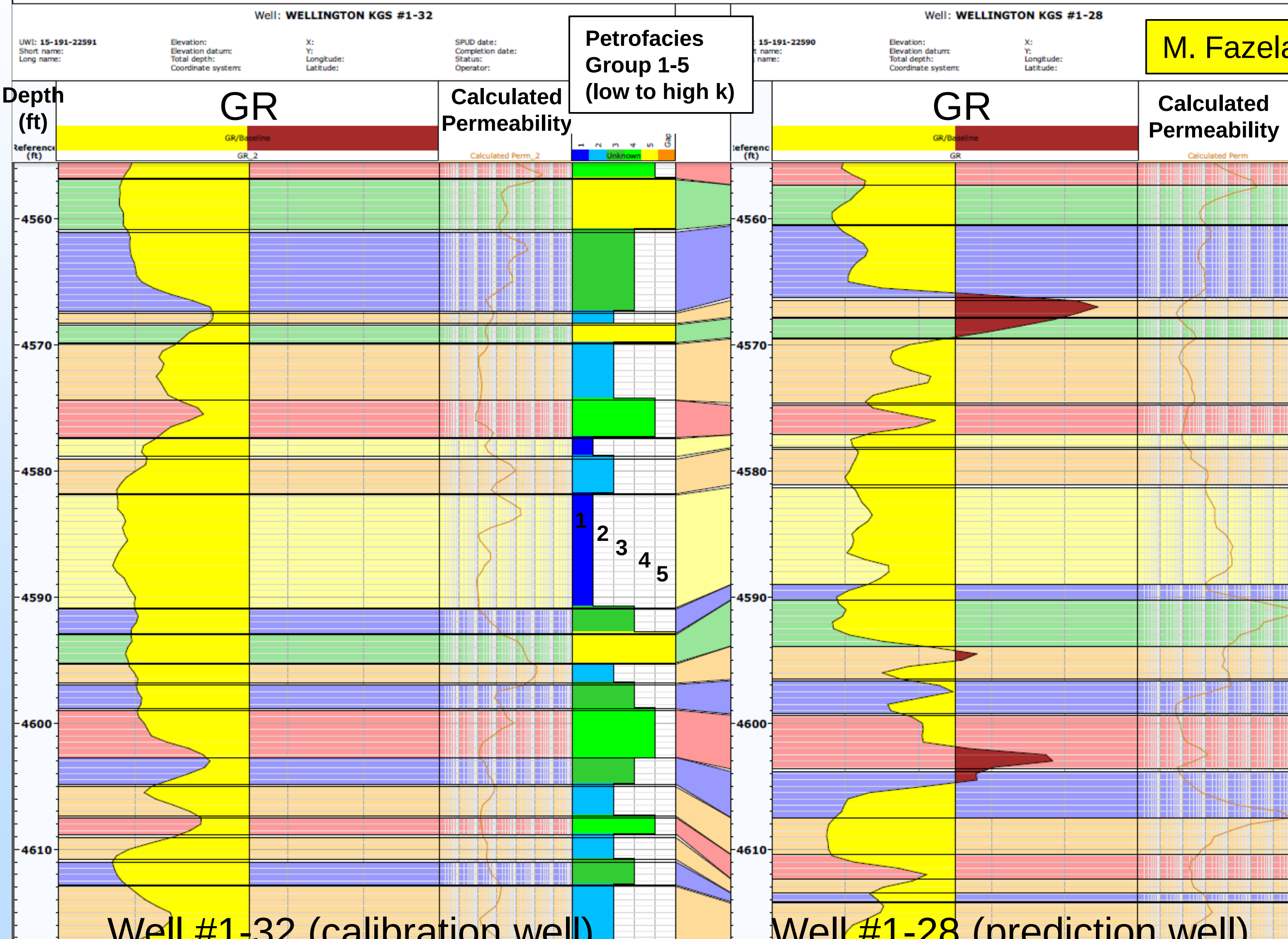
Project: Wellington2

Author: Mina FAZELALAVI
Date: 7/2/2013

K_v Calibration and Correlation Using Techlog Derived Petrofacies in Mid Arbuckle

