Evaluating CO_2 Utilization and Storage in Kansas*

W. Lynn Watney[1] and Jason Rush[1]

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*Adapted from presentation by first author, as an update on DOE-funded projects, at Tulsa Geological Society dinner meeting, January 8, 2013

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Abstract

A multi-year interdisciplinary collaboration with local petroleum industry is evaluating technologies and methodologies to support CO_2 utilization and storage in Kansas. The study has two main objectives 1) establishing the regional capacity and feasibility of storing CO_2 in the in the Lower Ordovician Arbuckle saline aquifer in southern Kansas and 2) modeling five fields in that region to evaluate suitability for CO_2-EOR. A follow-up small field test at Wellington Field in Sumner County Kansas will evaluate CO_2-EOR in the Mississippian dolomitic chert and CO_2 storage in the underlying Arbuckle.

The regional structural and stratigraphic analysis utilizes a developing digital well log database, donated regional 3D seismic data, reprocessed state-wide gravity-magnetics, and remote sensing information. Three basement tests have been drilled and 20 mi^2 of multicomponent seismic have been acquired at Wellington Field in Sumner County and Cutter Field in Stevens County operated by Berexco, LLC. These and three other Chester oil fields serve as calibration sites for the regional assessment. An online interactive mapper permits access to this information.

Key findings to date include initial estimates of CO_2 storage in the Arbuckle ranging from 8.8 and 75.5 billion metric tons. Core, logs, seismic, DST, geochemical and microbial analysis, and step-rate test at Wellington Field indicate that lower Arbuckle is a primary injection interval (~200 ft thick) overlain by widespread thick (~400 ft) baffle/barrier in mid Arbuckle. Geochemical and microbial analyses indicate that upper and lower portions of the Arbuckle saline aquifer are not in hydraulic communication. Thick (~120 ft) Lower Mississippian ("Pierson Formation.") shaly strata augment the Chattanooga Shale in south-central Kansas as a potential caprock. Initial simulations for CO_2-EOR in the Chester sandstone reservoir at Pleasant Prairie South indicate 1.4 million tons of CO_2 could be injected during CO_2-EOR at ~5 mcf CO_2/bbl of oil, leading to ~ 2 million bbls of incremental oil production, doubling current cumulative production.

Future Plans include evaluating best practices for monitoring and verifying CO_2 for the small scale injection and continuing to provide technical information to the petroleum industry for implementation of CO_2 utilization and storage.

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"Evaluating CO_2 Utilization and Storage in Kansas"

Update on DOE-funded projects

a) Characterization of CO_2 sequestration capacity southern Kansas (DE-FE0002056)
b) Small scale field test at Wellington Field, Sumner County (DE-FE0006821)
c) Arbuckle modeling with horizontal drilling (DE-FE0004566)

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KSCO2

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TULSA, OK.
EST. 1920

Outline

- **Locations of studies, schedule, fundamental principles**
- **Accomplishments**
  - **Regional geology & estimate of CO_2 storage capacity in the Arbuckle saline formation in southern Kansas**
  - **Source-sink network for CO_2 utilization and storage**
  - **Calibration sites for CO_2-EOR and Arbuckle saline formation**
    - **Wellington Field, Sumner County (2 new wells, seismic)**
    - **Cutter Field, Stevens County (1 new well, seismic)**
    - **Pleasant Prairie South, Eubank North, and Shuck fields**
      - **Make CO2-EOR ready**
- **Small scale field test at Wellington Field**
  - **Assessment of CO_2 injection zone, caprocks, and isolation from USDW (*Mississippian CO2-EOR & Arbuckle saline aquifer*)**
  - **CO_2 plume management through simulation and MVA**
  - **70,000 metric tons CO2 from nearby ethanol plant**
- **Spin-off research on the Mississippian Lime Play & Lower Paleozoic hydrocarbon system**
- **Summary**

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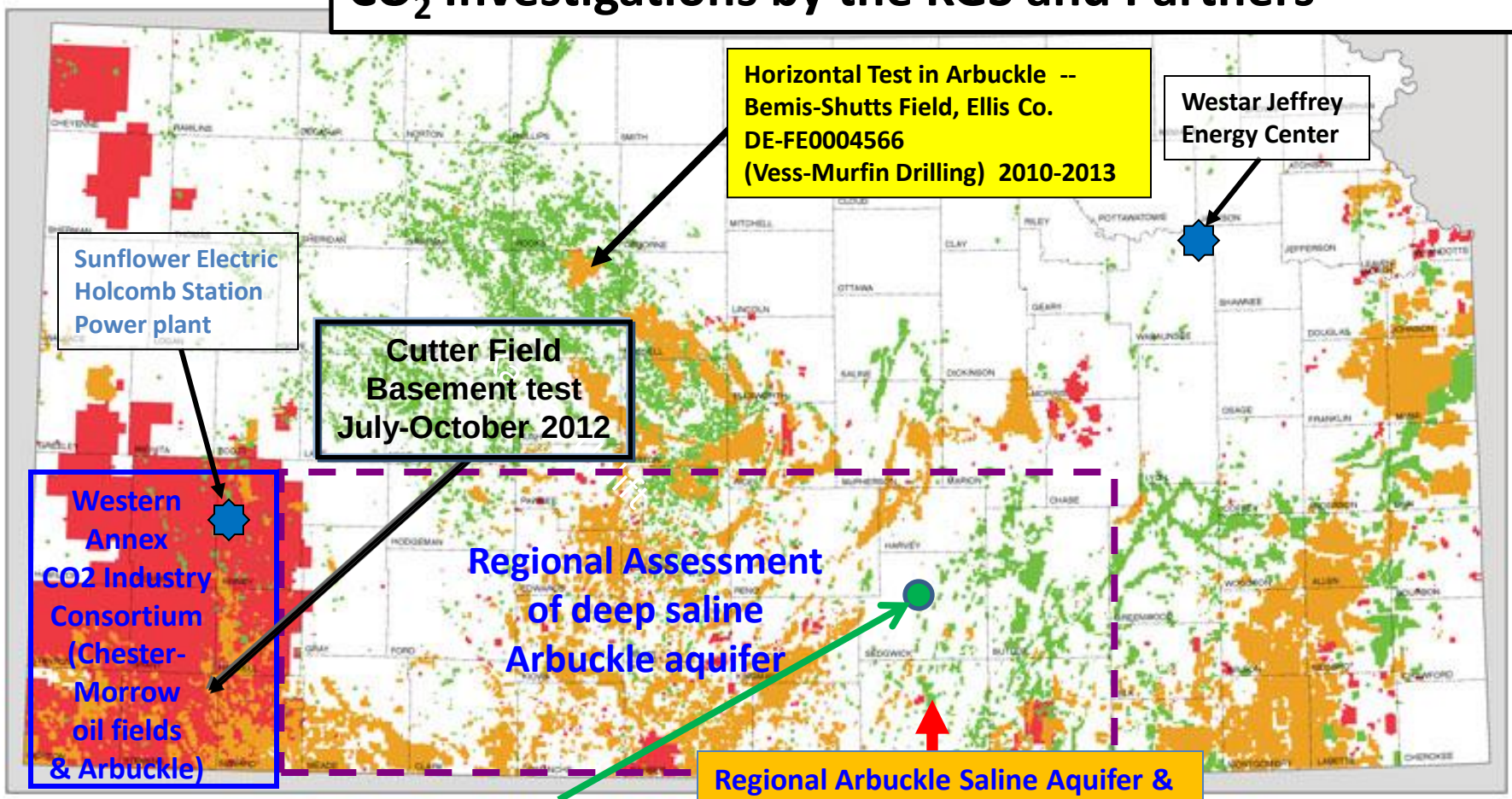
Oil and Gas Map of Kansas & Areas of DOE-Funded CO_2 Investigations by the KGS and Partners



Regional Arbuckle Saline Aquifer & EOR-CO2 Mississippian chert reservoir

Wellington Field (DE-FE0002056)

Funded Jan. 2010-February 2014

Small Scale Field Test @Wellington (DE-FE0006821) (BEREXCO)

Funded Oct 1, 2011-2015

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

Presenter's notes: Projects are to evaluate feasibility for miscible CO_2-EOR in the Mississippian tripolitic chert reservoir and CO_2 sequestration potential in the underlying Arbuckle Group saline aquifer.

Activities at Wellington Field are being carried out through BEREXCO, a subcontractor, who is assisting in acquiring seismic, geologic, and engineering data for analysis. Activities in the regional study are carried out by Bittersweet Energy, Inc., who is characterizing the Arbuckle Group (saline) aquifer in southern Kansas. IHR/Marty Dubois is managing the industrial partnership to prove-up potential of CO_2 -EOR in select Chester/Morrow fields in SW Kansas.

Over 200 mi^2 of donated 3D seismic is being reprocessed and depth-converted in the Western Annex and 10 mi^2 of new multicomponent 3D will be acquired to assist in choosing a well location.

A basement test was scheduled to be drilled in southwestern Kansas in2 to augment two recently drilled basement tests at Wellington Field. Sunflower Electric Power Corporation in Hays has endorsed the project.

Southwest Kansas CO_2-EOR Initiative

Industry Partners (modeling 4 Chester/Morrowan oil fields to make CO2 ready)

IHR Improved Hydrocarbon Recovery LLC

HEDKE-SAENGER GEOSCIENCE, LTD

SUNFLOWER ENERGY LLC

fairfieldnodal

CIMAREX

GloriOil

BEREXCO

Anadarko Petroleum Corporation

Dawson-Markwell Exploration Co.

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

ORGANIZATIONAL STRUCTURE

Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas

Principal Investigators

Jason Rush -- Joint PI
W. Lynn Watney - Joint PI

UNIVERSITY OF KANSAS

Kansas Geological Survey

Co-Principal Investigators

Kerry D. Newell -- stratigraphy, geochemistry
Jason Rush -- Petrel geomodeling and data integration
Richard Miller -- geophysics
John Doveton-- log petrophysics and core-log modeling
Jianghai Xia -- gravity-magnetics modeling & interpretation
Marios Sophocleous --geohydrology

Key Personnel

John Victorine -- Java web app development
David Laflen -- manage core & curation
Mike Killion -- modify ESRI map service for project
Jennifer Raney -- asst. project manager
Debra Stewart, Dan Suchy -- data management
Yevhen 'Eugene' Holubnyak, Petroleum Engineer
Fatemeh "Mina" FazelAlavi, Engineering Research Assistant

KU Department of Geology

Co-Principal Investigators

Evan Franseen --sedimentology, stratigraphy
Robert Goldstein -- diagenesis, fluid inclusion
David Fowle -- reactive pathways, microbial catalysis
Jennifer Roberts -- reactive pathways, microbial catalysis
George Tsoflias -- geophysics

Grad Research Assistants

Aimee Scheffer (graduated) -- biogeology & geochemistry
Breanna Huff -- biogeology
Christa Jackson -- biogeology and geochemistry
Ayrat Sirazhiev (graduated) -- geophysics
Yousuf Fadolalkarem -- geophysics
Brad King -- diagenesis

SUBCONTRACTS

Berexco, Beredco Drilling -- *Wichita, KS*

Wellington Field access; drilling, coring, completion and testing; modeling and simulation

Key Personnel

Dana Wreath - manager, reservoir and production engineer
Randy Koudele - reservoir engineer
Bill Lamb - reservoir engineer

Bittersweet Energy, Inc., *Wichita, KS*

Tom Hansen, Principal, Wichita, Geological Supervision - regional data, Arbuckle hydrogeology
Paul Gerlach -- regional data acquisition, 2 yrs.
Larry Nicholson -- regional data acquisition, 2 yrs.
Anna Smith -- regional data acquisition, 2 yrs.
Ken Cooper, Petrotek Engineering, Littleton, CO- engineer, well injection, hydrogeology
John Lorenz, Scott Cooper, FractureStudies, Edgewood, NM -- core fracture study

Kansas State University

Seismic and Geochemical Services

Co-Principal Investigators

Saugata Datta -- reactive pathways and reaction constants
Abdelmoneam Raef -- seismic analysis and modeling

Grad Research Assistants

Robin Barker (graduated)
Derek Ohl - seismic analysis and modeling
Randi Isham -- seismic
Brent Campbell - aqueous geochemistry

Southwest Kansas CO2 EOR Initiative - Chester Morrow

Martin Dubois, IHR, LLC -- team lead, geomodeling
John Youle, Sunflower Energy -- core and depositional models
Ray Sorenson, consultant -- data acquisition and advising
Eugene Williams, Williams Engineering -- reservoir modeling

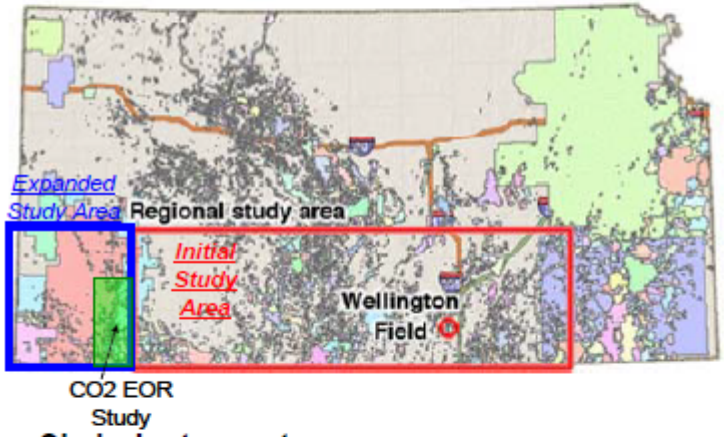
Services

LOGDIGI, LLC, *Katy, TX* - wireline log digitizing
David G. KOGER, *Dallas, TX* - remote sensing data and analysis
Weatherford Laboratories, *Houston, TX* -- core analyses
CMG - Simulation Services, *Calgary, Alberta* --greenhouse gas simulation and software
Halliburton, *Liberal, KS* -- wireline logging services
Hedke-Saenger Geoscience, LTD., *Wichita, KS* - geophysical acquistion, interpret & design
Susan E. Nissen, *McLouth, KS* -- Geophysical Consultant, volumetic curvature
Lockhart Geophysical, *Denver, CO* -- acquis & interpret 2D shear wave, gravity & mag
Fairfield Industries, Inc., *Denver, CO* -- 2D, 3D multicomponent seismic processing
Paragon Geophysical Services, *Wichita, KS* -- 3D seismic acquisition
Echo Geophysical, *Denver, CO* -- 3D seismic processing
Converging Point - QC seismic acquisition
Noble Energy, *Houston, TX; Denver, CO* -- collaborating co., fields adjoining Wellington

Organizational chart (continued)

Southwest Kansas CO2 EOR Initiative
Chester and Morrow Reservoirs

Western Annex to Regional CO2 Sequestration Project (DE-FE0002056) run by the Kansas Geological Survey



Six Industry partners:

- Anadarko Petroleum Corp.
- Berexco LLC
- Cimarex Energy Company
- Glori Oil Limited
- Elm III, LLC
- Merit Energy Company

Support by:
Sunflower Electric Power Corp.

The SW Kansas part of project

- CO2 EOR technical feasibility study – Chester IVF and Morrow
- Part of larger KGS-industry CCS and EOR study
- Will not inject CO2 – paper study only
- Get fields in study "CO2-ready"

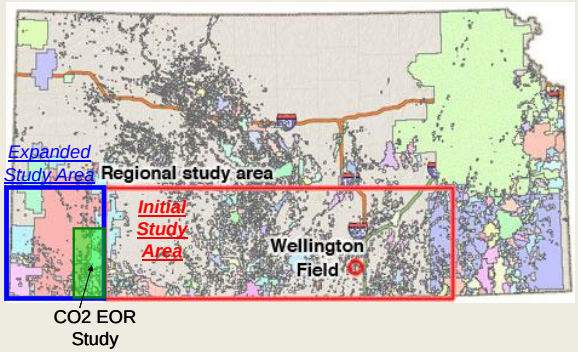
Technical Team:

	Project Role	Company
Martin Dubois	Team Lead, geo-model	IHR LLC
John Youle	Core and depo-models	Sunflower Energy
Ray Sorenson	Data sleuth and advisor	Consultant
Eugene Williams	Reservoir engineering	Williams Petroleum
Dennis Hedke	Geophysicist	Hedke & Saenger
Peter Senior	Reservoir modeling	MS student, KU
Susan Nissen	Geophysicist	Consultant
Lynn Watney	Project PI	KGS
Jason Rush	Project PI	KGS
John Doveton	Log Petrophysics	KGS
Tom Hansen	Subcontract mngr., aquifer	Bittersweet Energy
Paul Gerlach	Regional stratigraphy, data	Charter Consulting
Larry Nicholson	Regional stratigraphy, data	Consultant

Southwest Kansas CO_2-EOR Initiative

Evaluate CO_2 sequestration potential in Arbuckle Group saline aquifer and CO_2-EOR in four fields in southwestern Kansas

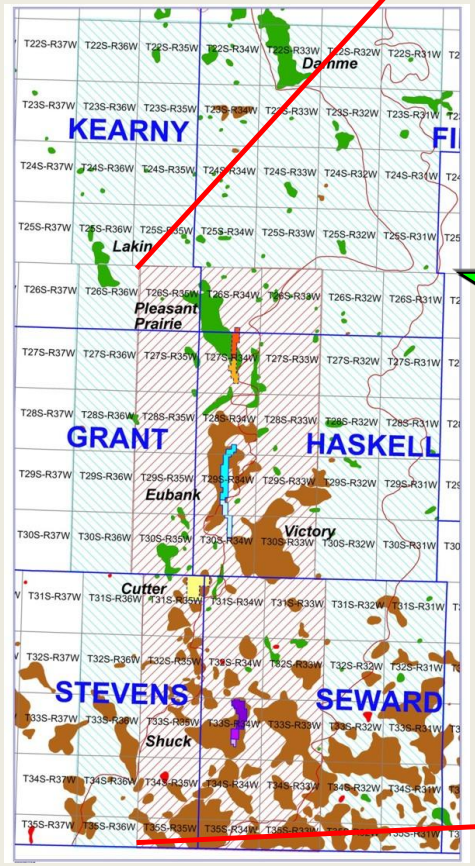
Southwest Kansas CO2 Consortium (*Western Annex*)

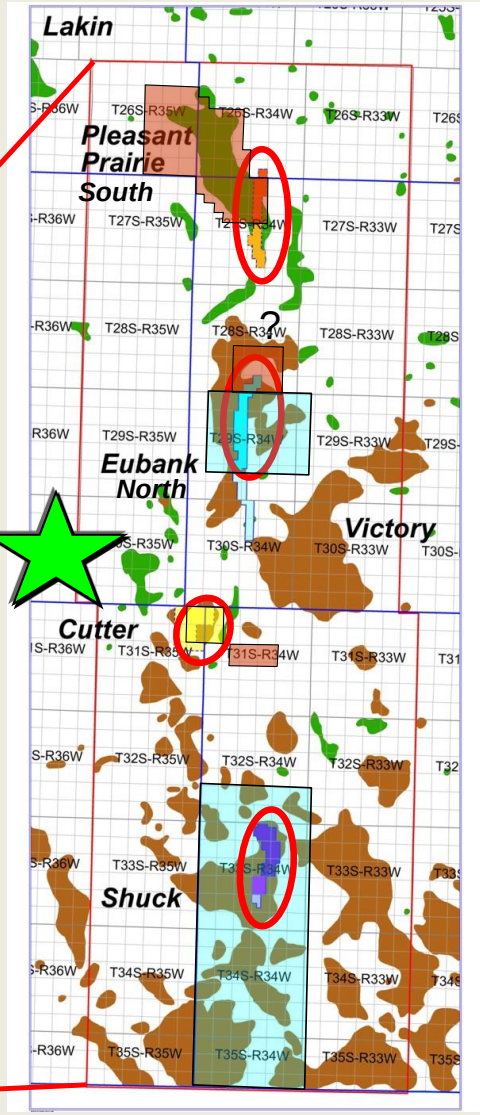


Chester/Morrow Sandstone (IVF) &

Deep saline Arbuckle aquifer

Seismic blocks are color coded by operator (~120 mi^2 of 3D seismic)





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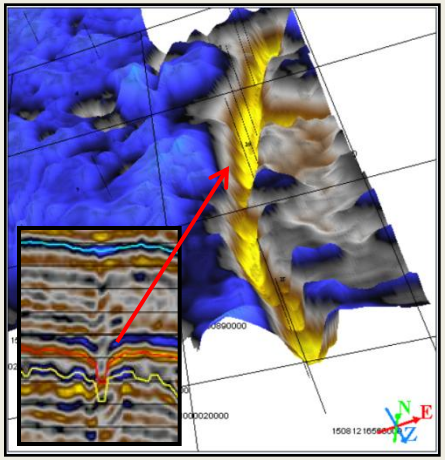
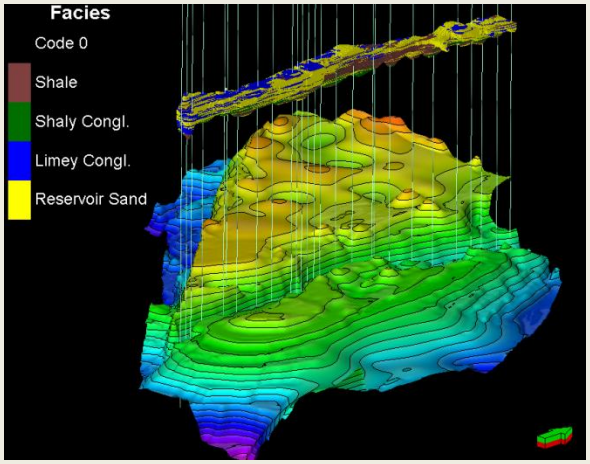
Southwest Kansas CO_2-EOR Initiative

Integrated Multi-Discipline Project for CO_2-EOR Evaluation

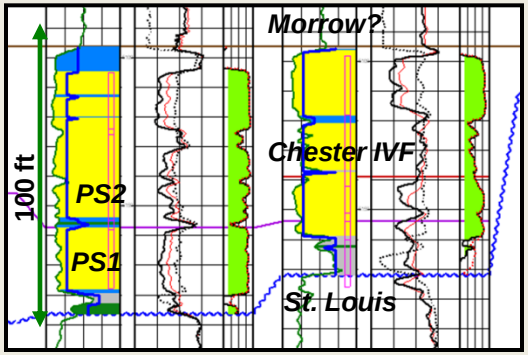
Static Model

Geophysics:
structure, attributes, faults

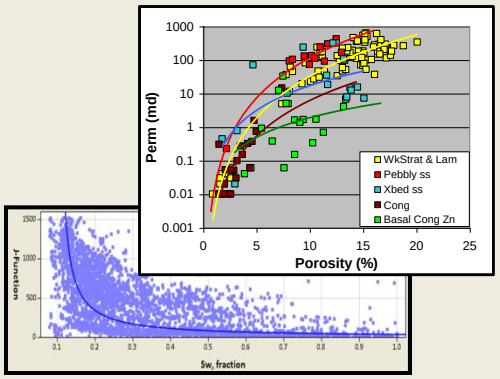




Geology:
Formation tops, sequence stratigraphy, core lithofacies, lithofacies prediction (NNet)

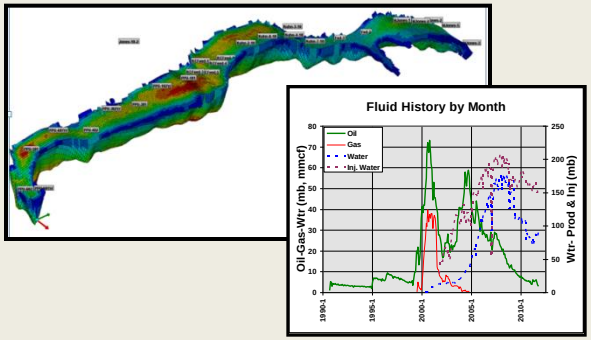


Petrophysics:
Core K-Phi, corrected porosity, free water level, J-function



Engineering:
PVT and fluid analysis, recurrent histories, dynamic modeling

Dynamic Model



Dubois, 2012

Example from modeling of Pleasant Prairie South

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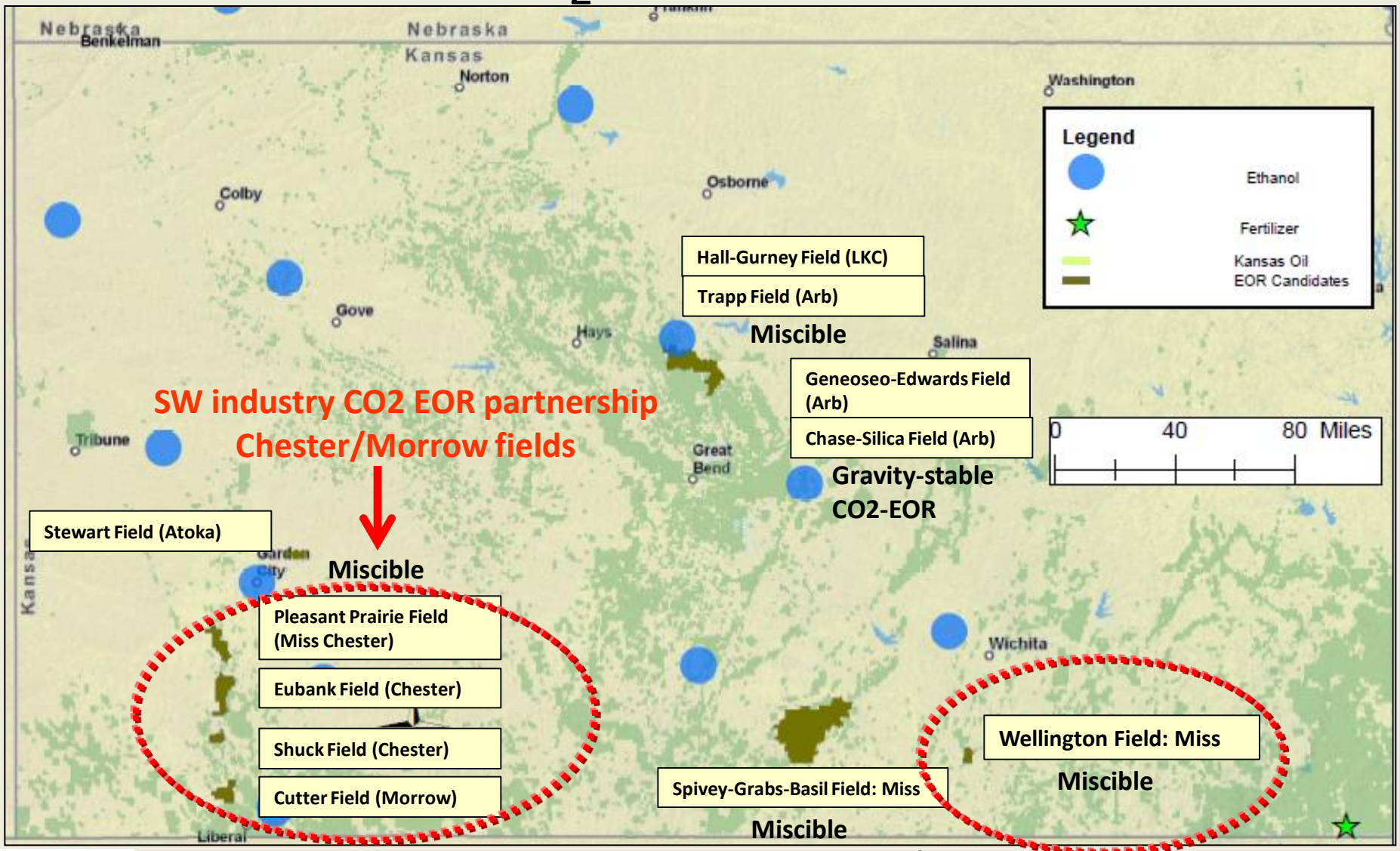
Source-Sink Network for CCUS

