Geologic Carbon Storage in the Lower Ordovician Arbuckle Group Saline Aquifer in Kansas

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Confluence C (Westin Denver Downtown)

Overview

- Small scale field test at Wellington Field
- One of two calibration sites for southern Kansas CO_2 storage assessment (65,000 km^2)
- Plans remain to inject up to 40,000 tonnes (0.75 BCF) $scCO_2$ into Gasconade Dolomite of Arbuckle Group at Wellington Fld.
- 3D geocellular geomodel based on two basement tests and 434 m of core, wireline logs, 3D multi-component seismic volume and well testing
- Predict behavior of $scCO_2$ plume based on compositional simulator
- Monitor overlying Mississippian oil reservoir for leakage

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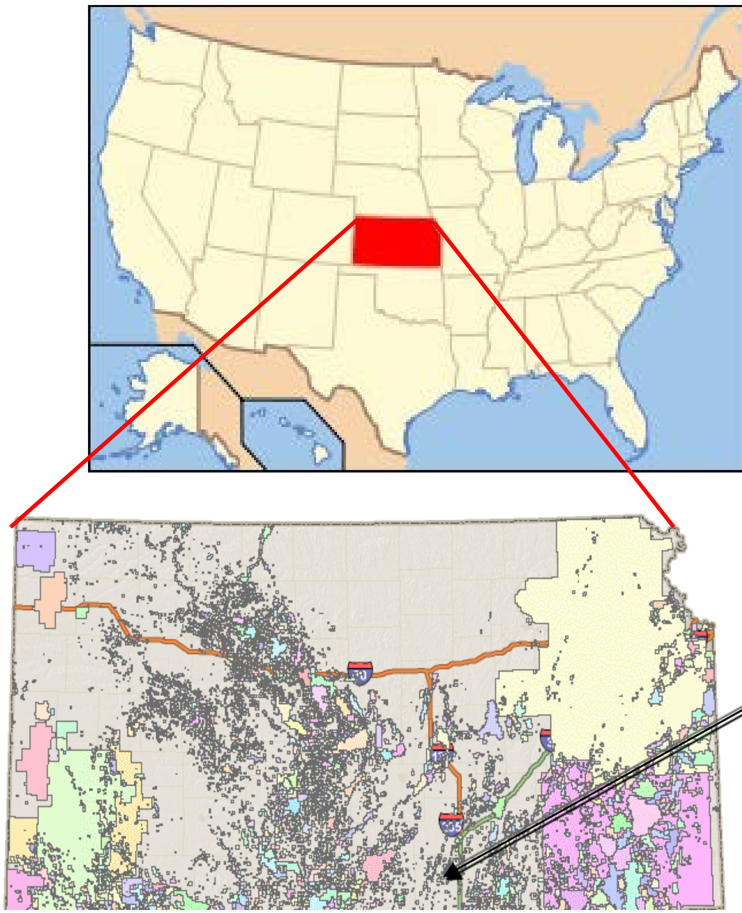
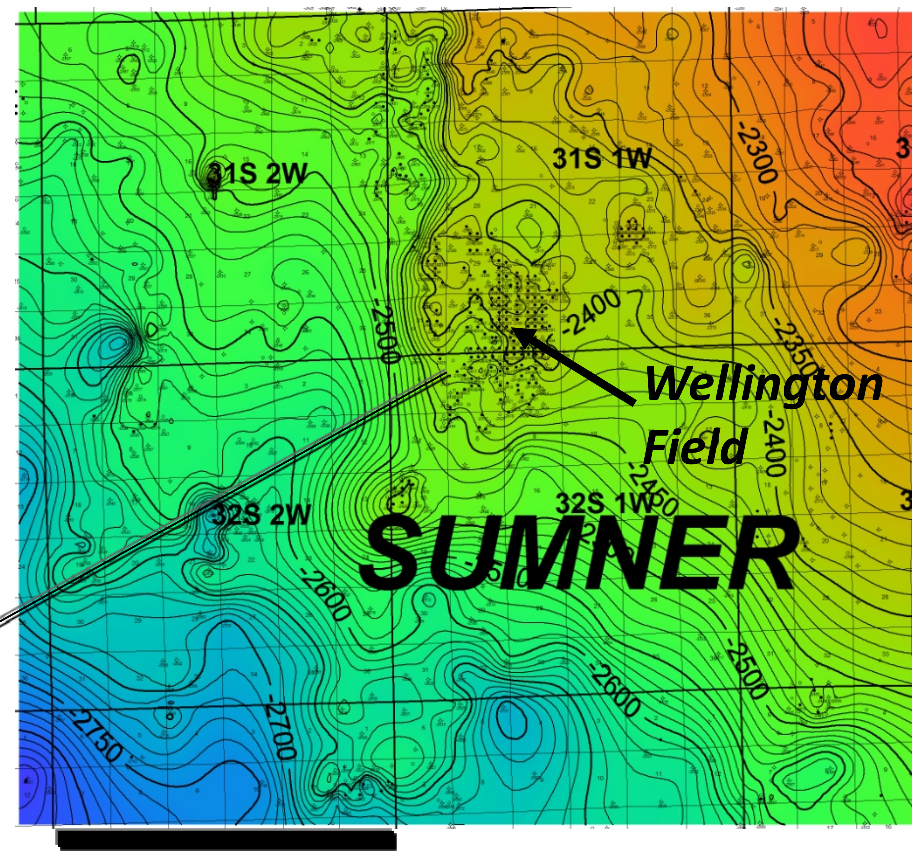
The study is a collaboration, multi-disciplinary effort between the KGS, Geology Departments at Kansas State University and The University of Kansas, BEREXCO, INC., Bittersweet Energy, Inc. Hedke-Saenger Geoscience, Ltd., Improved Hydrocarbon Recovery (IHR), Anadarko, Cimarex, Merit Energy, GloriOil, Dawson-Markwell Exploration, and Noble Energy.

Wellington Field

Site of Proposed Small Scale Field Test



Top Mississippian Structure, 10 ft C.I.