M. Fazelalavi, KGS

baffle zone mid-Arbuckle

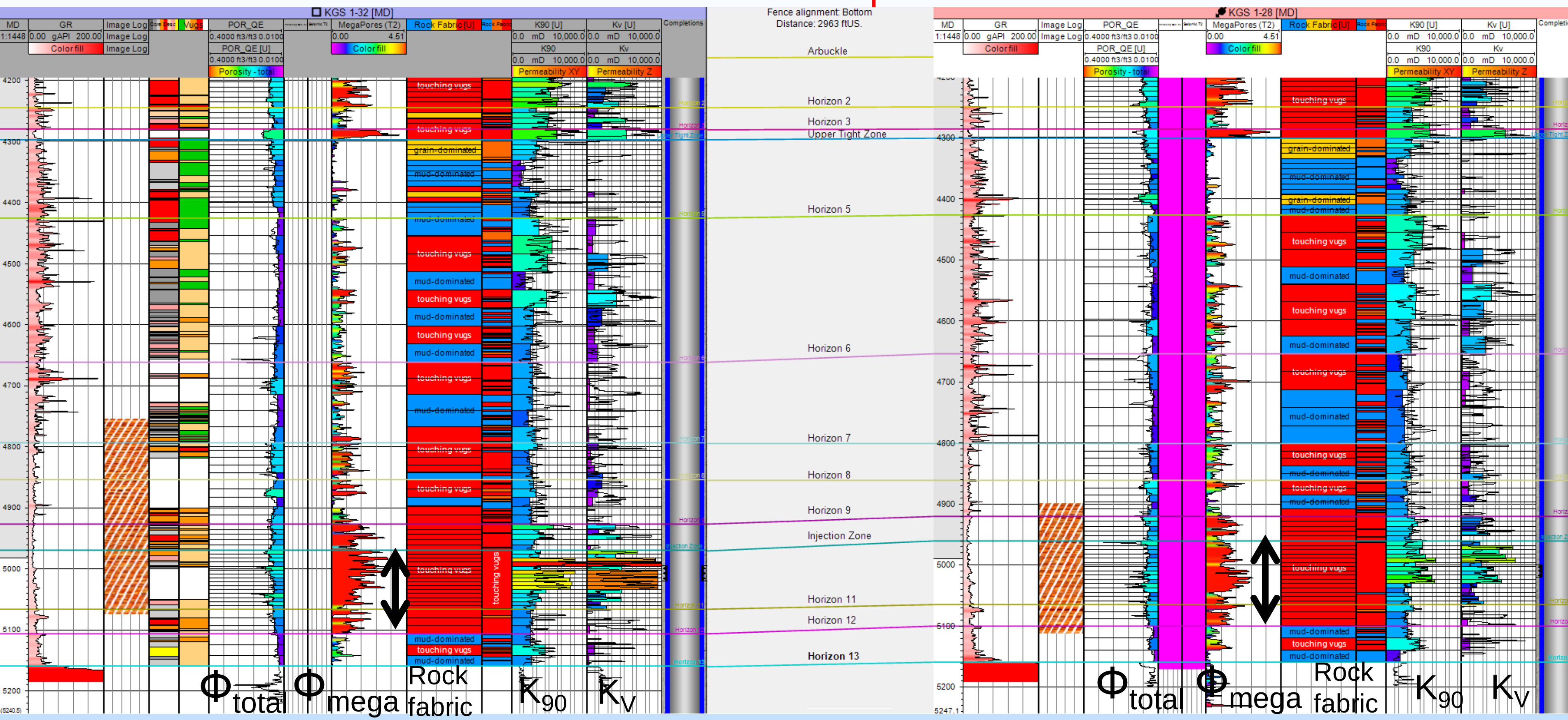


Well #1-32 (calibration well)

Well #1-28 (prediction well)