(*Carbon Capture, Utilization, and Storage*)

- **Infrastructure for capture and use of CO_2 in Kansas**
  - **1st Step** – Capture from Kansas ethanol plants and use in CO_2-EOR
  - **2nd Step** - Capture from other Kansas point sources and connect pipelines to other regional supplies; use for
    - 1) CO_2-EOR and
    - 2) saline formation sequestration/disposal

KSCO2

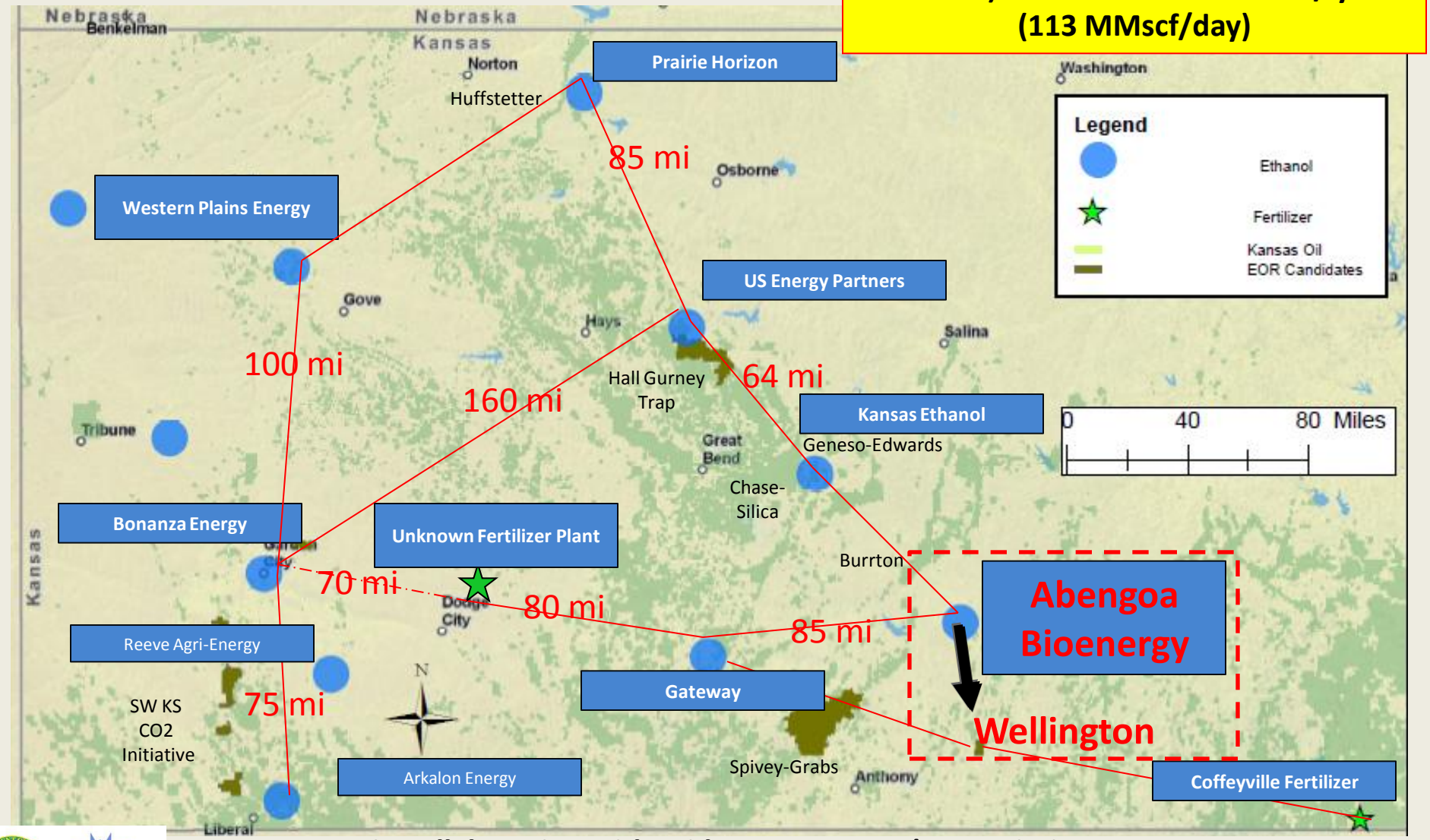
Ethanol Plants and Selected Oil Fields for CO_2-EOR in Kansas



KGS in collaboration with Midwest Governor's Association & Clinton Foundation Climate Initiative

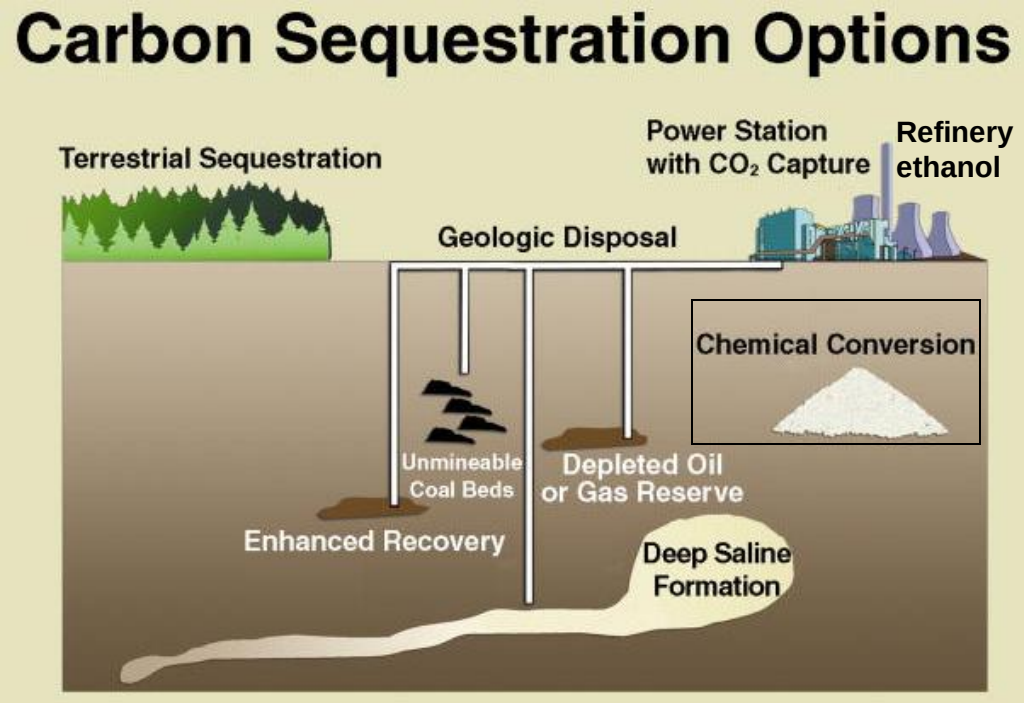
Ethanol CO_2 Pipeline Concept – Step 1

Total annual CO_2 emissions (ethanol + fertilizer): 2.2 million metric tons/ year (113 MMscf/day)



KGS in collaboration with Midwest Governor's Association & Clinton Foundation Climate Initiative

Preeminence of Deep Saline Aquifer Sequestration of CO_2



Industry participation in infrastructure development possible if CO_2-EOR is viable

Global annual CO_2 emissions ≈ $8 * 10^9$ tons

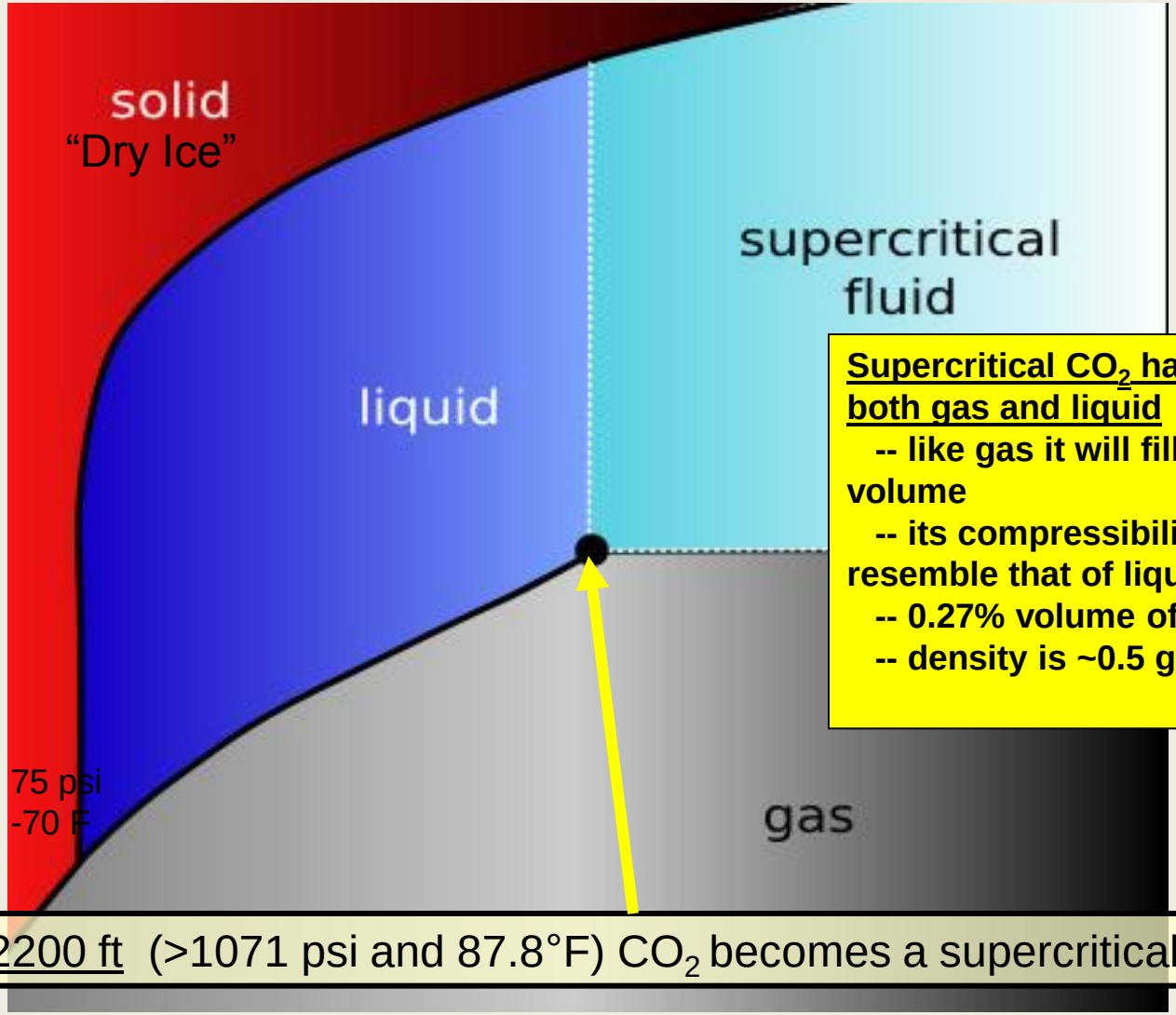
Earth Policy Institute

>400 yrs Current Global emissions

Formation Type	10^9 Metric Tons	%
Saline Aquifers	3,297 – 12,618	91.8 – 97.5
Unmineable Coal Seams	157 – 178	4.4 – 1.4
Mature Oil & Gas Reservoirs	138	3.8 – 1.1
Total Capacity	3,592 – 12,934	100.0

DOE & NETL, "Carbon Sequestration Atlas of the US and Canada", 2008

Supercritical CO_2



Pressure

<u>Supercritical CO_2 has properties of both gas and liquid</u>

-- like gas it will fill any given volume

-- its compressibility properties resemble that of liquid

-- 0.27% volume of gas phase

-- density is ~0.5 g/cc (brine >1 g/cc)

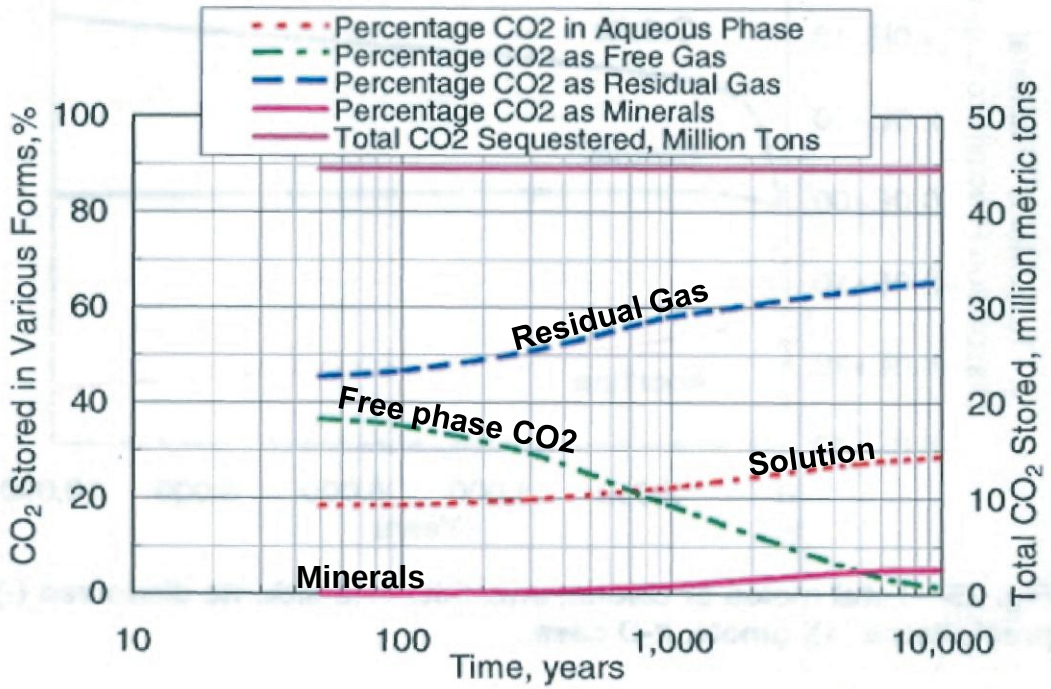
<u>@ depths >2200 ft</u> (>1071 psi and 87.8°F) CO_2 becomes a supercritical fluid

Temperature

Fate and Entrapment of CO_2 in Saline Aquifers

Injected CO_2 entrapped in 4 different ways

- some dissolves in brine
- some gets locked as residual gas (saturation)
- some trapped as minerals
- Remaining CO_2 – resides as free phase
  - Sub- or super-critical as per *in situ* conditions (depth/pressure and temperature)



Ozah, 2005 – In situ CO_2 distribution after 50 years of injection

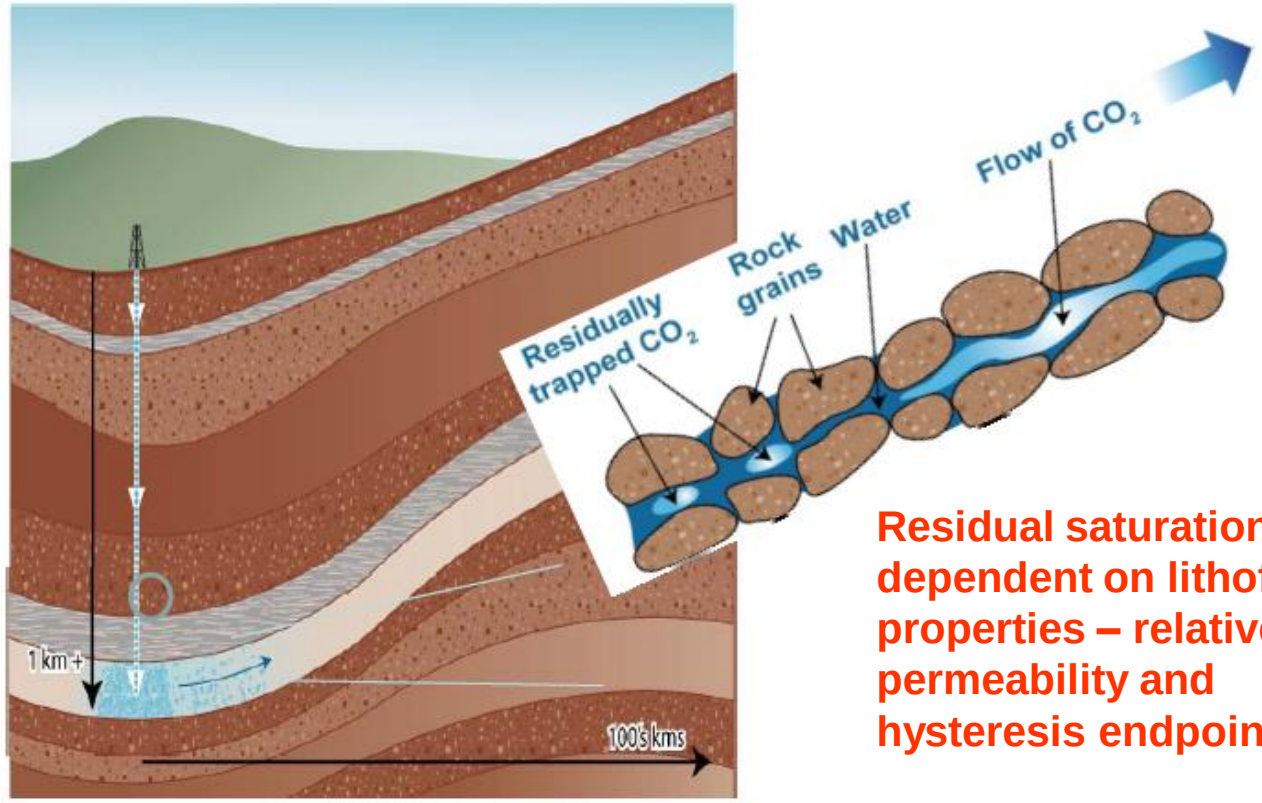
CO_2 Entrapment Audit:

1. ***Residual gas***
   - ***Start 45% to End 65%***
2. ***Solution***
   - ***Start 18% to End 28%***
3. ***Minerals***
   - ***Start negligible to End 5%***
4. ***Free Phase***
   - ***Start 37% to End 2%***

CO_2 Entrapment as Residual Gas

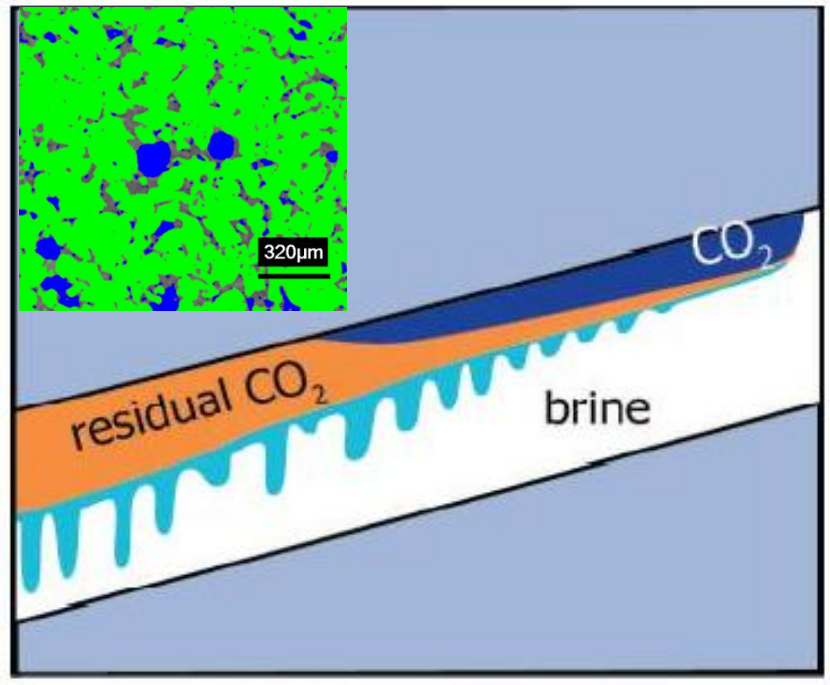
IEA Greenhouse Gas R&D Programme

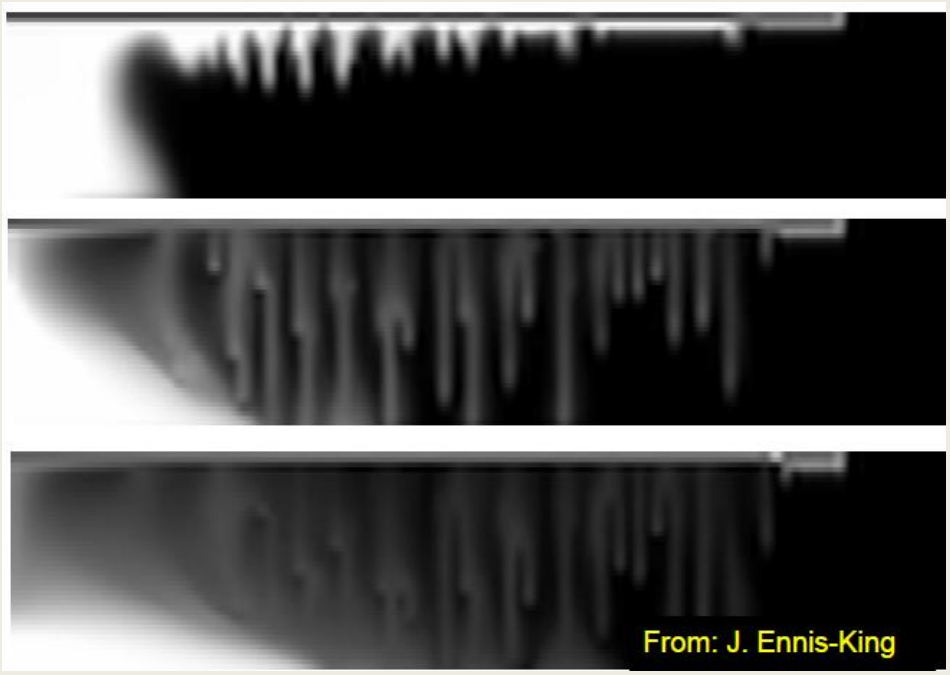
Residual Trapping



Residual saturation dependent on lithofacies properties – relative permeability and hysteresis endpoints

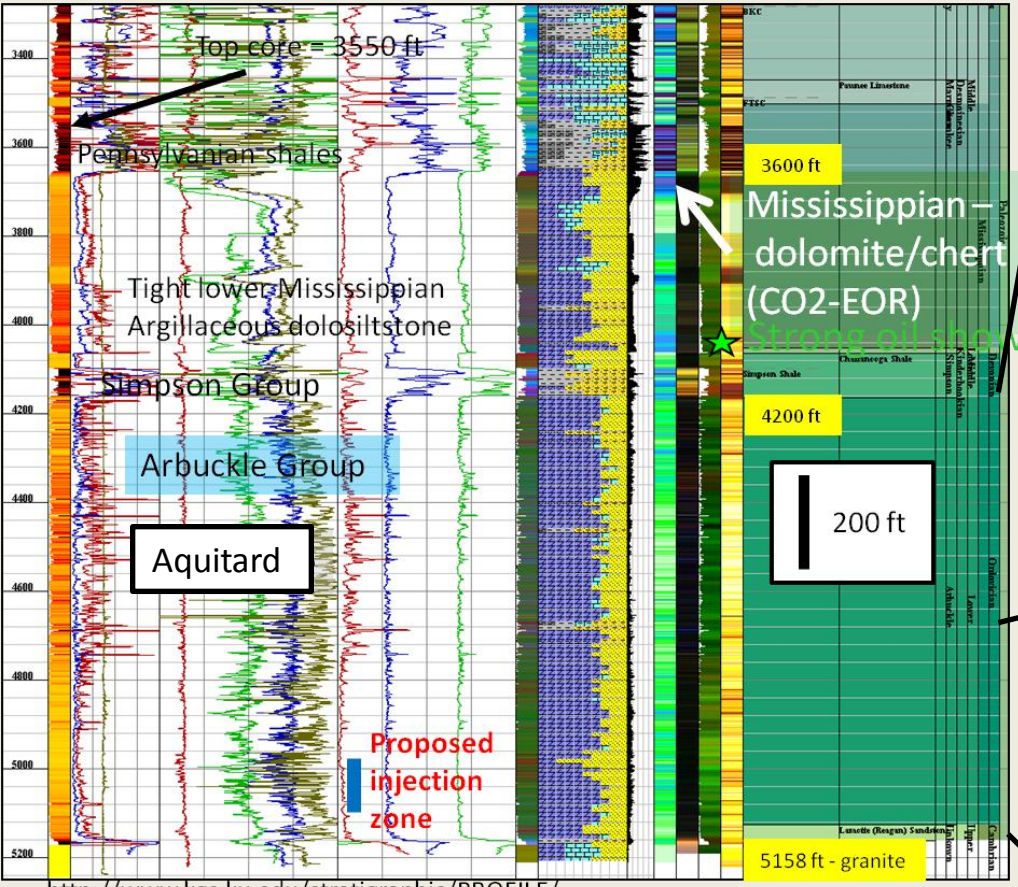
Dissolution of CO_2 in Brine
Convection Cycle Increases Entrapment