6 mi (10 km)

20 MM Barrel Mississippian Oil Field above Arbuckle Group

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

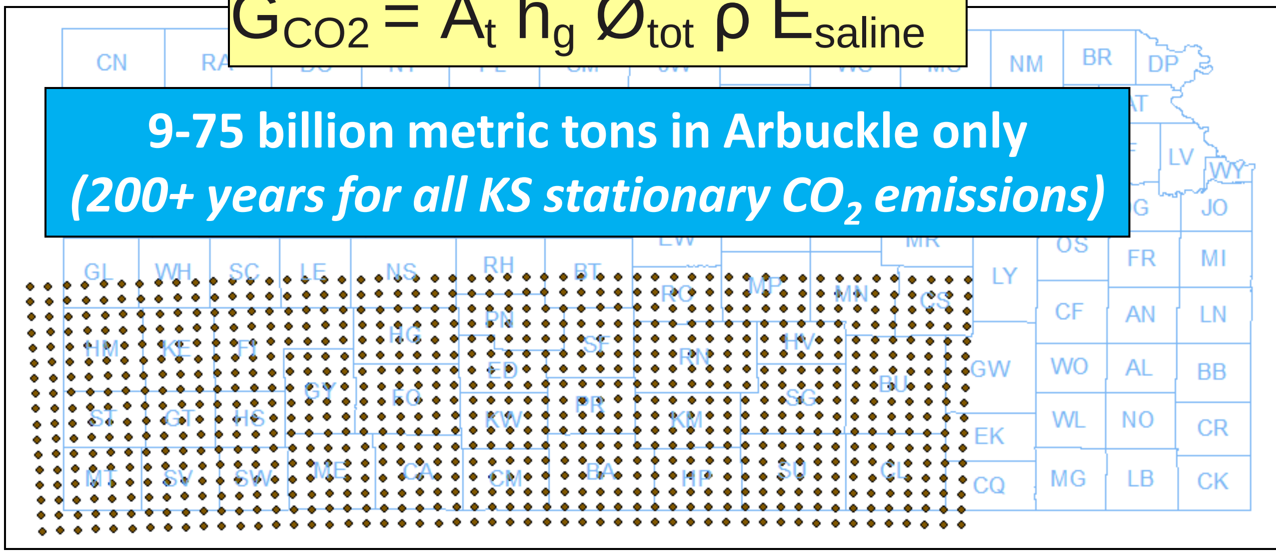
Initial CO_2 Storage Capacity Estimate

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)



- $Ø_{tot}$ = **total bulk volume of pore space available**
- **ρ = CO2 density**
- E_{saline} = **fraction of the total pore volume that will be occupied by the injected CO2**
- E_{saline} **ranges between 0.40 and 5.5 percent over the 10th to 90th percent probability range**

Metric tons CO_2 per Grid Cell
10 km^2
(3.8 mi^2)