Whole Core C/A - Log Integration
Arbuckle Saline Aquifer – Petrel^{tm}

Core well #1-32 3500 ft apart #1-28



Mud-dominated

Grain-dominated

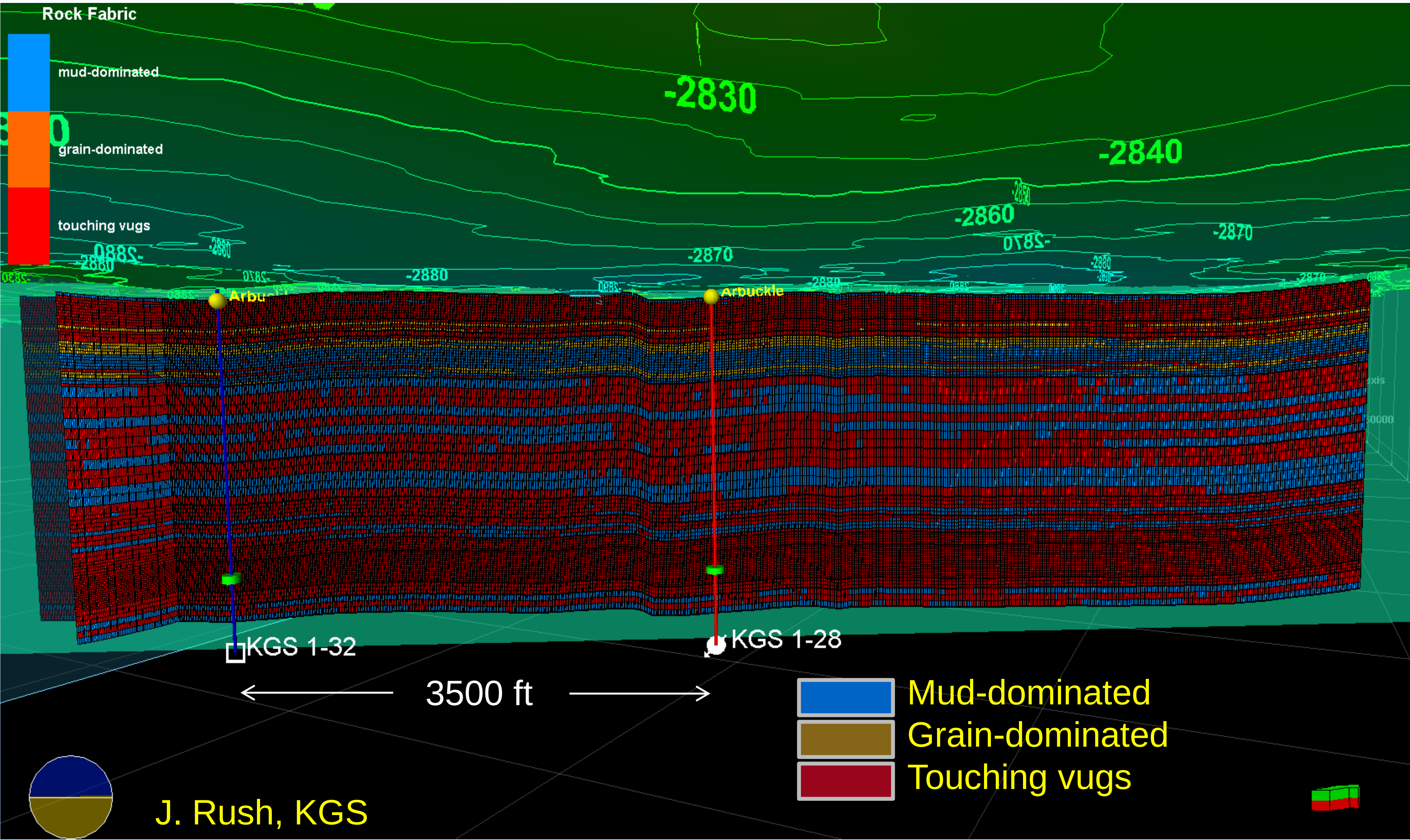
Touching vugs

J. Rush, KGS

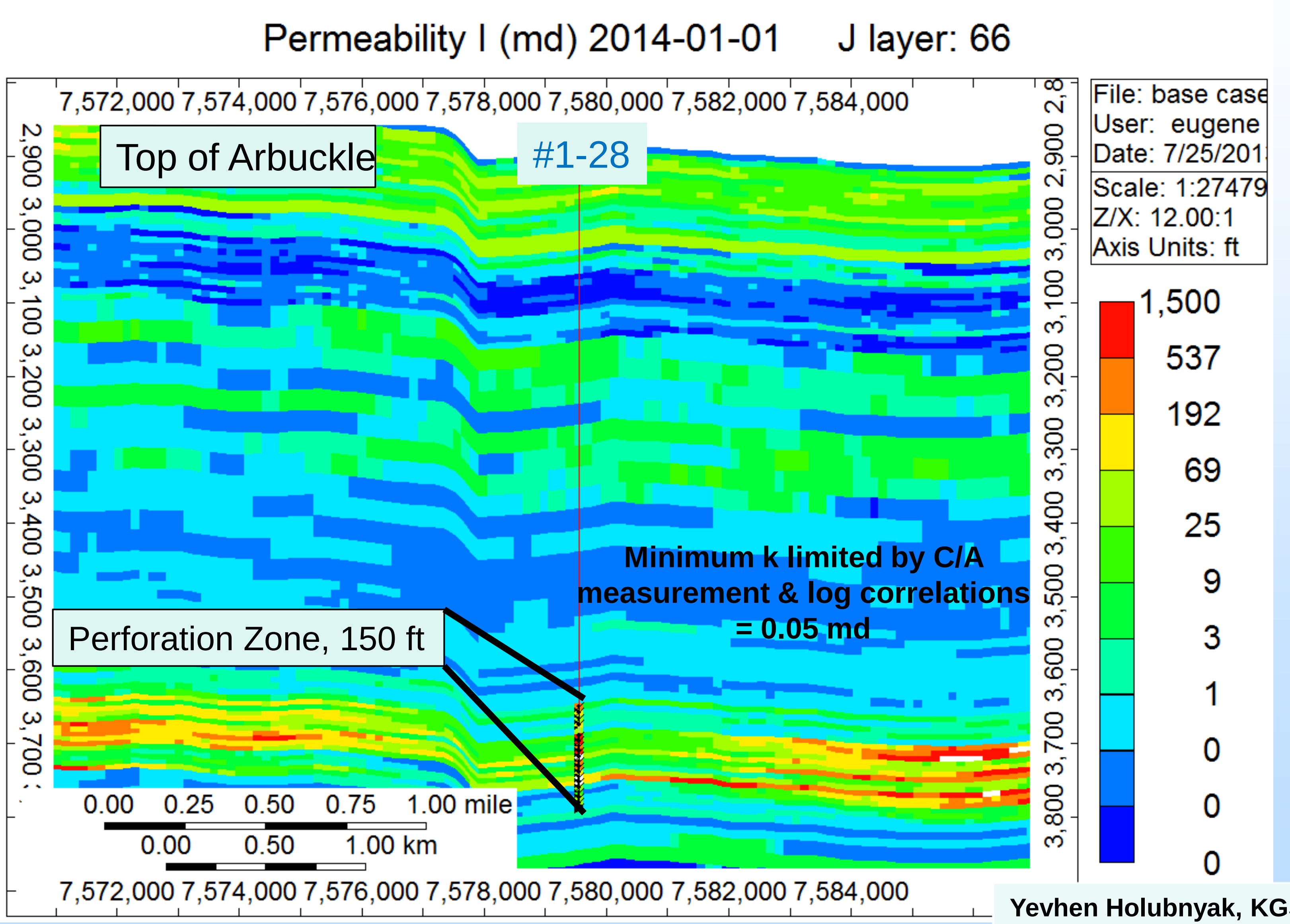
Stratigraphic cross section KGS #1-32 to KGS #1-28

Rock Fabric From Core and Logs correlated to Seismic Depth Volume Using Petrel^{tm}

(W-E profile between KGS #1-32 and #1-28)

