Carbon Sequestration in Kansas
Update on DOE funded projects

– a) characterization of CO_2 sequestration capacity southern Kansas (FE0002056)
b) small scale field test at Wellington Field, Sumner County (FE0006821)

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Lawrence, KS 66047

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

NETL

Kansas Environmental Conference

August 7-9, Hyatt Regency, Wichita, Kansas

2012

Kansas Department of Health and Environment

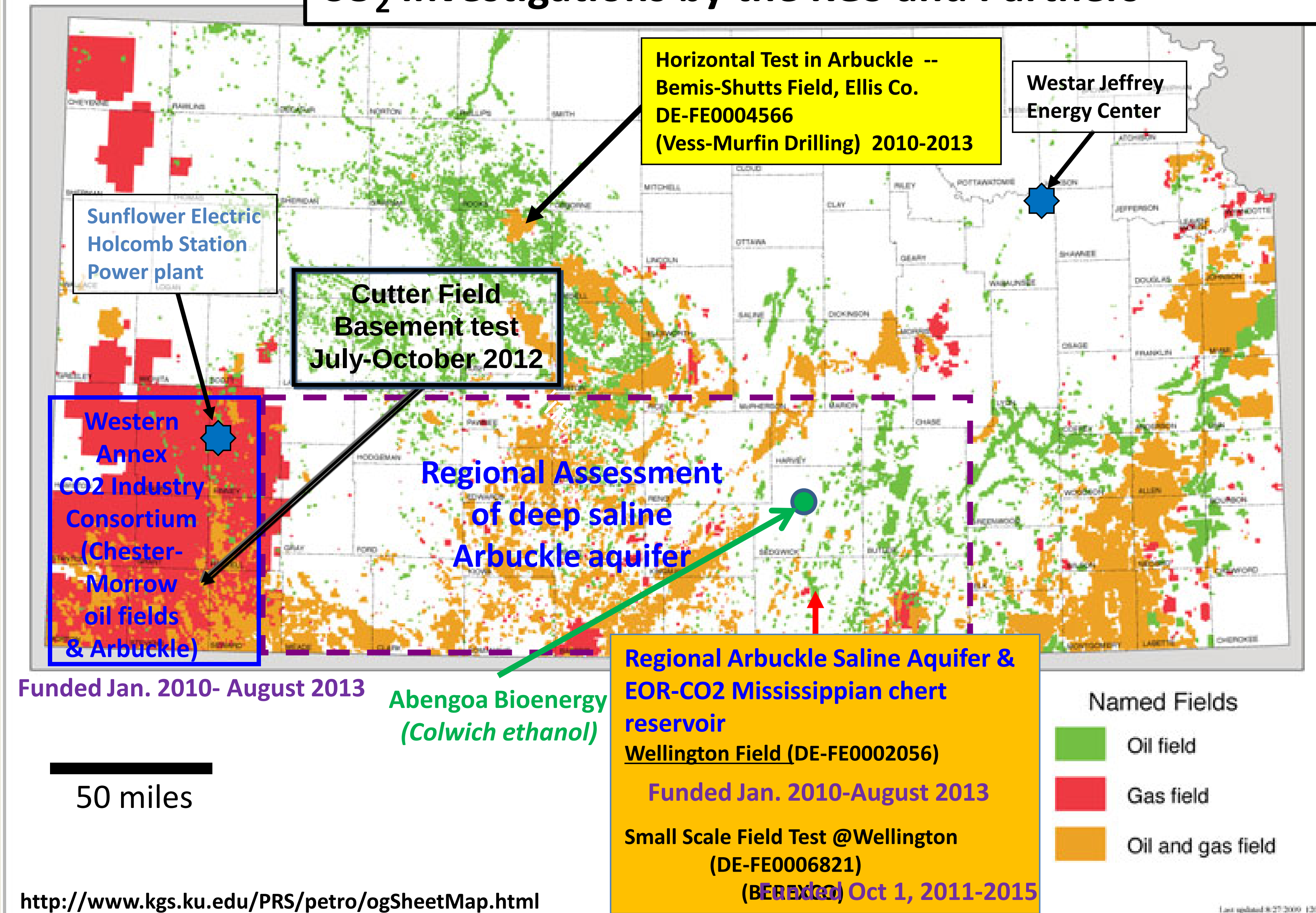
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Outline

- **Locations of studies, schedule**
- **Accomplishments**
  - Capacity for CO_2 sequestration in Arbuckle saline formation in southern Kansas
  - Source-sink network for CO_2 sequestration
  - Calibration sites for CO_2-EOR and Arbuckle saline formation
    - Wellington Field, Sumner County, 2nd year
    - New seismic and basement test @ Cutter Field, Stevens County, July-Oct. 2012
- **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
- **Summary**

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

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

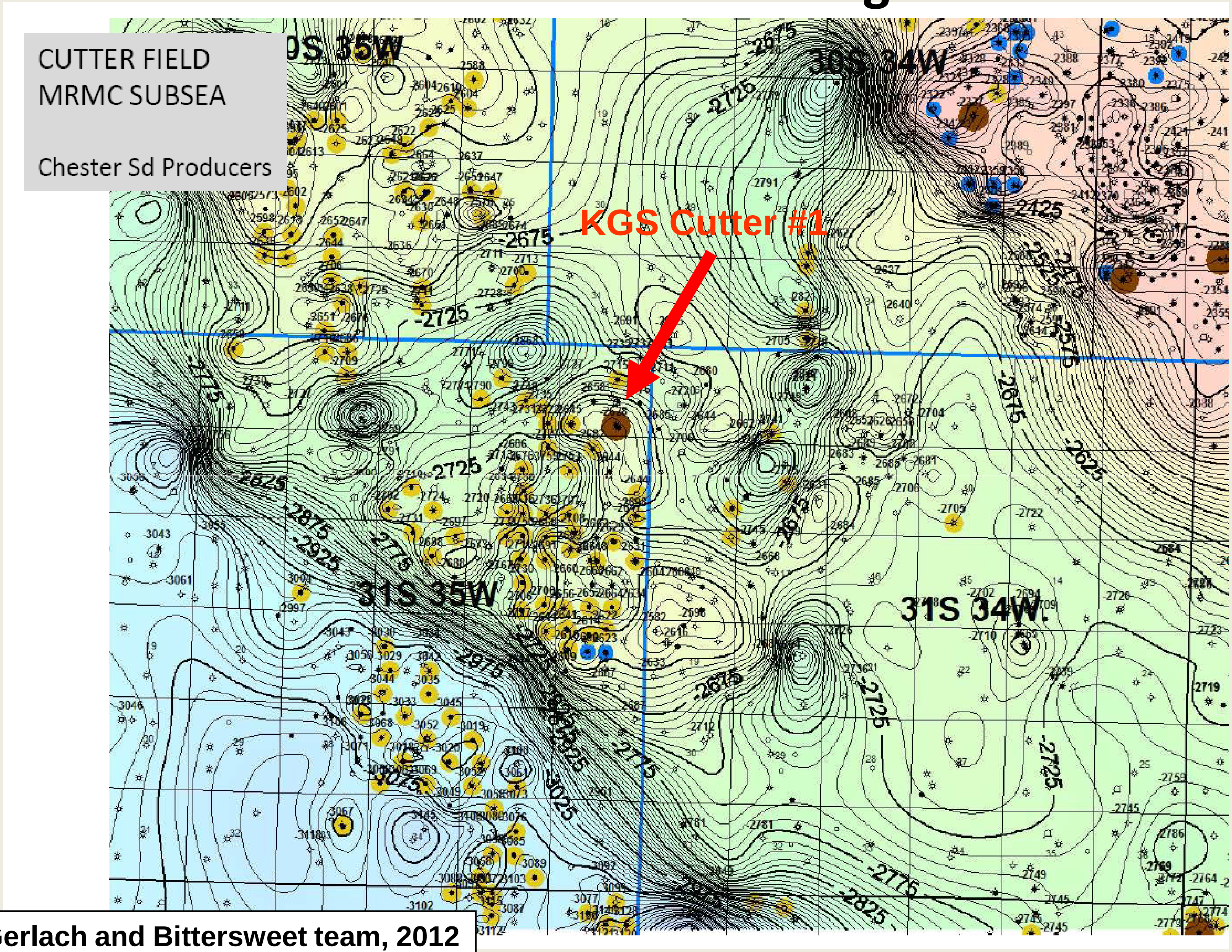


3D Seismic and Basement Test
Cutter Field, Stevens County
July-October 2012

- Repeat work done at Wellington Field serving as western calibration site
- Integrate Cutter Field into regional geologic framework
  - Well based mapping, gravity, magnetics, and remote sensing
  - 120 mi^2 of regional three dimensional seismic imaging

BEREXCO

KGS Cutter #1 well on Mississippian structural plateau on local structural high



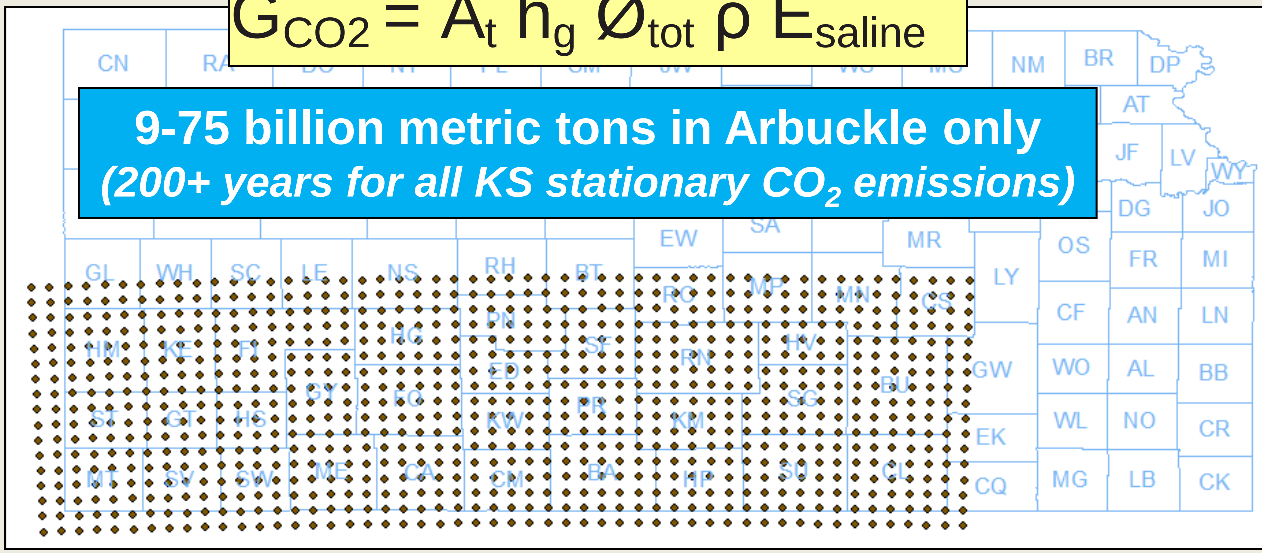
Gerlach and Bittersweet team, 2012

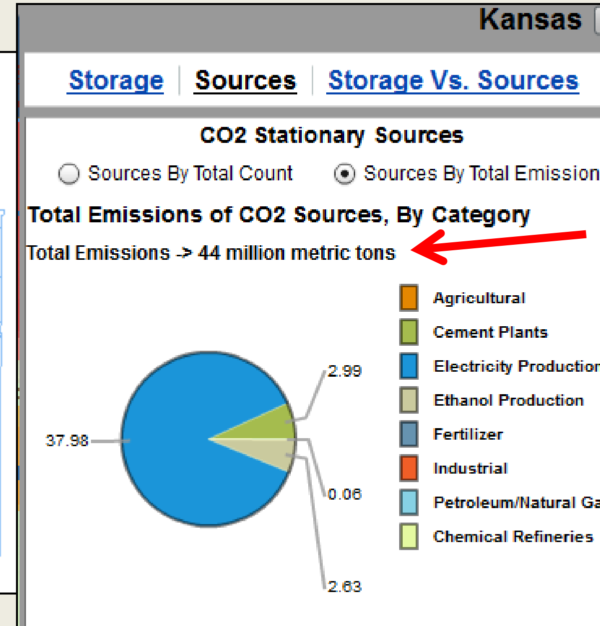
Initial CO_2 Storage Capacity Estimate

(reported April 2011 for NATCARB) Deep Arbuckle Saline Formation

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

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 km^2
(3.8 mi^2)