0.769 tonne/m3

1 m3 = 6.29 bbls

8.179 bbl/tonne CO2

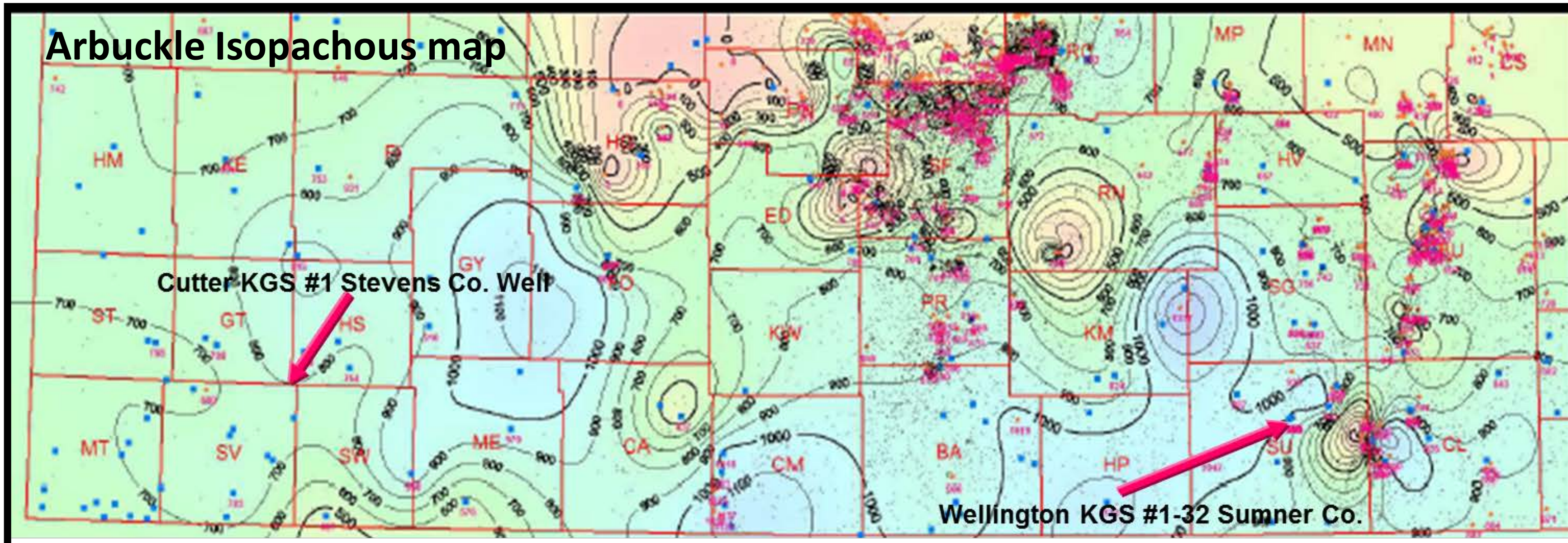
Gerlach and Bittersweet team, 2012

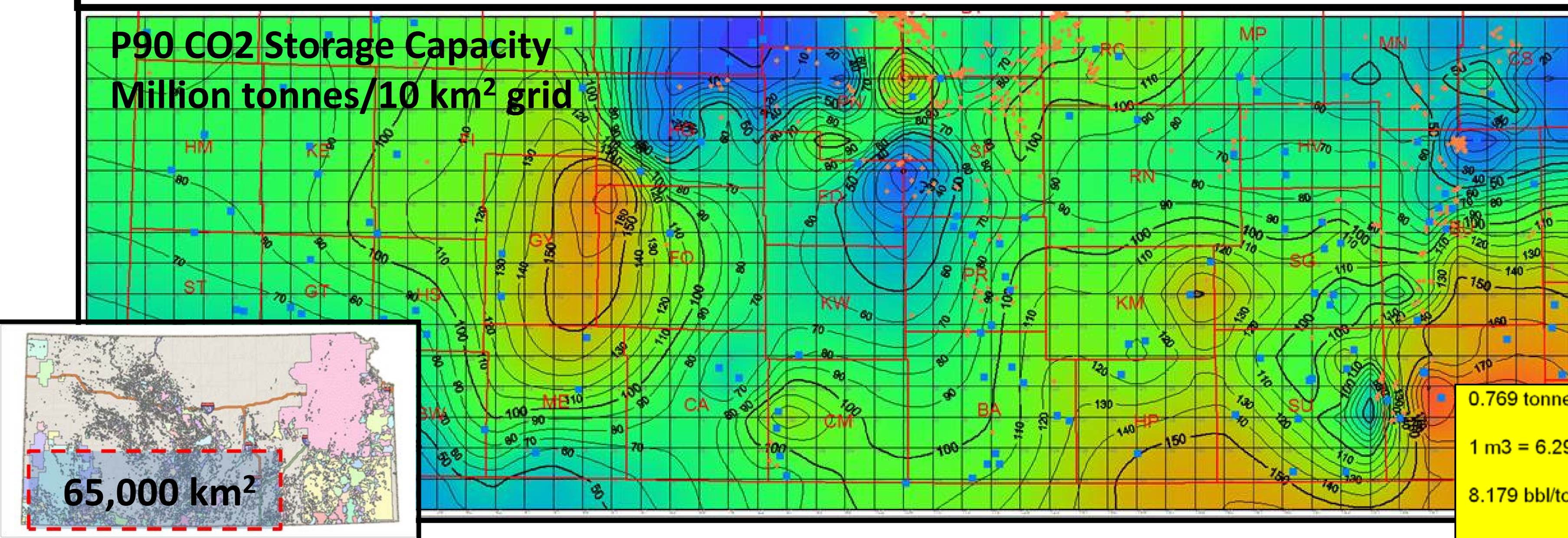
Each grid cell is 10K (+/-)

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

Thickness (ft) (top) & Initial (P90) Estimate of CO_2 Storage (millions tonnes/10 km^2 cell) (bottom) in Southern Kansas





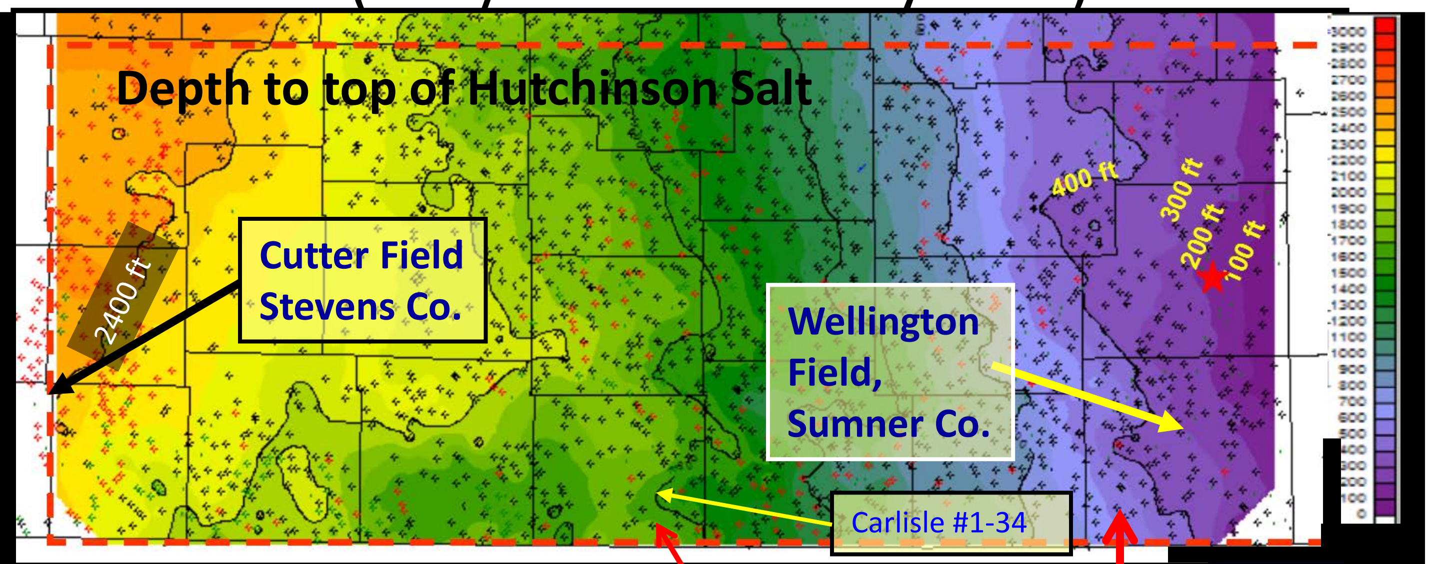
0.769 tonne/m3

1 m3 = 6.29 bbls

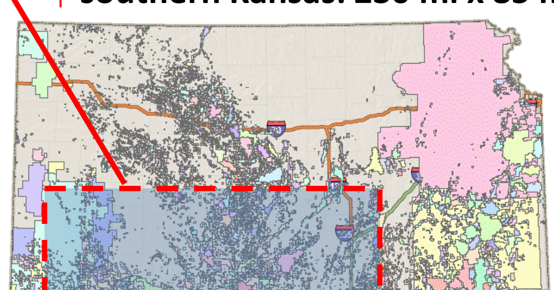
8.179 bbl/tonne CO2

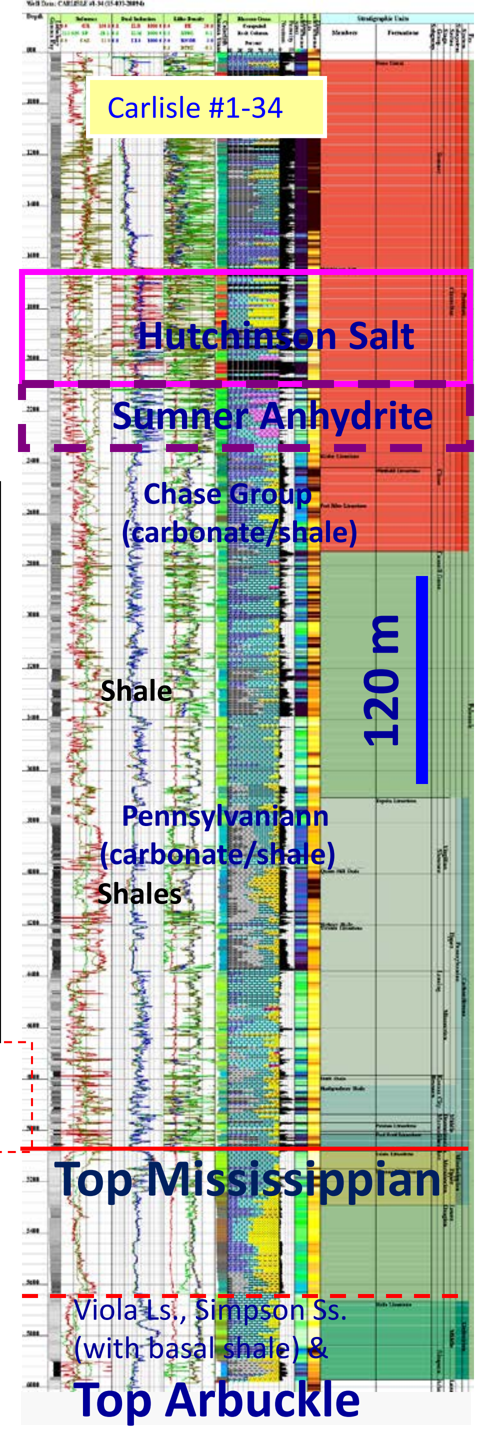
Regional Study Area for CO_2 Storage Assessment