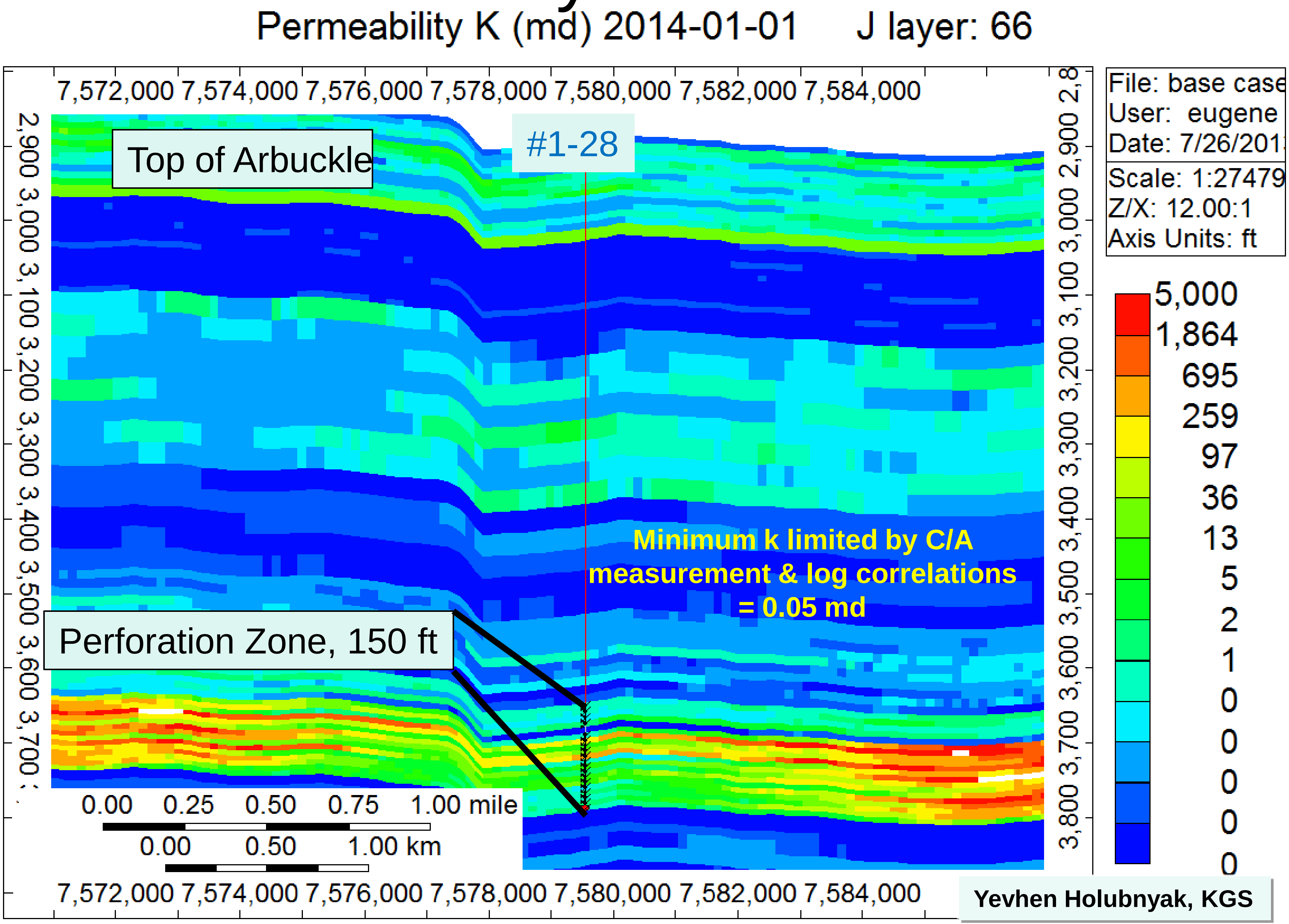


Upscaled Horizontal Permeability in CMG Dynamic Model



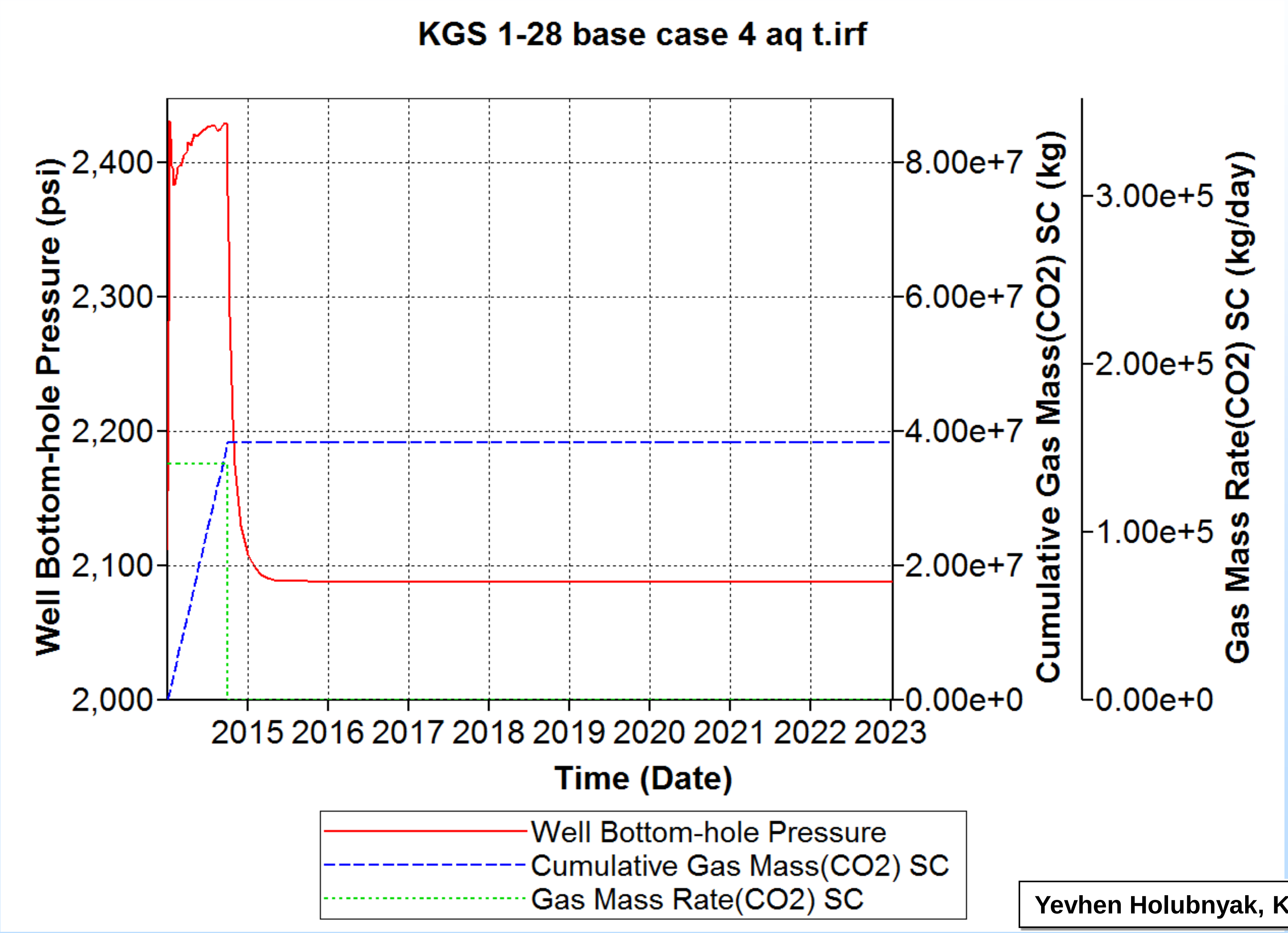
Yevhen Holubnyak, KGS