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

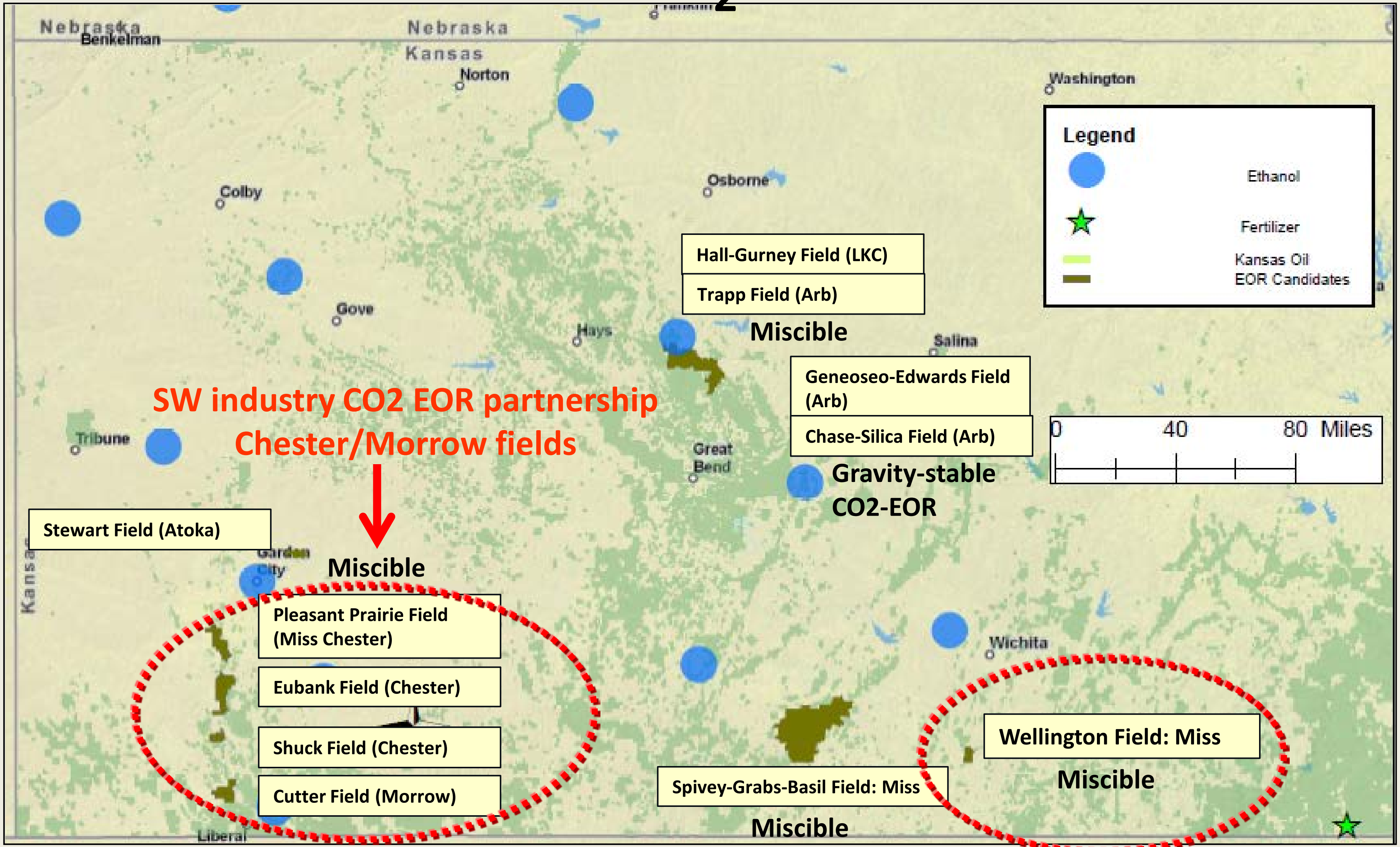
P90	
75,464,988,970	Total All Cells
190,903,682	High Cell
88,411,323	Median Cell
90,703,112	Mean Cell

Gerlach and Bittersweet team, 2012

Source-Sink Network for CO_2 Sequestration

- **Infrastructure for capture and use of anthropogenic 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 CO_2-EOR and saline formation sequestration

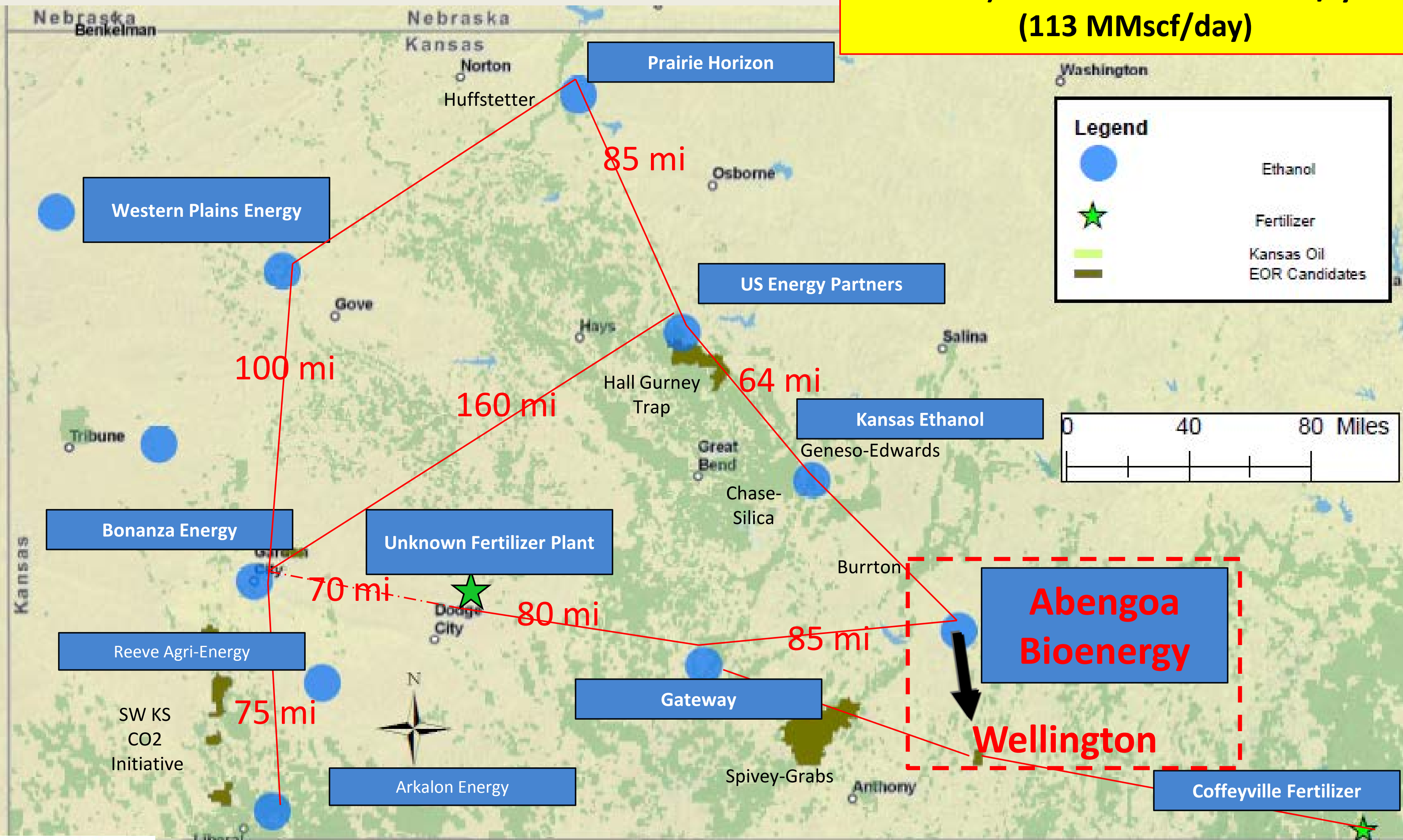
Ethanol Plants and Selected Oil Fields for CO_2-EOR



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

Calibration Site for CO_2-EOR and Arbuckle Saline Formation

1. **Wellington Field, Sumner County**
    1. **12 mi^2 of multicomponent seismic**
    2. **Two wells drilled to basement**
        1. 1600 ft of core and comprehensive wireline logs of caprocks and injection zones
        2. Porosity, permeability, pore type, fractures
        3. Geochemistry
        4. Rock mechanics
        5. Formation imaging
        6. DST and step rate/interference test to sample fluids, characterize flow units for phi-k assessment, continuity

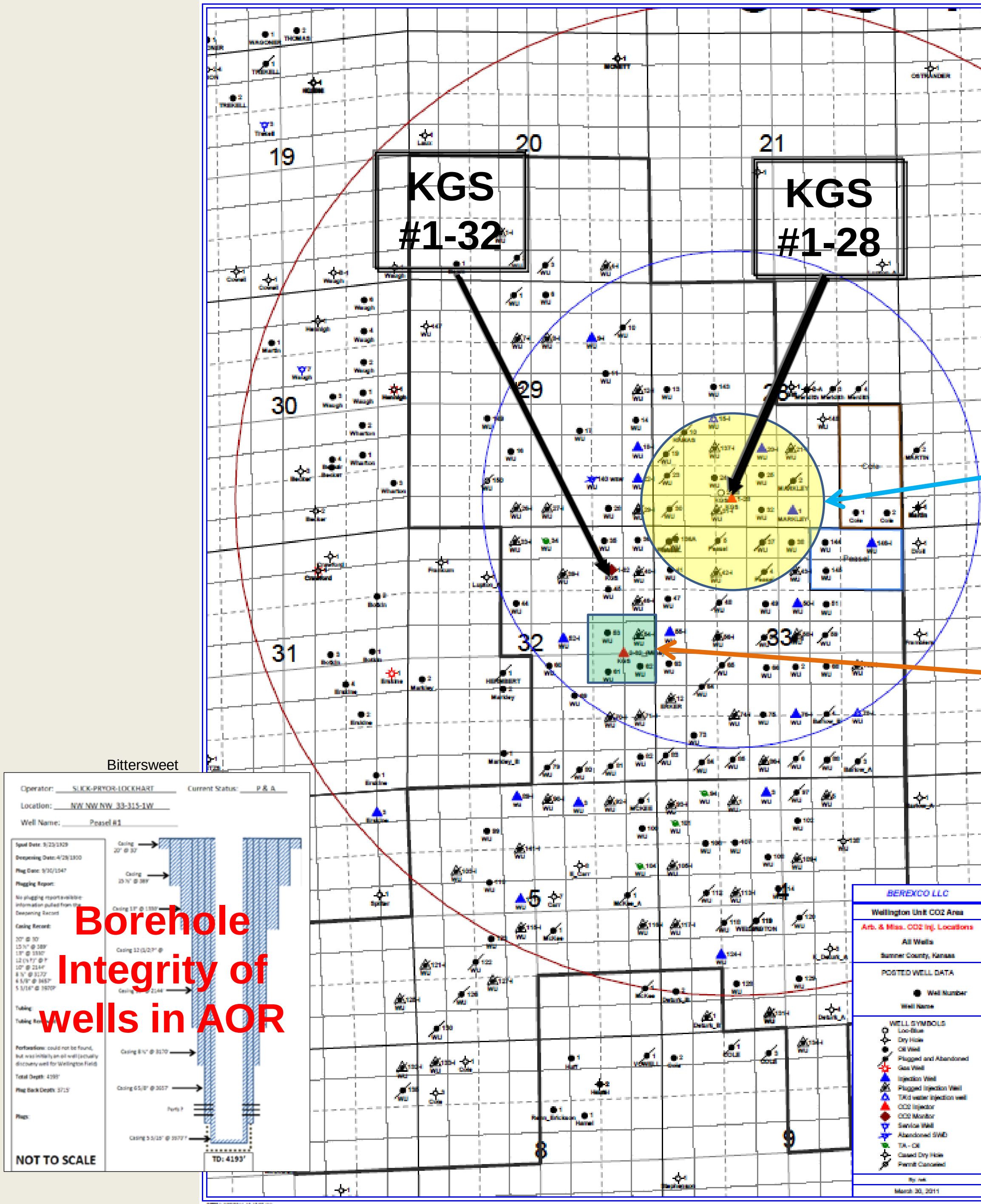
Calibration Site for CO_2-EOR and Arbuckle Saline Sormation (continued)

2. **Establish and characterize baffles, barriers, flow units**
3. **Construct integrated geomodel for simulation**
   1. Interpolate key rock properties from 3D seismic
      1. Map properties of hydrostratigraphic units & caprocks
      2. Map fractures and faults extending well and test data
4. **Coupled geomechanical-fluid flow simulation of CO_2**
   1. Parameterization – core, log, test , geochemical data
   2. Predict plume dimensions through time
   3. Predict pressures, stress, and interaction with caprock
   4. Predict fate of CO2 plume and closure
   5. Define AOR and placement of MVA equipment

Plans

Small Scale Field Test at Wellington Field

1. **Class II permit for CO_2-EOR pilot and Class VI permit for CO_2 saline test (submit application to EPA in September 2012)**
2. **Establish CO_2-EOR injection and install MVA in the Mississippian oil reservoir**
   - Drill injection well and monitoring well and install MVA
   - Inject 30,000 metric tons (**mid 2013**)
   - Test model, and account and verify CO_2 to meet 99% sequestration.
   - Effectiveness, economics, and scaling facilities
3. **Inject 40,000 metric tons CO_2 into Arbuckle saline formation with permit and DOE funding (~2014)**
4. **Test & refine model, verify and account for CO_2 injected to ensure 99 % CO_2 storage permanence in the injection zone**