-- Deep Saline Arbuckle Aquifer Overlain by Thick Evaporites (Salt/Halite & Anhydrite)



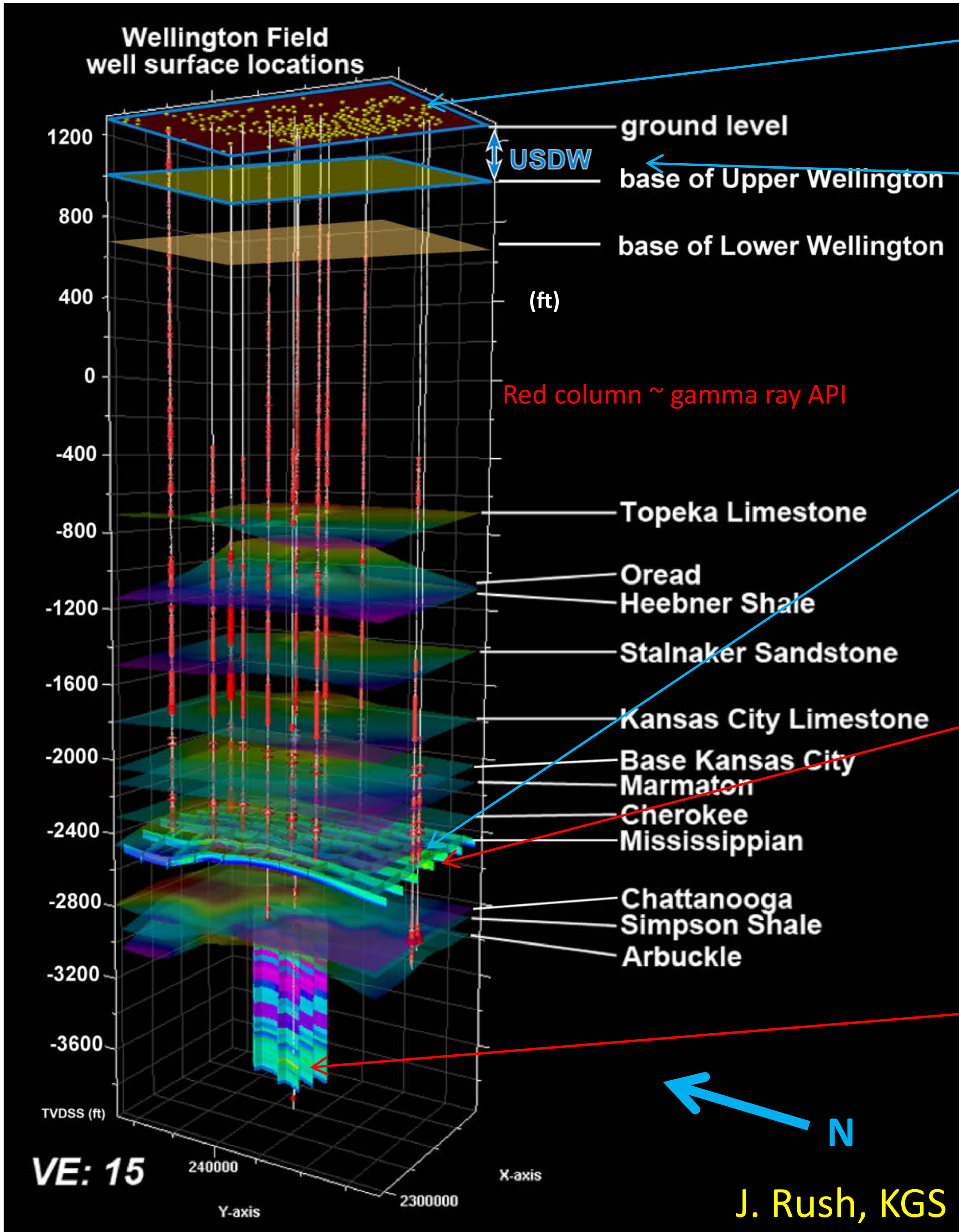
Regional study area of CO_2 project in southern Kansas: 230 mi x 85 mi





Thickness of Permian evaporites ranges from 400 to 2000 ft (120-600 m) in southern Kansas

CO2-EOR & Saline Injection, Wellington Field



- InSAR & CGPS
  → surface deformation
- IRIS seismometers & 3C accelerometers

- Tracers to detect injected CO_2
- Monitor ~600 ft deep well below shallow evaporite cap rock

- Test for CO_2 in Mississippian wells
(*Underpressured oil reservoir should trap any vertically migrating CO2*)

<u>Inject 28,000 tonnes of CO_2</u> into Mississippian oil reservoir to demonstrate CO_2-EOR and 99% assurance of storage with MVA