Upscaled Vertical Permeability in CMG Dynamic Model



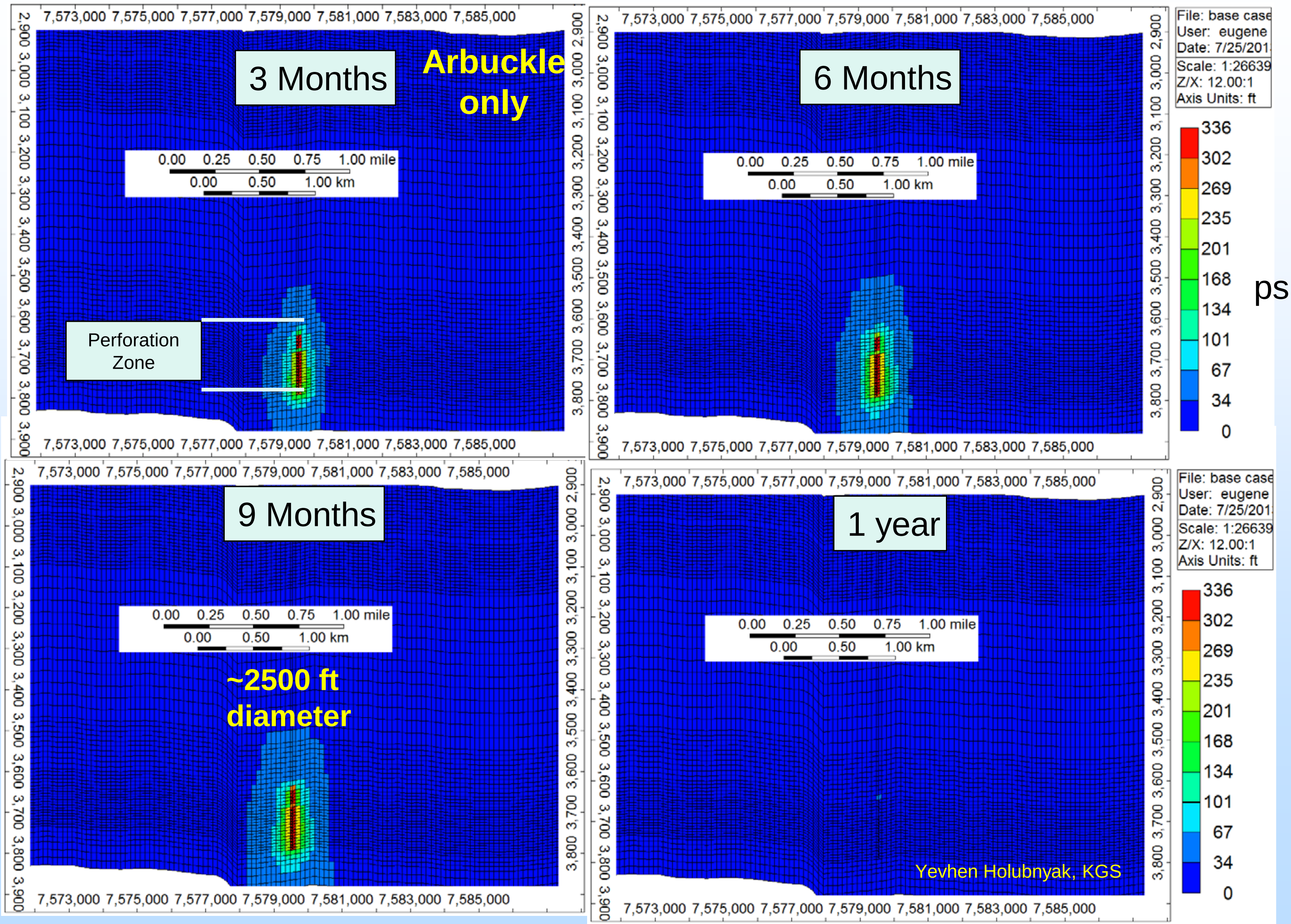
Yevhen Holubnyak, KGS

Bottom Hole Pressure, 325 psi max. (0.485 psi/ft) 120 tonne/day, 40,000 tonne total CO_2