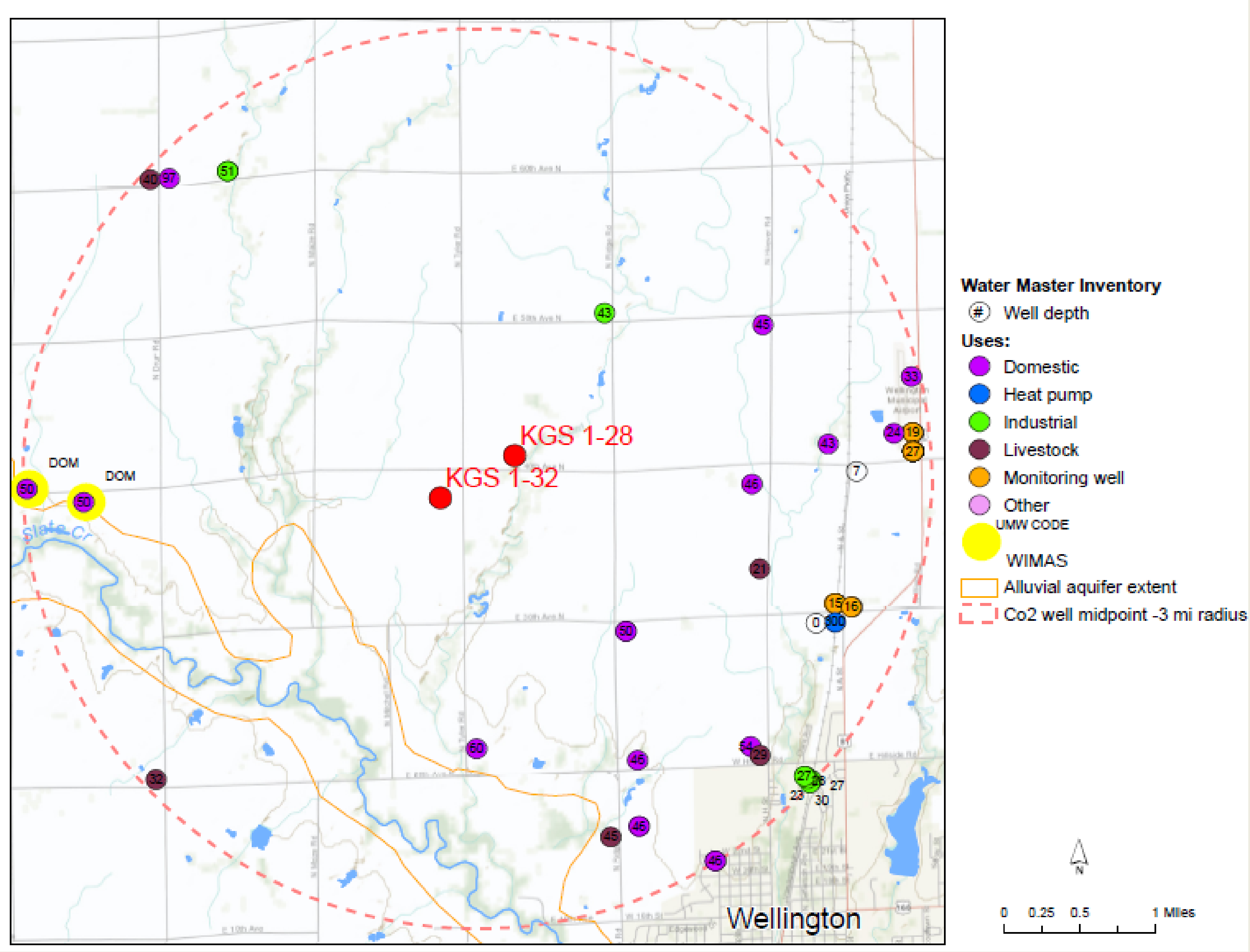


Boreholes penetrating Mississippian oil reservoir in Wellington Field

- Location of Mississippian boreholes to be monitored during and after CO_2 injection into the Arbuckle via KGS #1-28
- Location of Mississippian injection borehole and 5-spot pattern of producing boreholes

1 mile

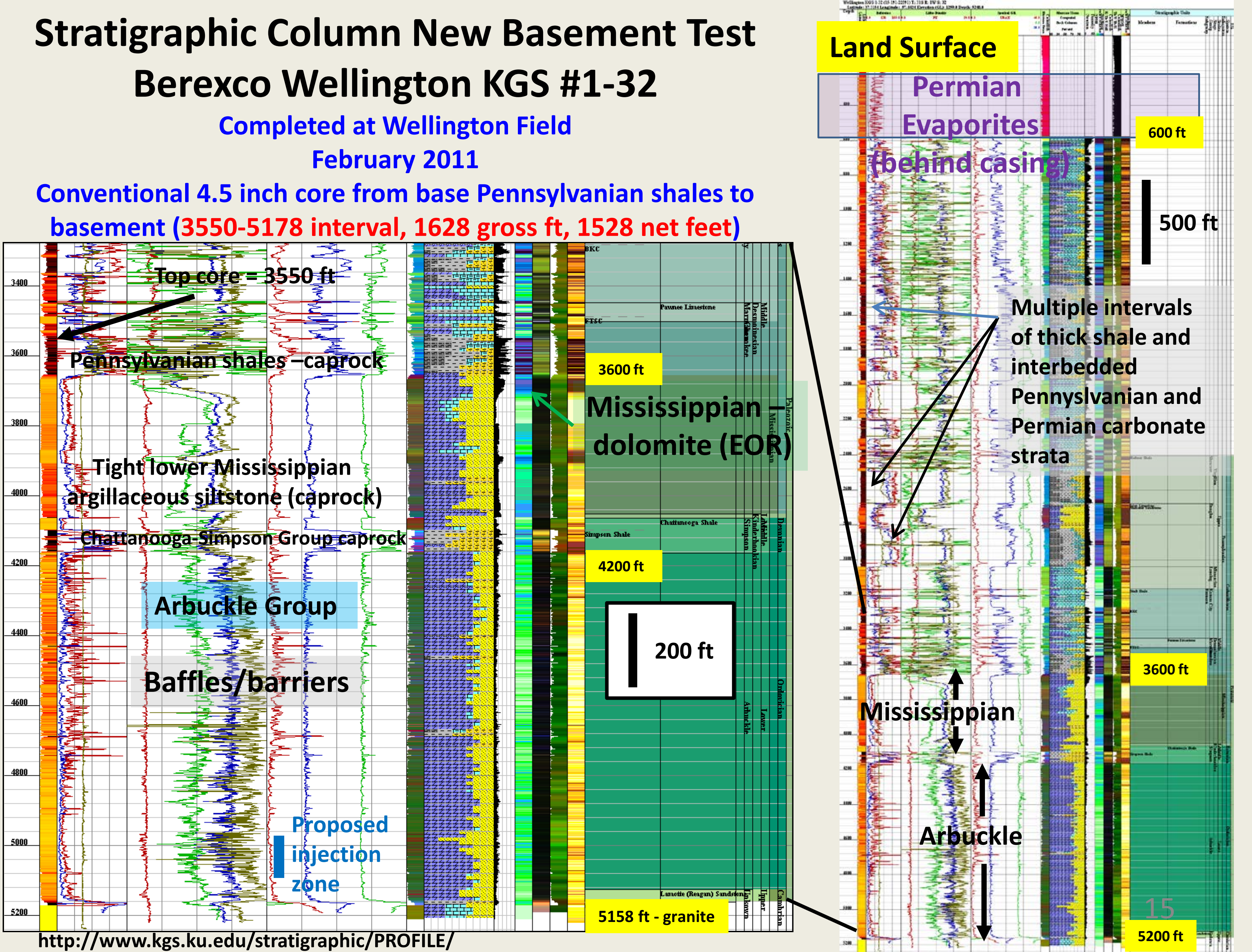
Groundwater Wells



- No major municipal supply within 3 miles of 1-28 (proposed Arbuckle CO2 injector)

Stratigraphic Column New Basement Test
Berexco Wellington KGS #1-32

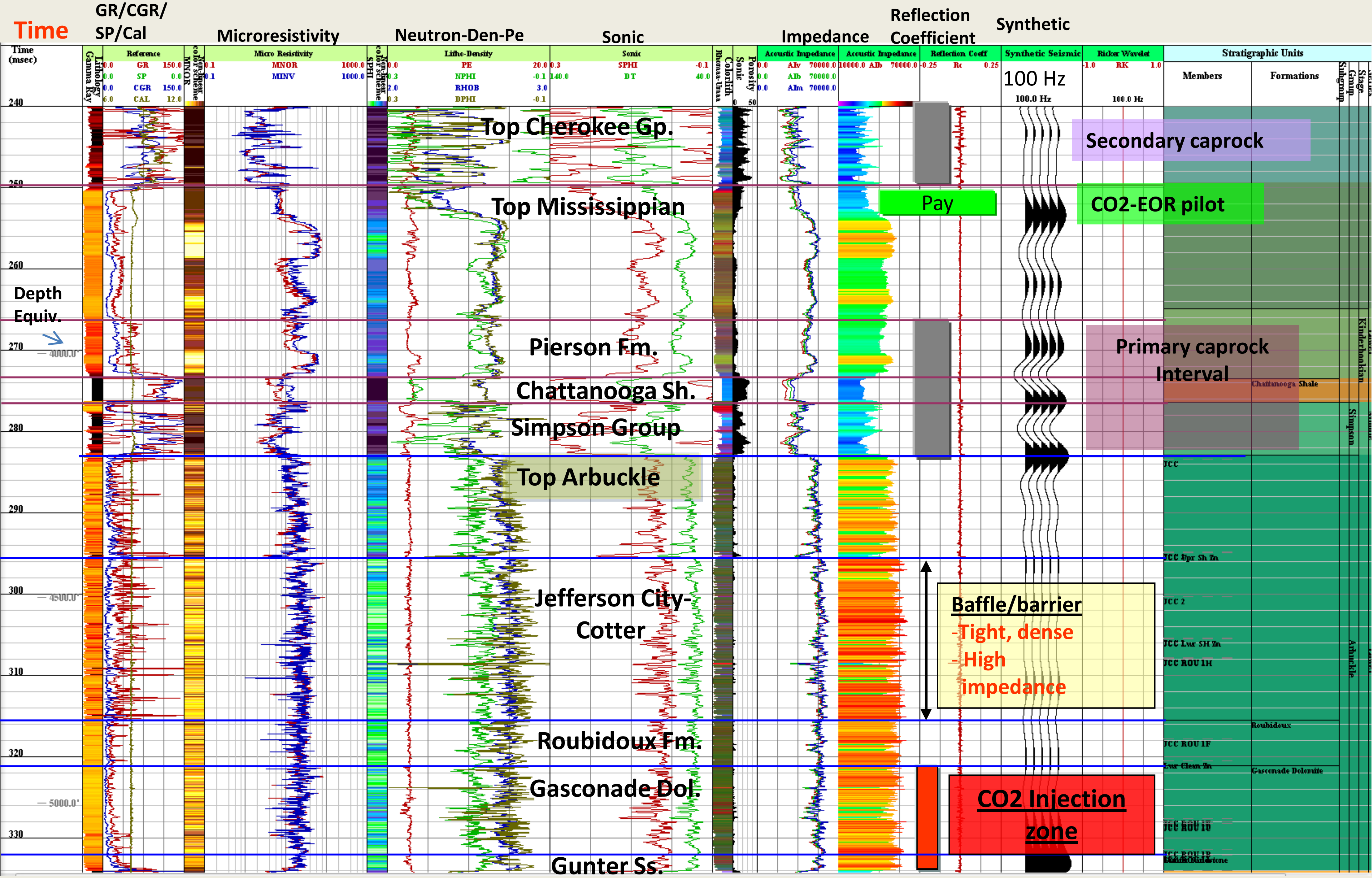
Completed at Wellington Field
February 2011
Conventional 4.5 inch core from base Pennsylvanian shales to basement (3550-5178 interval, 1628 gross ft, 1528 net feet)



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

CO_2 injection zones in Arbuckle saline formation and Mississippian oil reservoir, and associated caprocks

-- Well profile in 2-way travel time of KGS #1-28 illustrating synthetic seismogram and seismic impedance (velocity x density) and well log suite used to derive these seismic properties



Precambrian granite – bottom of core

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

Upper Primary Caprock Interval

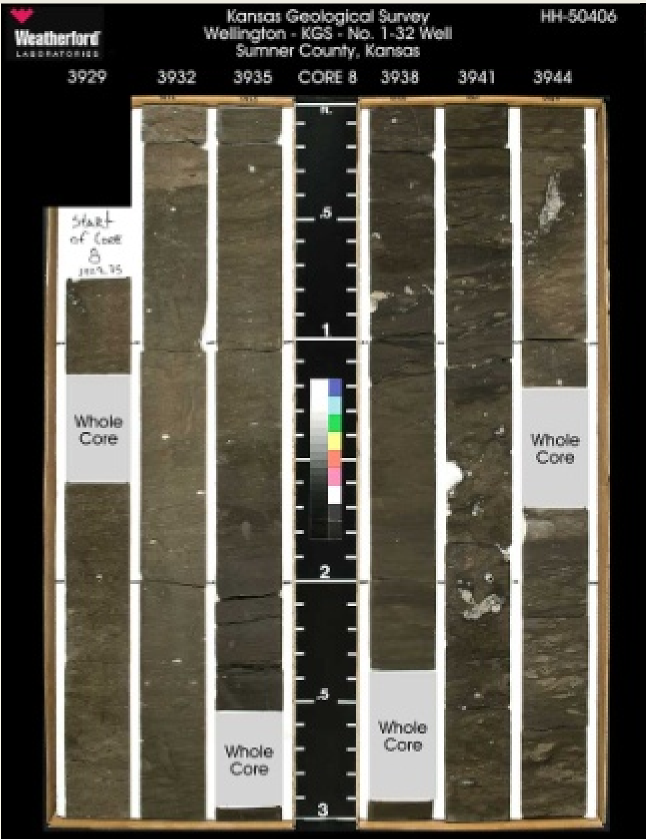
(core slabs from KGS #1-32)