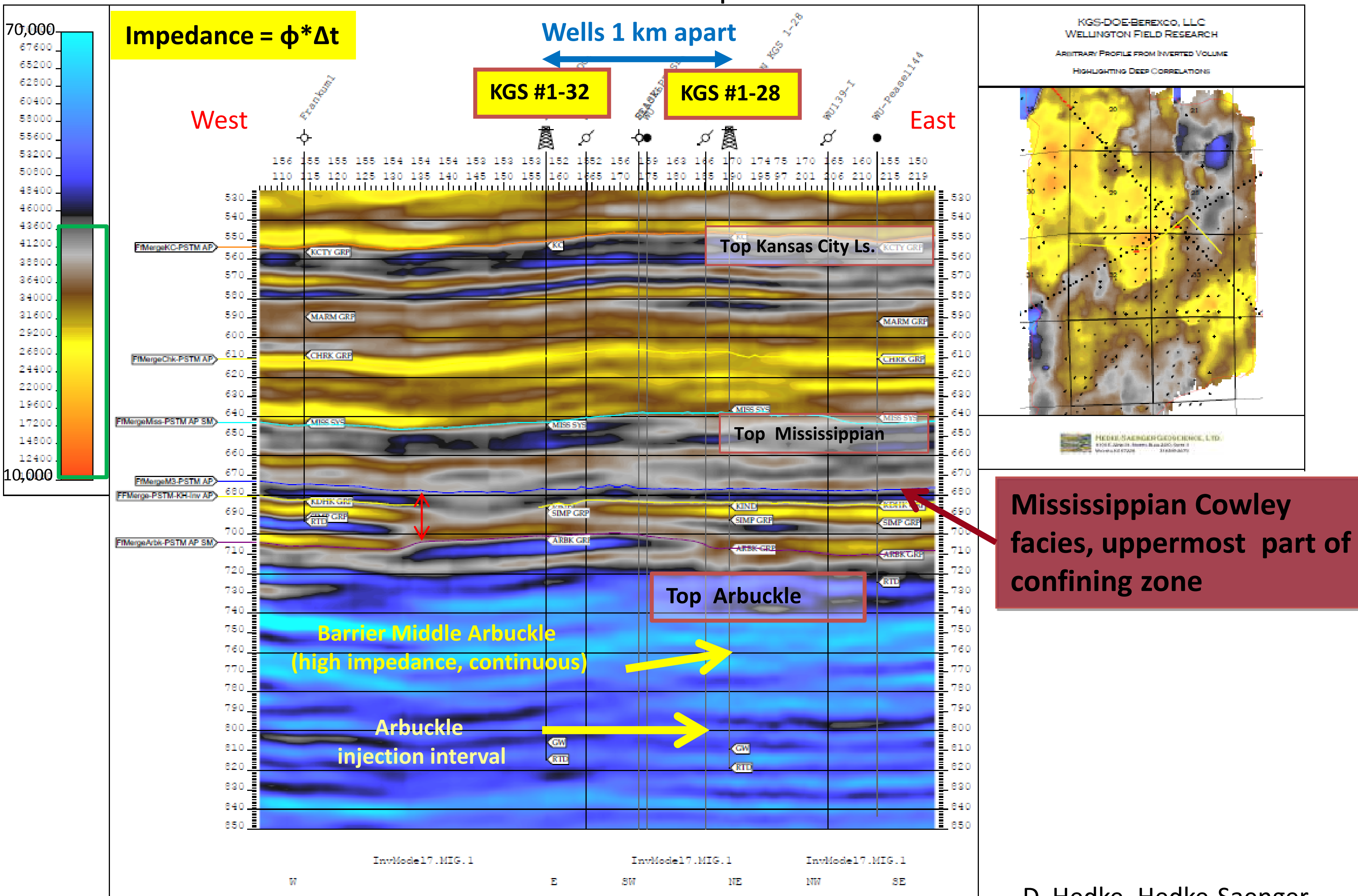
<u>Pending Class VI permit and DOE funding -- Inject up to ~40,000 tonnes of CO_2</u>

- U-Tube, CASSM and cross hole seismic
- DTS & acoustic fiber optics (long string fiber pending)

Primary Confining Zone Continuous in the Wellington Area

(Mississippian argillaceous Cowley facies + Chattanooga Shale + Simpson Group)

West-East Seismic Impedance PSTM

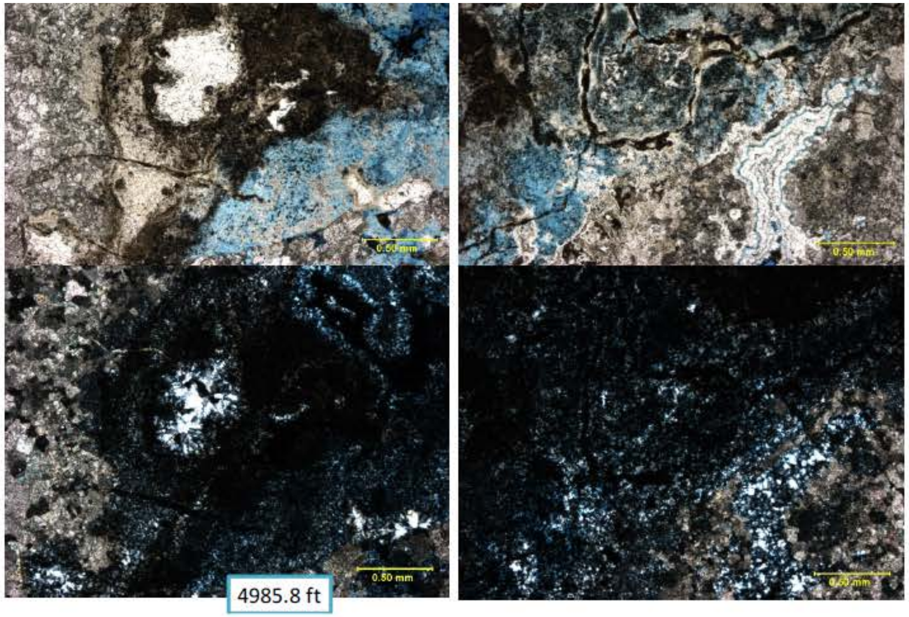


D. Hedke, Hedke-Saenger

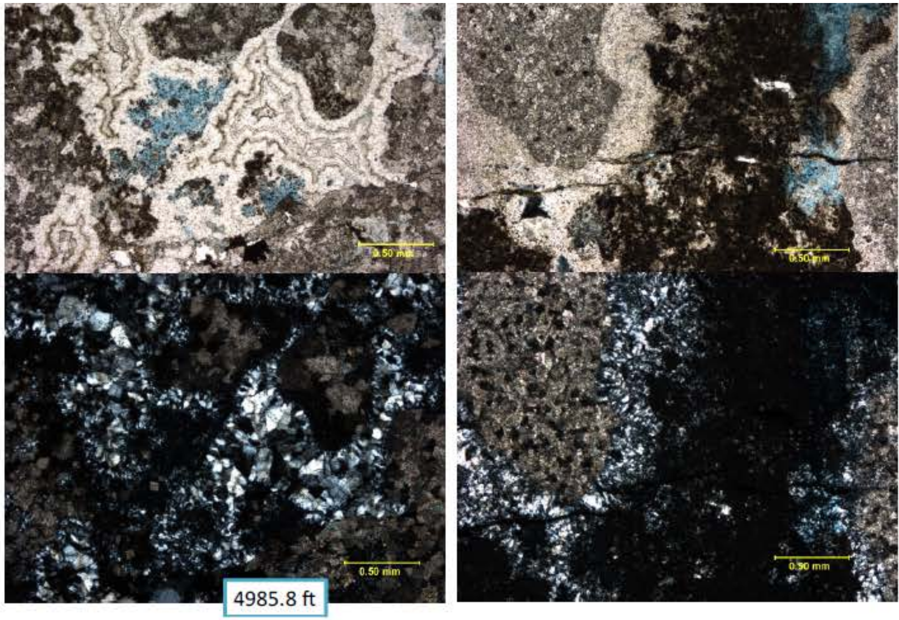
Aquifer Characterization
Arbuckle Saline Aquifer