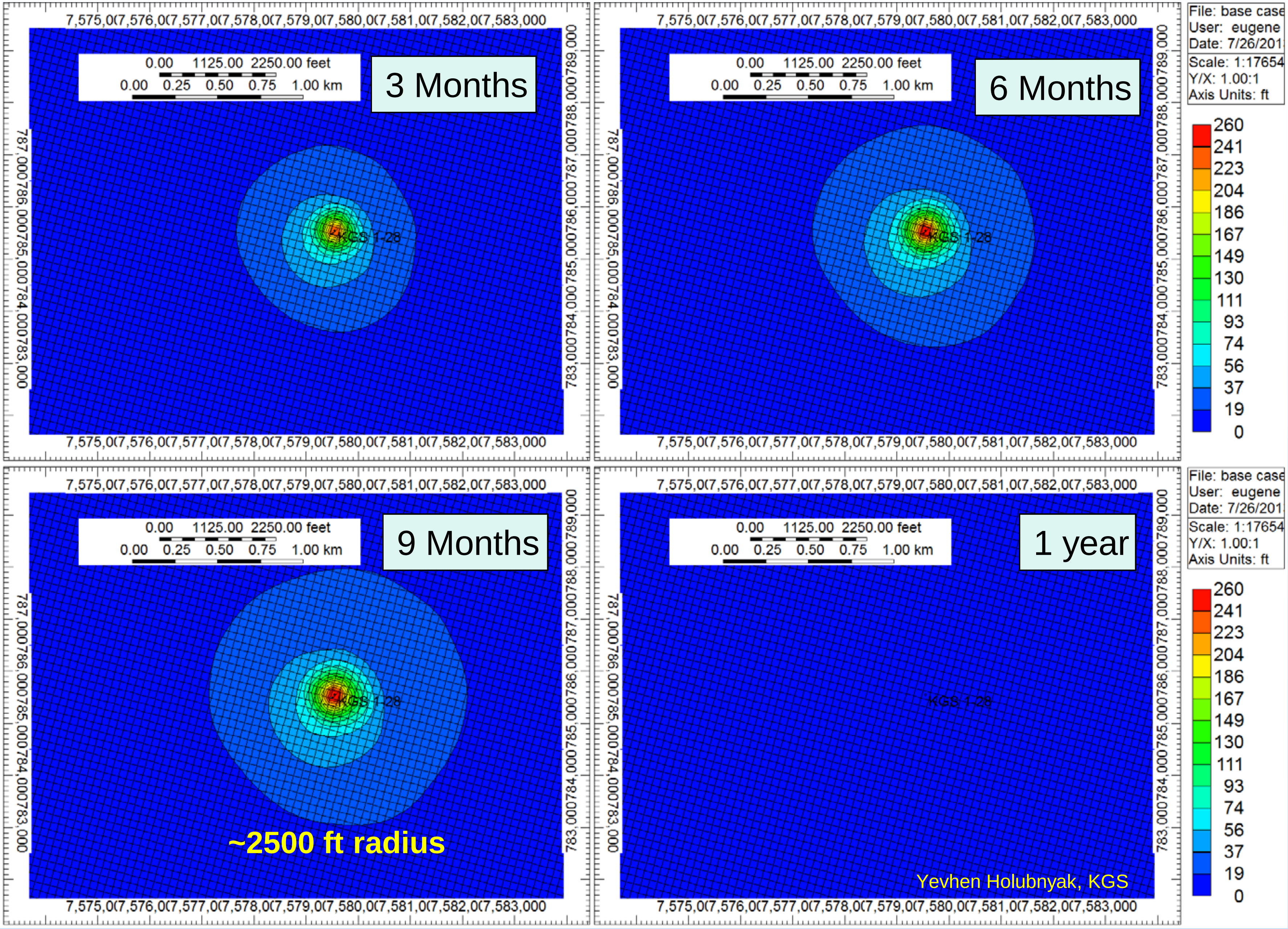


Yevhen Holubnyak, KGS

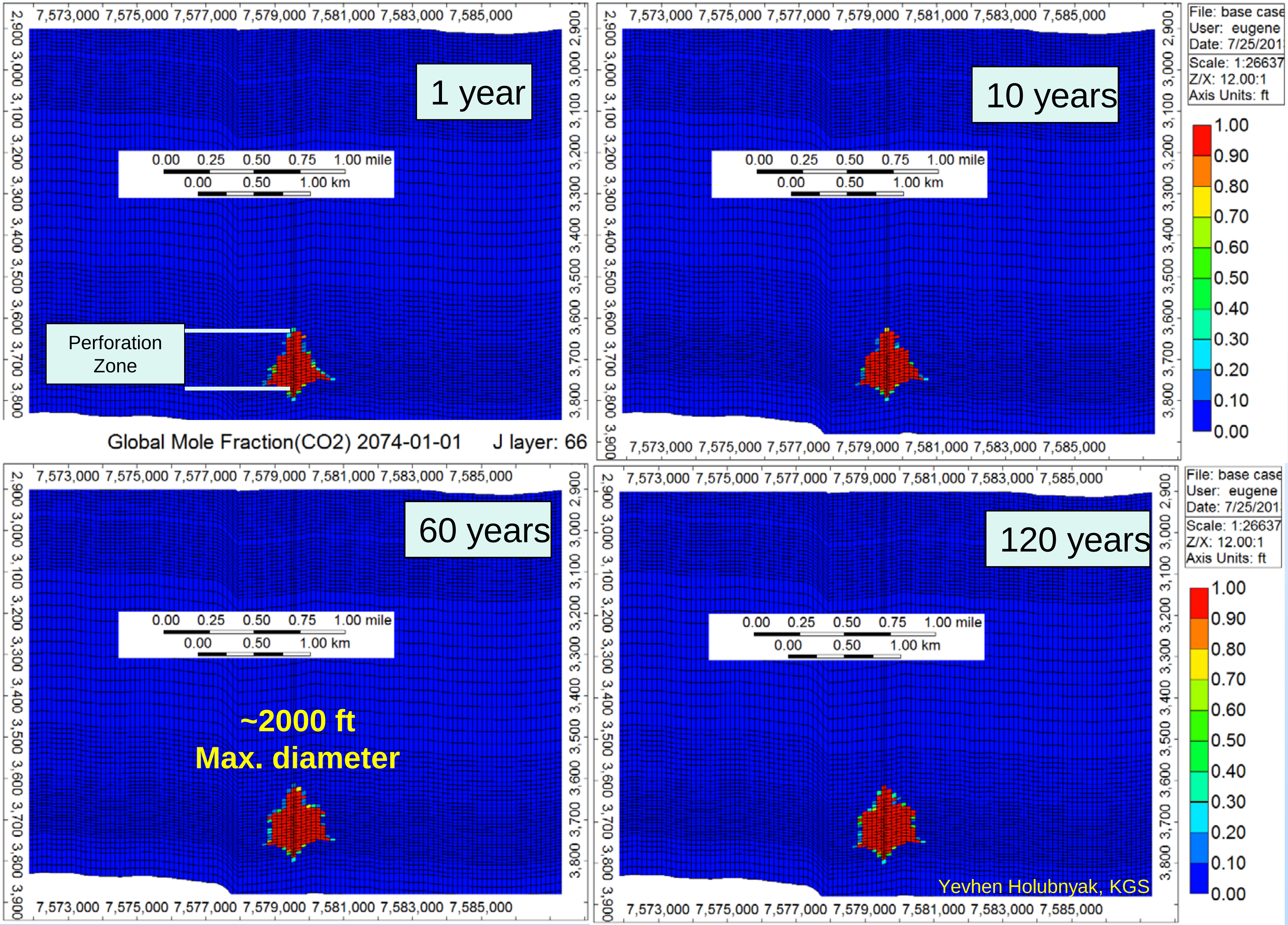
Vertical Delta Pressure Distribution



Lateral Delta Pressure Distribution

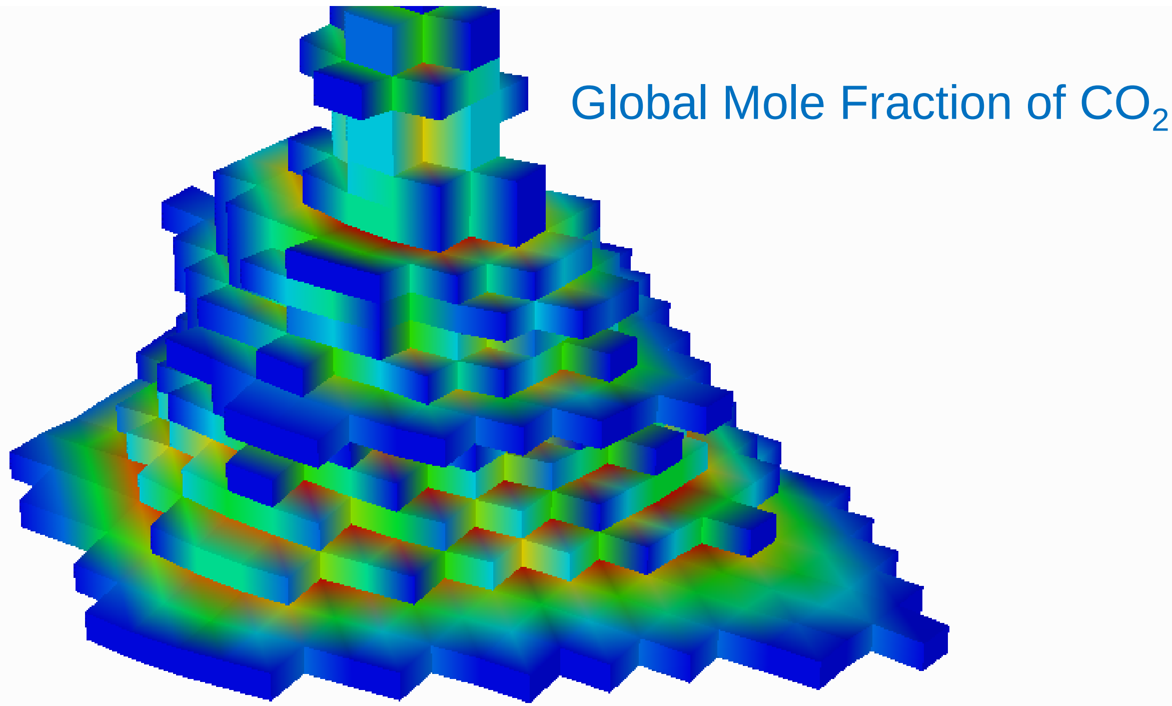


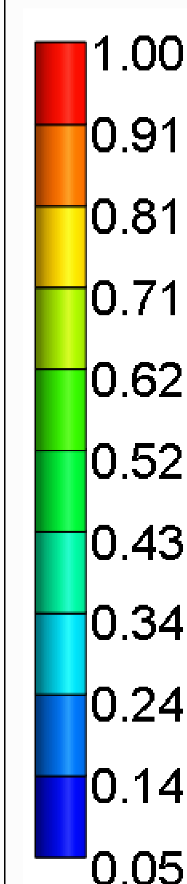
CO_2 Plume Vertical Extent in the Arbuckle



Free Phase CO_2 Extends Out Along Flow Units of Injection Zone

40,000 tonnes confined to Arbuckle injection interval 1 year after injection





- **Maximum diameter <2000 ft; layered aquifer in 150 ft injection interval**
- **Utilize seismic, whole core, and Techlog[tm] for Petrel[tm] static model**
- **CMG compositional dynamic model**

Yevhen Holubnyak, KGS

Accomplishments to Date

- **Multiple static and dynamic models of injection zone and caprock**
- **Class VI Injection Permit – completing internal review**
- **Latest modeling results for Class VI application**
  - Transmissibility of the Arbuckle saline aquifer – new $k_{v,h}$, injection below conservative fracture gradient