-- Convection included in simulators

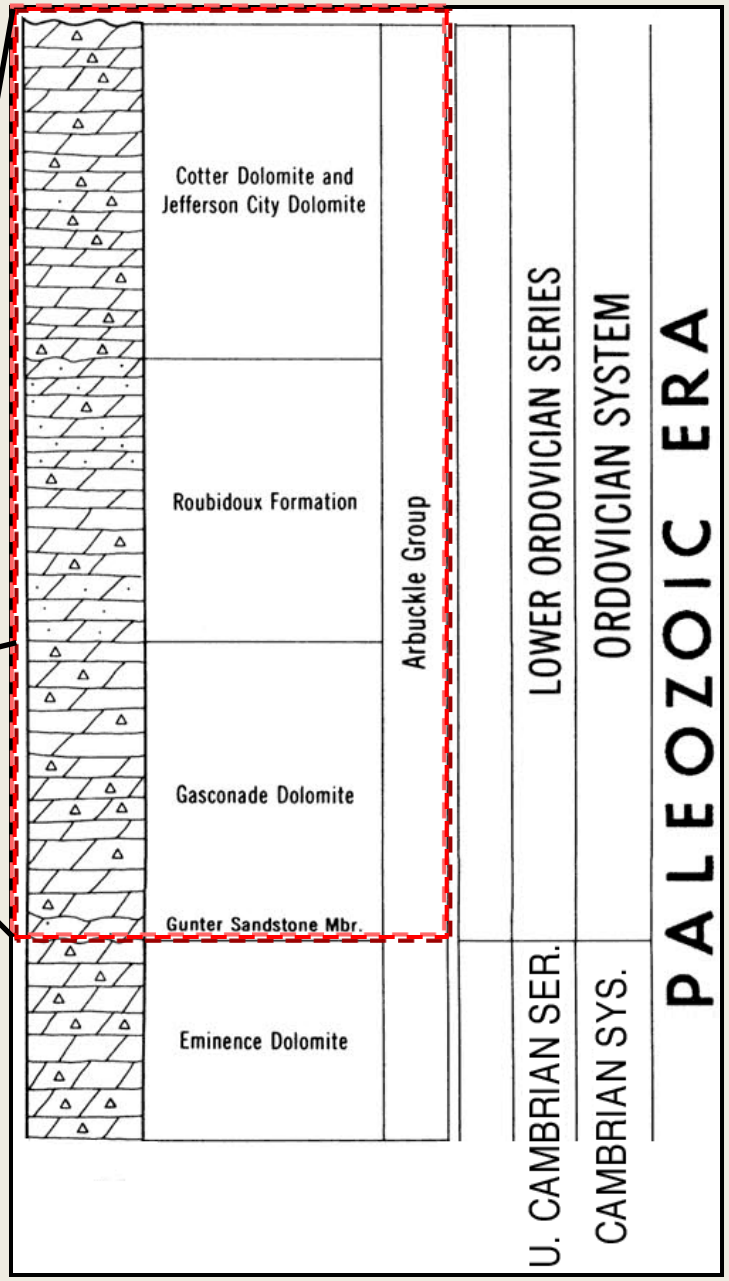
Western Interior Plains Aquifer & Ozark Plateau Aquifer System



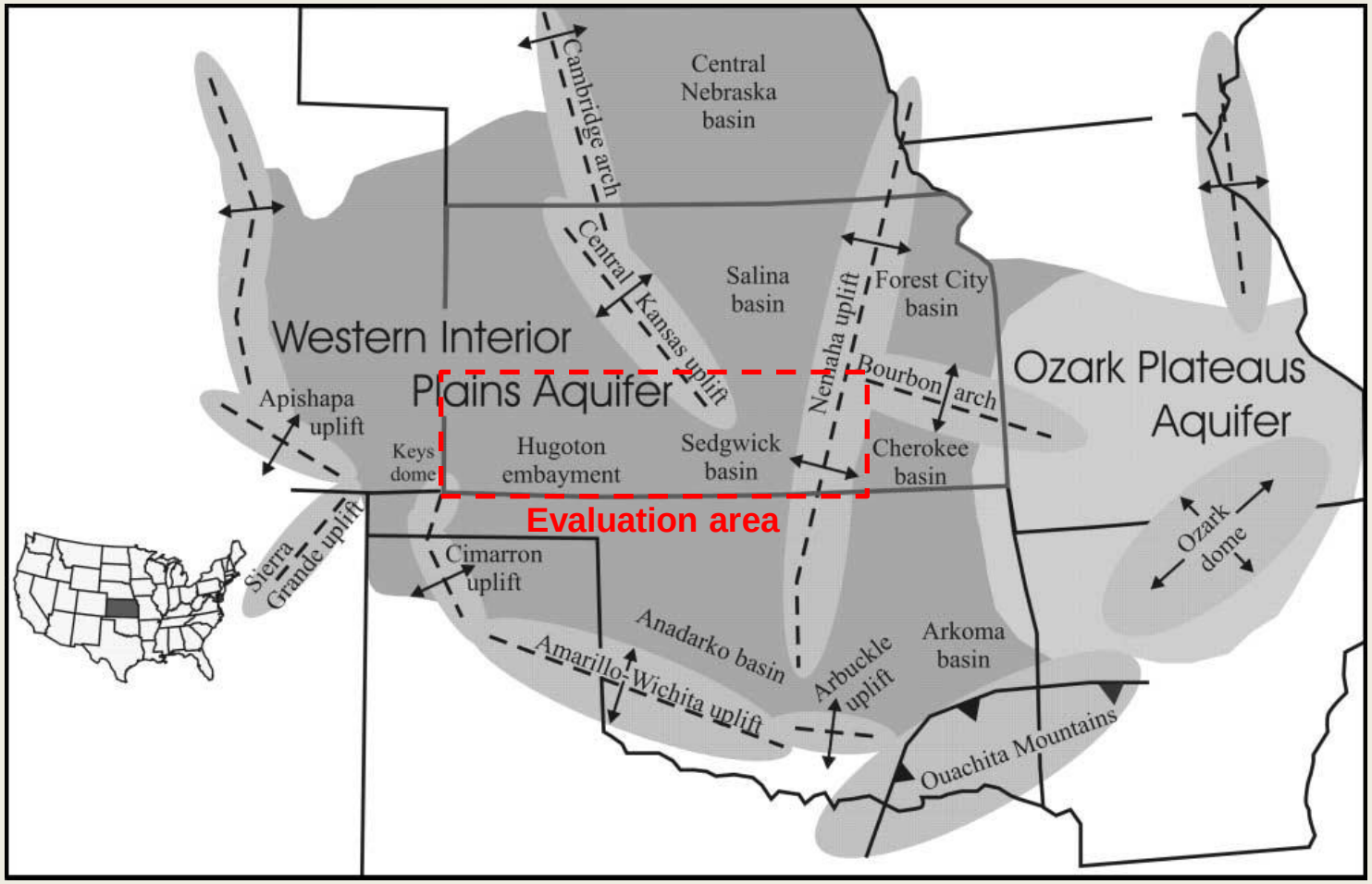
http://www.kgs.ku.edu/stratigraphic/PROFILE/

Cored well, Berexco Wellington KGS #1-32 at Wellington Field, Sumner County

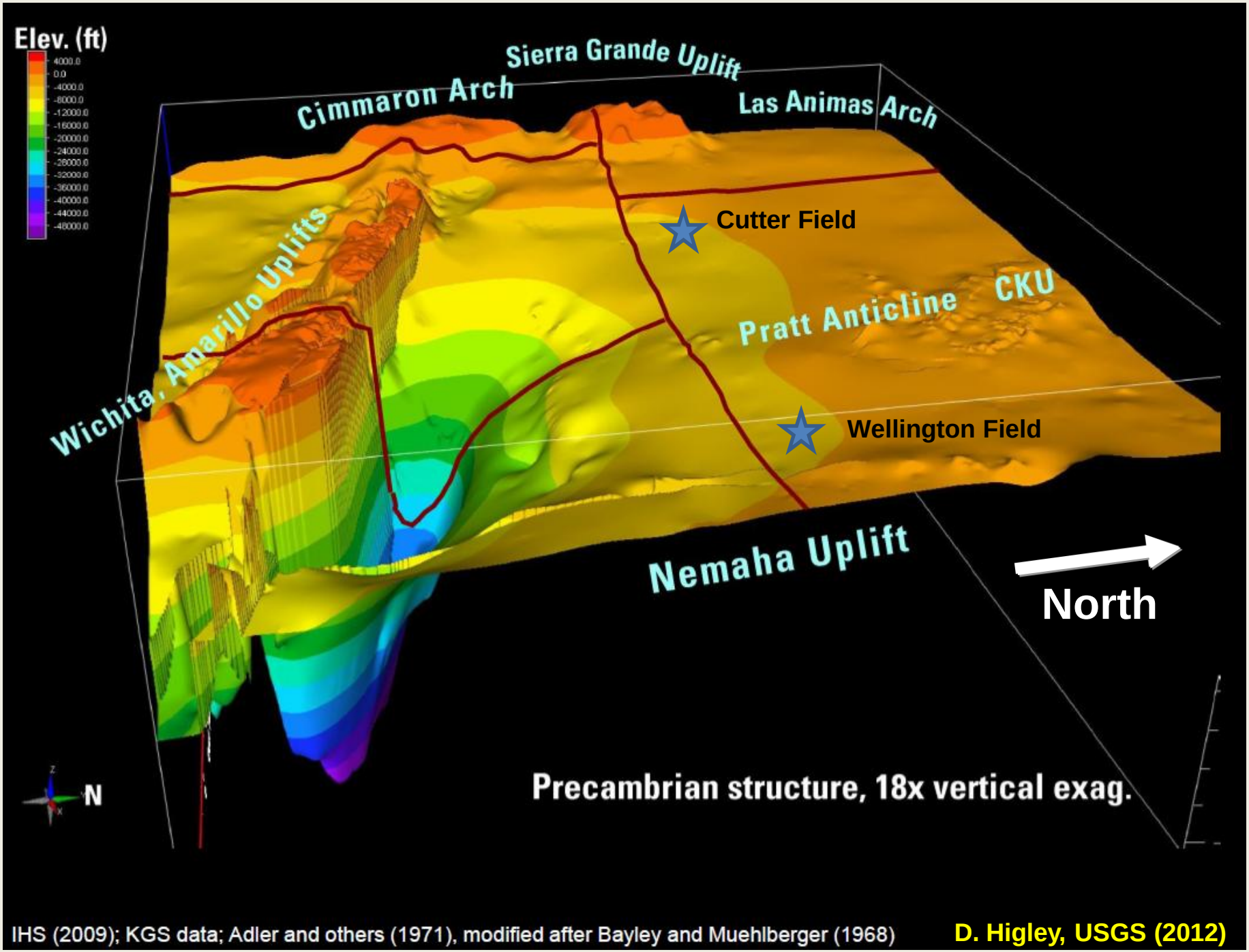
Lower Ordovician Arbuckle Group



Structural features and Paleozoic aquifer systems of the mid-continent



modified from Merriam, 1963; from Jorgensen et al. (1993).
Carr et al., AAPG Bulletin, v. 89, no. 12 (December 2005), pp. 1607–1627

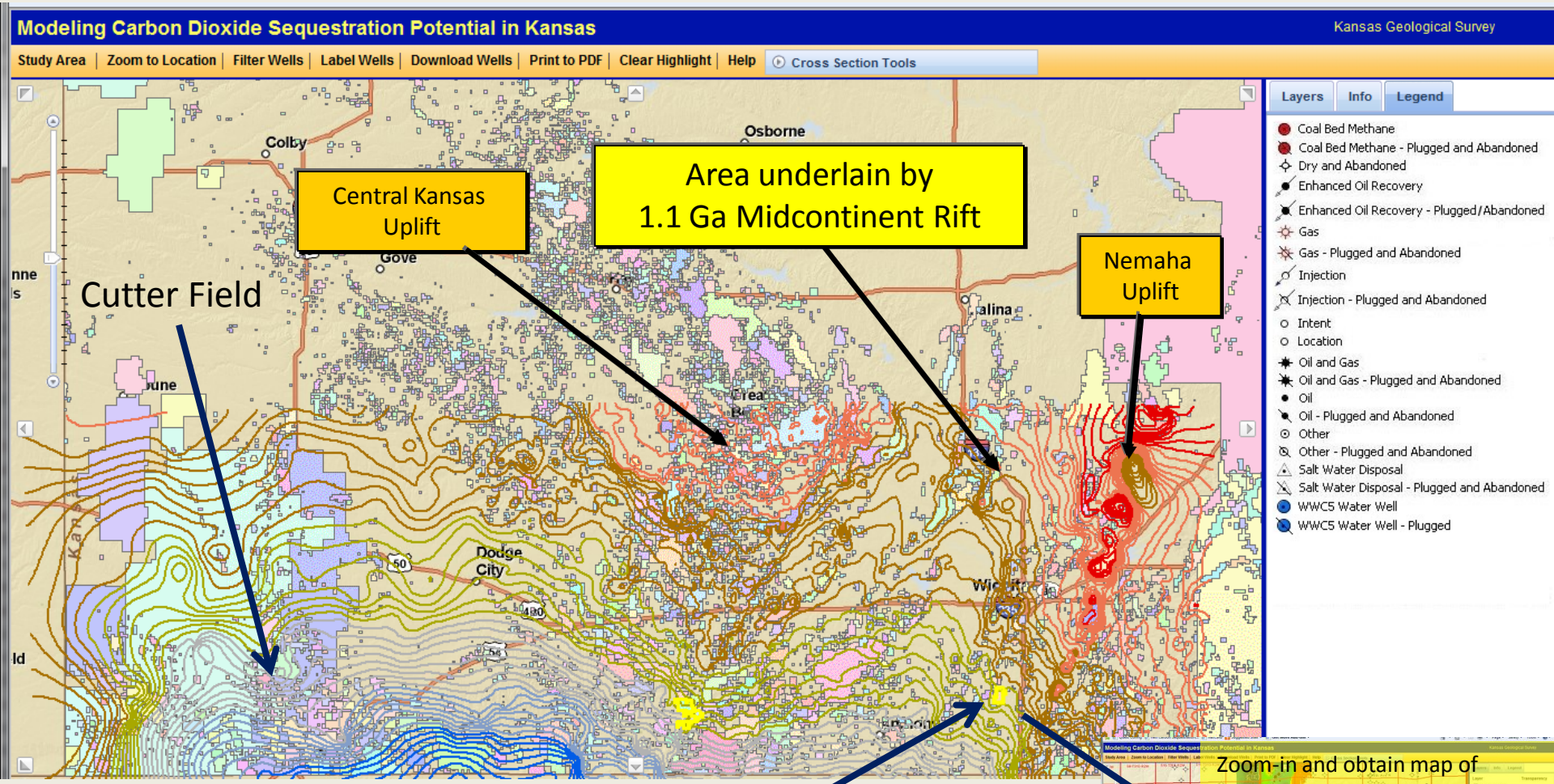


IHS (2009); KGS data; Adler and others (1971), modified after Bayley and Muehlberger (1968)

D. Higley, USGS (2012)

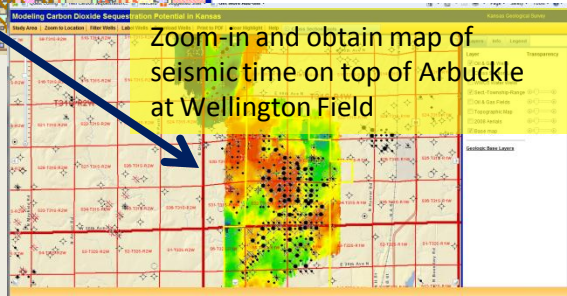
Web-based Interactive DOE-CO2 Project Mapper

Overlay of Oil and gas field outlines and
Top Arbuckle Group in study area of southern Kansas



Contours = Elevation on Top of Arbuckle

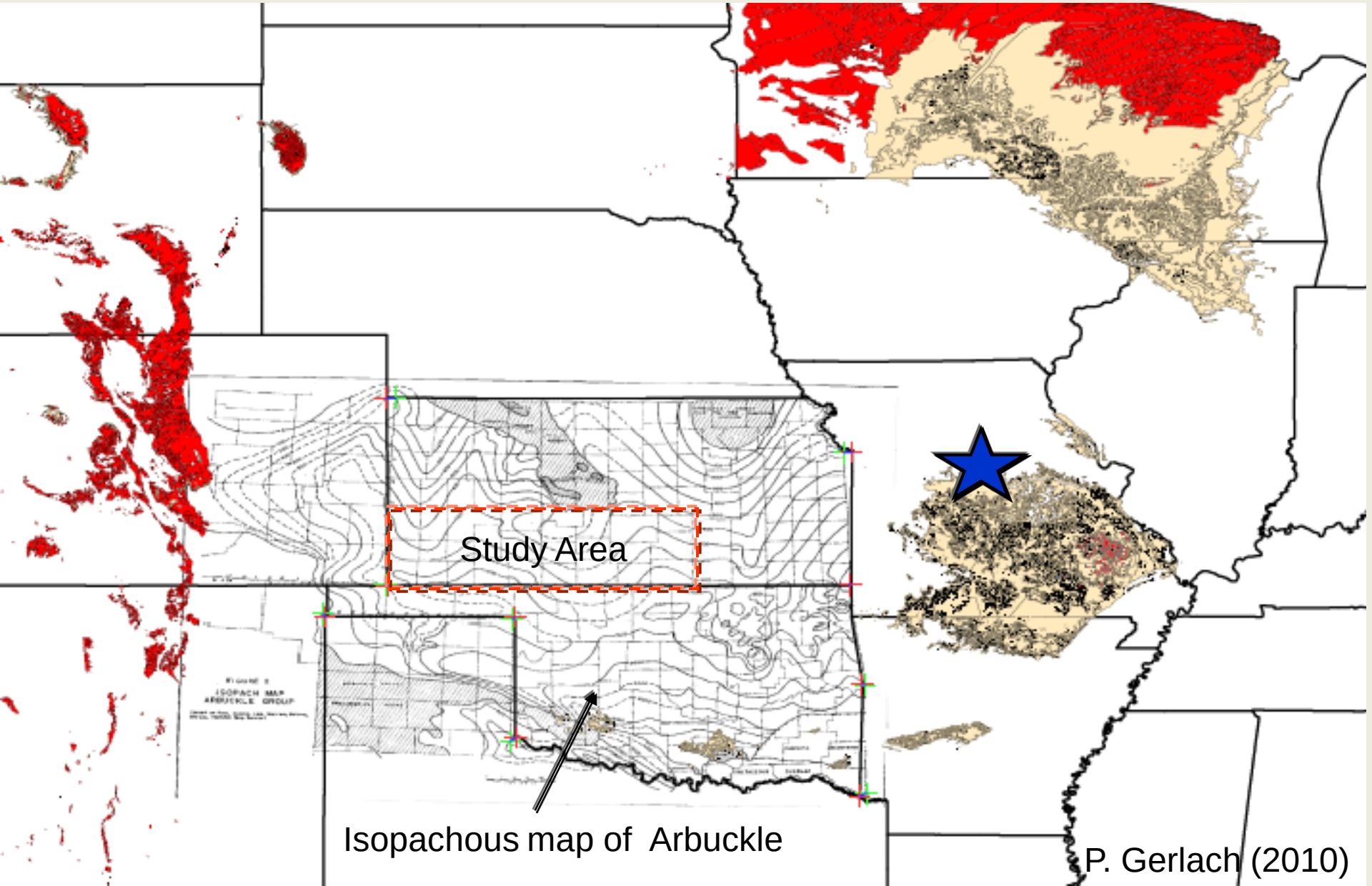
Wellington Field



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

Outcrops of Arbuckle Strata and Isopachous Map of Arbuckle

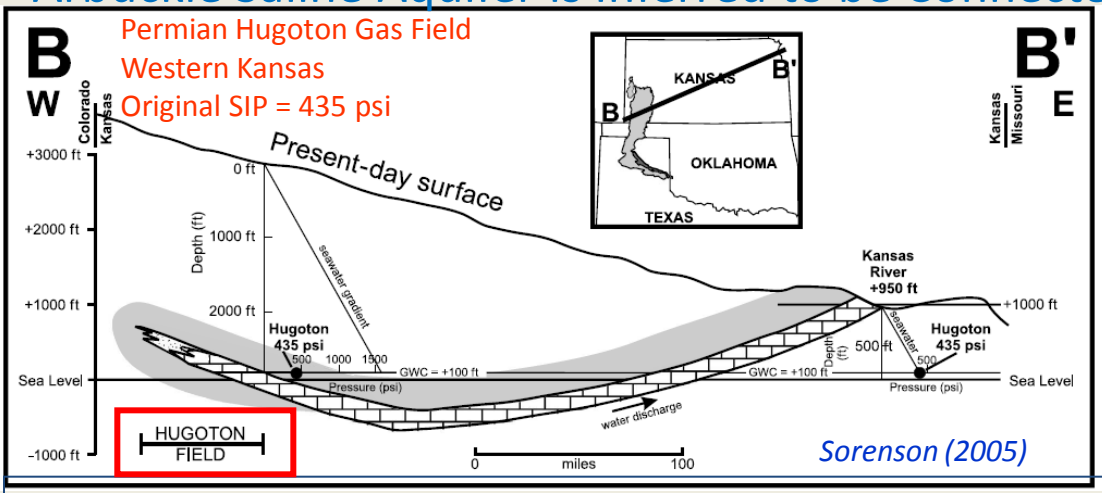
lowest elevation of surface exposures on west flank of Ozark Uplift along Missouri River at Jefferson City, Missouri (~450 ft)



P. Gerlach (2010)

Arbuckle saline aquifer is an open system

Arbuckle Saline Aquifer Is Inferred to be Connected to the Outcrop in Central Missouri

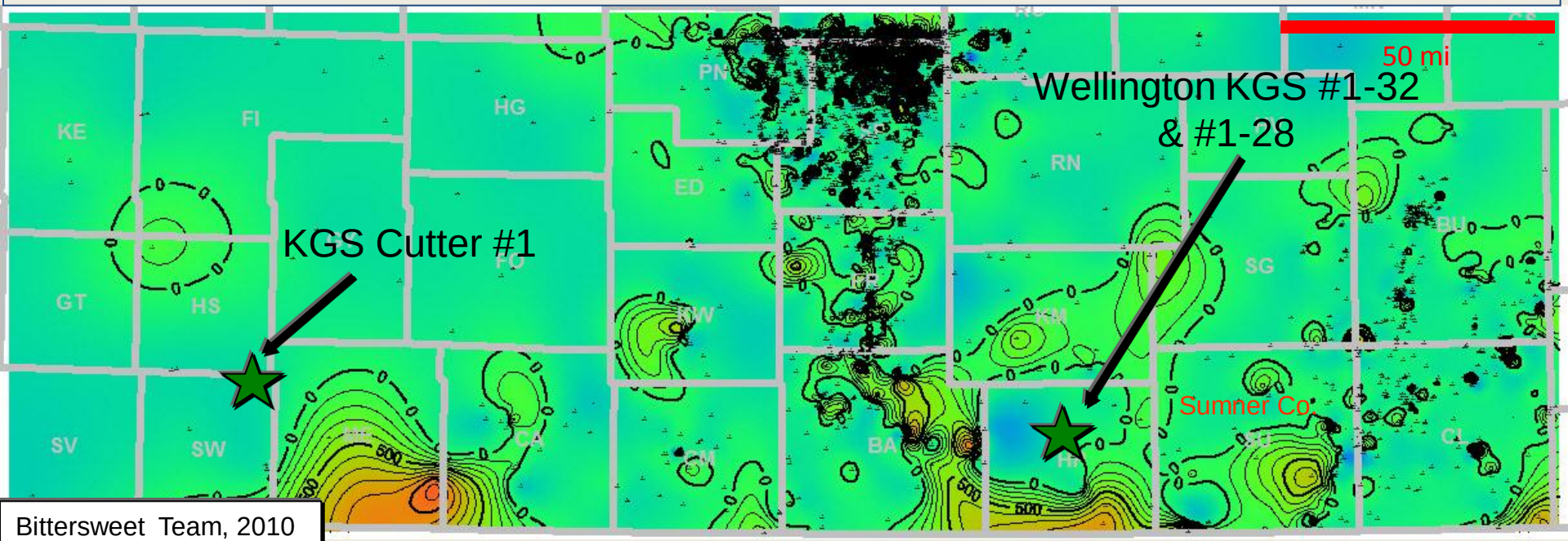


Arbuckle exposure at base of Missouri River, north-central Missouri –

Reference elevation 450 ft at surface exposures located ~200 mi northeast

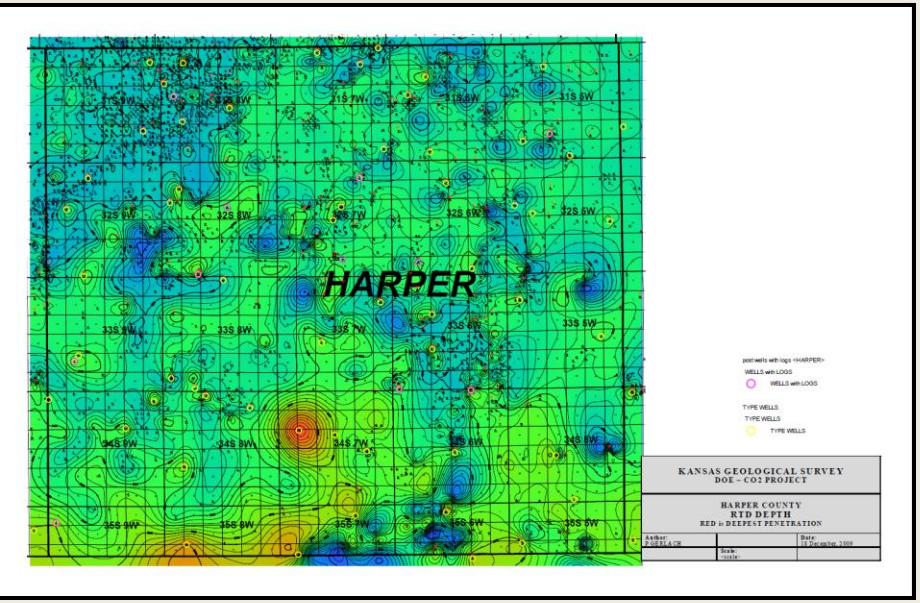
Assume hydrostatic gradient = 0.465 psi/ft

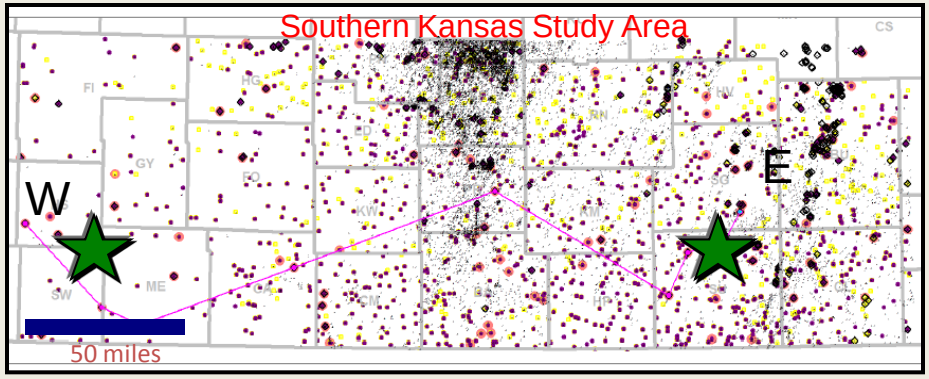
Map below represents difference between 1) estimated hydraulic head at base of Arbuckle test intervals assuming Arbuckle is connected to surface exposures at 450 ft above sea level and 2) measured shut-in pressure