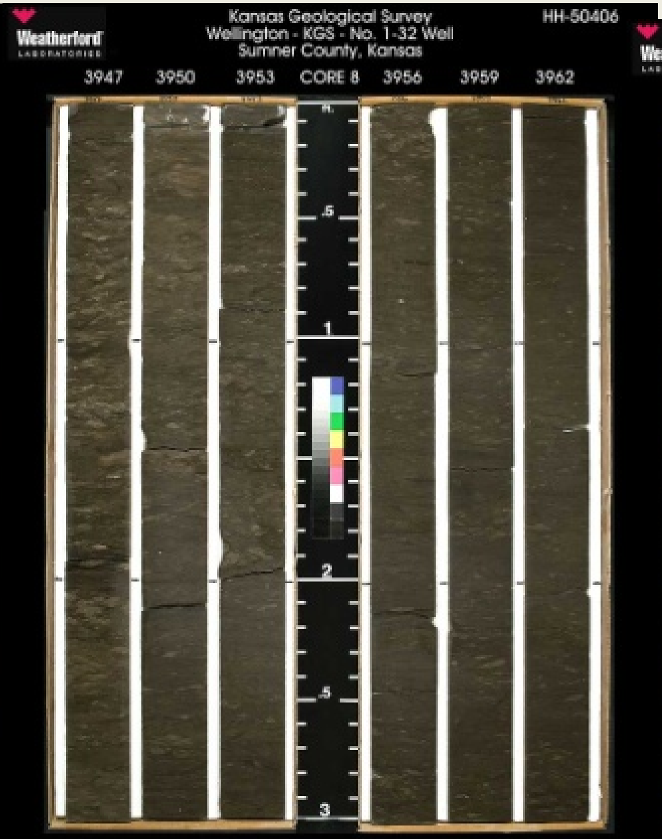
Lower Mississippian PIERSON LIMESTONE (~120 ft thick) : Dark, organic, argillaceous siltstone

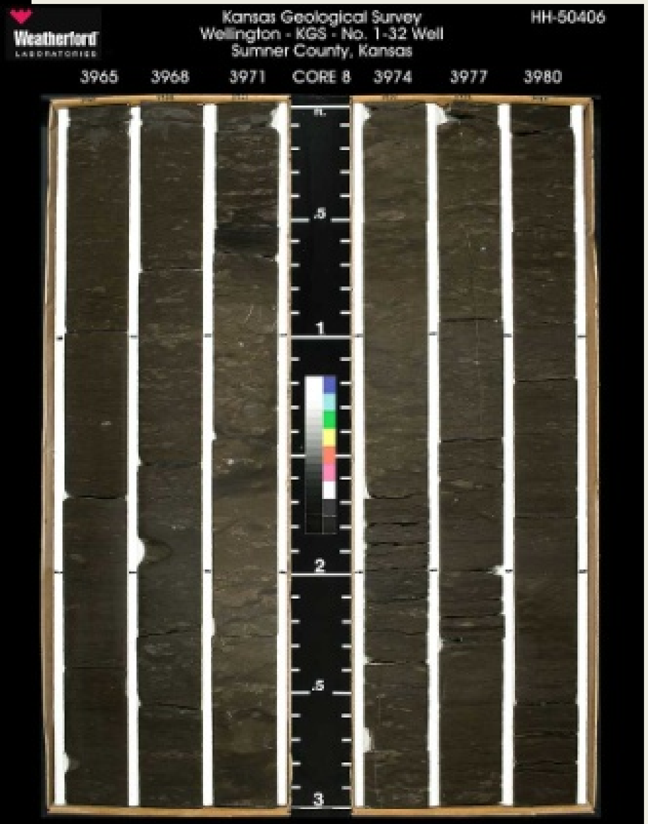
3927- 3939: olive gray, argillaceous dolomitic siltstone; 50% silt; wispy shale laminations; indistinct bedding; faint discontinuous laminations; gradational contact

3939-3975.6: medium dark gray; very argillaceous dolomitic siltstone; faintly laminated irregular; 30% silt; 3972-3973 cm-sized irregular calcareous nodules/coarse calcite; faint lenticular bedding alternating olive gray and medium dark gray

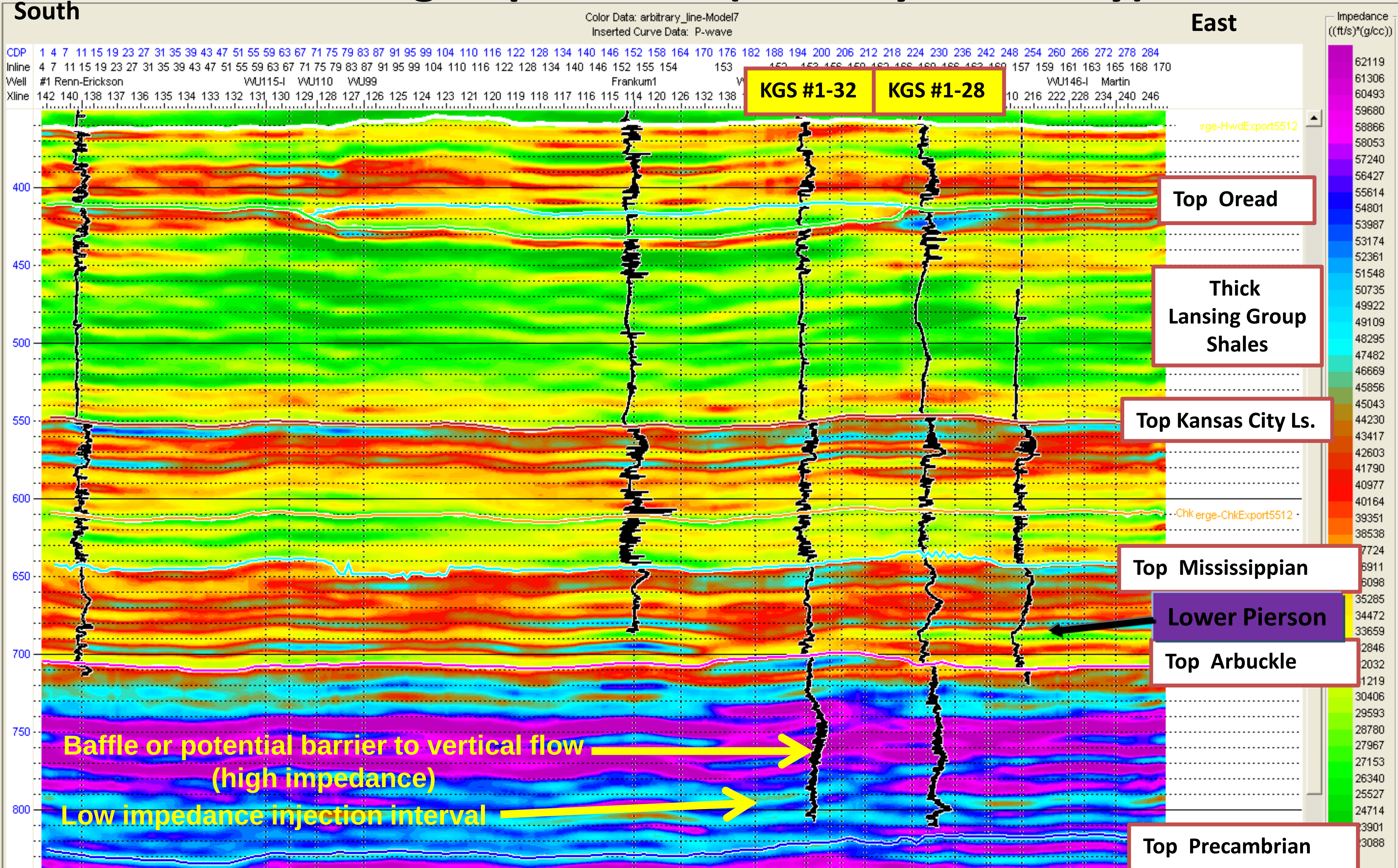
3975.6-3993: very dark greenish gray; shale; tight; dolomitic; around 20% silt; scattered black shale laminae; uniform; scattered pyrite; 3983 starts increasing silt; gradational contact







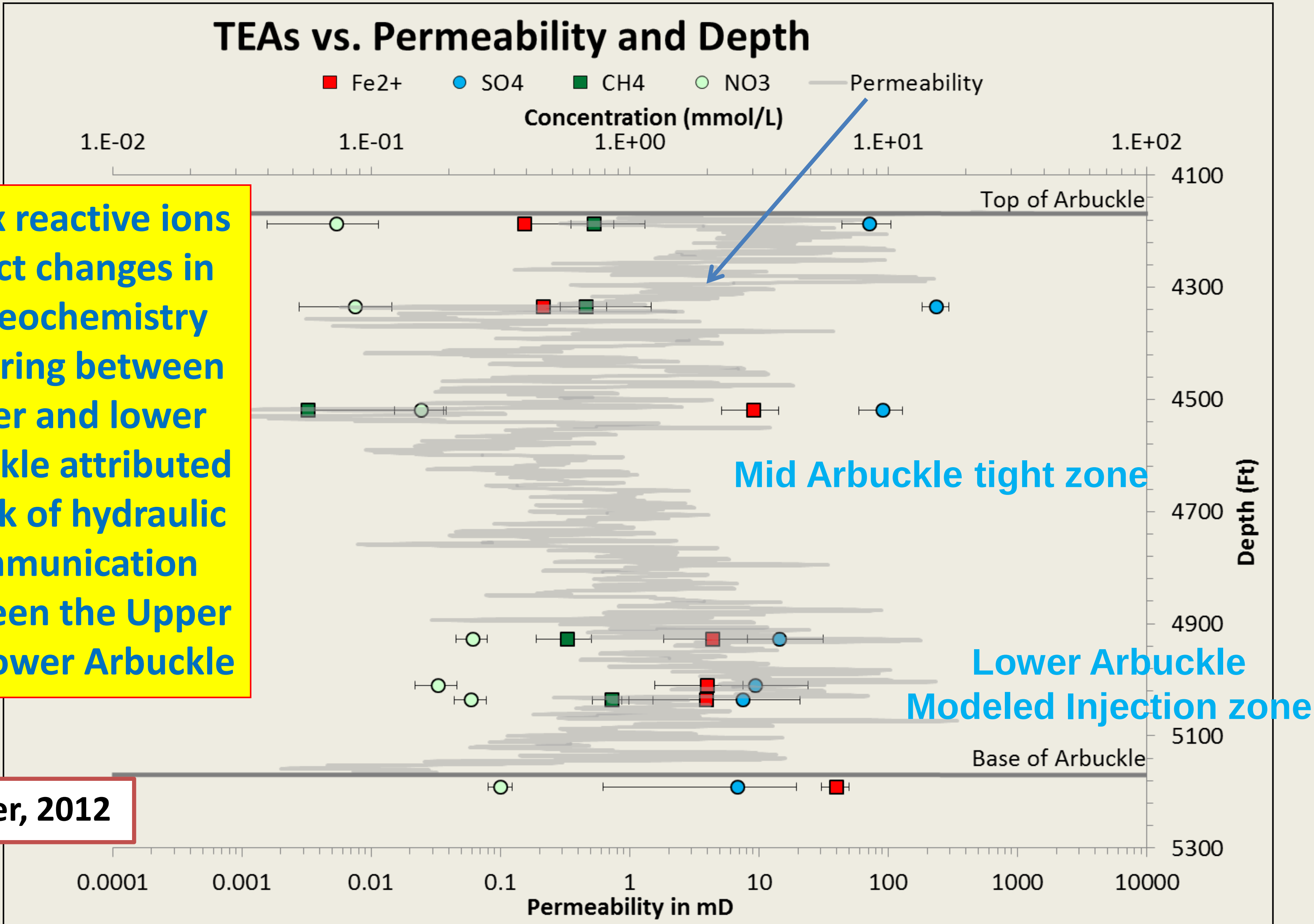
Arbitrary Seismic Profile in time – showing impedance (velocity x density)