- Dominantly cherty dolomite
- **Permeable** - Upper 70 m: porous medium pelleted dolomitic pack-stones and grainstones
- **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

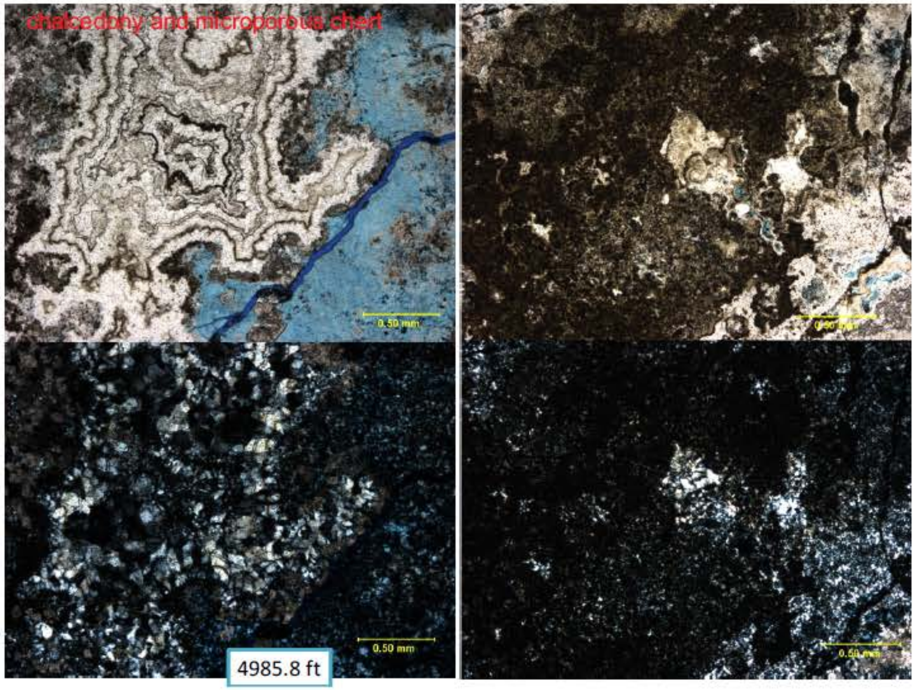
Plenty of Microporosity, Even in the Lower Arbuckle CO2 Injection Zone



4985.8 ft

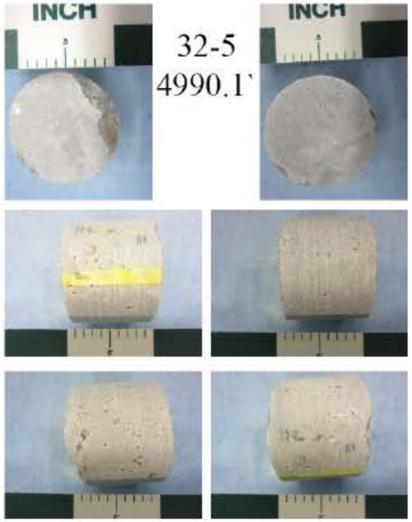


4985.8 ft

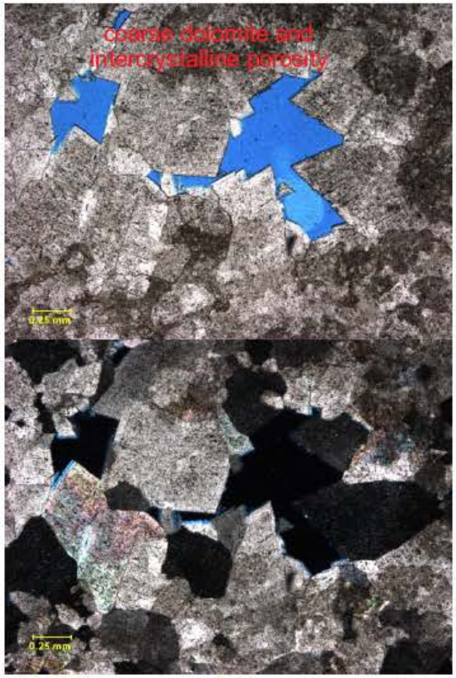


4985.8 ft

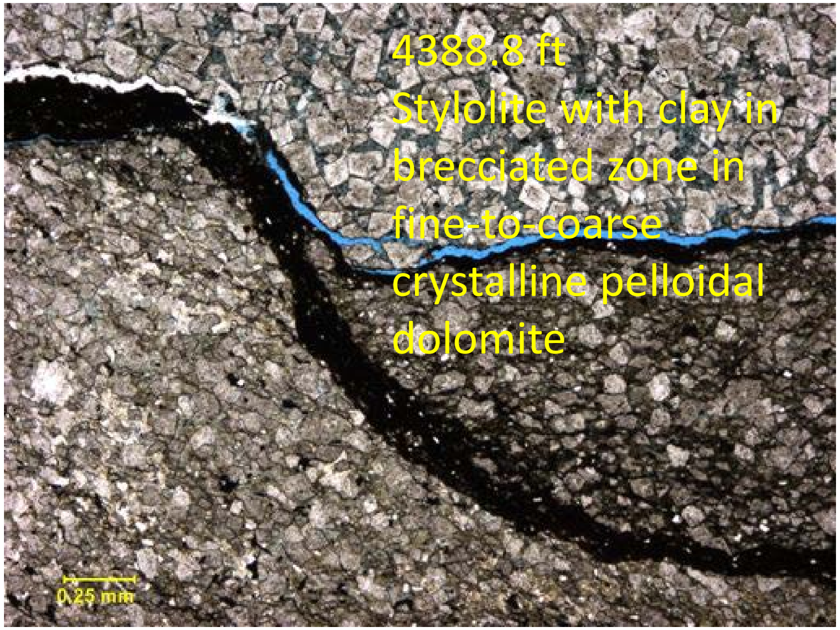
Lower Arbuckle
(Gasconade)
Lower hydrostratigraphic unit
Flow unit –
Proposed Injection unit