Bittersweet Team, 2010

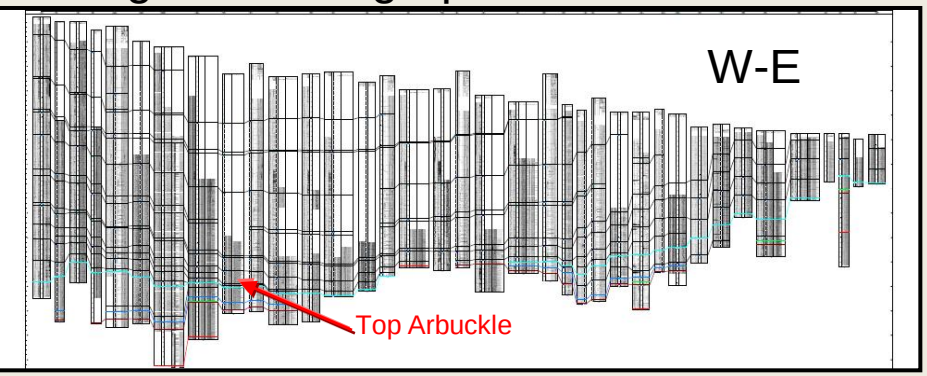
Selection and Correlation of Digital Type Wells for DOE-CO2 project

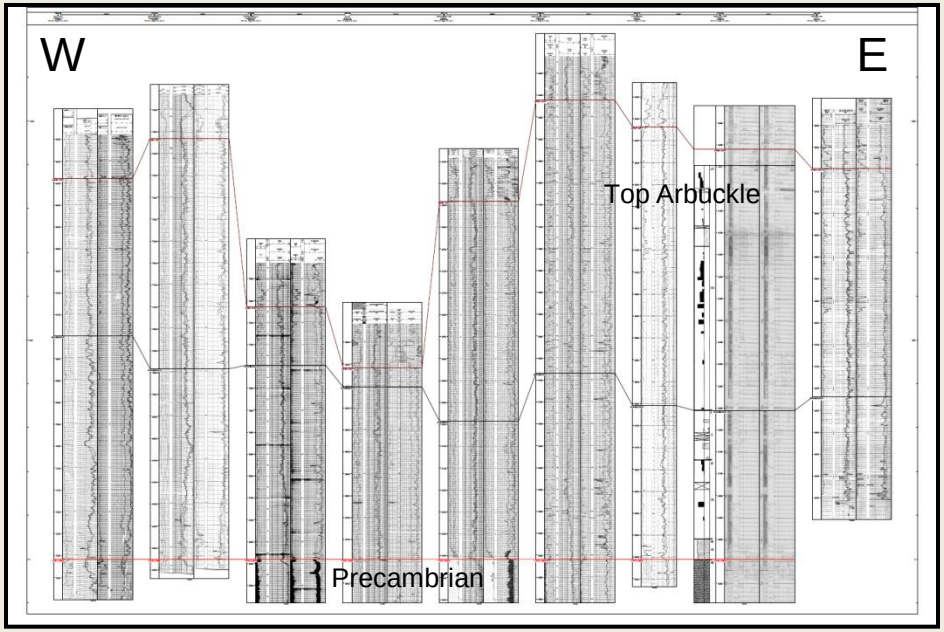




Internal Arbuckle correlations of hydrostratigraphic units and petrophysical properties with digital (LAS) logs

Regional stratigraphic correlation





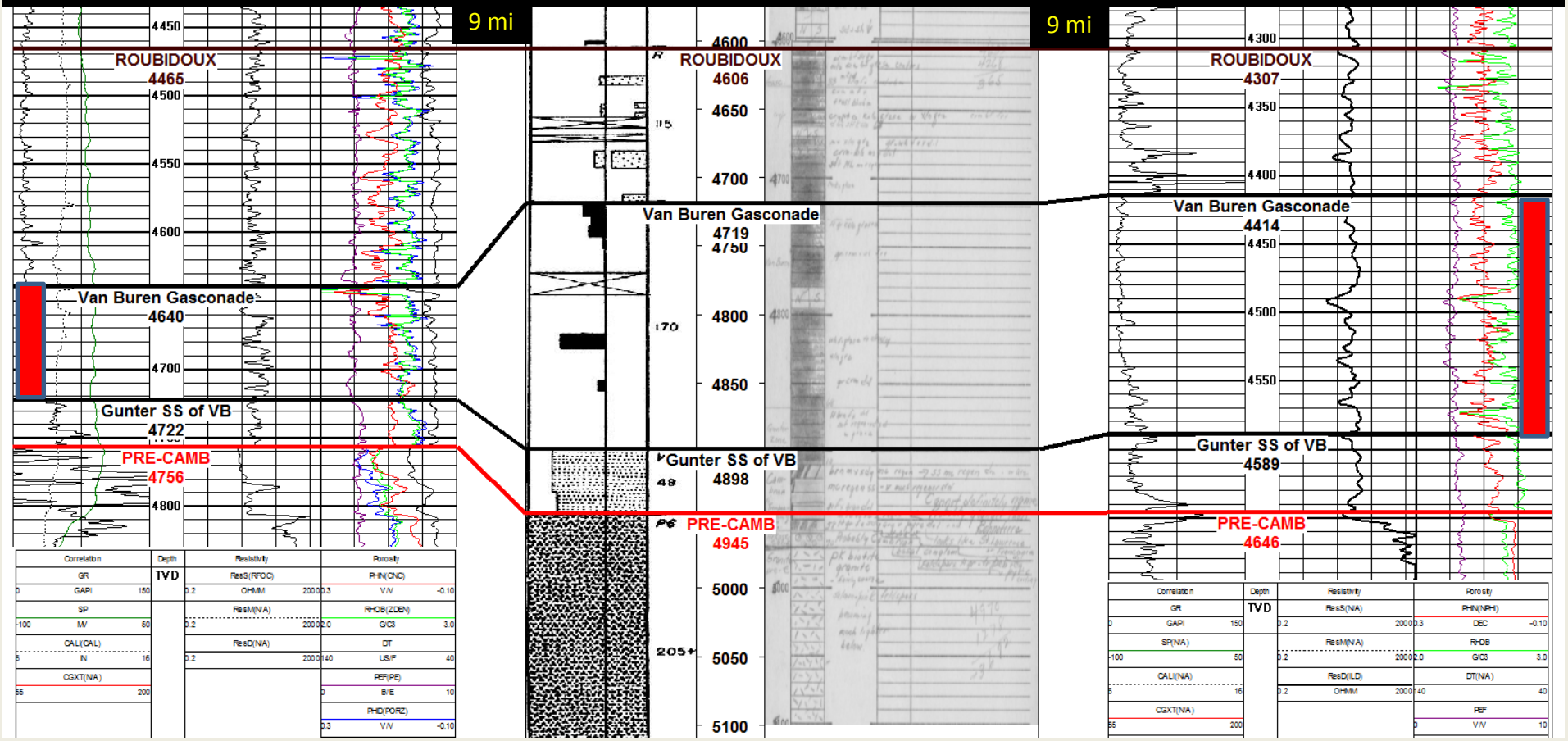
Bittersweet team (Gerlach, Nicholson, Hansen)

Quantifying Rock Properties of the Arbuckle in Southern Kansas

Quantitative Reservoir Characteristics

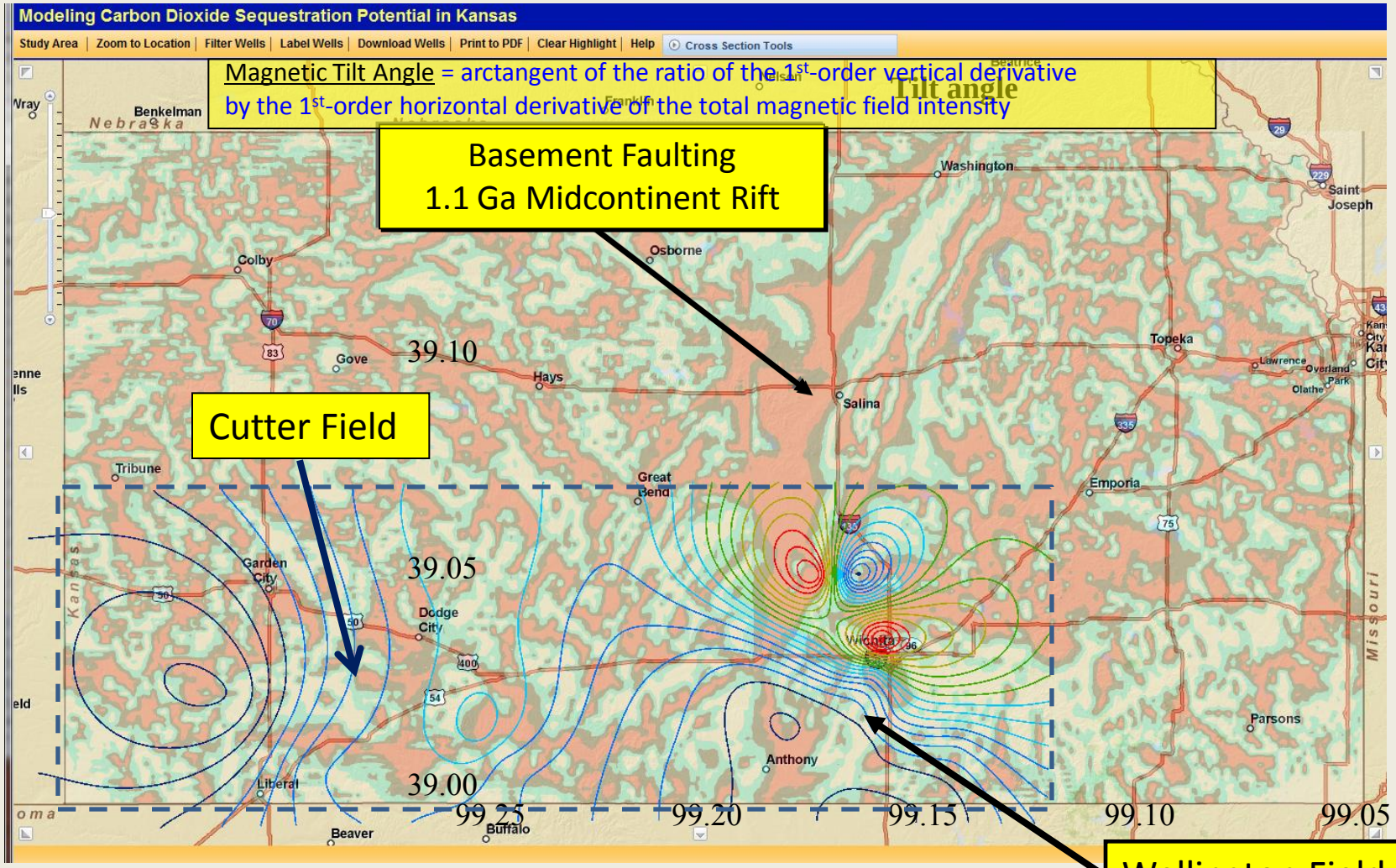
Correlated to

Internal Arbuckle Stratigraphy



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) – Bittersweet (Gerlach et al.)

Tilt angle map of the total magnetic field intensity in Kansas overlain with isopachous contours of Gasconade to Gunter Sandstone interval



isopach -> Red contour = thin, blue to purple = thick

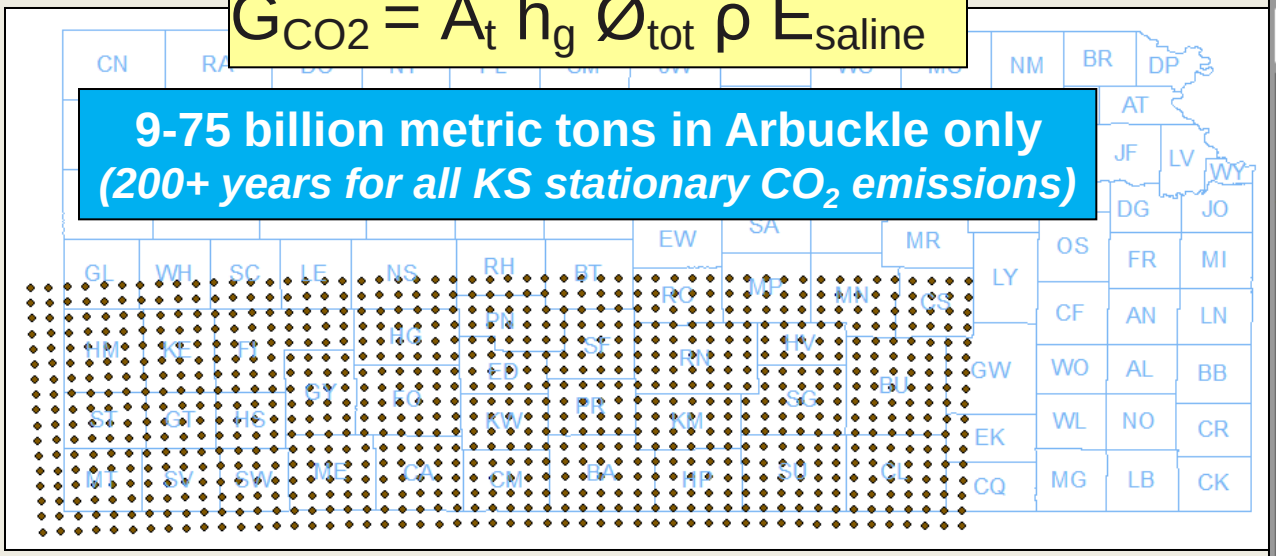
Snapshot from project's interactive mapper -- ***http://maps.kgs.ku.edu/co2/?pass=project***

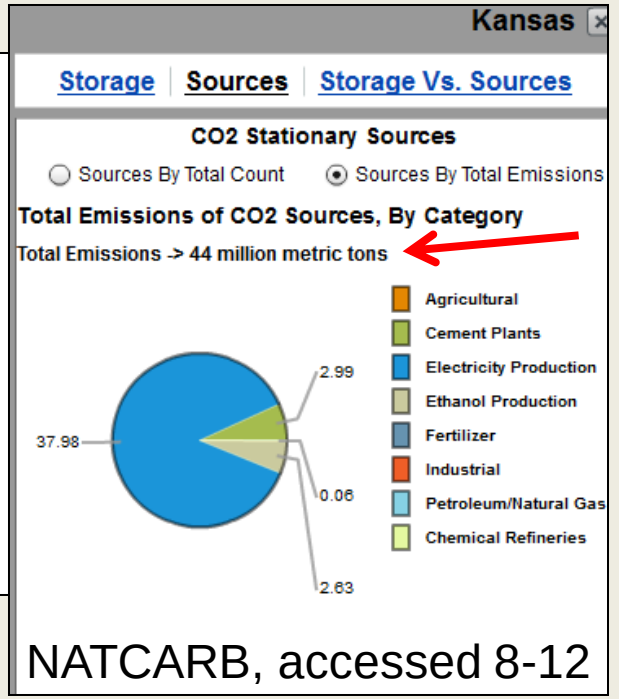
Initial CO_2 Storage Capacity Estimate

Deep Arbuckle Saline Formation (reported April 2011 for NATCARB)

$$G_{CO2} = A_t\ h_g\ \emptyset_{tot}\ \rho\ E_{saline}$$

9-75 billion metric tons in Arbuckle only
(200+ years for all KS stationary CO_2 emissions)





NATCARB, accessed 8-12

Metric tons CO_2 per Grid Cell
10 km²
(3.8 mi²)

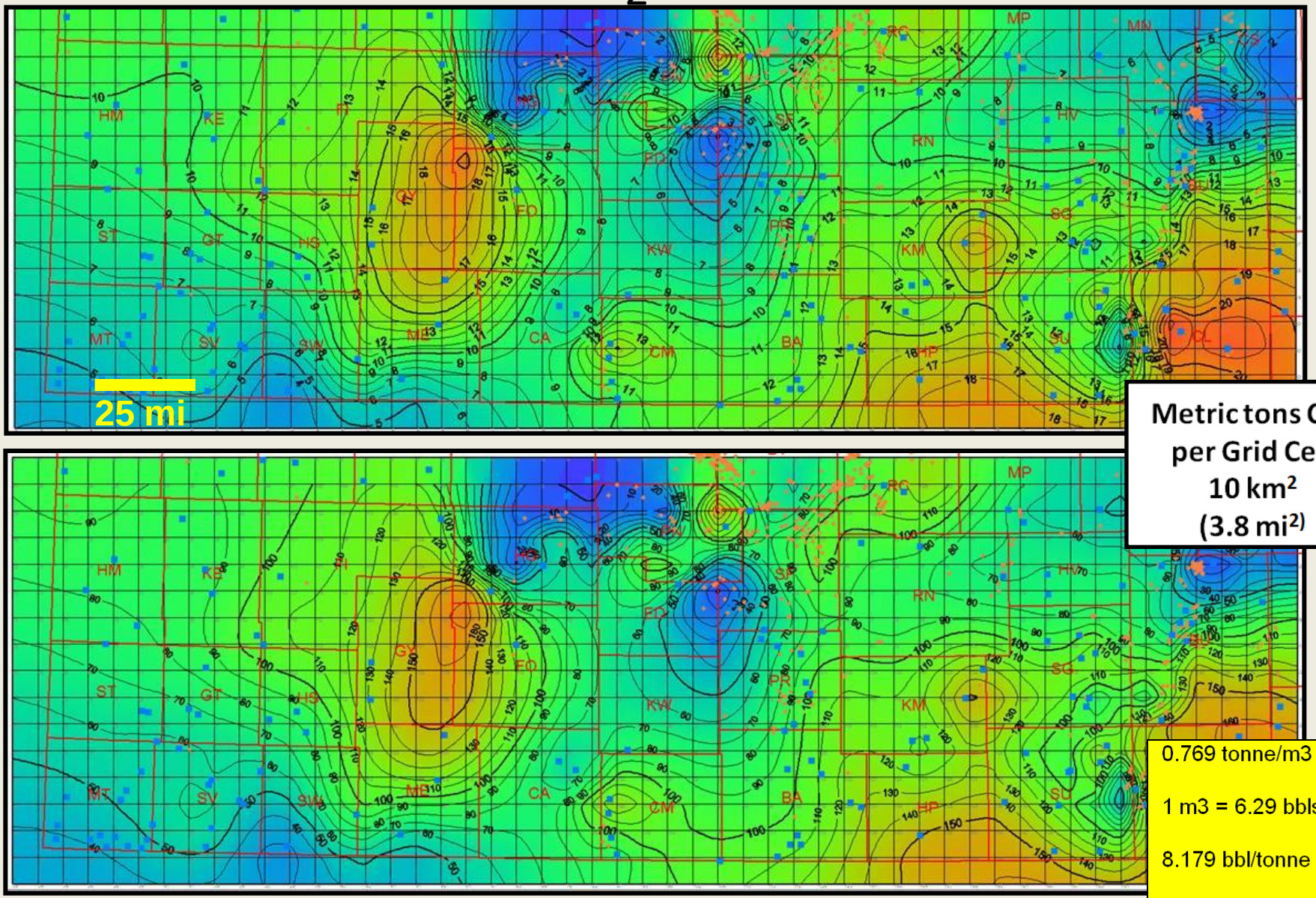
Each grid cell is 10K (+/-)

P10	
8,781,380,535	Total All Cells
22,214,247	High Cell
10,287,863	Median Cell
10,554,544	Mean Cell

P90	
75,464,988,970	Total All Cells
190,903,682	High Cell
88,411,323	Median Cell
90,703,112	Mean Cell

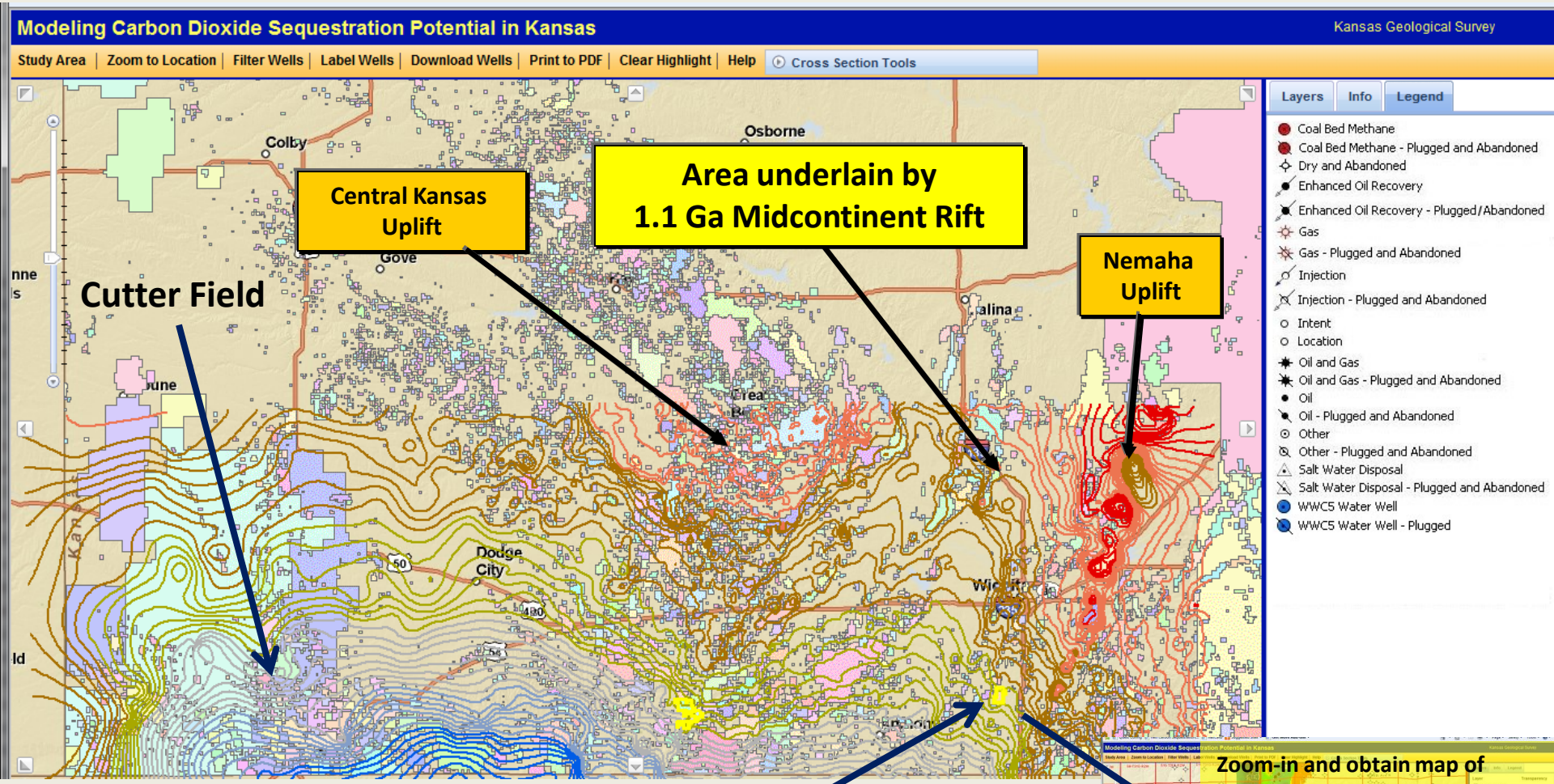
Gerlach and Bittersweet team, 2012

P10 (top) and P90 (bottom) Storage Volume CO_2 (million metric tons)



Web-based Interactive DOE-CO2 Project Mapper

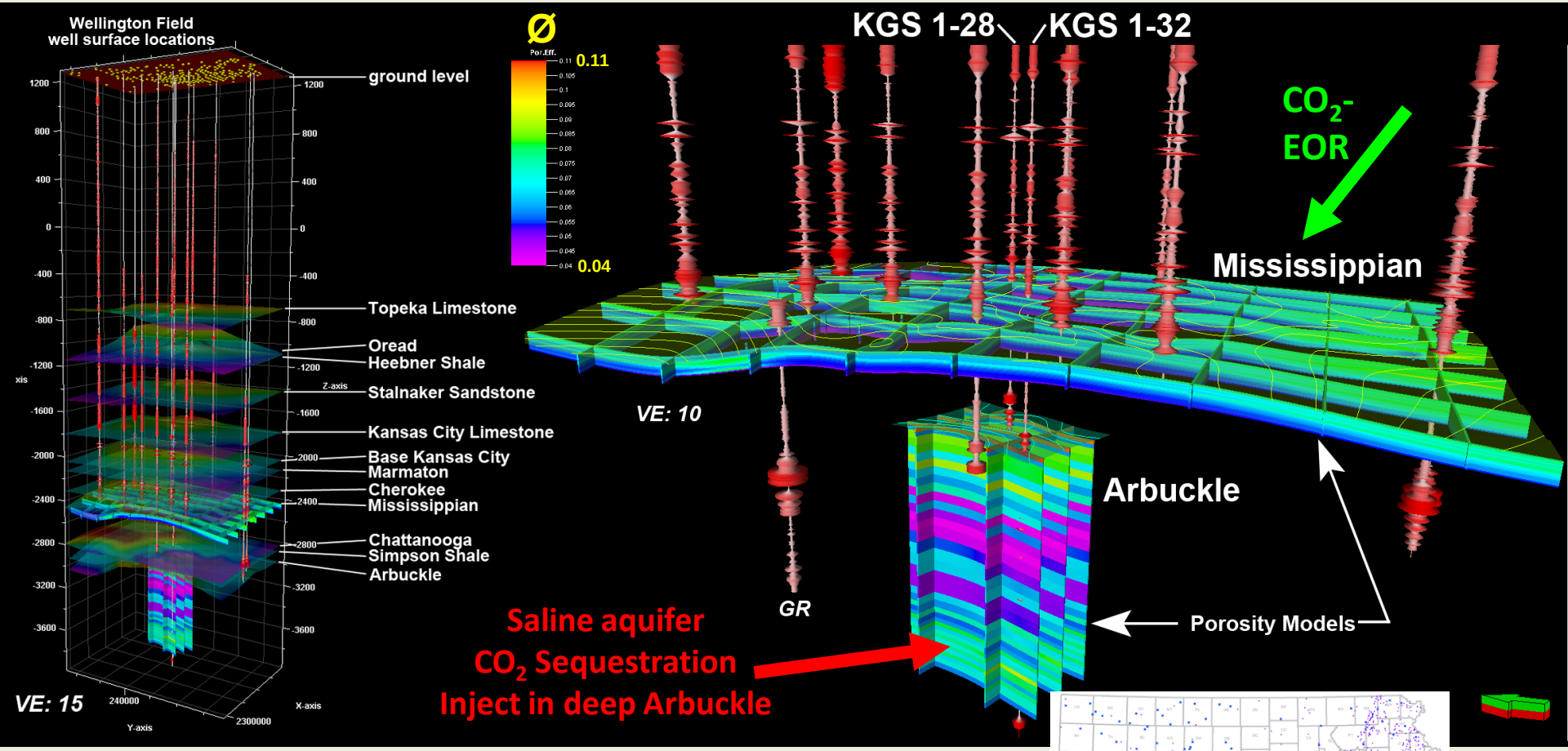
Overlay of Oil and gas field outlines and Top Arbuckle Group in study area of southern Kansas