Hedke – DOE/CO2

Permeability Profile of Arbuckle in #1-32

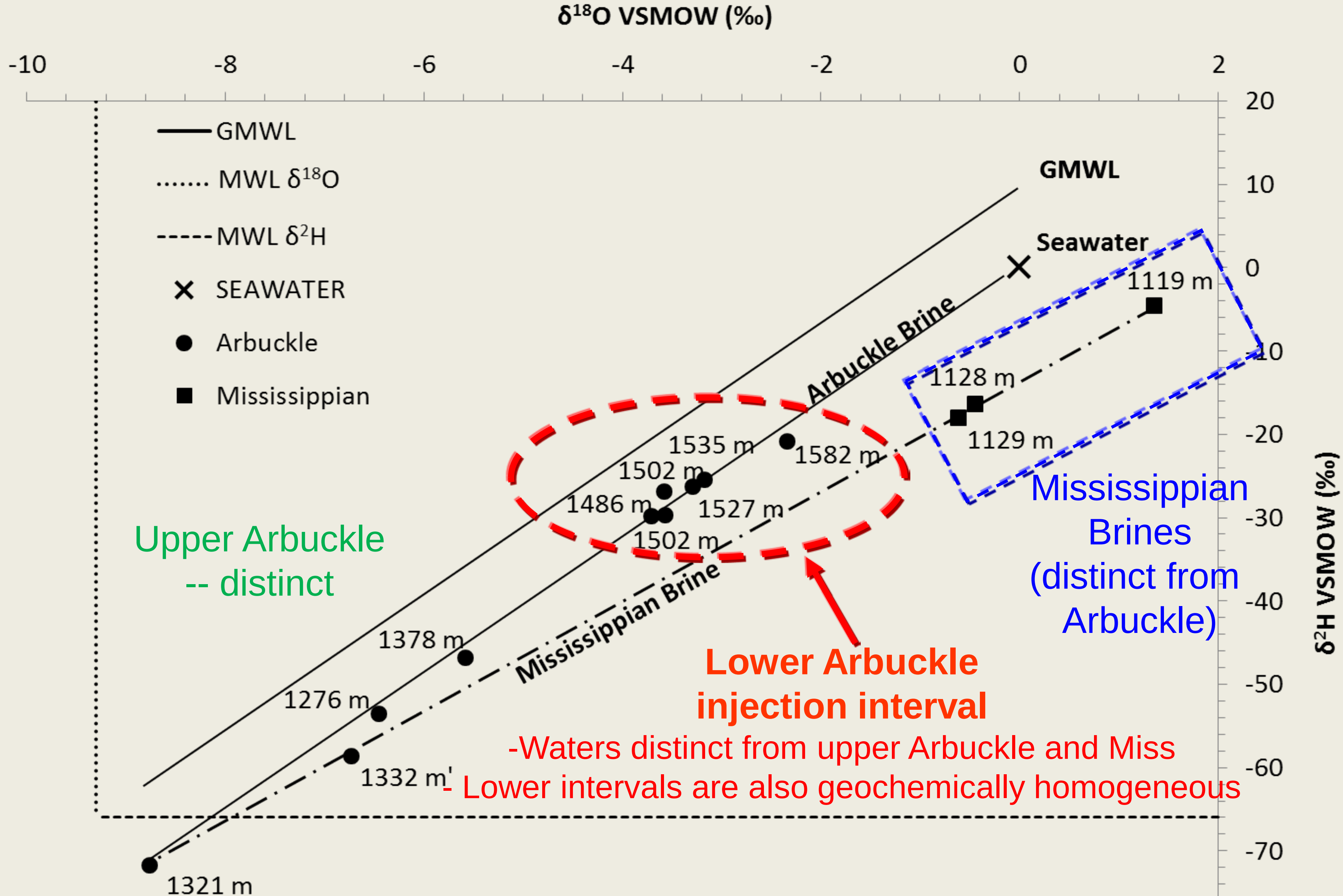
with concentrations of redox reactive ions; ferrous iron, sulfate, methane, and nitrate (Fe^{2+}, SO_4^{2-}, CH_4, NO_3^-) in KGS #1-32 & #1-28



Redox reactive ions reflect changes in biogeochemistry occurring between upper and lower Arbuckle attributed to lack of hydraulic communication between the Upper and Lower Arbuckle

Scheffer, 2012

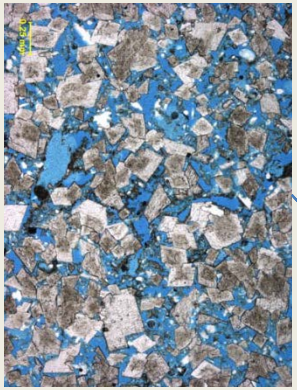
Oxygen & Hydrogen Isotopes of Brine

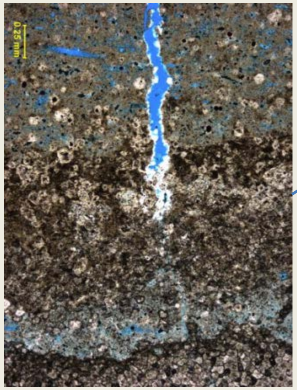


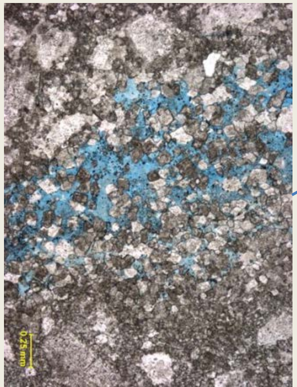
Scheffer, 2012

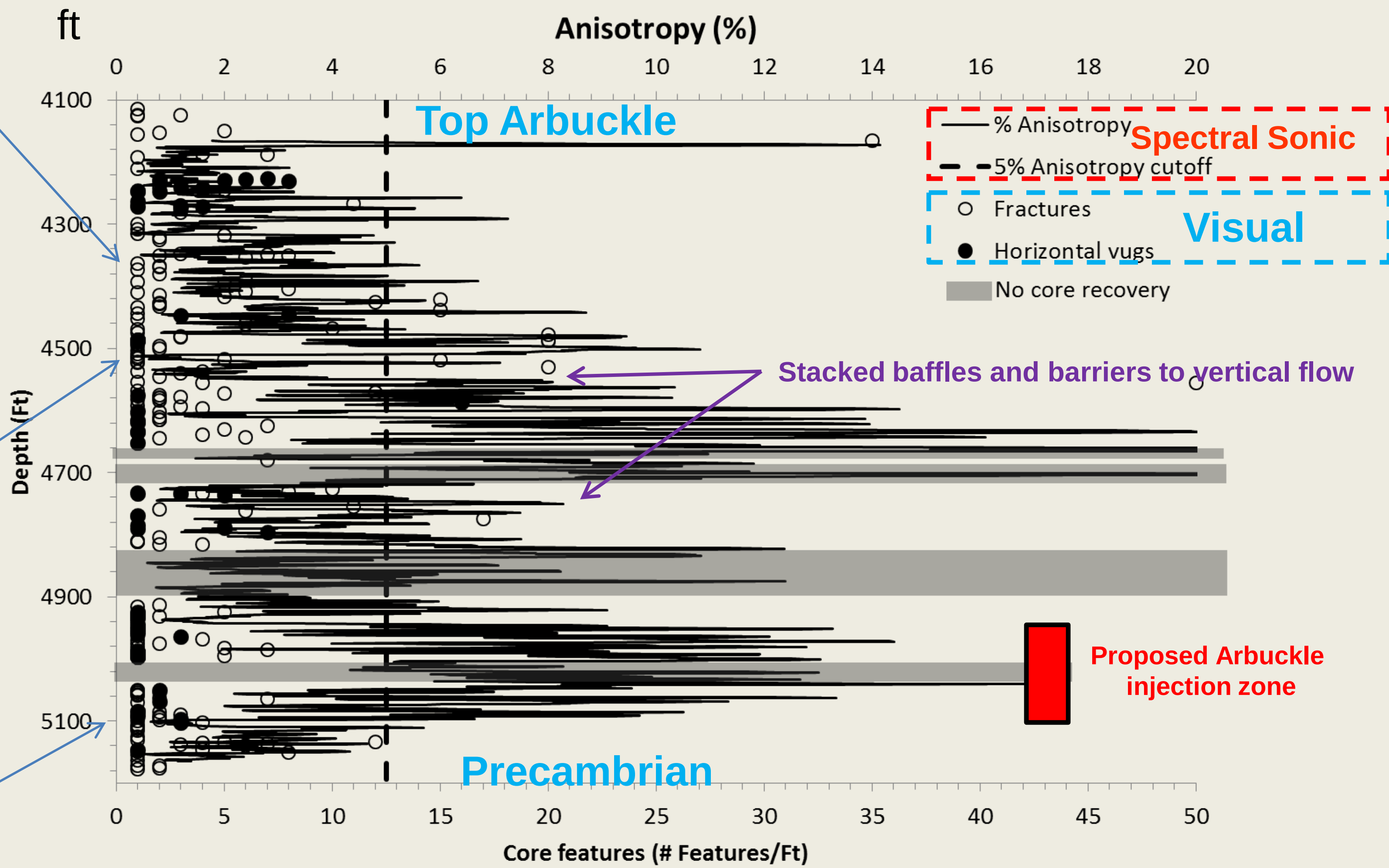
Fracture Characterization in Arbuckle

Spectral acoustic log & core description







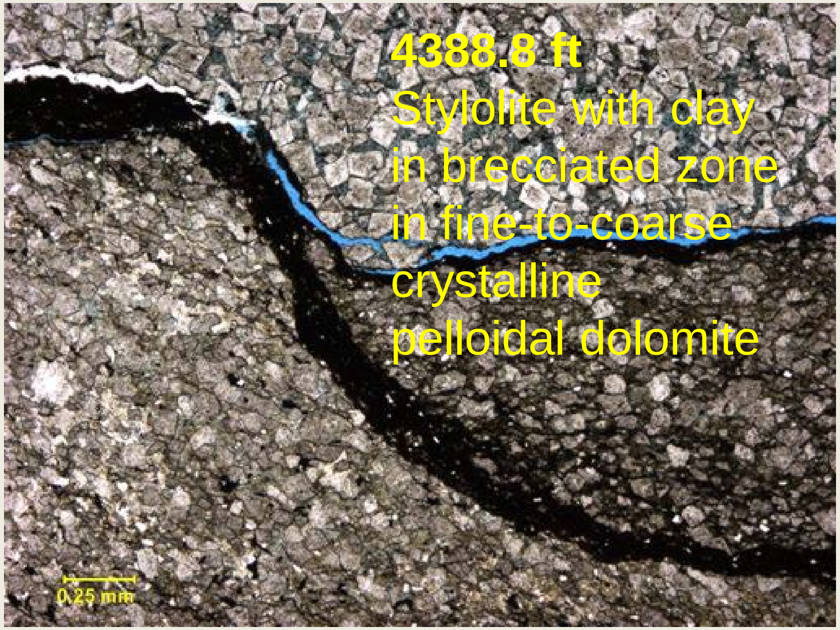


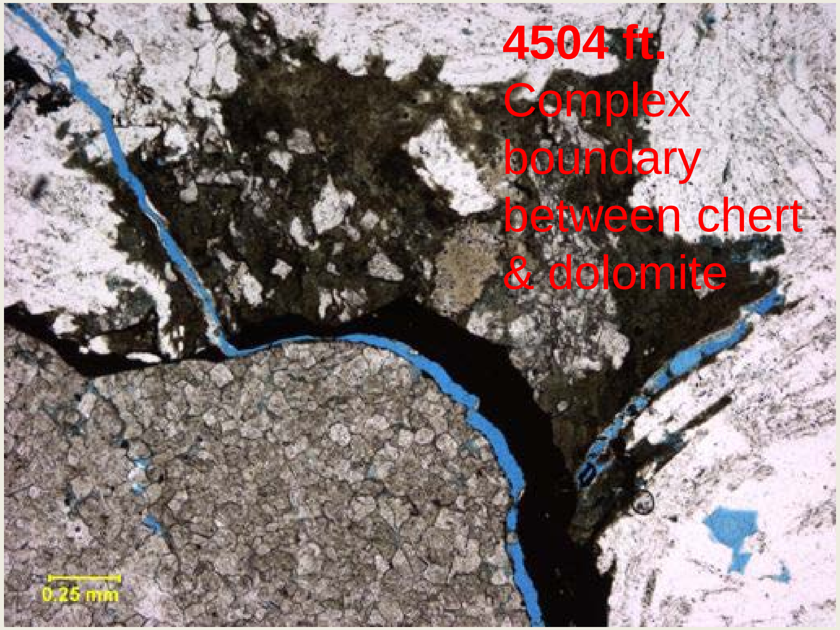
Scheffer, 2012

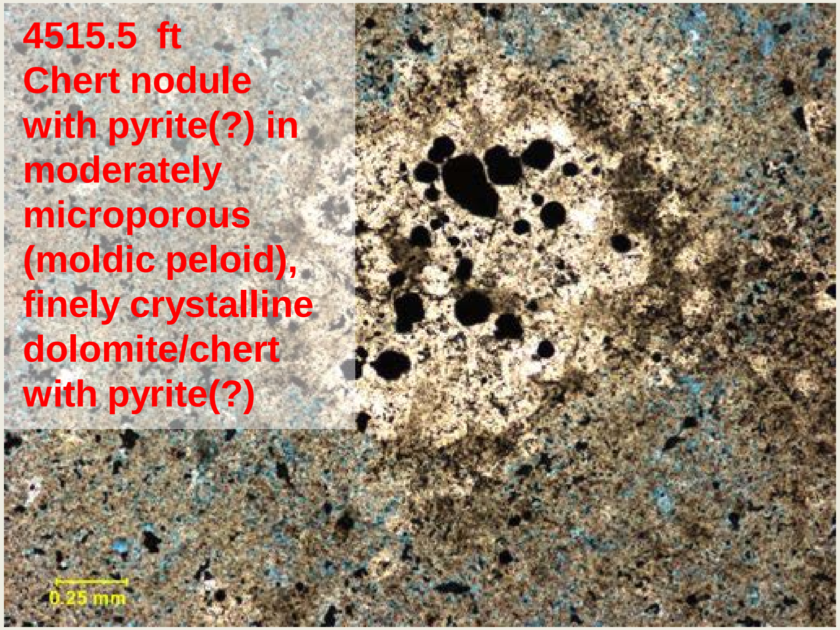
Rock Fabrics in "baffle" interval of middle Arbuckle