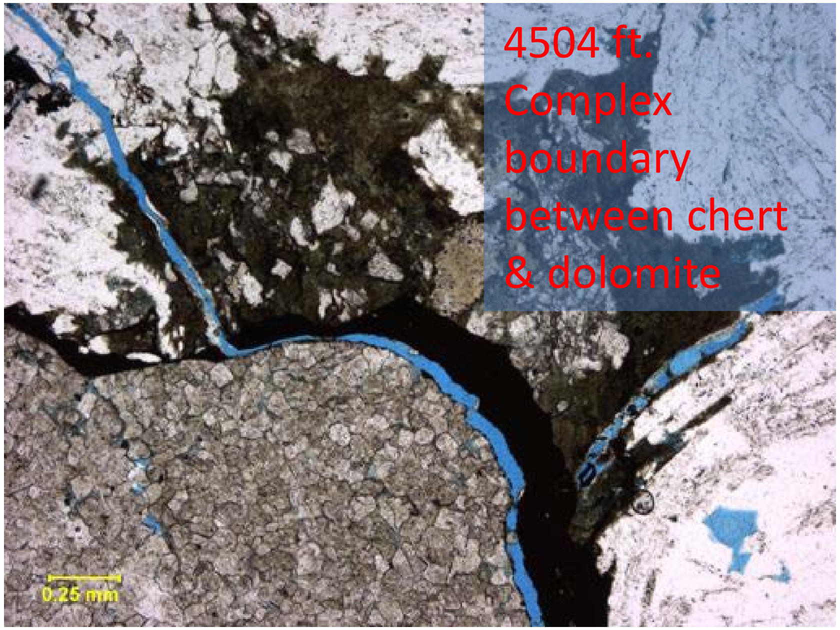
whole core: phi 2.2% 89 md

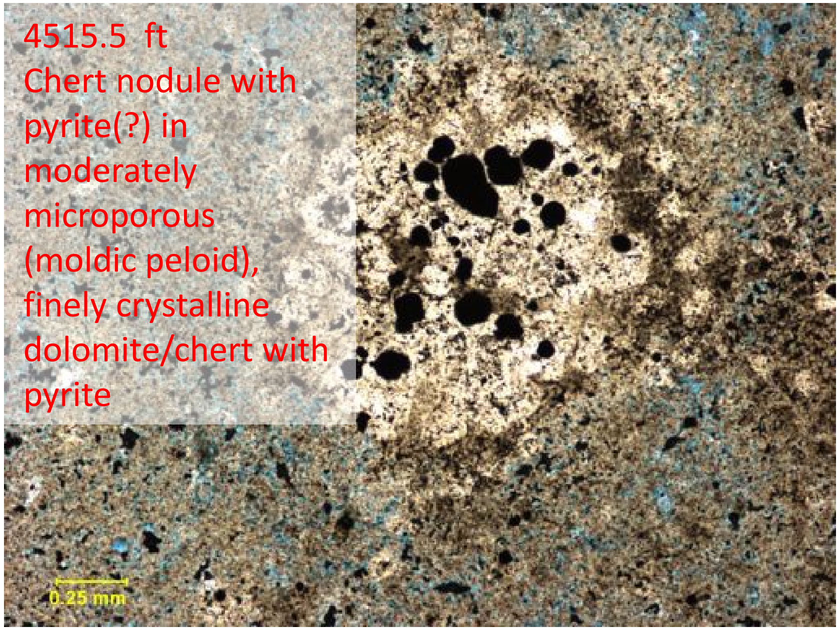


Rock fabrics in aquitard of middle Arbuckle Group
-- Thin section photomicrographs