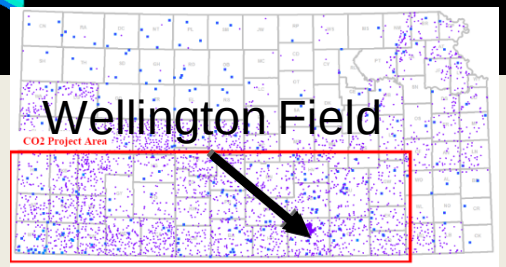


http://maps.kgs.ku.edu/co2/?pass=project

Wellington Field – Eastern Calibration Site

Mississippian siliceous dolomite reservoir & Arbuckle aquifer saline aquifer





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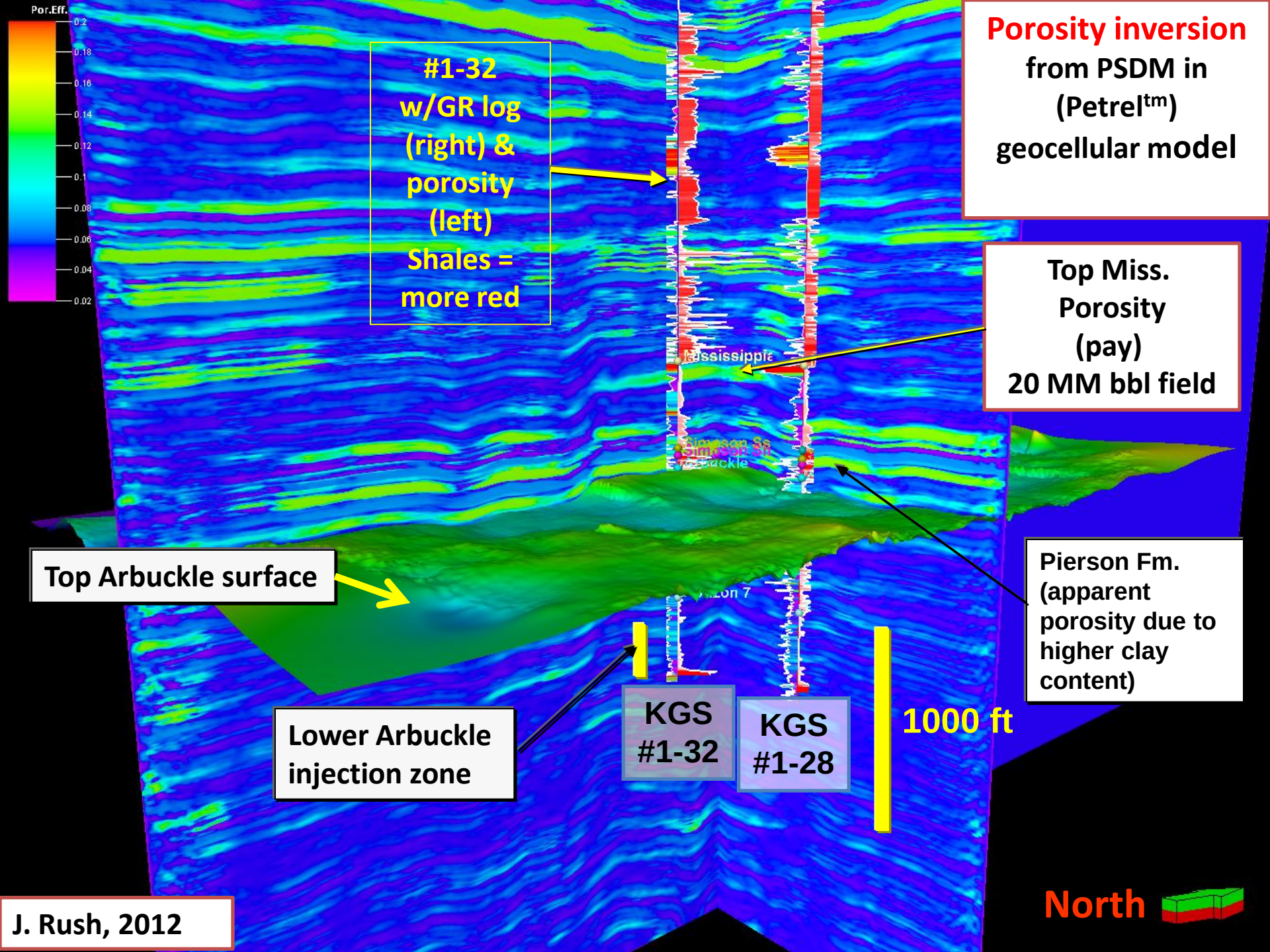
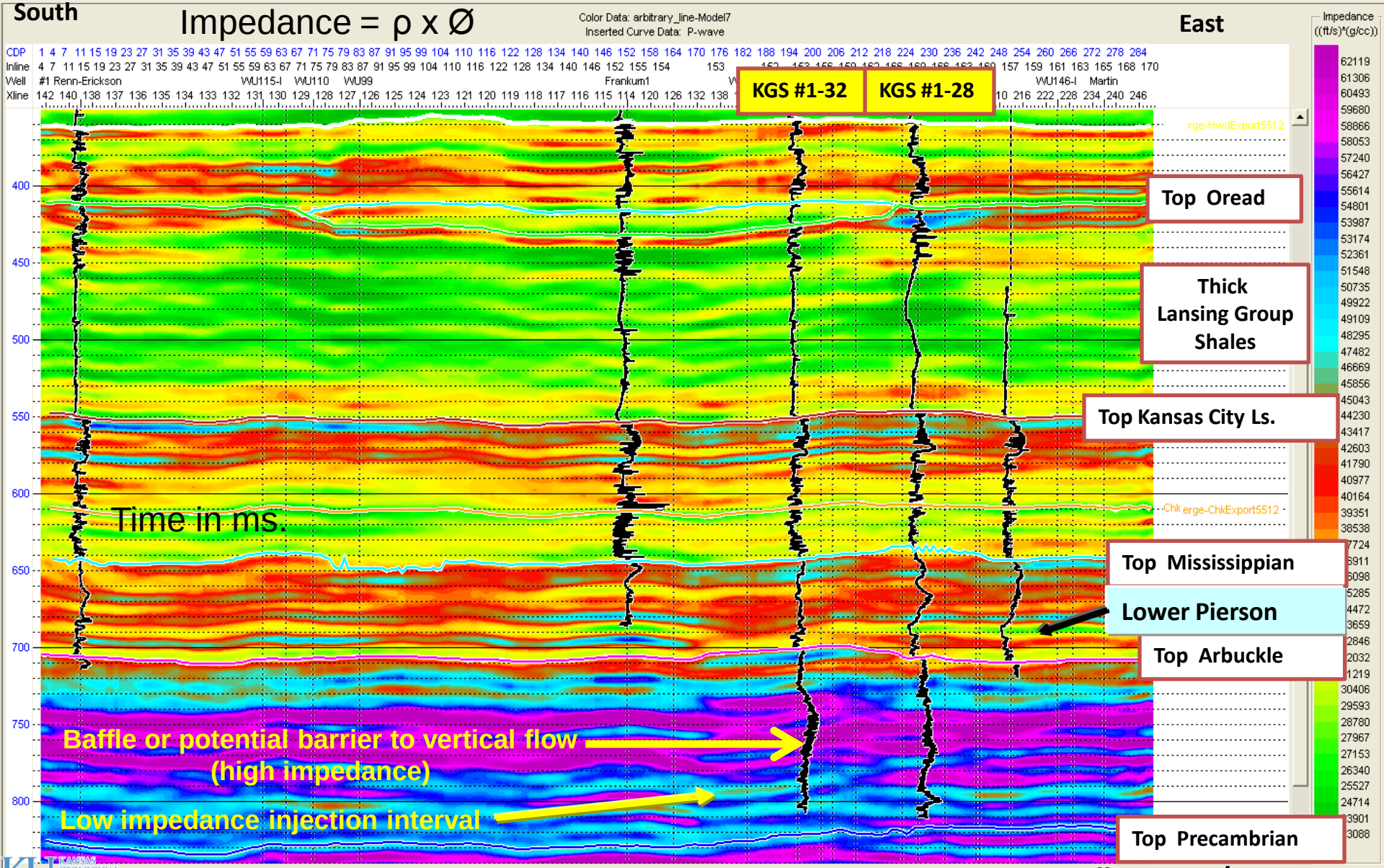
J. Rush (2011)


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 log (right) & porosity (left) Shales = more red
Porosity inversion from PSDM in (Petrel™) geocellular model
Top Miss. Porosity (pay) 20 MM bbl field
Mississippi
Simpson Sa
Simpson Sd
Arbuckle
Top Arbuckle surface
Pierson Fm. (apparent porosity due to higher clay content)
Lower Arbuckle injection zone
KGS #1-32
KGS #1-28
1000 ft
North
J. Rush, 2012

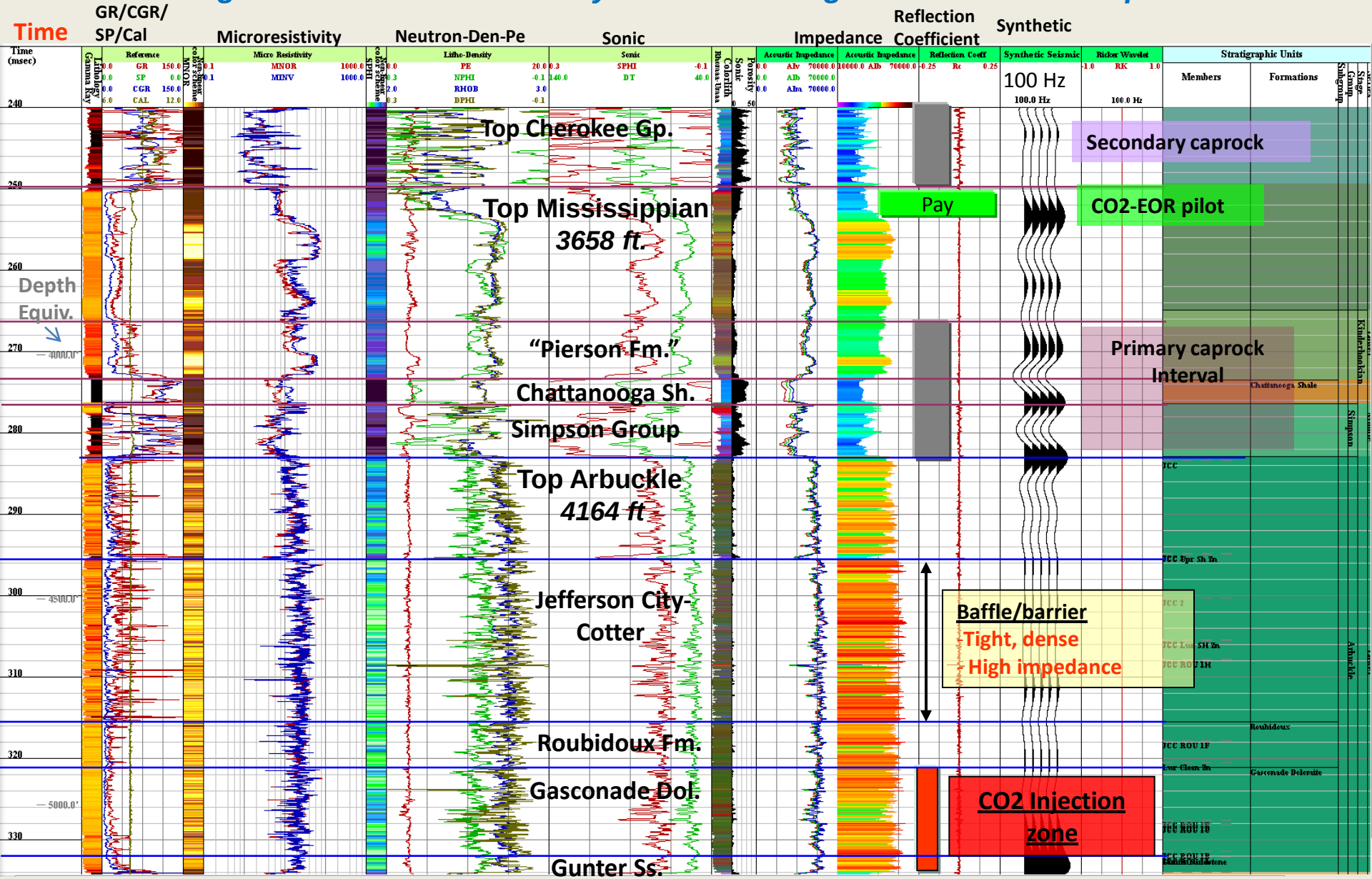
Arbitrary seismic impedance profile – Wellington Field

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



CO_2 Injection Zones in Arbuckle and Mississippian

Wellington Field KGS #1-28 --- Synthetic seismogram and seismic impedance



Precambrian granite – bottom of core = *5174 ft*

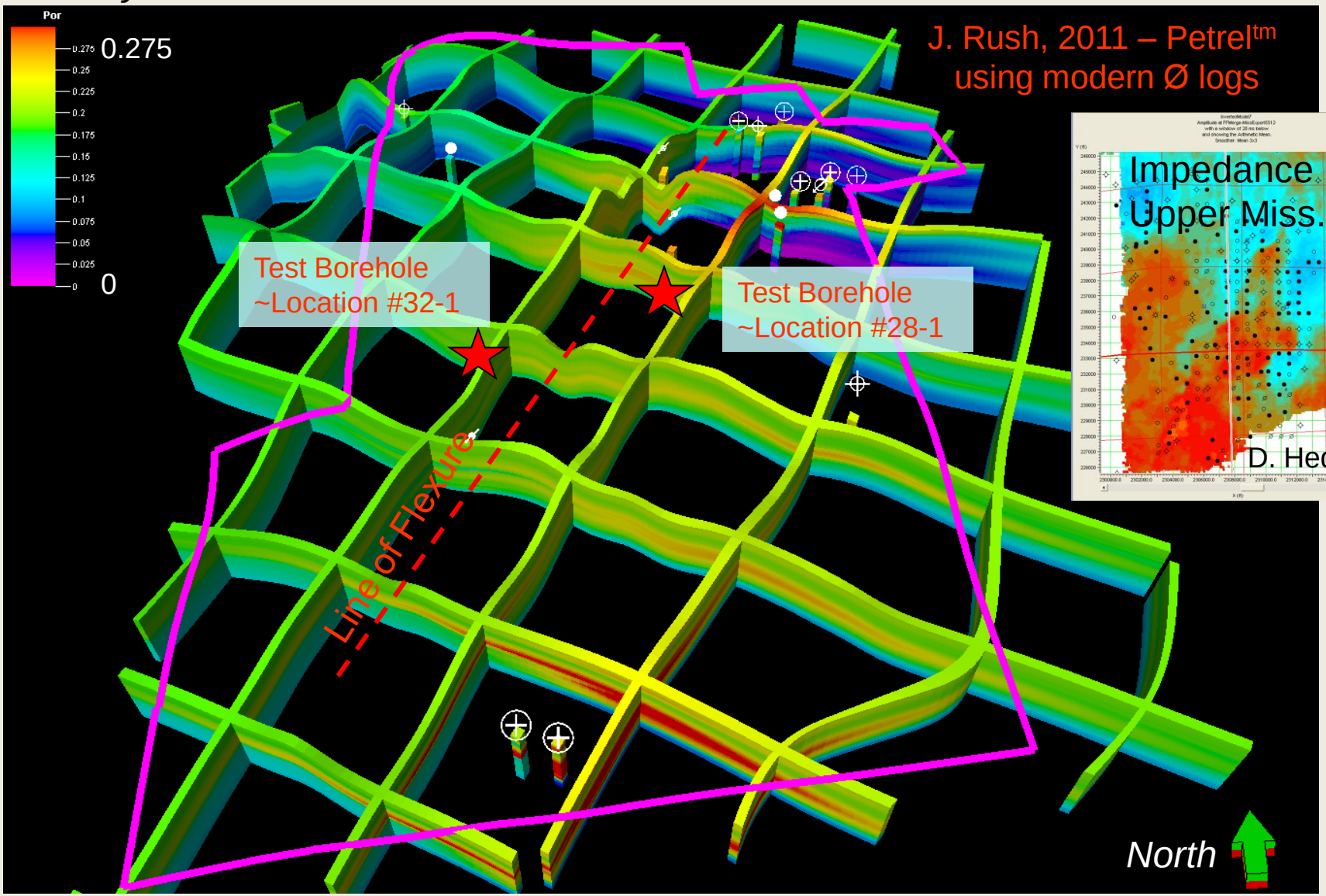
http://www.kgs.ku.edu/software/SS/

Wellington Field – 30,000 metric ton CO_2 pilot for EOR

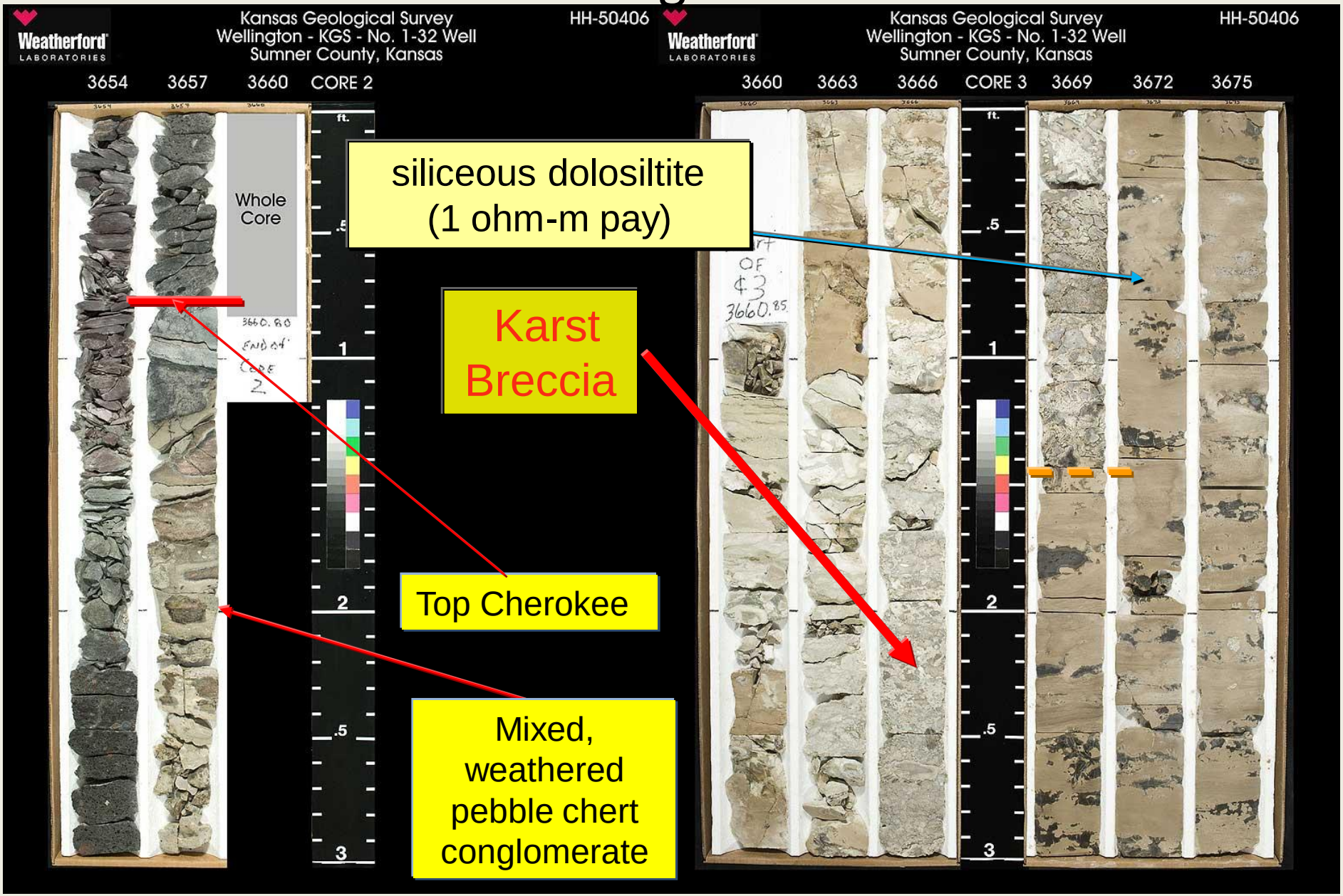
Porosity Fence Diagram

Pay zone at top of the Mississippian

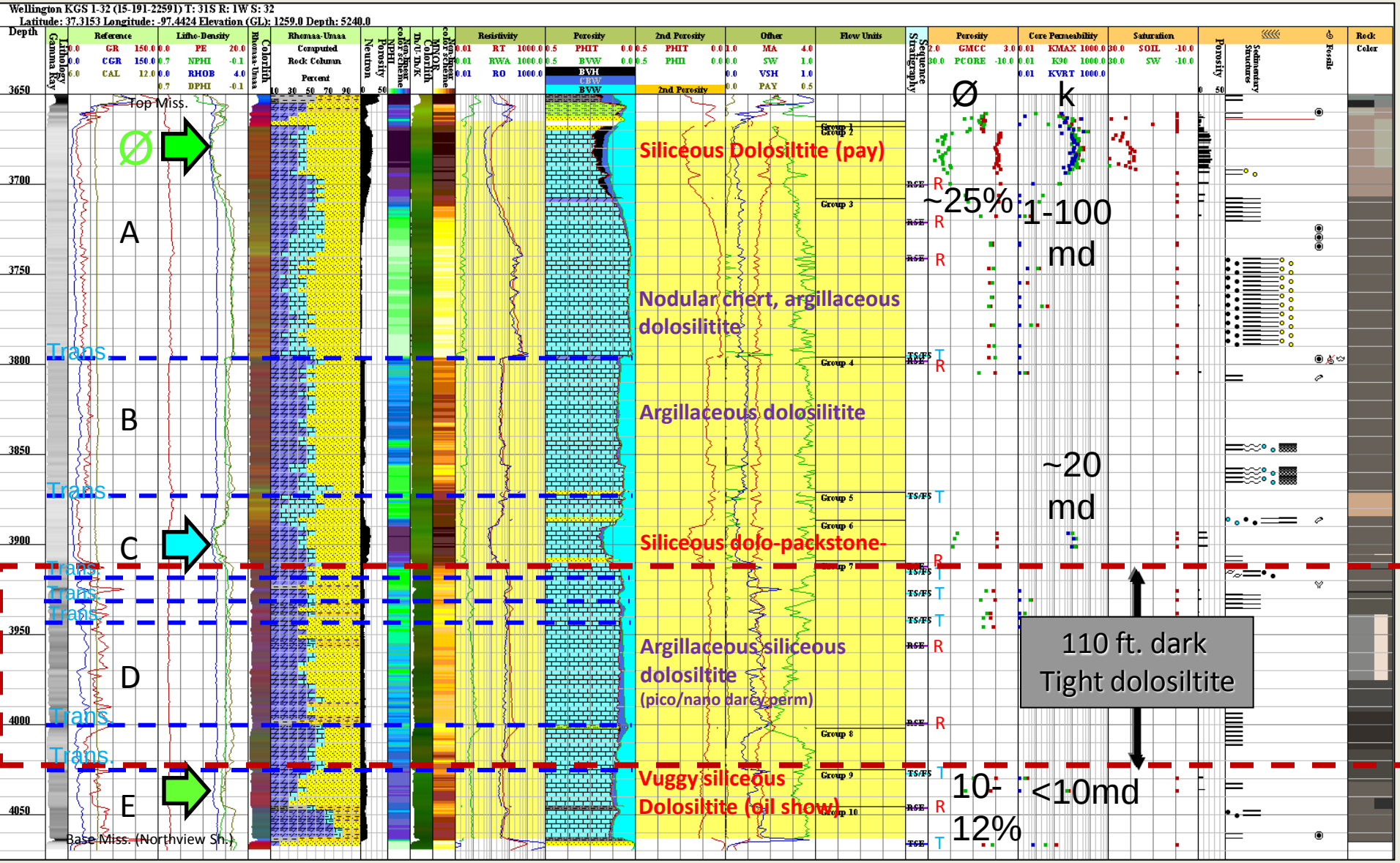
Porosity



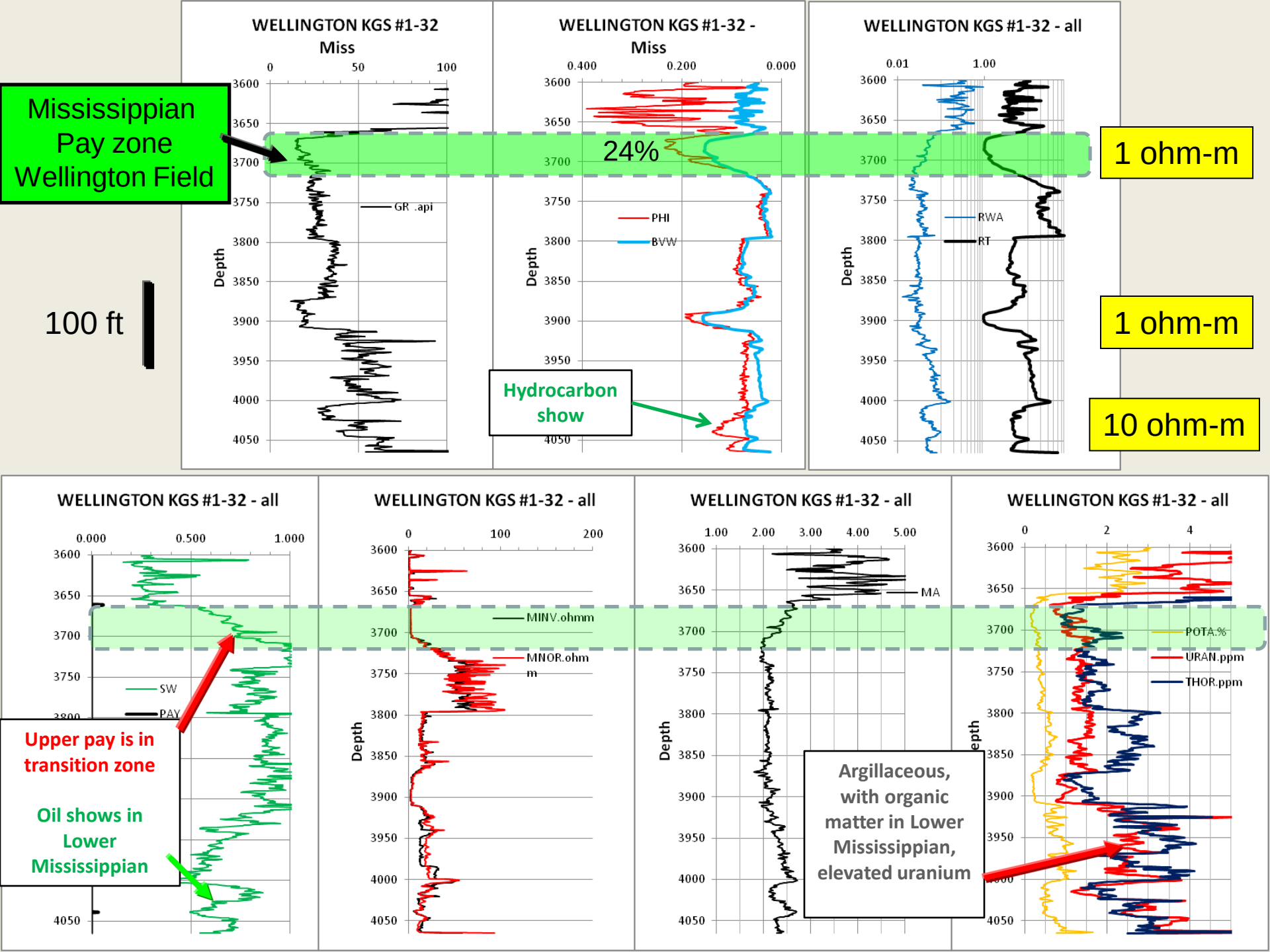
Mississippian Pay Zone in Berexco Wellington KGS #1-32