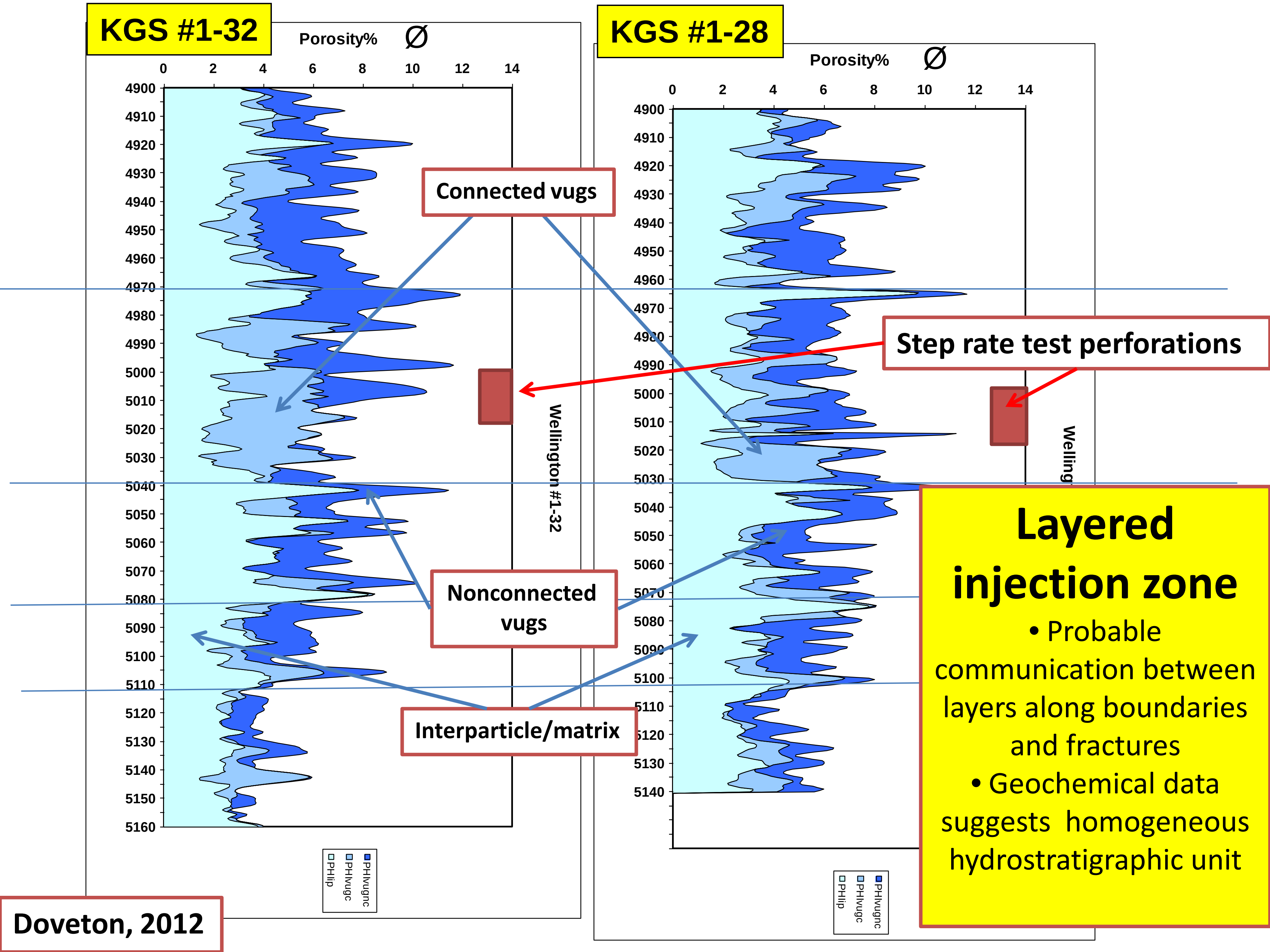
-- Thin section photomicrographs

Barker et al. (2012)









KGS #1-32
Porosity% Ø
KGS #1-28
Porosity% Ø
Connected vugs
Nonconnected vugs
Interparticle/matrix
Step rate test perforations
Wellington #1-32
PHIvugnc
PHIvugc
PHIip
Layered injection zone
• Probable communication between layers along boundaries and fractures
• Geochemical data suggests homogeneous hydrostratigraphic unit
Doveton, 2012

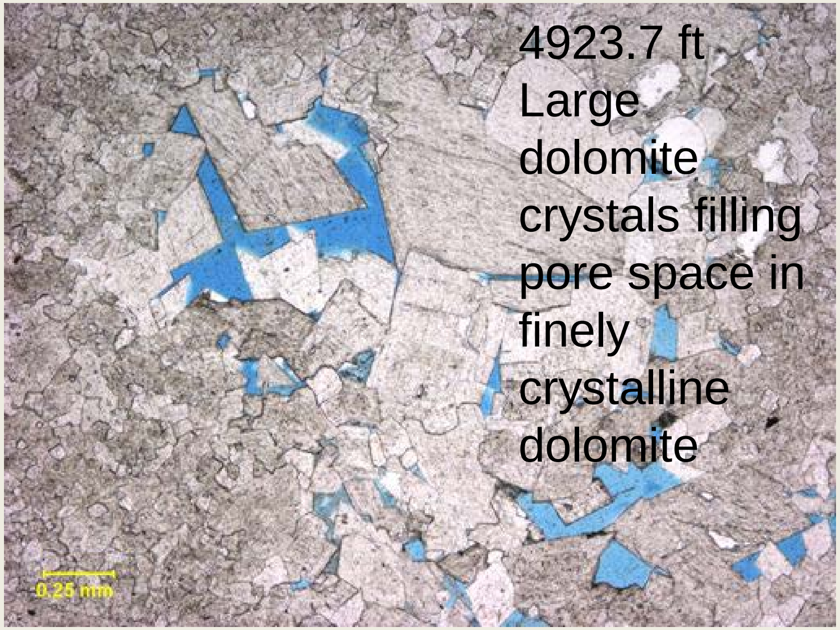
Core from Lower Arbuckle Injection Interval

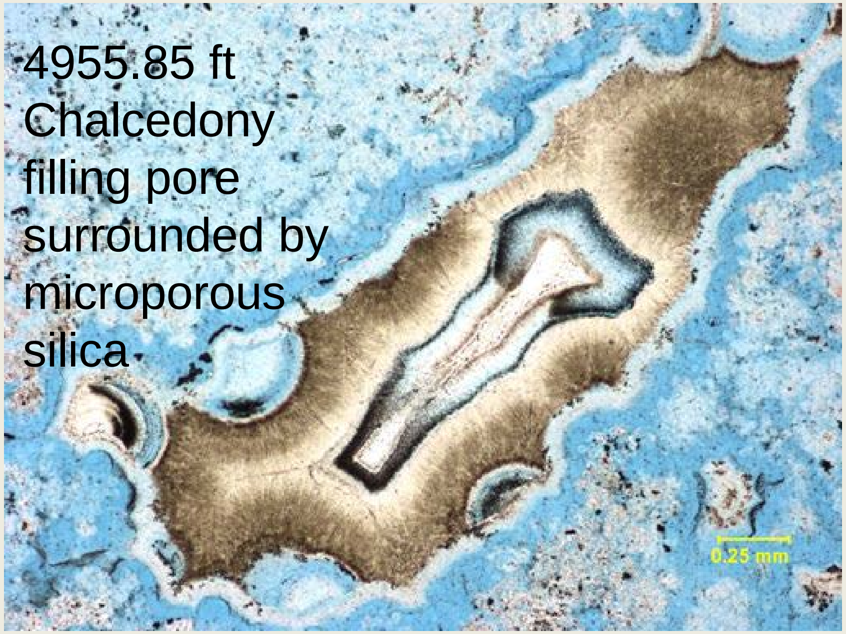
5089-92 ft

5080-83

5053-56

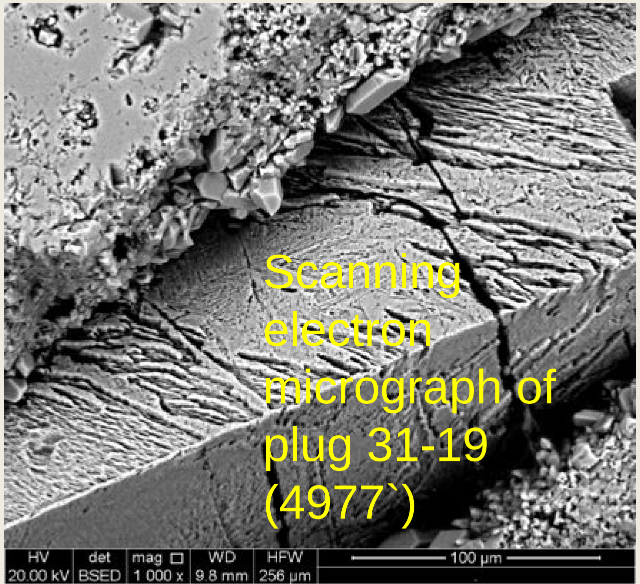
4995-97.7 ft



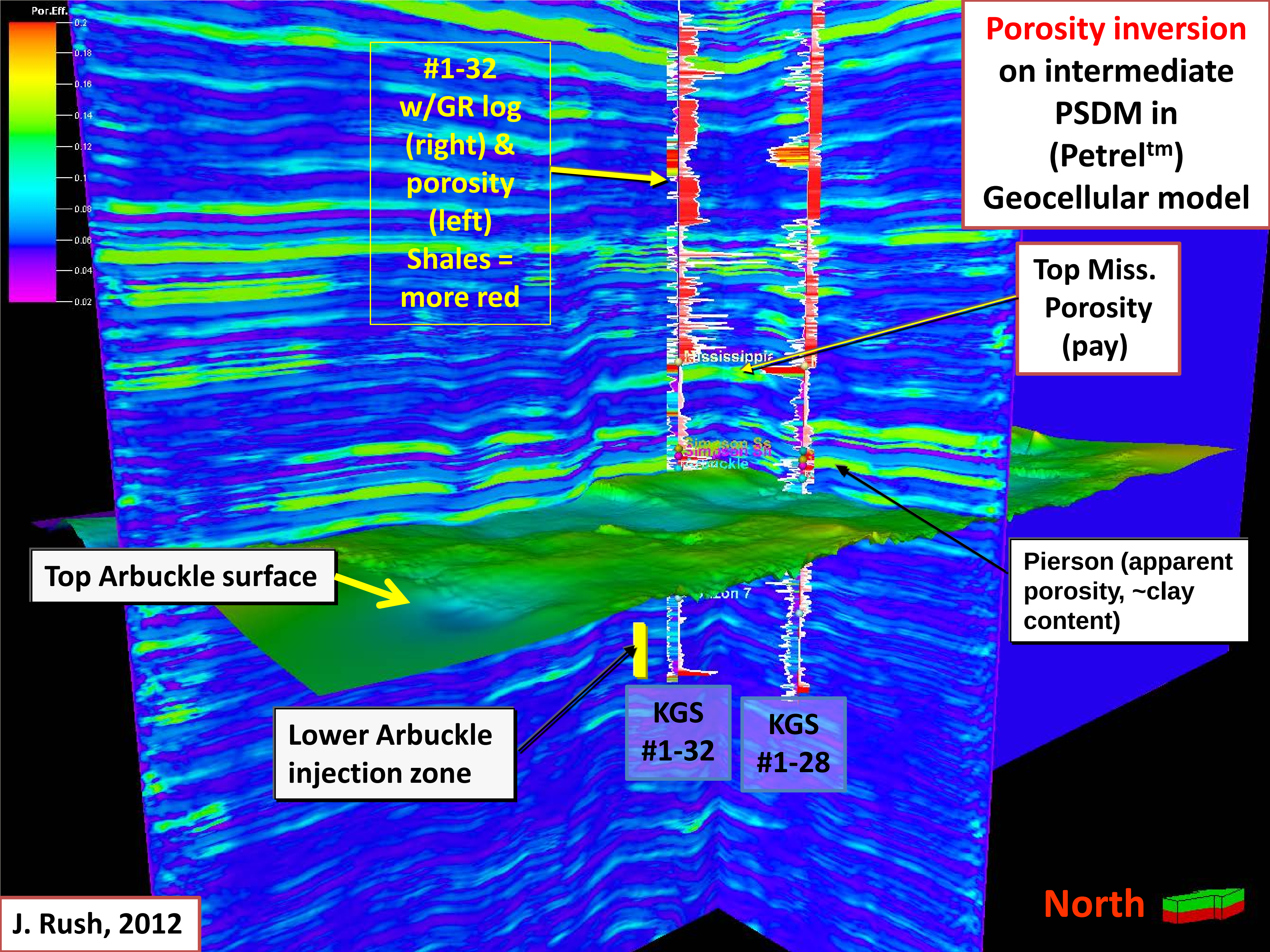


Rock Fabrics in proposed injection zone, lower Arbuckle
-- Thin section photomicrographs and SEM micrographs from KGS #1-32