  - Capacity of Arbuckle – adequate continuity and thickness
  - Fate of the CO_2 -- solution, dissolution, and capillary entrapment
  - Caprock integrity – fully cored and analyzed, phi-k, clay, continuity, mechanical properties
- **Kansas Class VI application directed to facilitate the review process and enable discussions with EPA on appropriate financial assurance and an early closure of this small scale test.**

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 (325 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 late 2013

– Begin field work for Class II EOR activities after negotiations with new source of CO_2 are completed

– Inject CO_2 into Mississippian oil reservoir first (mid 2014), followed by saline aquifer (mid 2015)

– Incorporate continuous and surface fiber optic acoustic recording

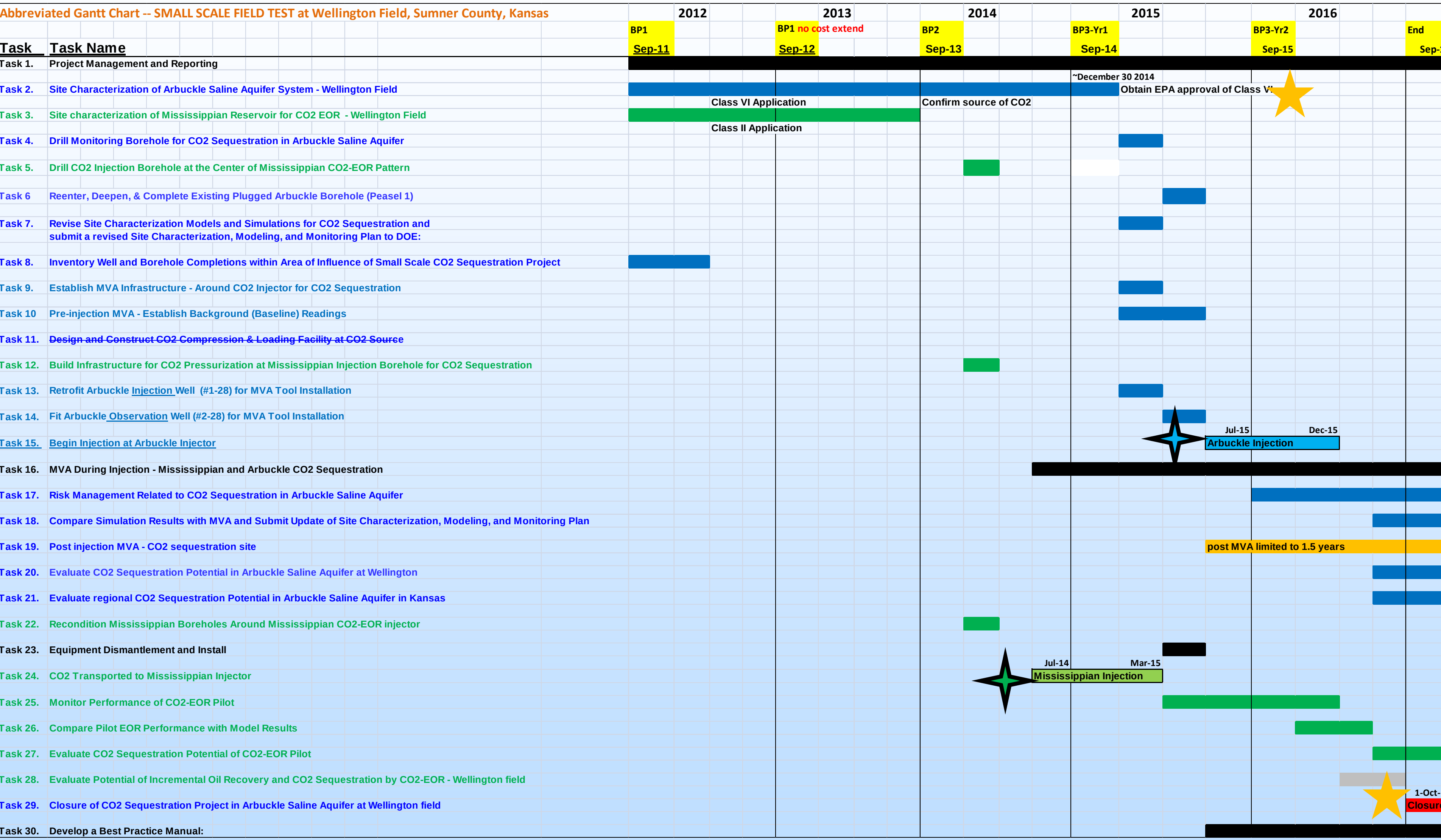
(recently funded proposal, FOA 798 – Rob Trautz, PI, EPRI)