Cored Well, Berexco Wellington KGS #1-32
Top Mississippian to Kinderhook Shale (410 ft)

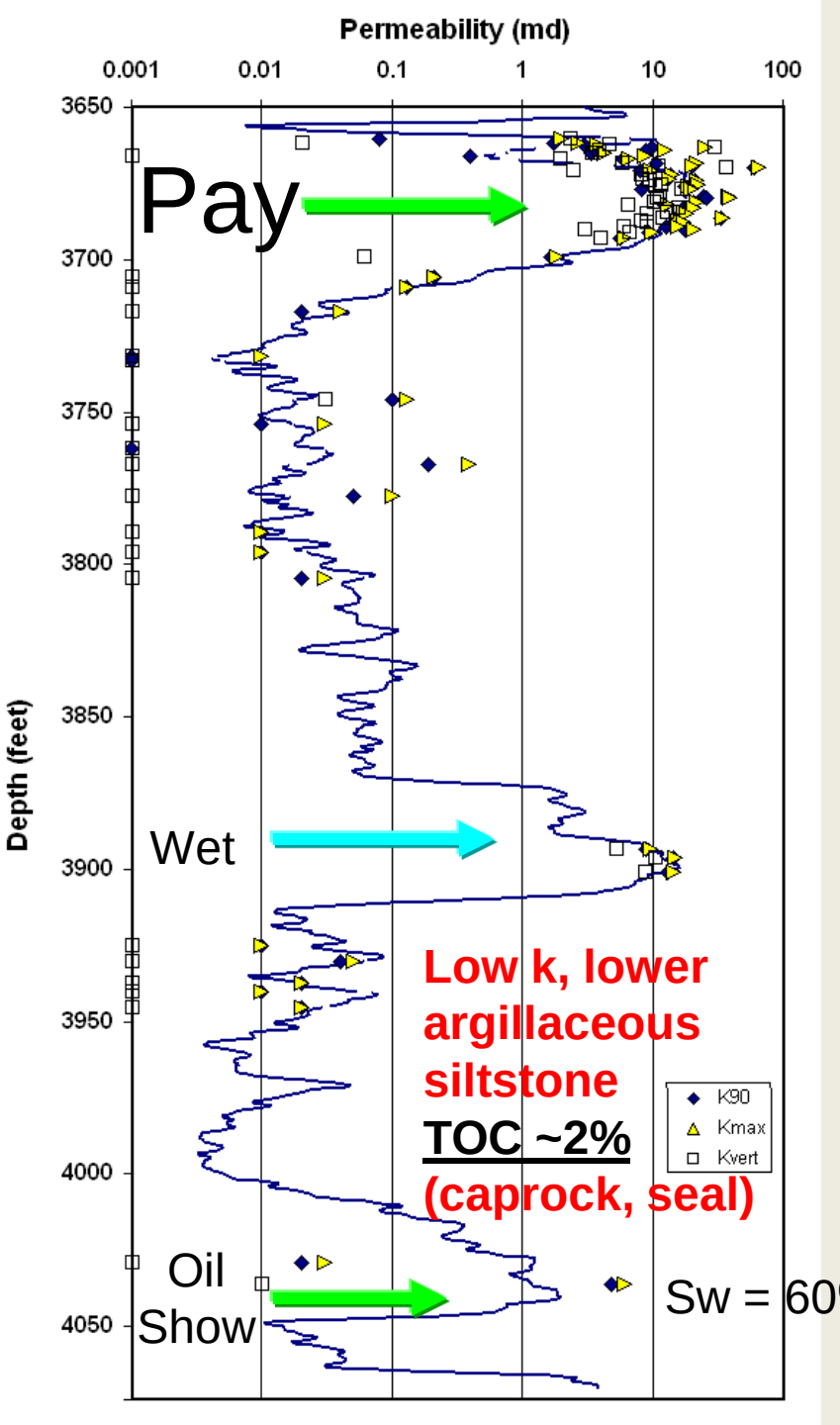


Freeware:http://www.kgs.ku.edu/stratigraphic/PROFILE/


Mississippian
Pay zone
Wellington Field
100 ft
WELLINGTON KGS #1-32
Miss
GR .api
WELLINGTON KGS #1-32 -
Miss
PHI
BVW
24%
Hydrocarbon
show
WELLINGTON KGS #1-32 - all
RWA
RT
1 ohm-m
1 ohm-m
10 ohm-m
WELLINGTON KGS #1-32 - all
SW
PAY
Upper pay is in
transition zone
Oil shows in
Lower
Mississippian
WELLINGTON KGS #1-32 - all
MINV.ohmm
MNOR.ohm
m
WELLINGTON KGS #1-32 - all
MA
Argillaceous,
with organic
matter in Lower
Mississippian,
elevated uranium
WELLINGTON KGS #1-32 - all
POTA.%
URAN.ppm
THOR.ppm
Depth

Permeability profile entire Mississippian

KGS #1-32 Wellington : Estimation of permeability based on *magnetic resonance imaging (MRIL^{tm})* using porosity and T2 center-of-gravity versus core Kmax, K90, and Kvert core permeabilities

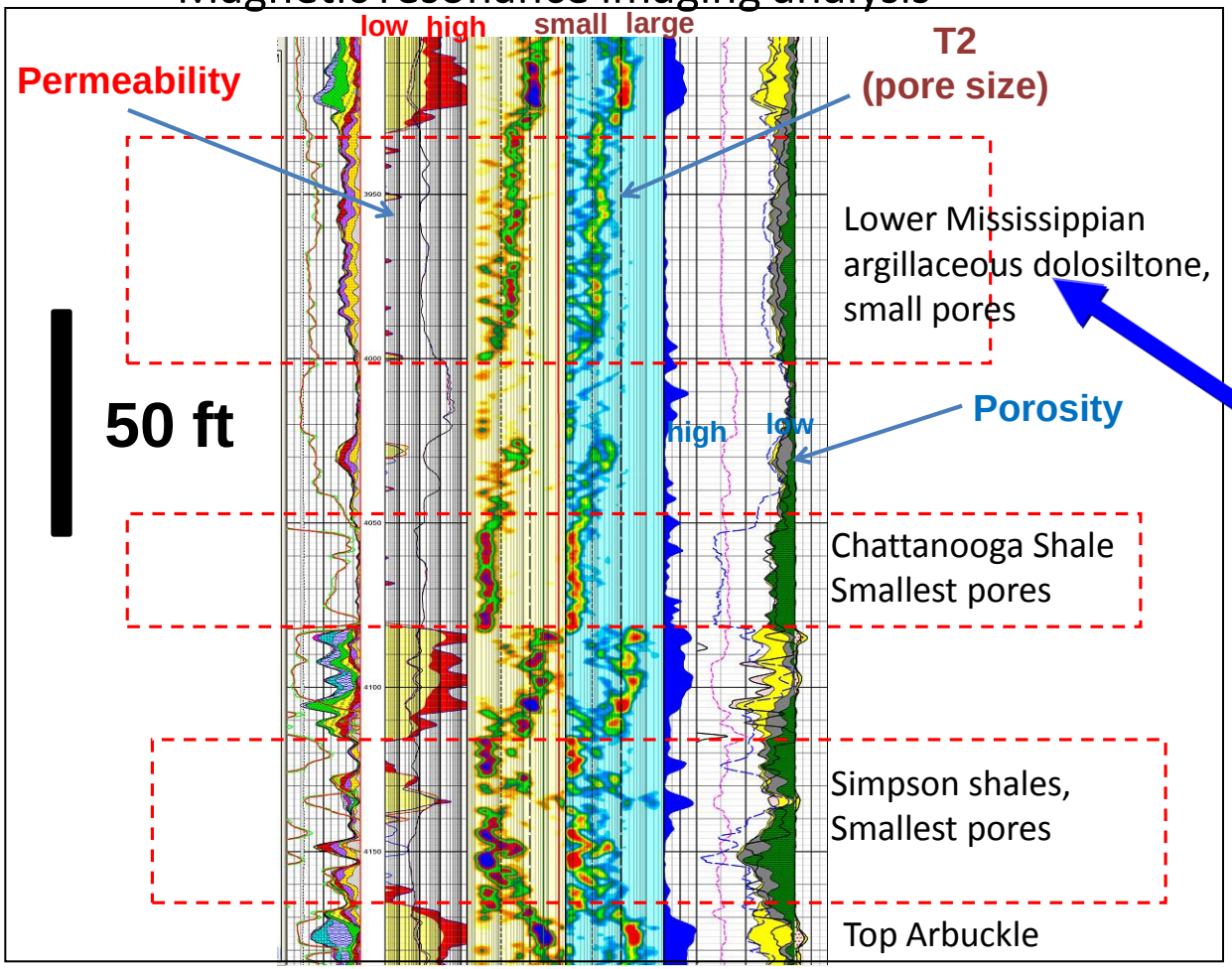


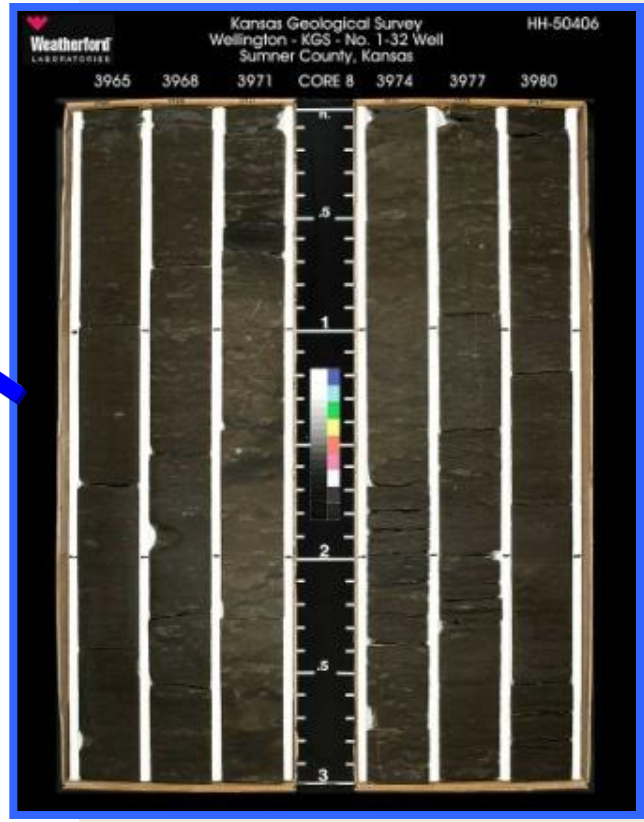
Doveton & Fazelalavi, July 2012

230 ft Gross Thickness of Primary Caprock above Arbuckle

– nance log

#1-28, lower Miss to top Arbuckle
Magnetic resonance imaging analysis





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

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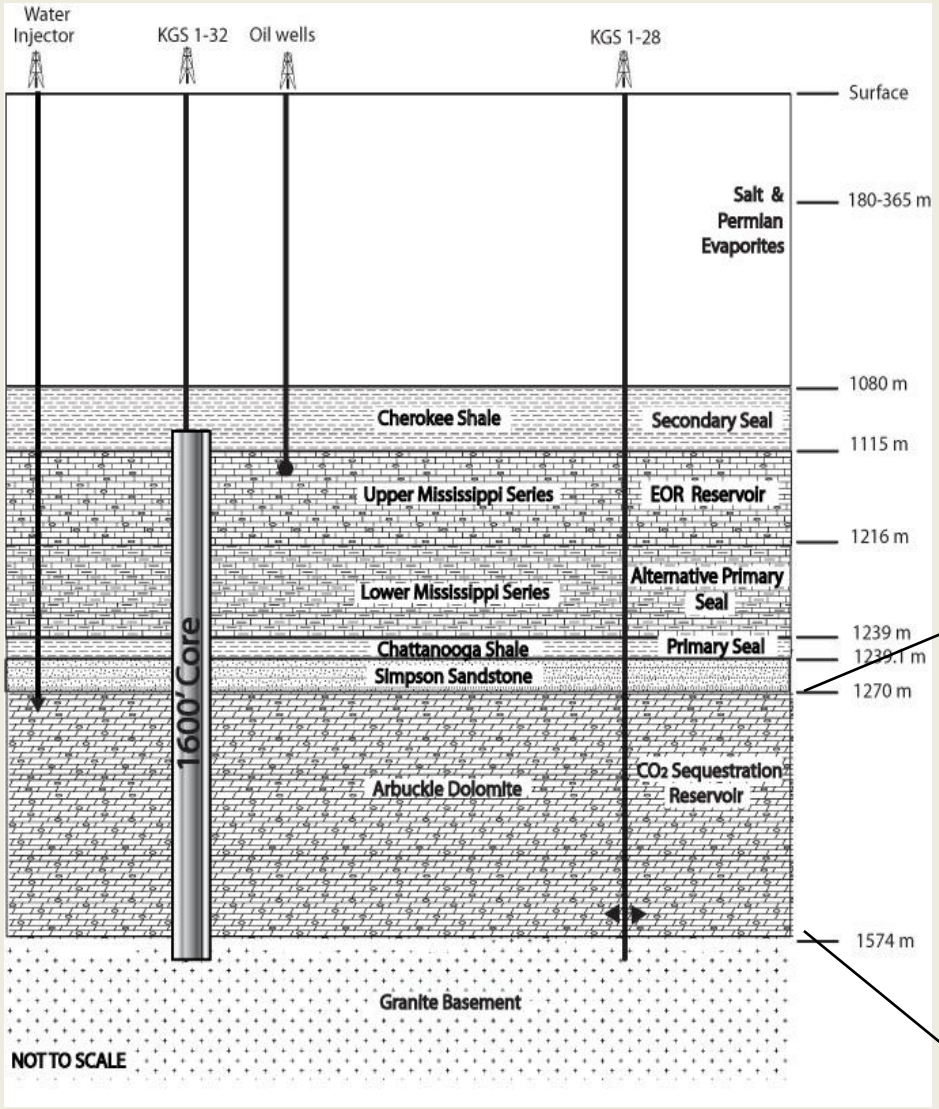
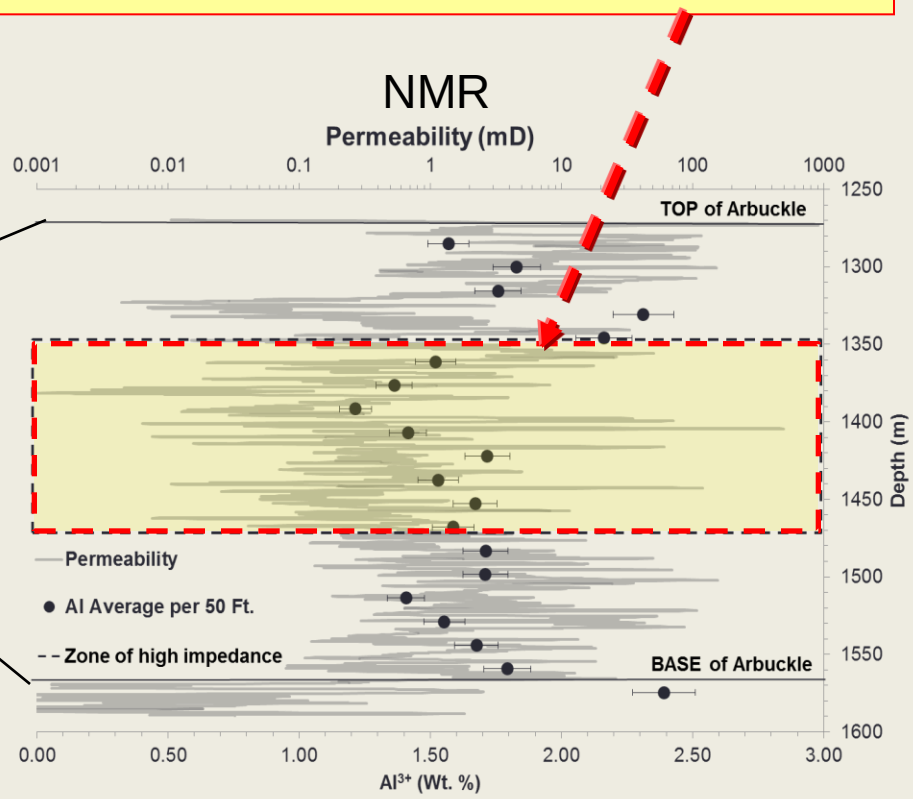
Mid-Arbuckle Flow Barrier KGS #1-32



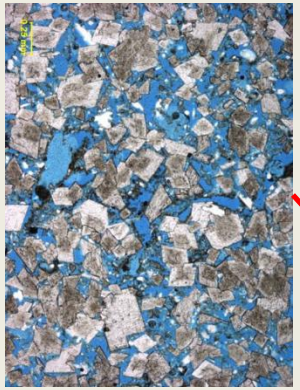
- 400 ft of tighter rock
- Widespread high seismic impedance

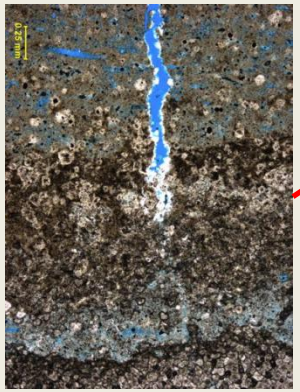


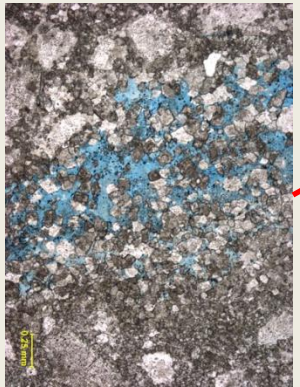
Scheffer, 2012

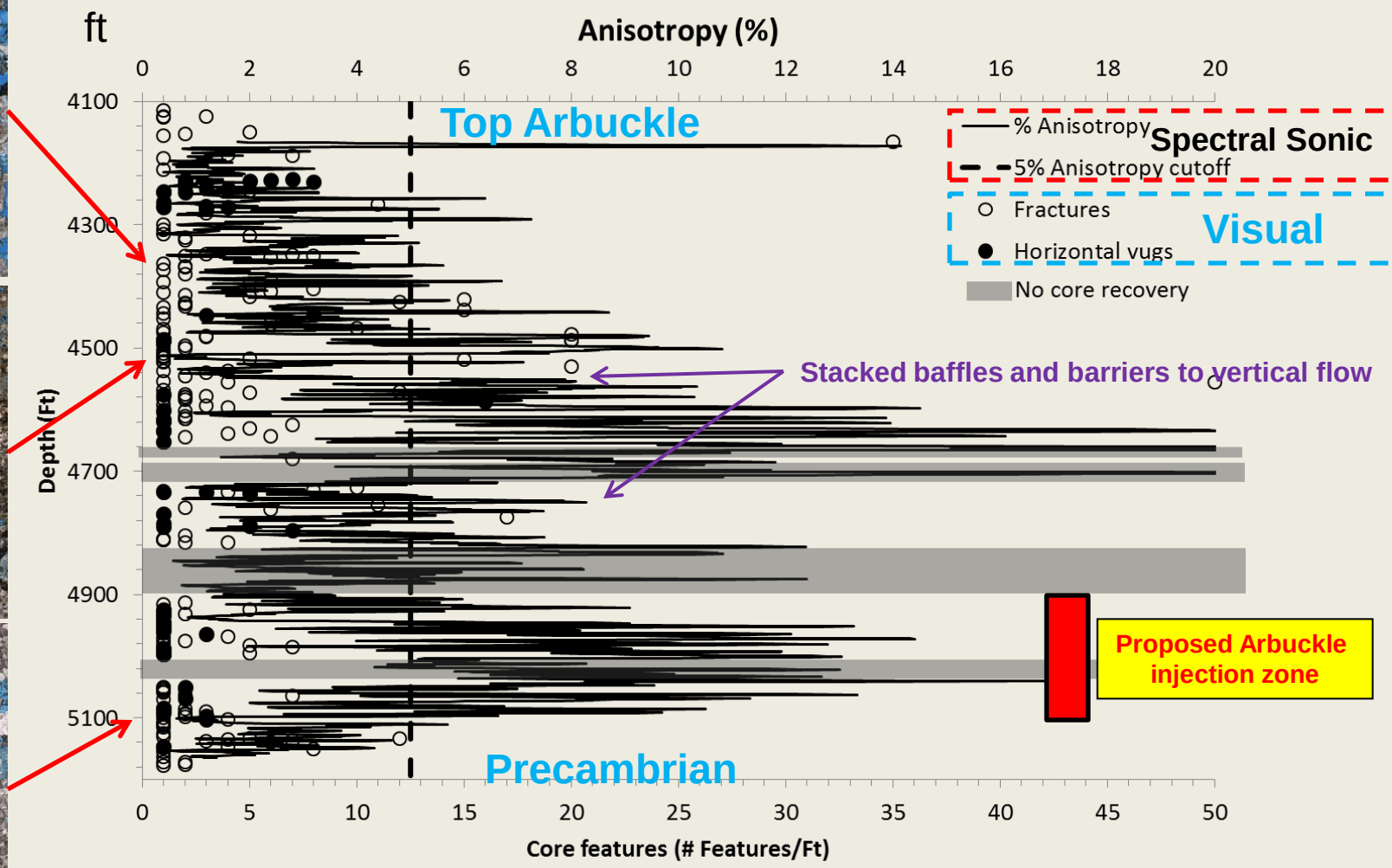
Zonal Fracturing in Arbuckle, KGS #1-32

Spectral acoustic log, core, microresistivity imaging









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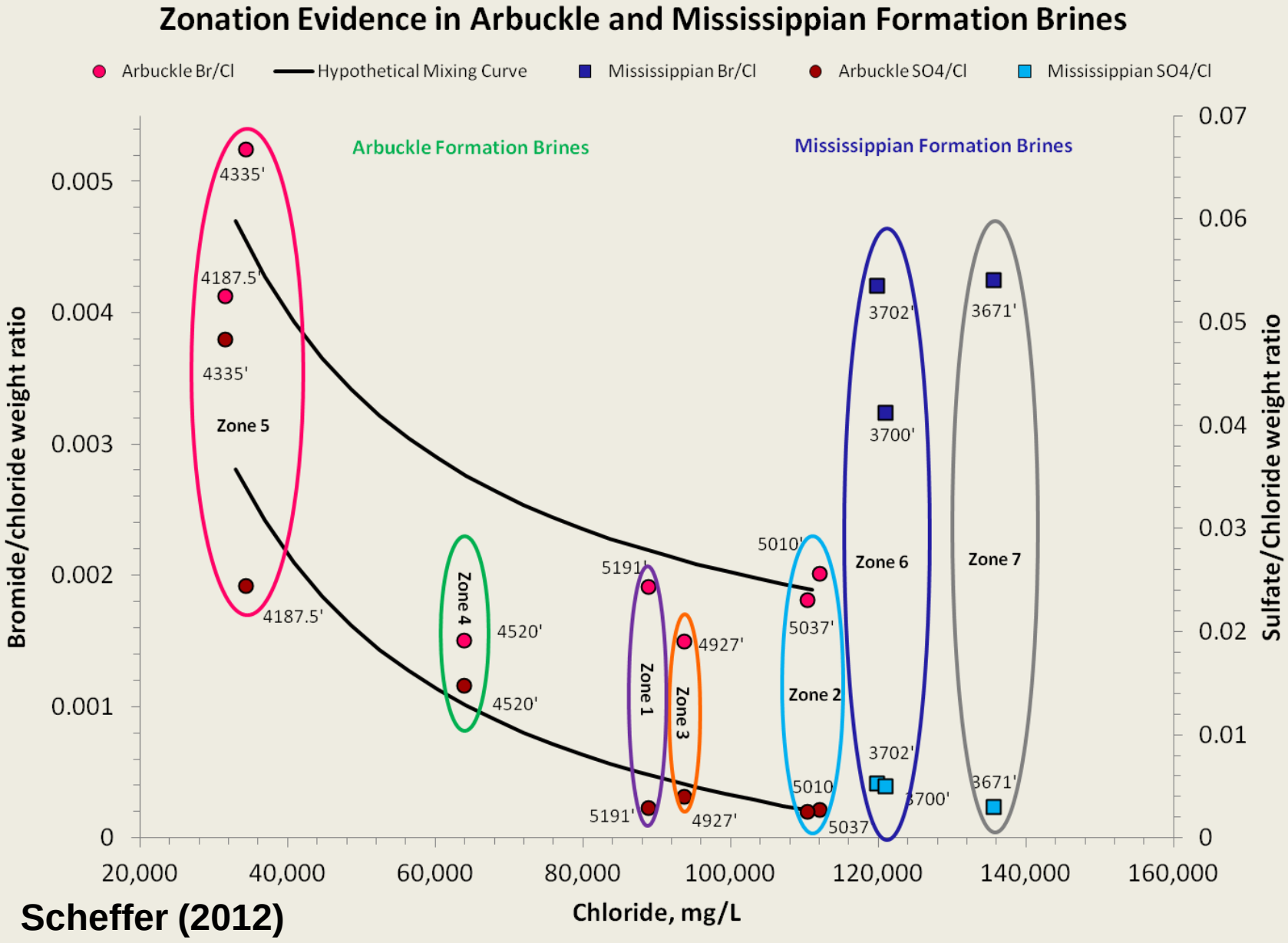
Scheffer, 2012; Lorenz and Cooper, 2011