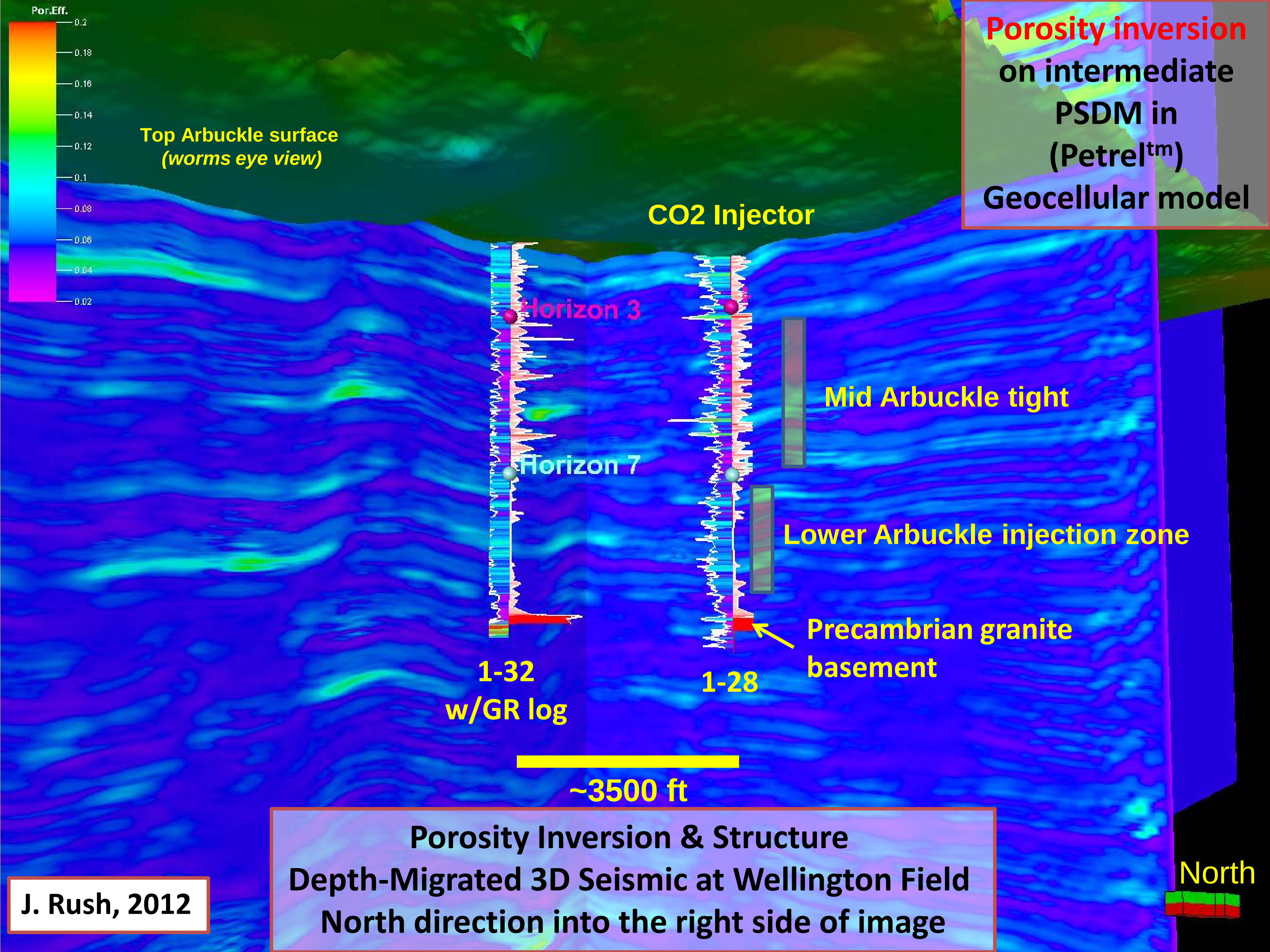
Dolomite-chert contact could be a potential reaction site with preferential dissolution of dolomite and formation of fractures along reaction fronts.



Barker et al. (2012)



Porosity inversion on intermediate PSDM in (Petrel^{tm}) Geocellular model
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
Top Miss. Porosity (pay)
Pierson (apparent porosity, ~clay content)
Top Arbuckle surface
Lower Arbuckle injection zone
KGS #1-32
KGS #1-28
North
J. Rush, 2012


Por.Eff.
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
Top Arbuckle surface
(worms eye view)
Porosity inversion
on intermediate
PSDM in
(Petrel tm)
Geocellular model
CO2 Injector
Horizon 3
Horizon 7
Mid Arbuckle tight
Lower Arbuckle injection zone
Precambrian granite
basement
1-32
w/GR log
1-28
~3500 ft
Porosity Inversion & Structure
Depth-Migrated 3D Seismic at Wellington Field
North direction into the right side of image
J. Rush, 2012
North

Provisional Coupled Geomechanical-Flow Model of 40,000 tons CO_2 injection into lower Arbuckle

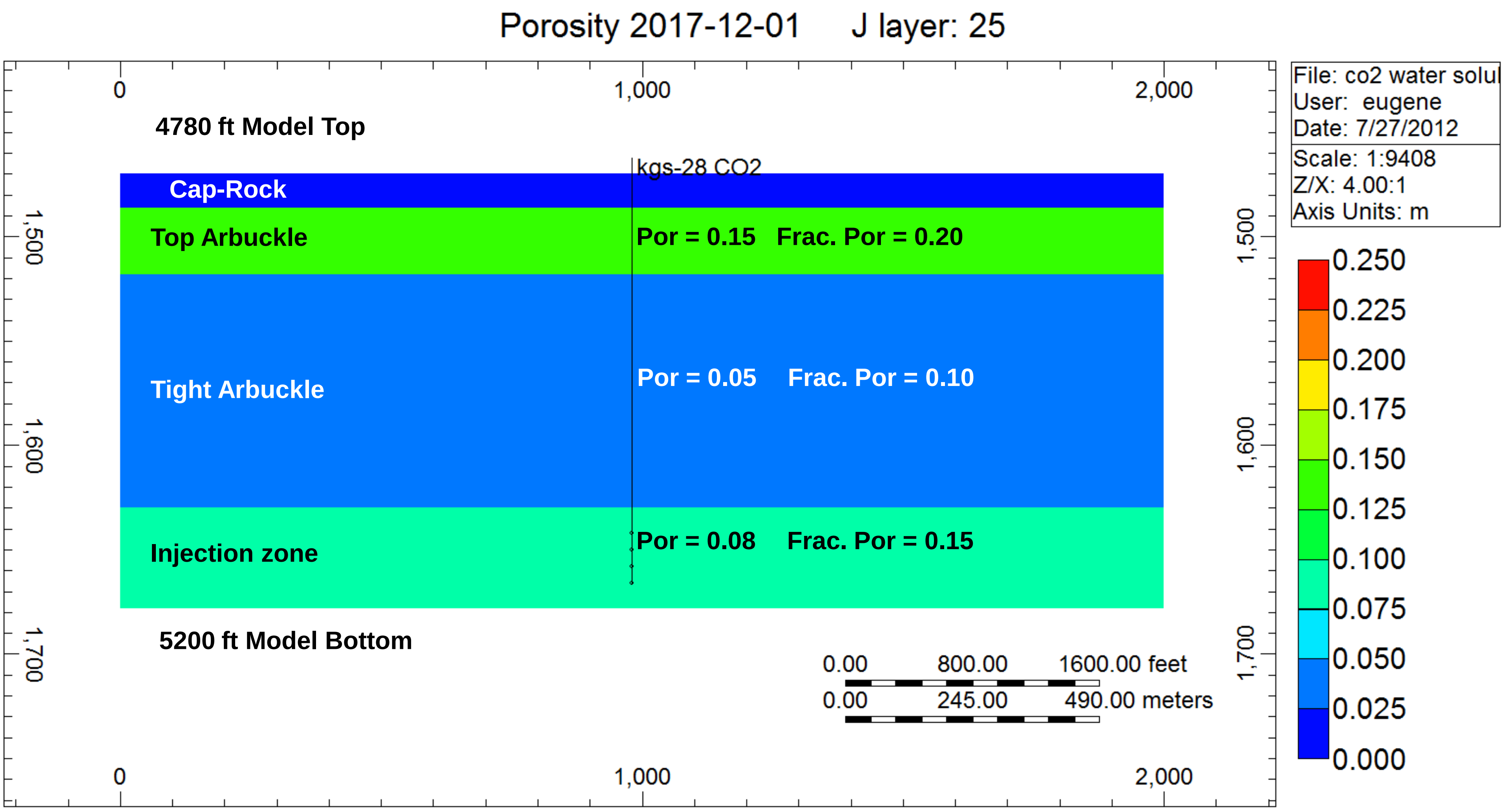
Model Properties

- 3D Homogeneous Grid (*yet to included updated geomodel*)
- Pressure and CO_2 Solubility Considerations
- Dual porosity – matrix porosity and fractures
- This particular model **<u>has yet to include:</u>**

  - Potential faults or compartments within the reservoir (to be obtained from latest processing of 3D seismic

  - Additional sealing units, overlying Mississippian formation

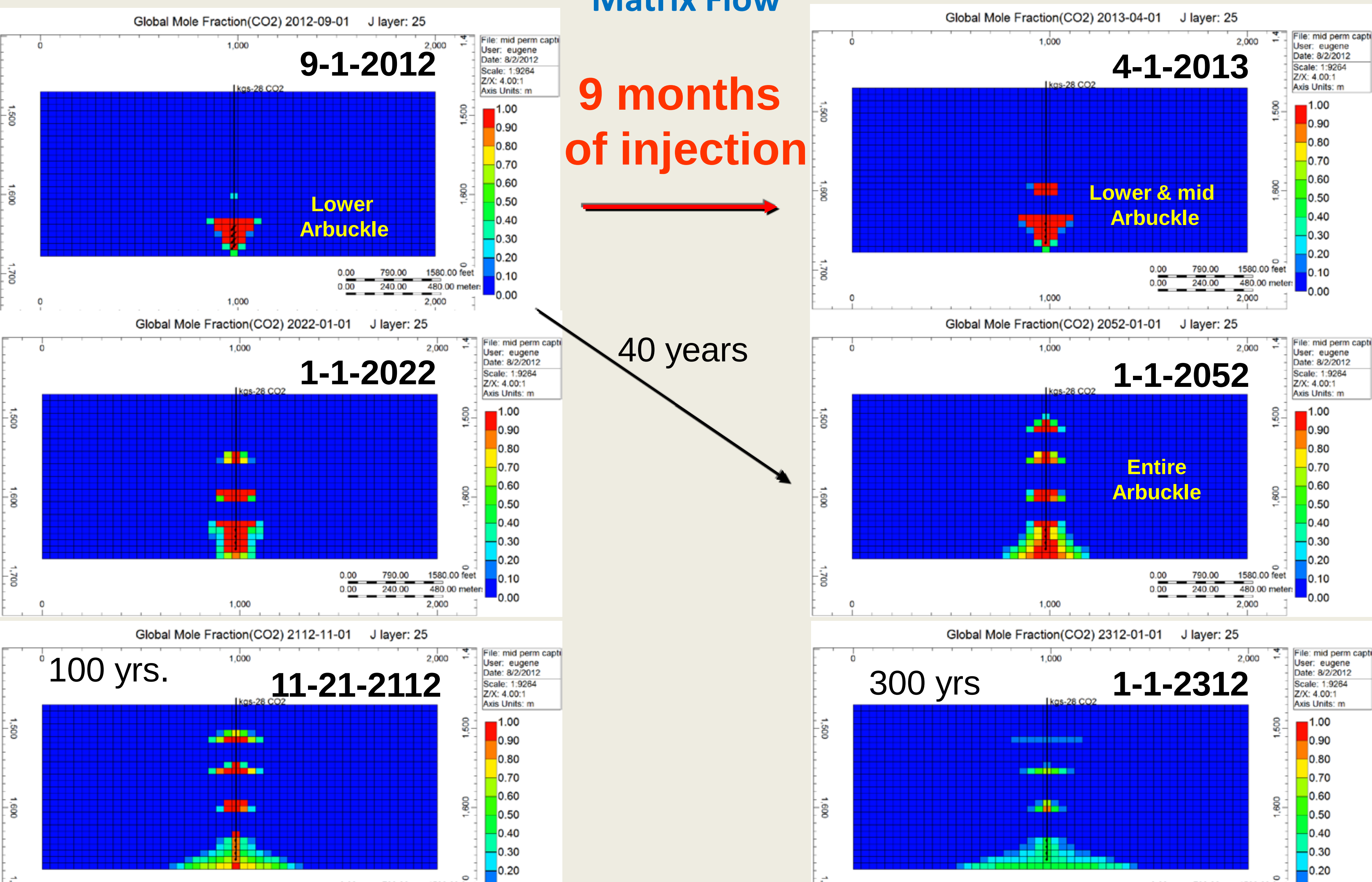
Coupled geomechanical-fluid flow modeling of CO_2 injection into lower Arbuckle