Appendix

ORGANIZATION CHART

Name	Project Job Title	Primary Responsibility
Kansas Geological Survey		
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	
TBN	Graduate Research Assistant	Aqueous geochemistry
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

Gantt Chart – DE-FE0006821



Project ends 9/30/16

Bibliography

List peer reviewed publications generated from project per the format of the examples below

- Journal, multiple authors:
  - Barker, R., Watney, W., Scheffer, A., Strazisar, B., Rush, J.., Bhattacharya, S., Campbell, B., and Datta, S*, in review, Geochemical and Mineralogical Characterization of the Arbuckle aquifer: Studying mineral reactions and its implications for CO_2 sequestration: Chemical Geology.

Bibliography

- Publication:

  - Watney, W.L., 2013, January 31st, AAPG Mississippian Forum, Oklahoma City, OK, Mississippian Carbonate and Chert Reservoirs in Kansas: Integrating Log, Core, and Seismic Information -- Lynn Watney (based primarily on Wellington Field) – discussion of caprock and Arbuckle as a disposal zone for brine and CO2
  - Watney, W.L., 2013, February 18-19, Applied Geoscience Conference, Houston, TX, Mississippian Exploration: Stratigraphy, Petrology, and Reservoir Properties -- Lynn Watney (based on new data from Wellington Field, considerations for CCUS, and regional mapping) – include caprock and disposal of brine and CO2
  - Watney, W.L., Newell, K.D., Holubnyak, E., and Raney, J., 2013, "Oil and Gas in Central Kansas Potential for Enhanced Oil Recovery Using CO2", regarding use of petroleum coke in refinery that would include CO2 generation: to McPherson Kansas Development Corporation hosted meeting, April 3.
  - Watney, W.L., 2013, Analysis of the Late Devonian to Early Carboniferous (Fransnian-Tornaisian) Woodford (Chattanooga) Shale, presentation to AAPG Forum Woodford, Oklahoma City, April 11. This is an important caprock in Kansas and Oklahoma.
  - Watney, W.L., 2013, Petrophysical Analyses and Integrated Approaches, April 16-19, AAPG Short Course, Austin, TX. Centerpiece of the course material comes from the DOE-CO2 project.
  - Watney, W.L., 2013, Mississippian Exploration: Stratigraphy, Petrology, and Reservoir Properties with an emphasis on Wellington Field, April 23, Denver, RMAG & PTTC Symposium titled, "Making Money with Science", April 23, Denver, Colorado.
  - W. Lynn Watney, John Youle, Dennis Hedke, Paul Gerlach, Raymond Sorenson, Martin Dubois, Larry Nicholson, Thomas Hansen, David Koger, and Ralph Baker, 2013, Sedimentologic and Stratigraphic Effects of Episodic Structural Activity During the Phanerozoic in the Hugoton Embayment, Kansas USA: AAPG Annual Meeting, Oral presentation, Pittsburgh, PA, May 21
  - W. Lynn Watney, Jason Rush, Martin Dubois, Robinson Barker, Tiraz Birdie, Ken Cooper, Saugata Datta, John Doveton, Mina Fazelalavi, David Fowle, Paul Gerlach, Thomas Hansen, Dennis Hedke, Yevhen Holubnyak, Breanna Huff, K. David Newell, Larry Nicholson, Jennifer Roberts, Aimee Scheffer, Ayrat Sirazhiev, Raymond Sorenson, Georgios Tsoflias, Eugene Williams, Dana Wreath, John Youle, 2013, Evaluating Carbon Storage in Morrowan and Mississippian oil fields and Underlying Lower Ordovician Arbuckle Saline Aquifer in Southern Kansas: AAPG Annual Meeting, Poster, Pittsburgh, PA, May 20.

Bibliography

Publications:

- DOE Site visit and project review, June 3-5, 2013, Regional CO2 Storage, Wellington and Cutter field calibration sites, SW Kansas CO2-EOR Initiative, and Small Scale CO2 Test Injection at Wellington, Wichita, KS.
- Lyle, S., Buchanan, R., Watney, L., Rush, J., Raney J., and Brian Dressel, DOE Project Manager, 2013, Presentation to the KGS Annual Kansas Field Conference participants including Kansas legislators and state officials, morning of Tuesday, June 4th, Meet bus at site of Wellington KGS #1-32. Brought core and posters in addition to describing DOE-CO2 project and answering questions pertaining economics, safety, and policy.
- Papers at Midcontinent Section meeting AAPG,
- Seismic attribute analysis of the Mississippian chert at the Wellington field -- Aryrat Sirazhiev
- Core transect across Shuck Pool: A Chesterian incised valley fill succession in Seward County, KS -- John Youle
- Online Development of New Kansas Type Logs -- Paul Gerlach
- In Situ Validation of PSDM Seismic Volumetric Curvature as a Tool for Paleokarst Heterogeneity Studies: Results from an Extended-Reach Lateral at Bemis-Shutts -- Jason Rush
- Reservoir Engineering Aspects of Pilot Scale CO2 EOR Project in Upper Mississippian Formation at Wellington Field in Southern Kansas - Eugene Holubnyak
- Dynamic Modeling of CO2 Geological Storage in the Arbuckle Saline Aquifer at Wellington Field -- Eugene Holubnyak
- CO2 Enhanced oil recovery and CO2 sequestration potential of the Mississippian Chester -- Martin Dubois
- Systematic and episodic structural deformation in southern Kansas and implications for CCUS -- Lynn Watney
- Evaluating CO2 Utilization and Storage in Kansas -- Lynn Watney
- Core workshop -- Wellington KGS #1-32, Sumner County, and Cutter KGS #1, Stevens County, Kansas -- Lynn Watney