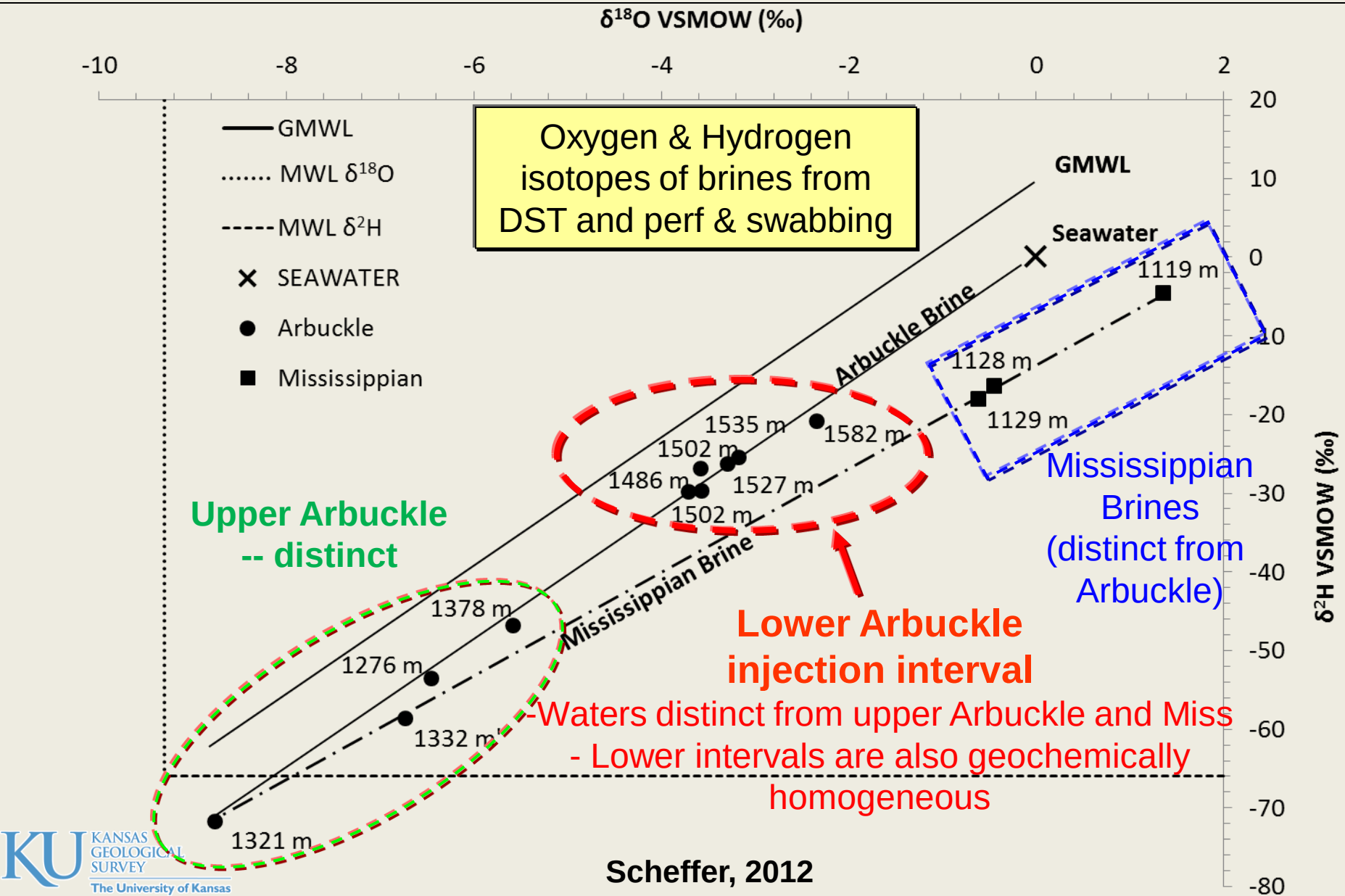
Arbuckle Hydrostratigraphy at Wellington Field

obtained from DST and perf & swab test



Scheffer (2012)

Lower and Upper Arbuckle are Not in Hydraulic Communication



Scheffer, 2012

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Selected Core from Lower Arbuckle

5089-92 ft

Proposed Injection Interval

Vug and interparticle Ø

5080-83

Crackle breccia w/ Ø

5053-56

Fracture Ø

4995-97.7 ft

Vugs and interparticle Ø

Fine interparticle Ø

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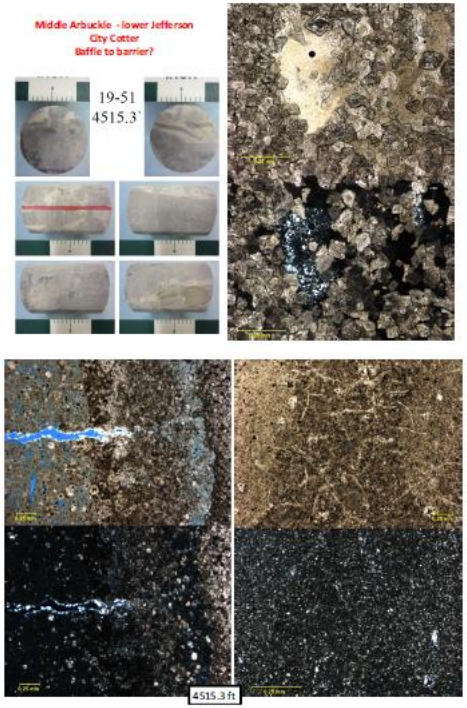
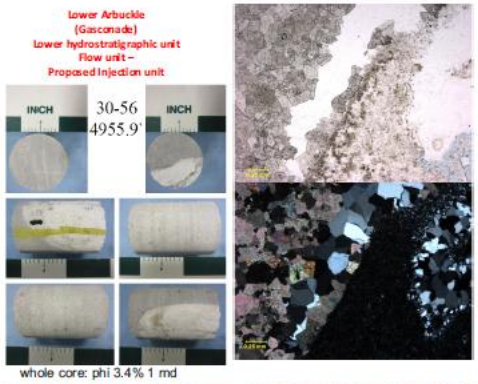
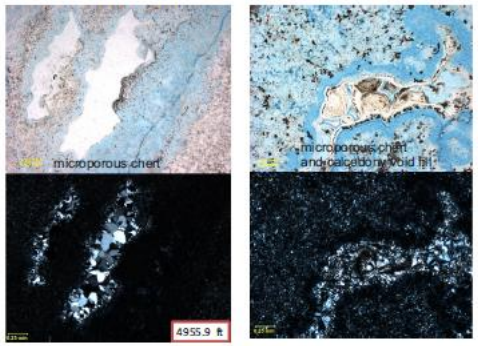
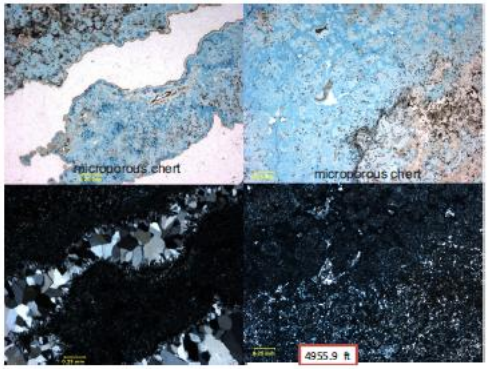
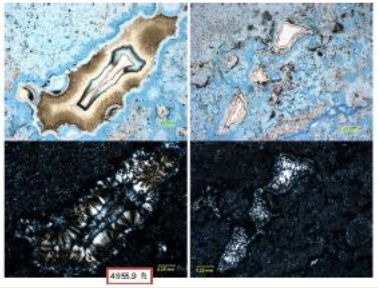
Thin Sections – Baffle Zone (Mid Arb.)



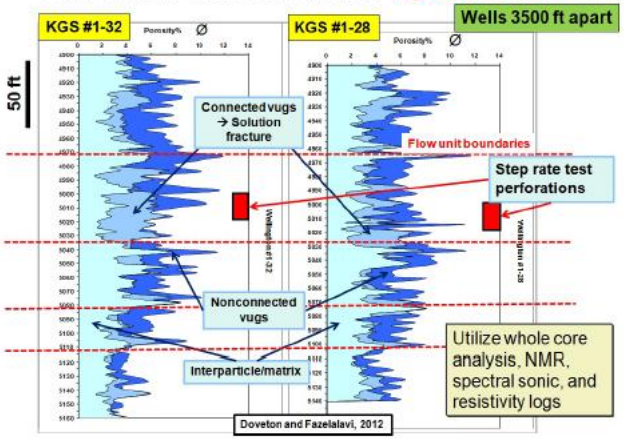




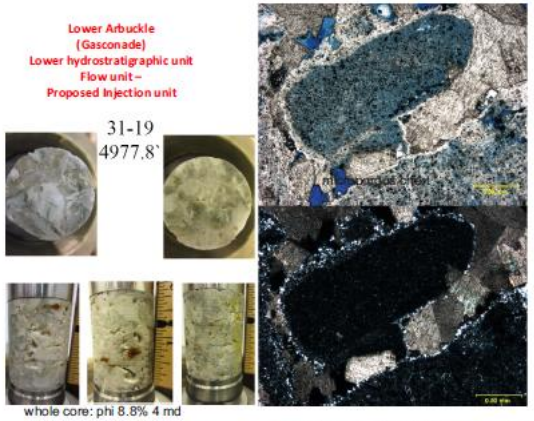


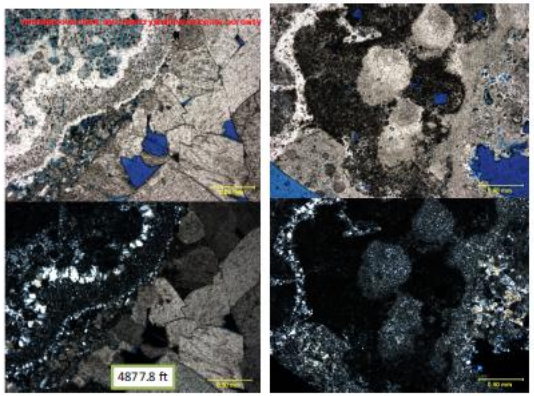


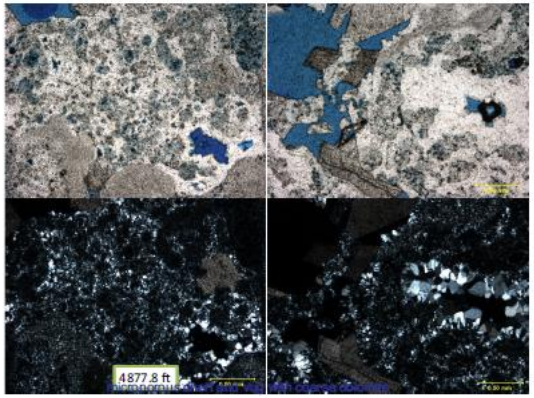
Flow units in the lower Arbuckle **injection zone**



Lower Arbuckle Injection Zone

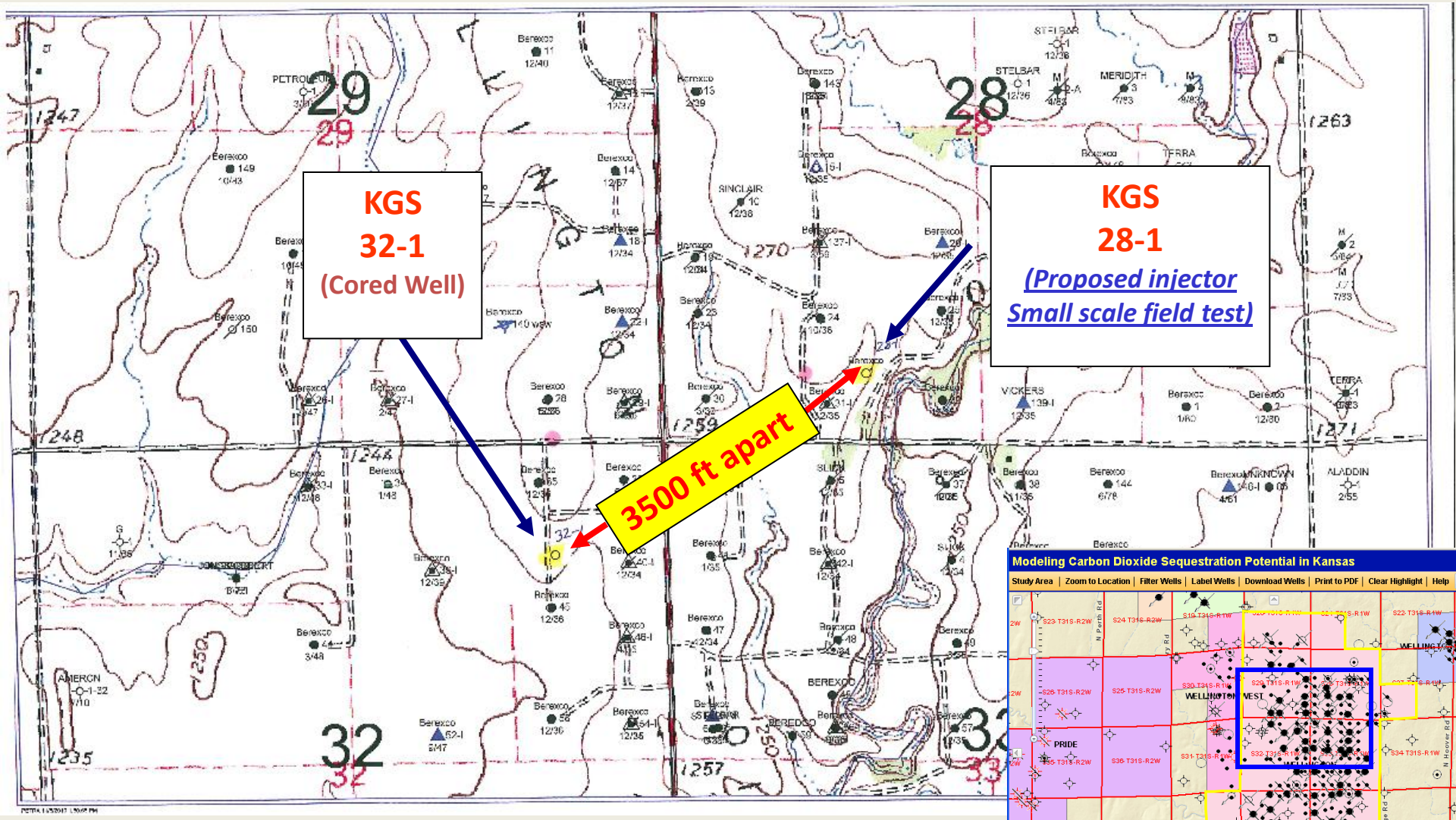






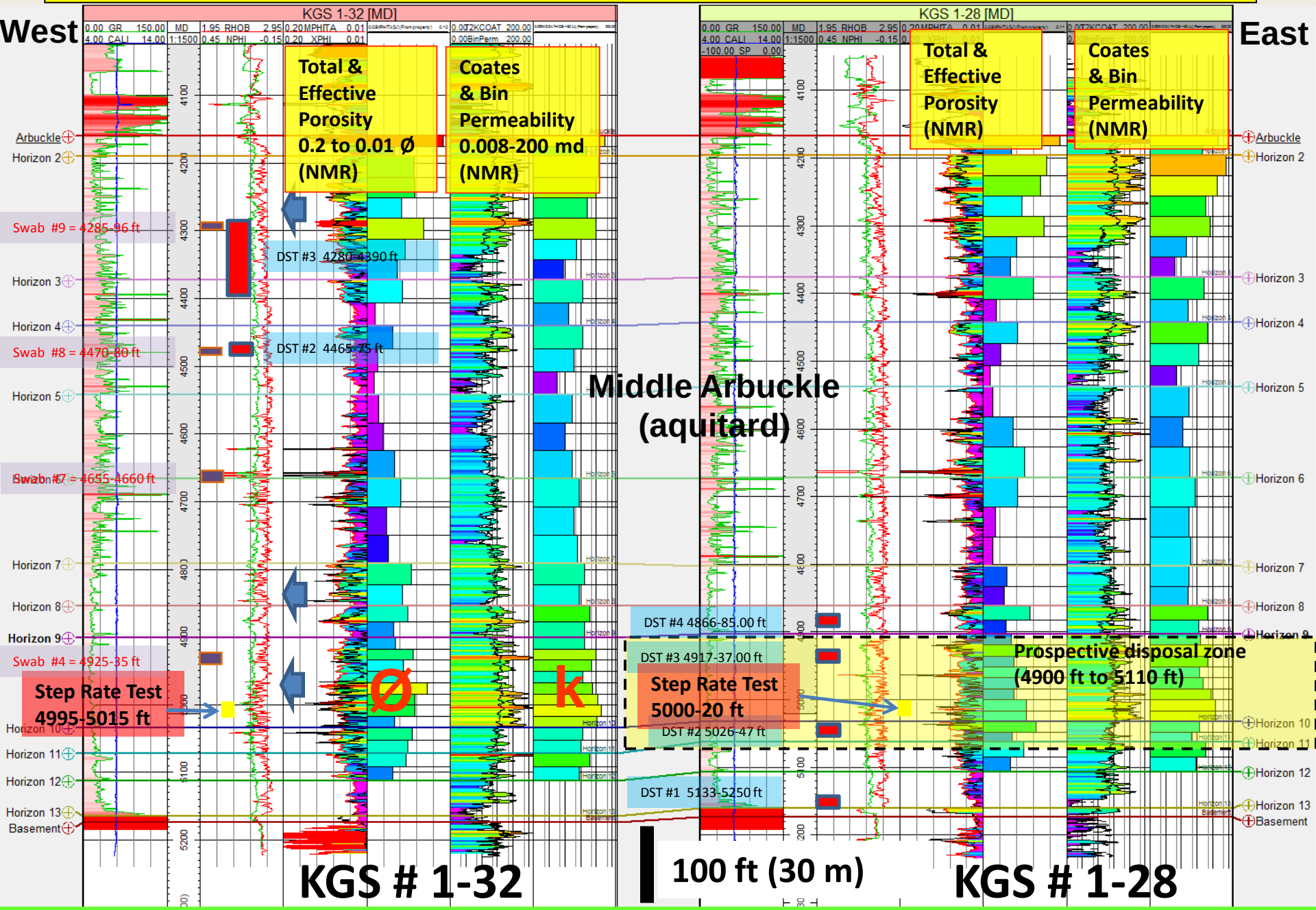
Pairs of photomicrographs
Plane light and crossed nicols

Surface Location of Basement Test (#1-32 & 31-28) Drilled in Wellington Field During Jan-Feb 2011



Step-rate (pulse test) between wells conducted August 2011

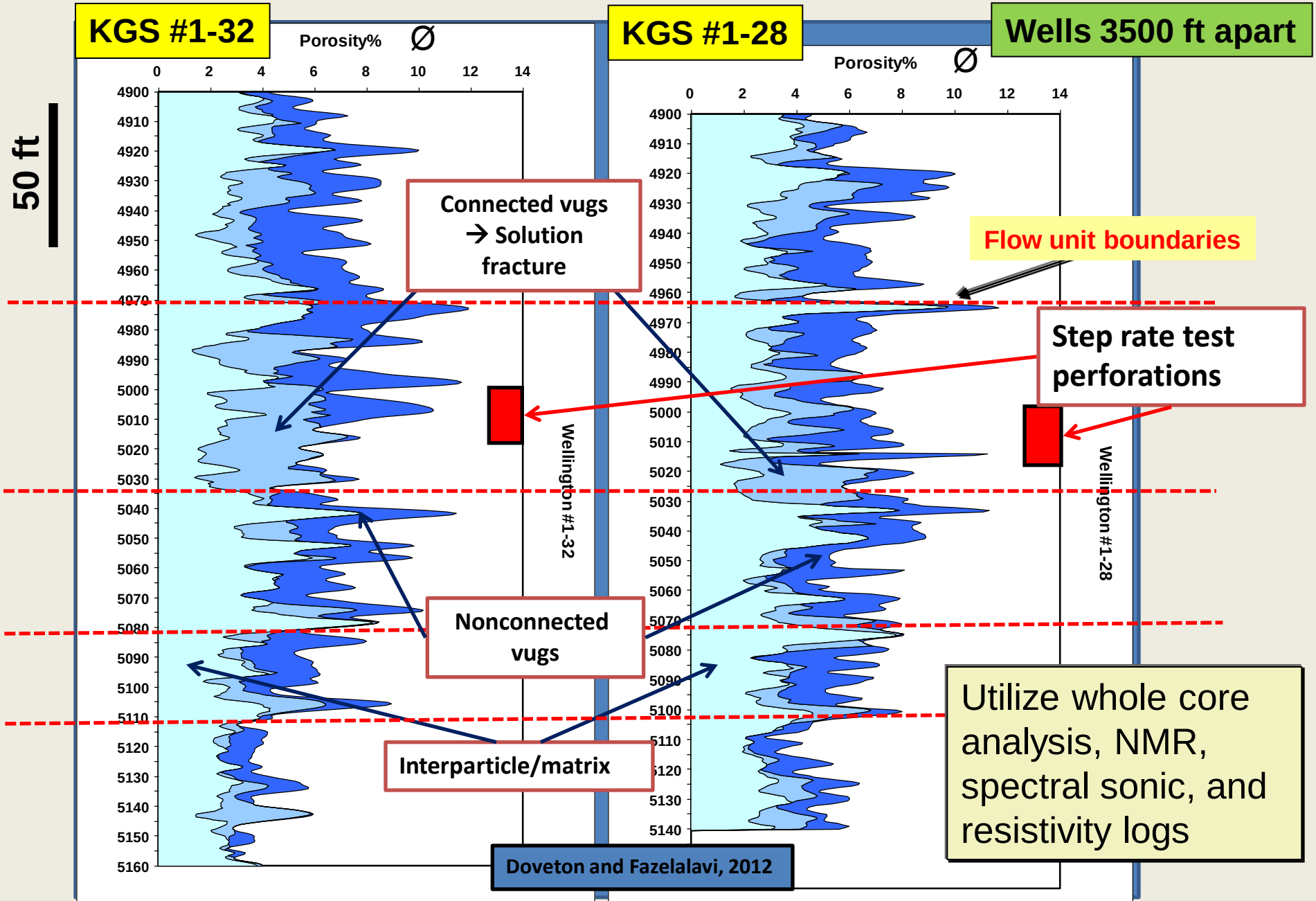
Cross section showing 20 ft interval of step rate test and proposed swab intervals in the Arbuckle



Upscaled hydrostratigraphic units in Arbuckle Group

HALLIBURTON

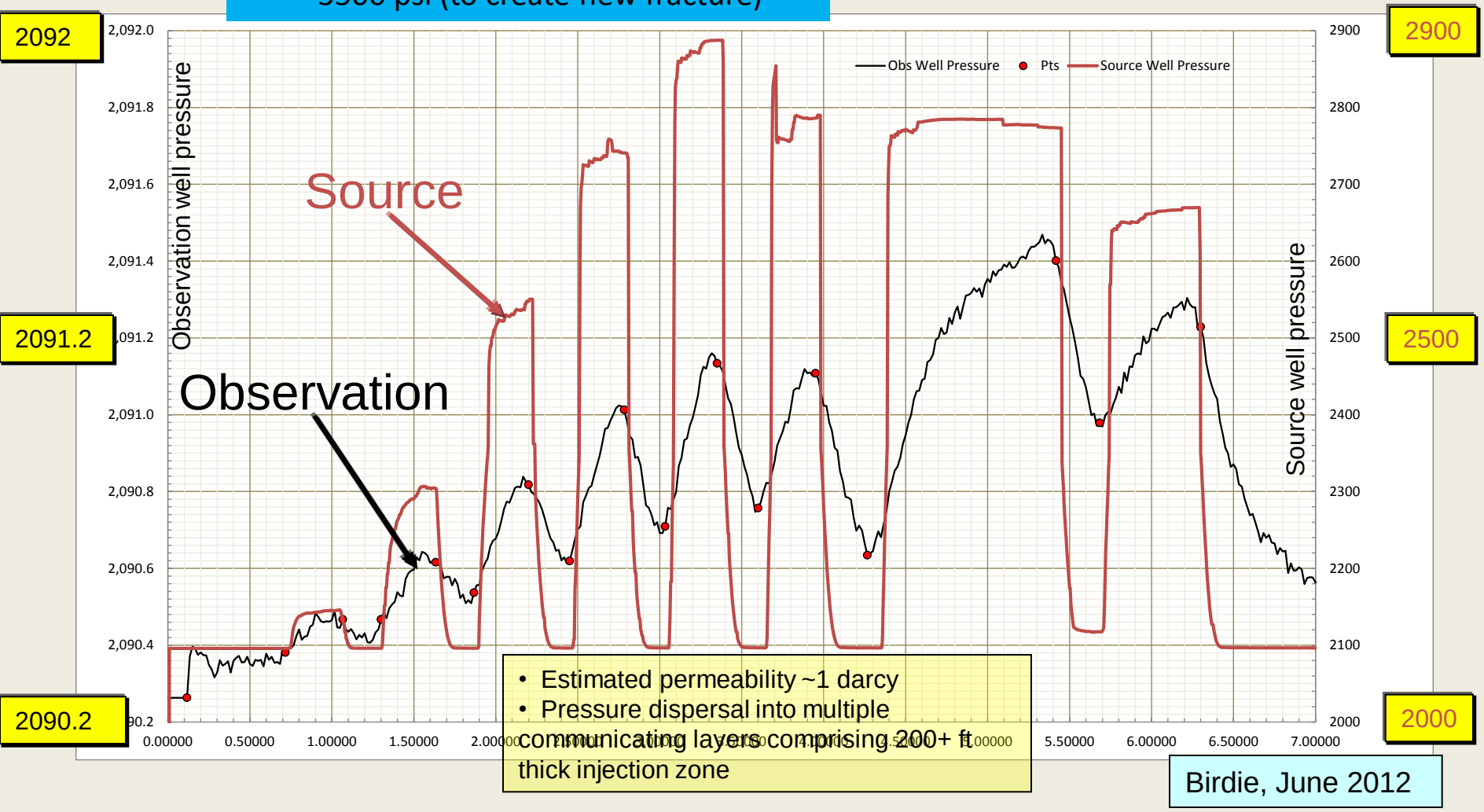
Flow Units in the Lower Arbuckle Injection Zone, ~4900-5160 ft
Gasconade Dolomite to Gunter Sandstone



Step-Rate Test Pressure-Time Plot

Source Well (#1-32) and Observation Well (#1-28) Pressures in 20 ft Perforated Zone in Lower Arbuckle Injection Interval

Est. fracture pressure = 0.7 psi/ft x 5000 ft
= 3500 psi (to create new fracture)



Time for observation well (#1-28) based on clock and start time for source well (#1-32)