Holubnyak, 2012

9 mo. Injection Scenario – High Permeability Case – 40 kt CO_2

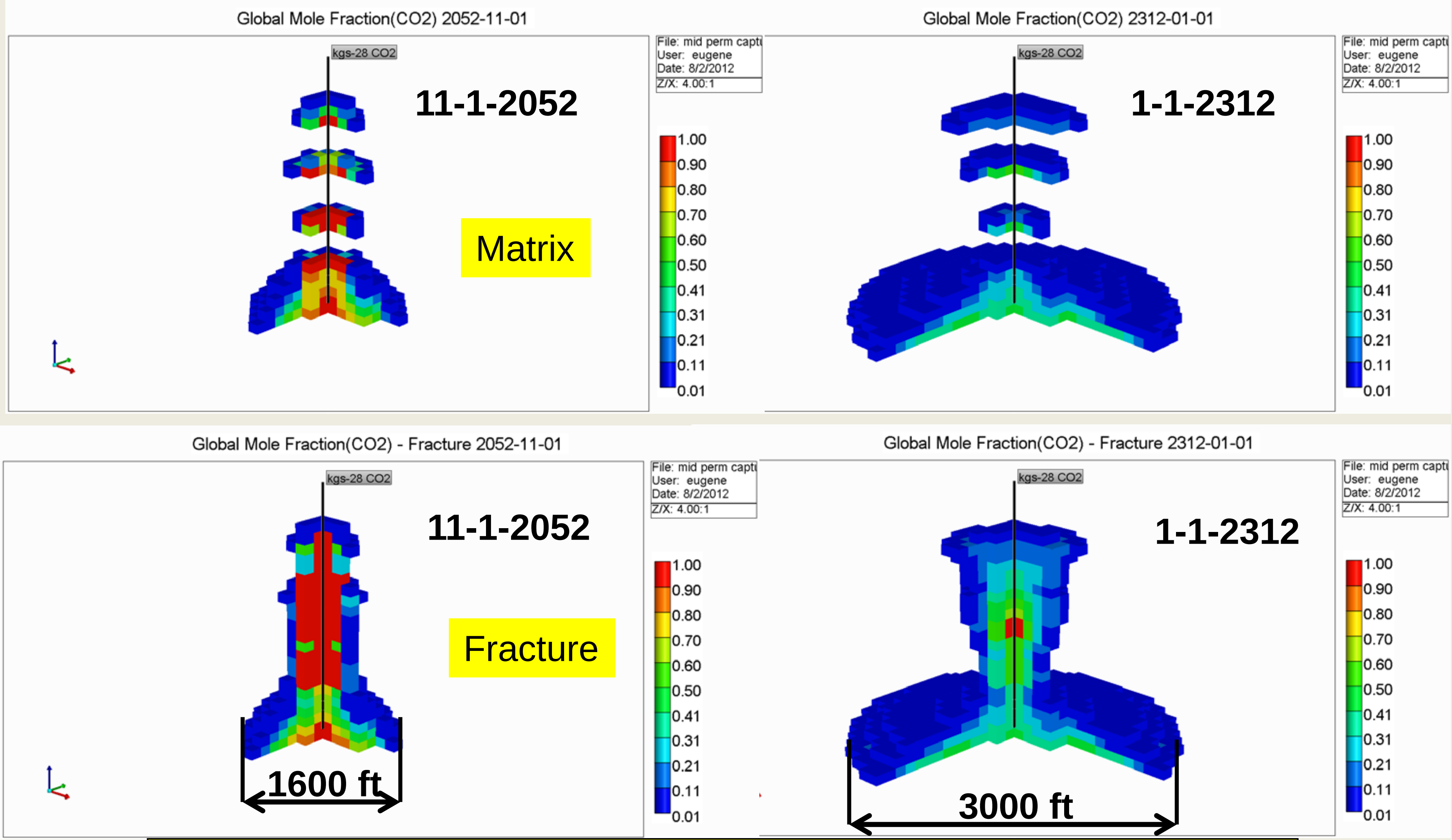
Matrix Flow



Holubnyak, 2012

3D View of CO_2 Spatial Distribution – High Permeability Case – 40 kt CO_2

Matrix and Fracture Flow

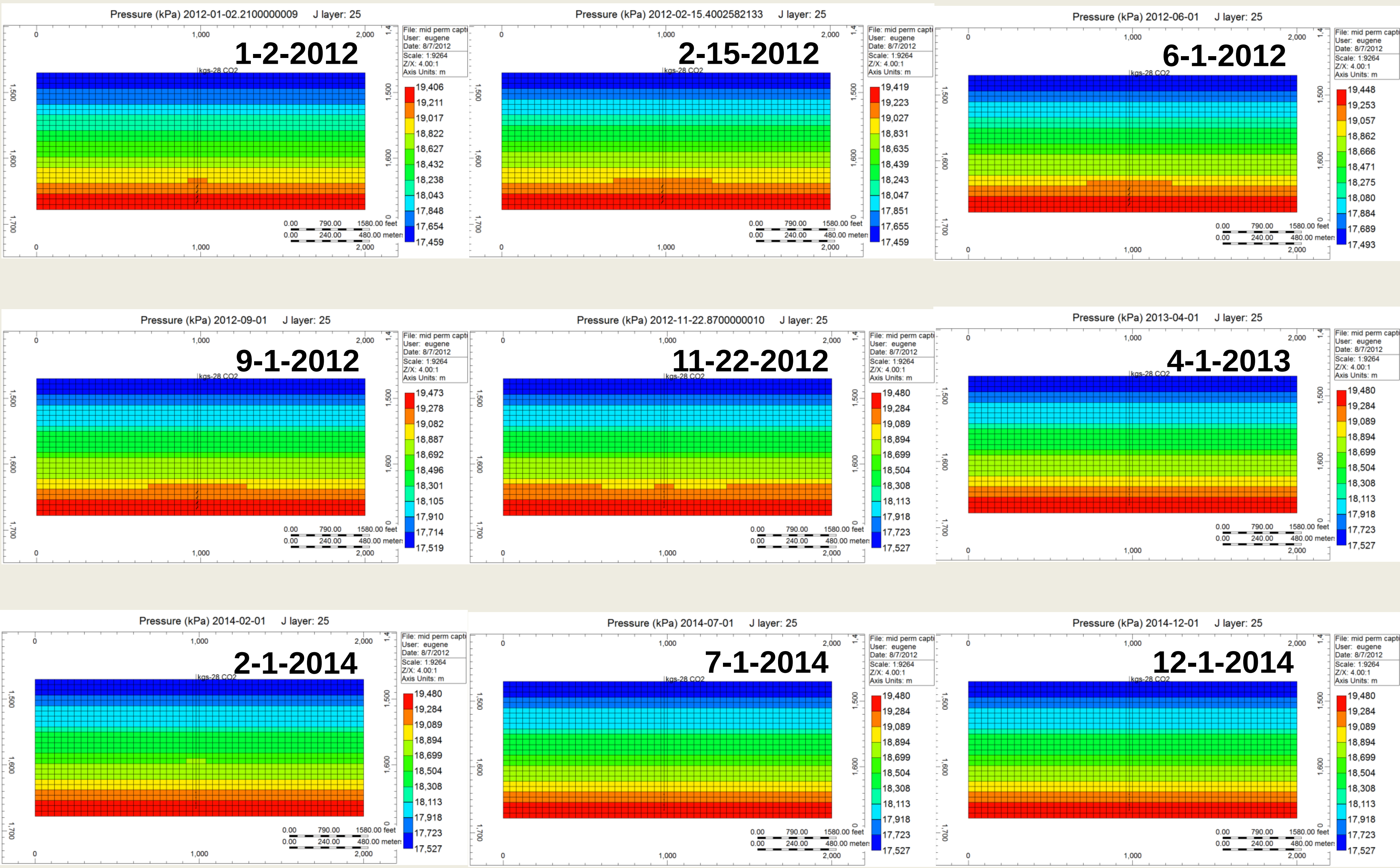


Note the significant amount of CO_2 trapped due to solubility and residual trapping effects in Lower Arbuckle zone

Holubnyak, 2012

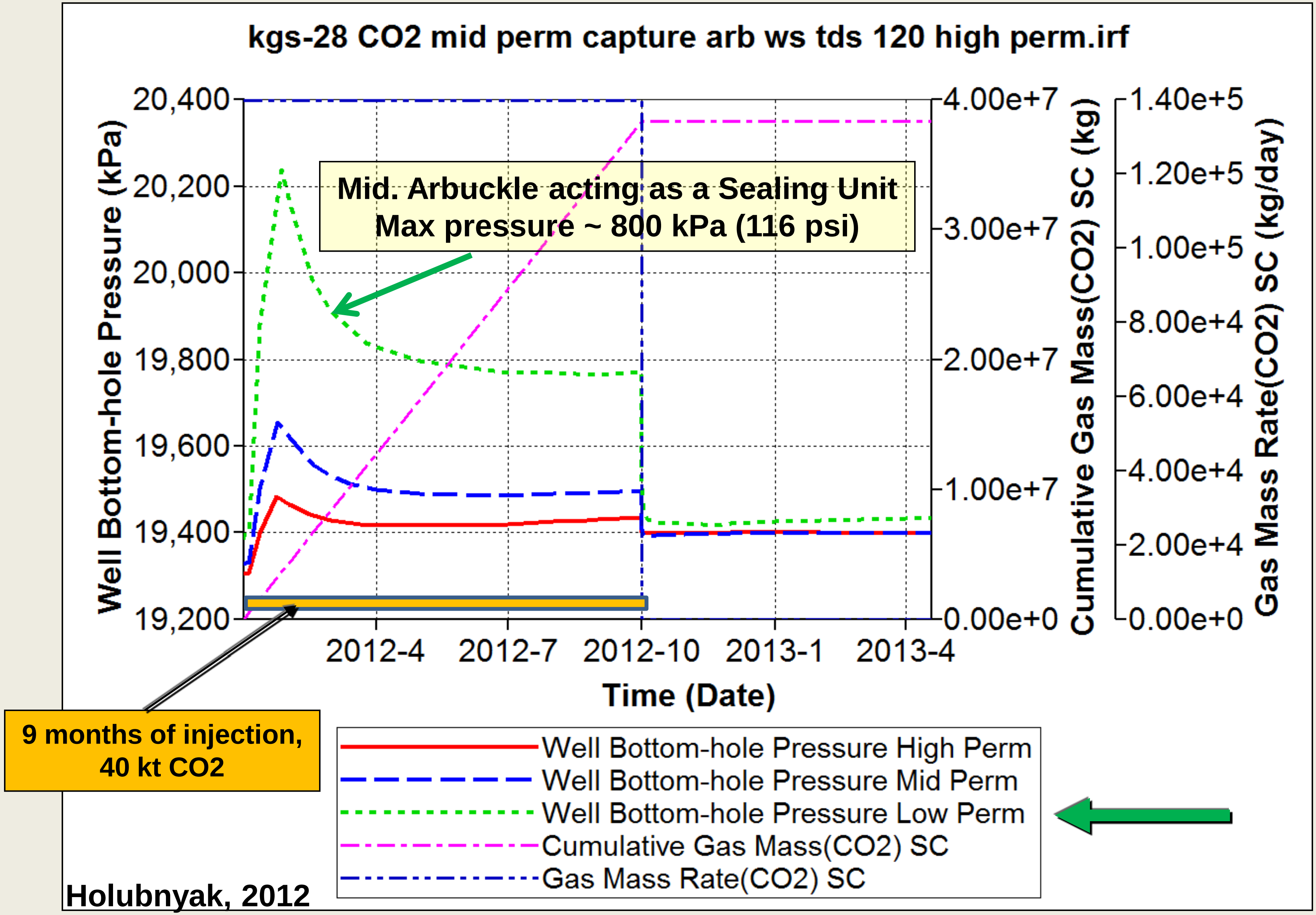
9 Months Injection Scenario – High Permeability Case – 40 kt CO_2

Pressure Distribution (kpa) Over 3 Years



Holubnyak, 2012

Pressure Response Comparison for 3 Cases– 40 Mt CO_2 Pressure, Cumulative Gas, and Gas Rate Plot



Summary of Penultimate Simulation Model for Class VI Application

- 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 (Low Arbuckle) due to:
  - Decreased velocity of CO_2 travel through less permeable medium
  - Residual and solubility trapping of the CO_2 in the mid-Arbuckle zone
- The increase in formation pressure due to CO_2 injection is insignificant and caprock/shales will not experience dangerous stress levels.

Presentation Summary

- Locations of studies, schedule
- Accomplishments
  - Capacity for CO_2 sequestration in Arbuckle saline formation in southern Kansas & CO_2-EOR in Mississippian
  - Source-sink network scenario for initiating CO_2 sequestration
  - Calibration sites for CO_2-EOR and Arbuckle saline formation
    - Wellington Field, Sumner County
    - New seismic and basement test @ Cutter Field, Stevens County, July-Oct. 2012
- 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
  - File application for Class VI geosequestration injection permit in September 2012

Acknowledgements & Disclaimer

Acknowledgements

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