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, Jason Rush, Joint PIs

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

KU KANSAS GEOLOGICAL SURVEY

The University of Kansas

Project Team

DOE-NETL Contract #FE0006821

KANSAS GEOLOGICAL SURVEY
The University of Kansas

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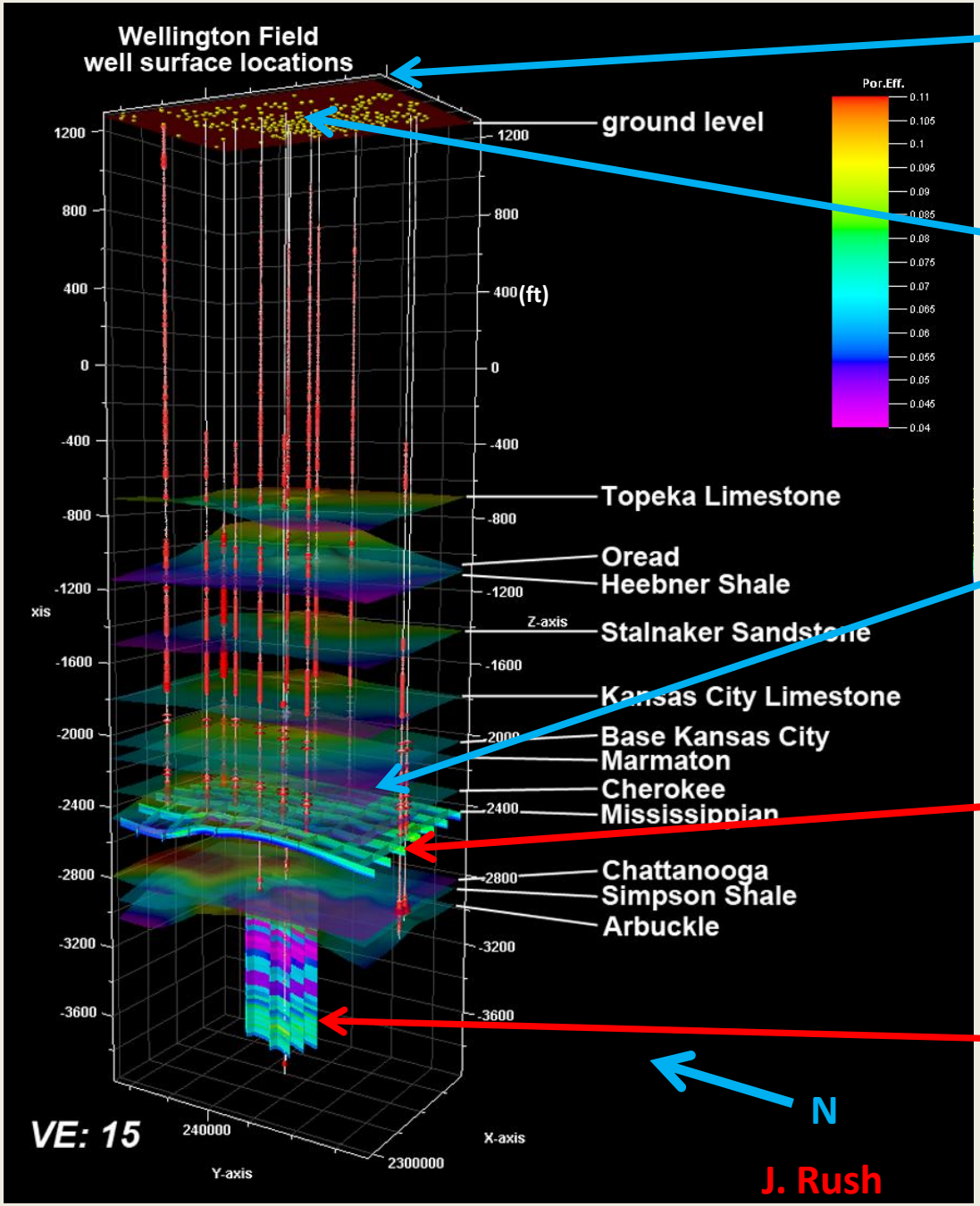
Sandia Technologies, LLC

Dan Collins, David Freeman

Finalize static & dynamic model for Class VI



- InSAR 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*)

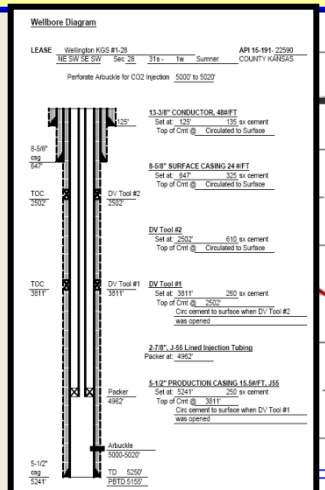
Inject 30,000 tonnes of CO_2 into Mississippian oil reservoir to demonstrate CO2-EOR and 99% assurance of storage with MVA

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

Boreholes Penetrating the Arbuckle Saline Aquifer in Wellington Field

Berexco, LLC has:

- 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 max.**

KANSAS GEOLOGICAL SURVEY
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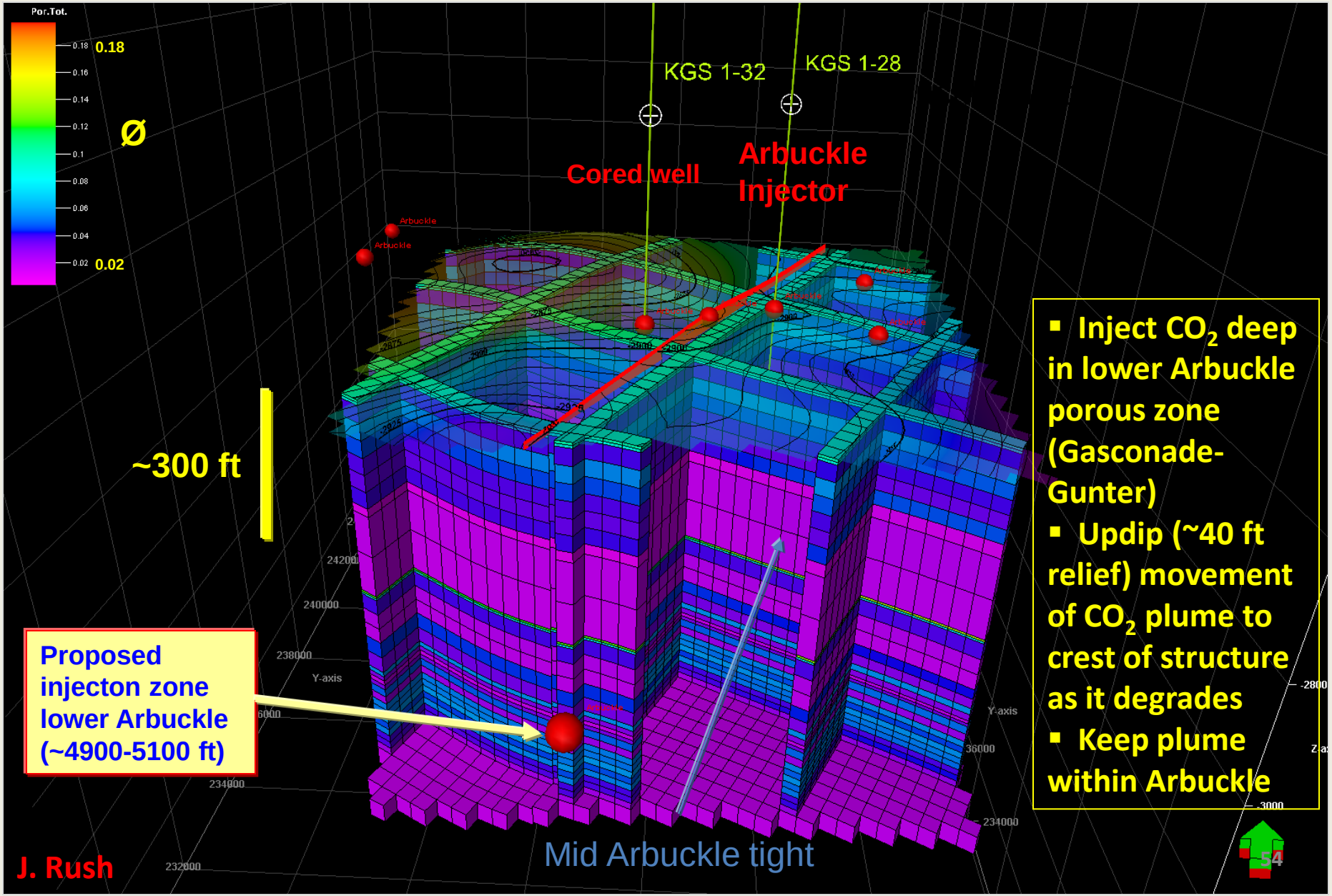
Petrel^{tm} geomodel of Arbuckle

(porosity & structure)

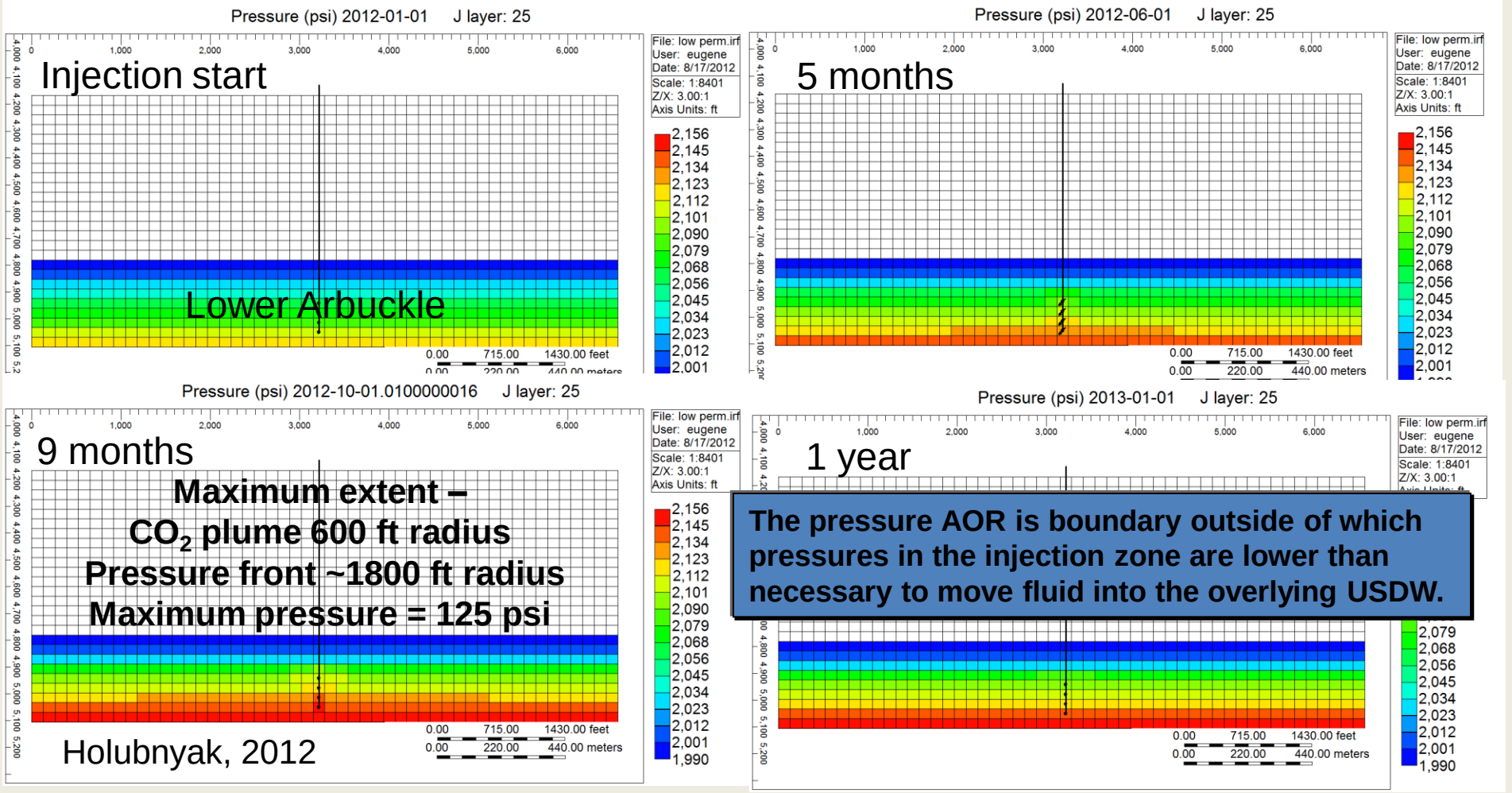


- Inject CO_2 deep in lower Arbuckle porous zone (Gasconade-Gunter)
- Updip (~40 ft relief) movement of CO_2 plume to crest of structure as it degrades
- Keep plume within Arbuckle

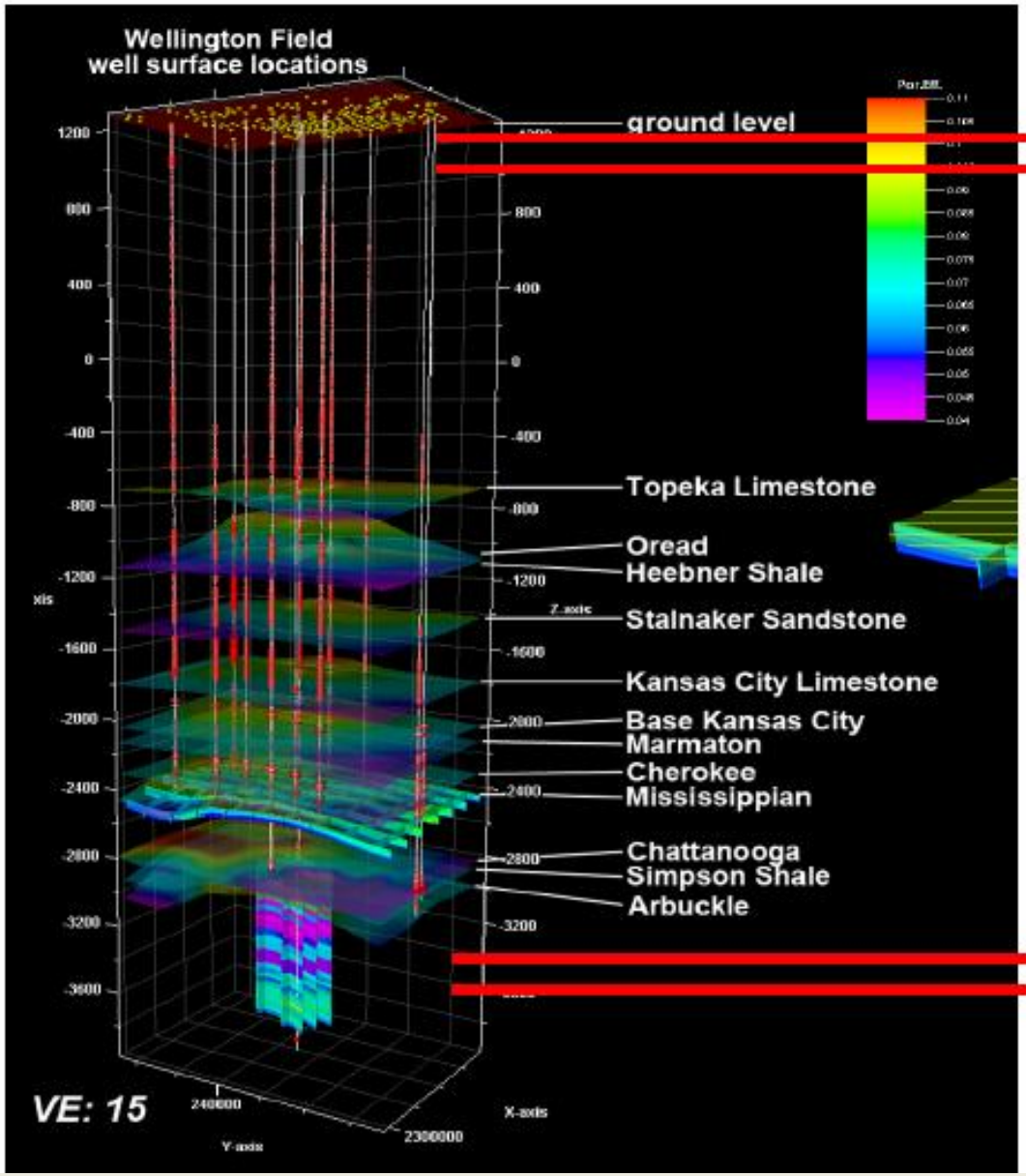
Simulated Pressure Profile around KGS #1-28

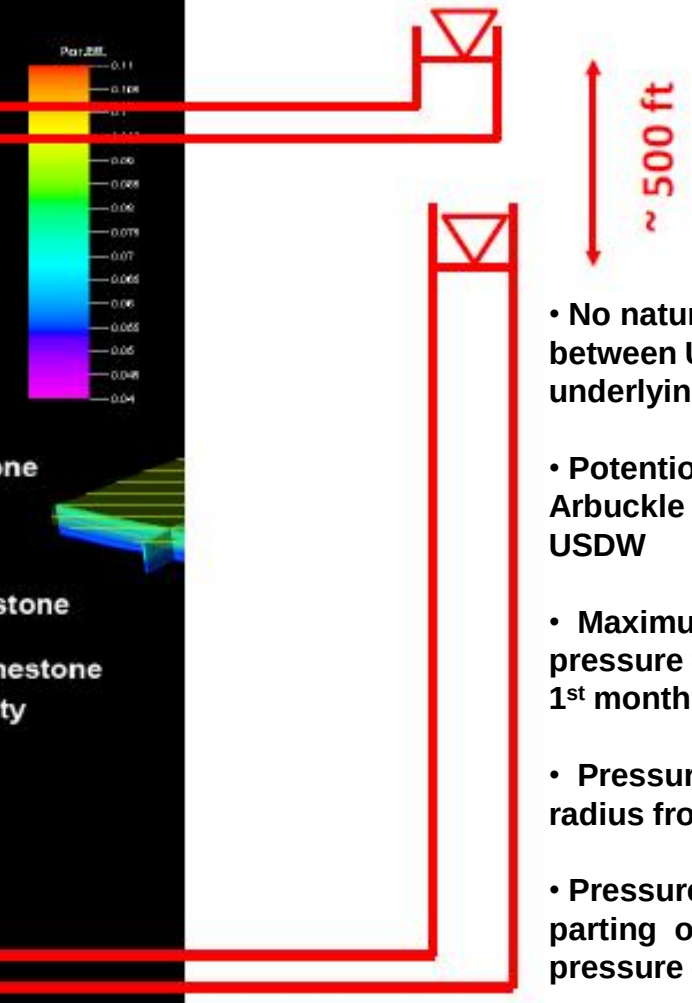
9 Months, 40 kt CO_2 injection scenario into lower Arbuckle – Low permeability case, (100-500 md), dual Ø

Elevated pressure limited to lower Arbuckle injection zone



Head Difference Between Arbuckle and USDW

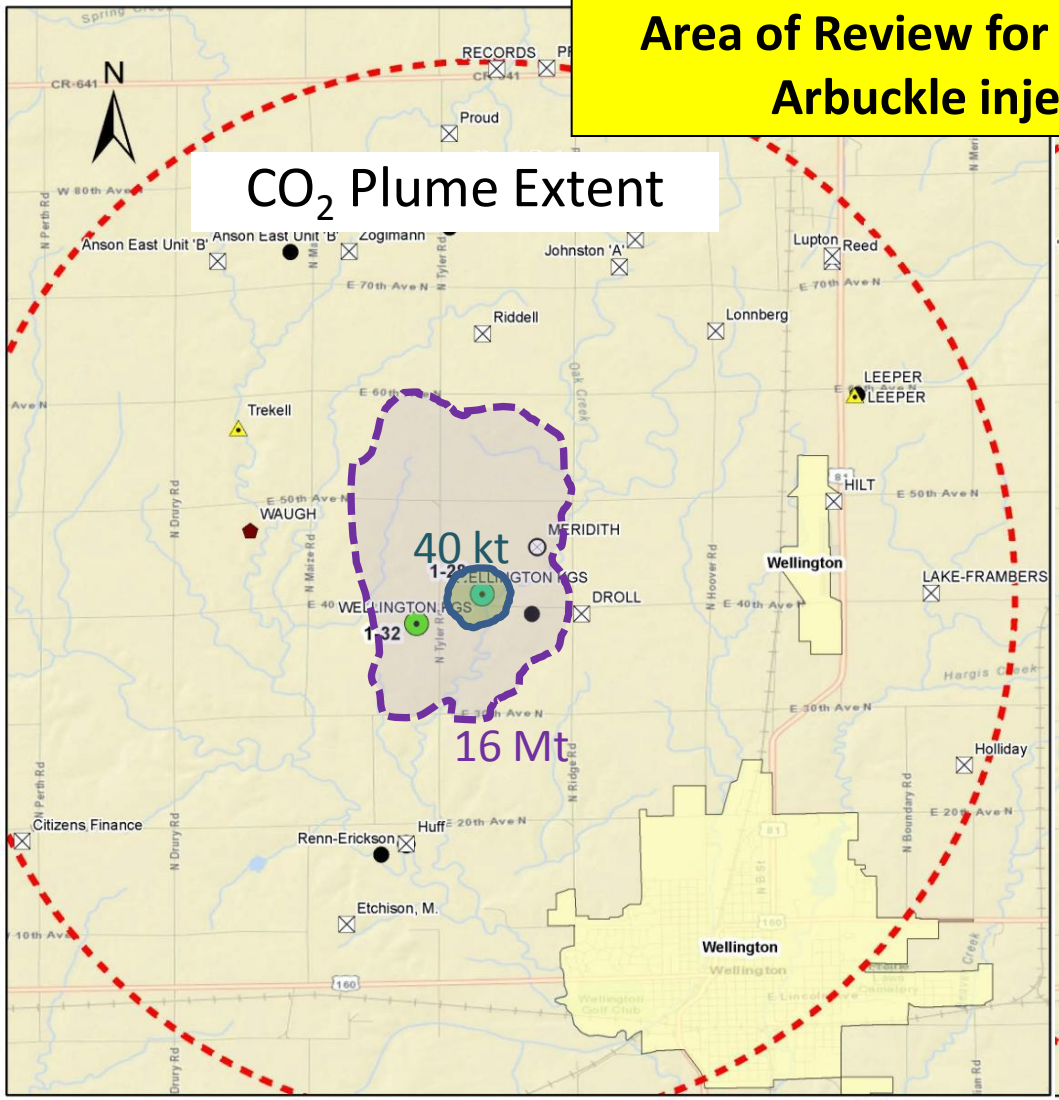




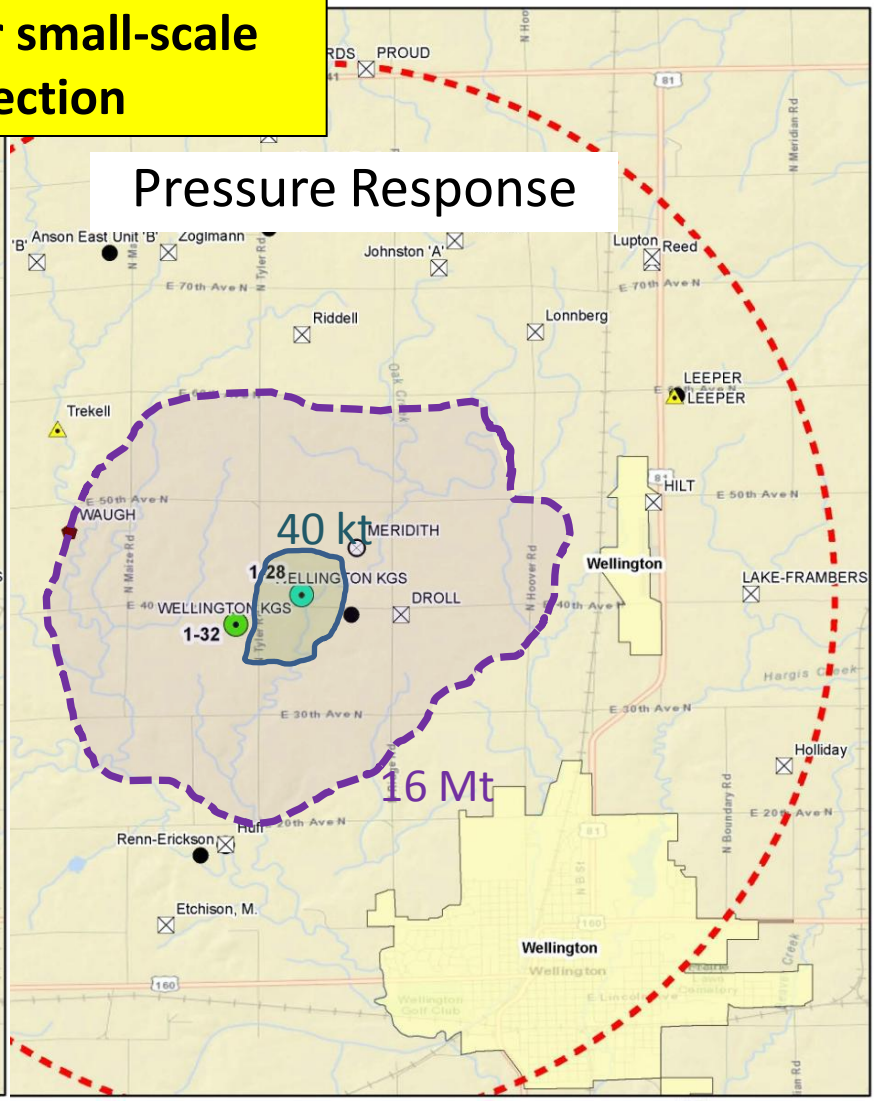
- **No natural connection between USDW and underlying Paleozoic strata**
- **Potentiometric surface of Arbuckle ~500 ft below USDW**
- **Maximum injection pressure = 125 psi within 1st month of injection**
- **Pressure front 1800 ft radius from injector**
- **Pressure well below parting or fracture pressure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

Area of Review for small-scale Arbuckle injection

CO_2 Plume Extent



Pressure Response



Legend

Arbuckle Wells
- <all other values>
- KGS 1-32
- KGS 1-28
- 5 Mile Radius

STATUS
- D&A
- OIL
- OIL-P&A
- OTHER
- SWD

Miles
0 0.4 0.8 1.6 2.4

Dynamic Simulation of CO_2 Injection in Saline Aquifer, Arbuckle Fm. in Wellington Field

Yevhen Holubnyak, KGS

Presentation Summary

- **Locations of studies, schedule, fundamentals**
- **Accomplishments**
  - **Regional geology & estimate of CO_2 storage capacity in the Arbuckle saline formation in southern Kansas**
  - **Source-sink network for CO_2 utilization and storage**
  - **Calibration sites for CO_2-EOR and Arbuckle saline formation**
    - **Wellington Field, Sumner County (2 new wells, seismic)**
    - **Cutter Field, Stevens County (1 new well, seismic)**
    - **Pleasant Prairie South, Eubank North, and Shuck fields**
- **Small scale field test at Wellington Field**
  - **Assessment of CO_2 injection zone, caprocks, and isolation from USDW**
  - **CO_2 plume management through simulation and MVA**
  - **70,000 metric tons CO2 from nearby ethanol plant**
- **Spin-off research on the Mississippian Lime Play & lower Paleozoic hydrocarbon system**
- **Summary**

KSCO2

You are invited to participate!

Acknowledgements & Disclaimer

Acknowledgements

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