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

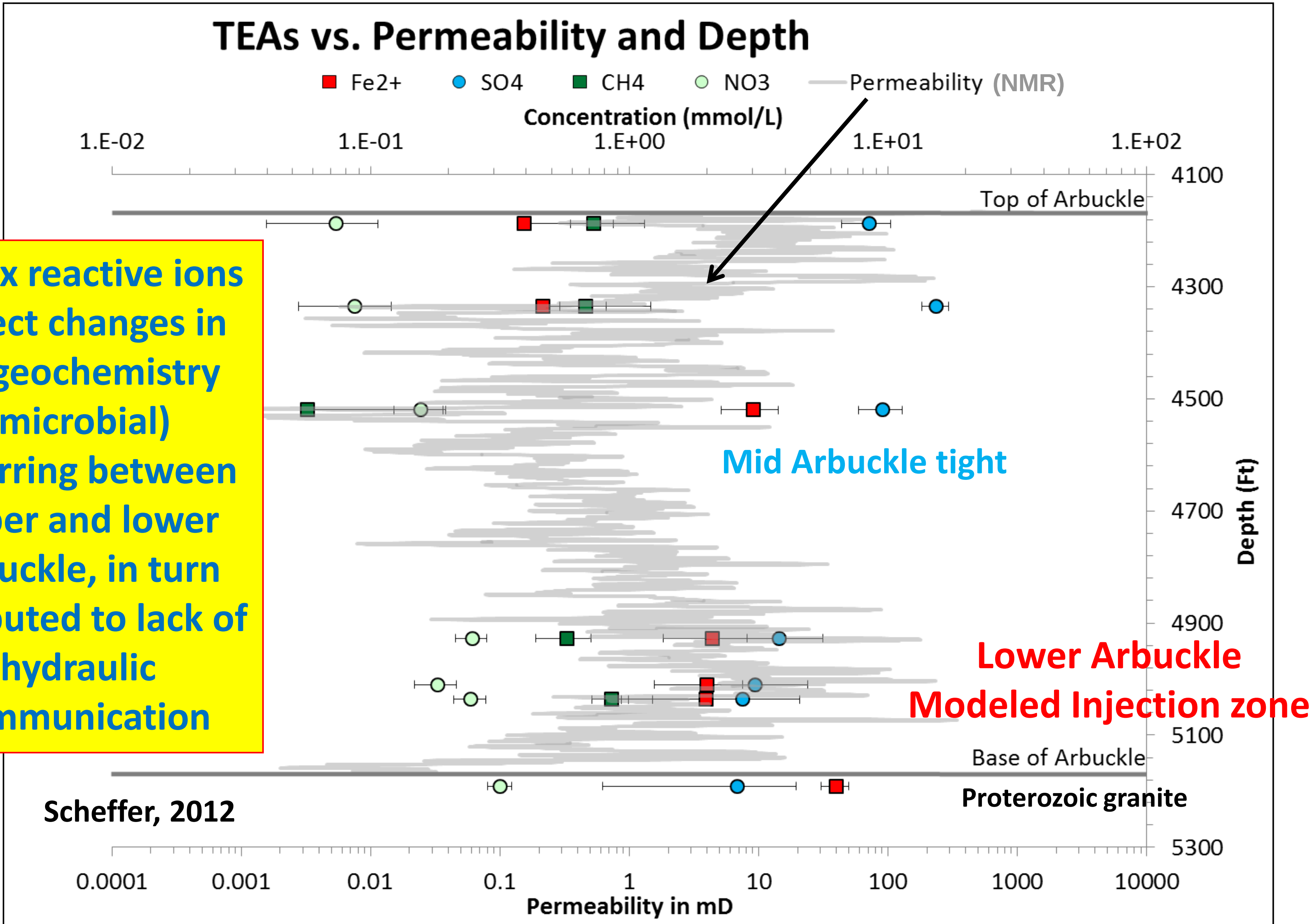




Barker et al. (2012)

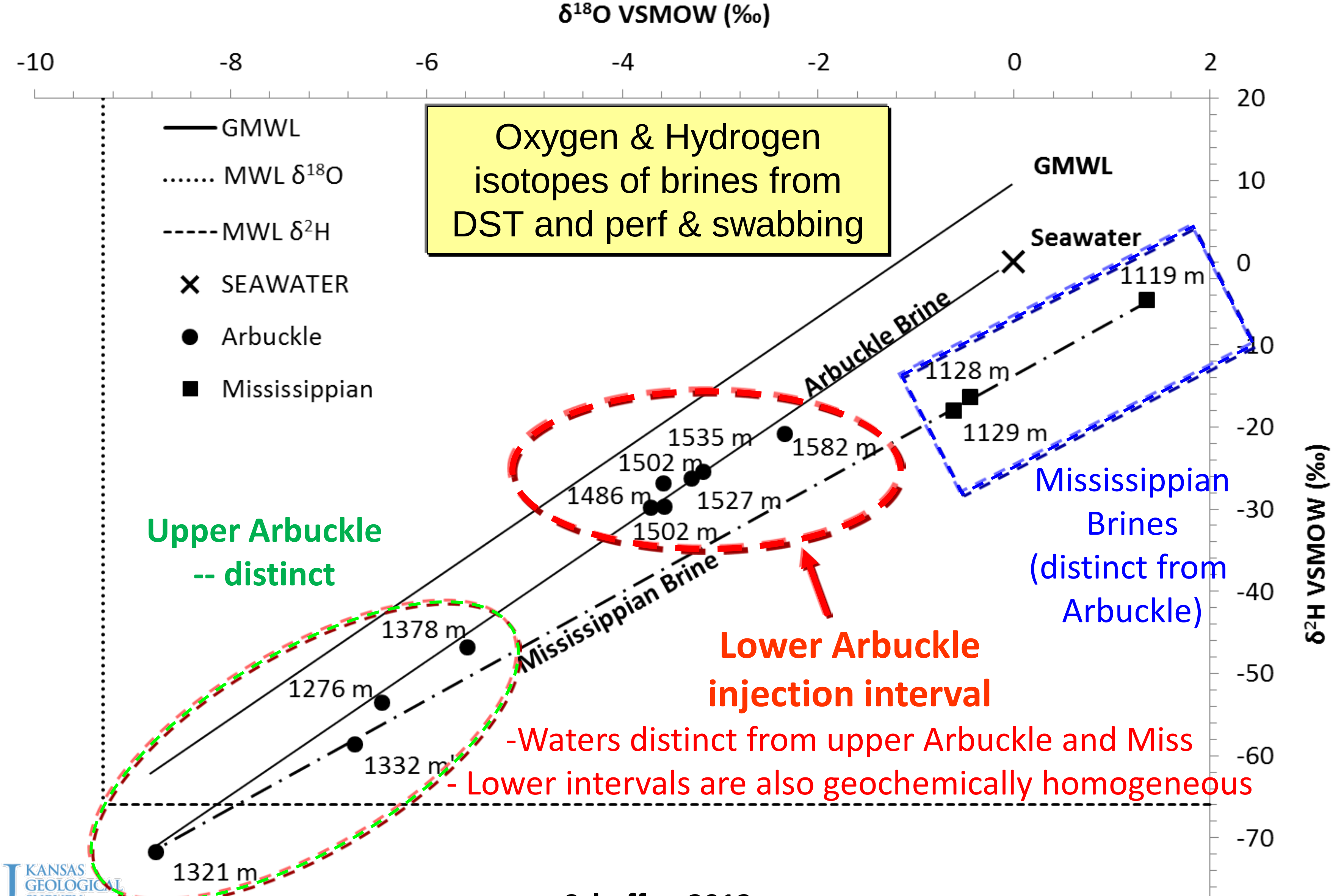
Permeability Profile of Arbuckle in Cored Well - #1-32

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

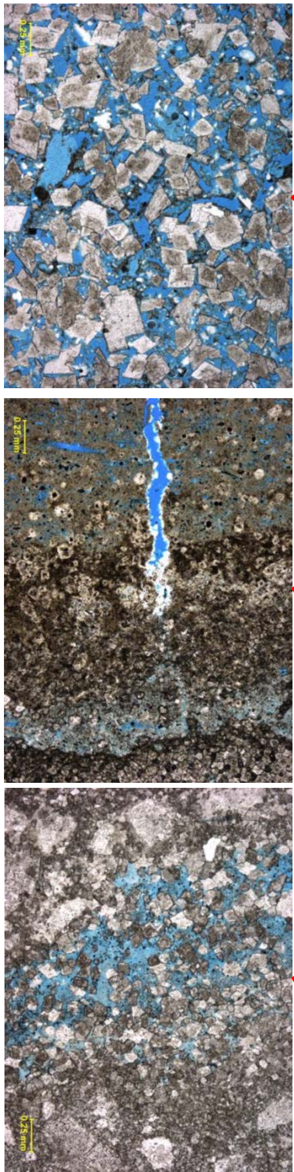
Lower and Upper Arbuckle Are Not in Hydraulic Communication

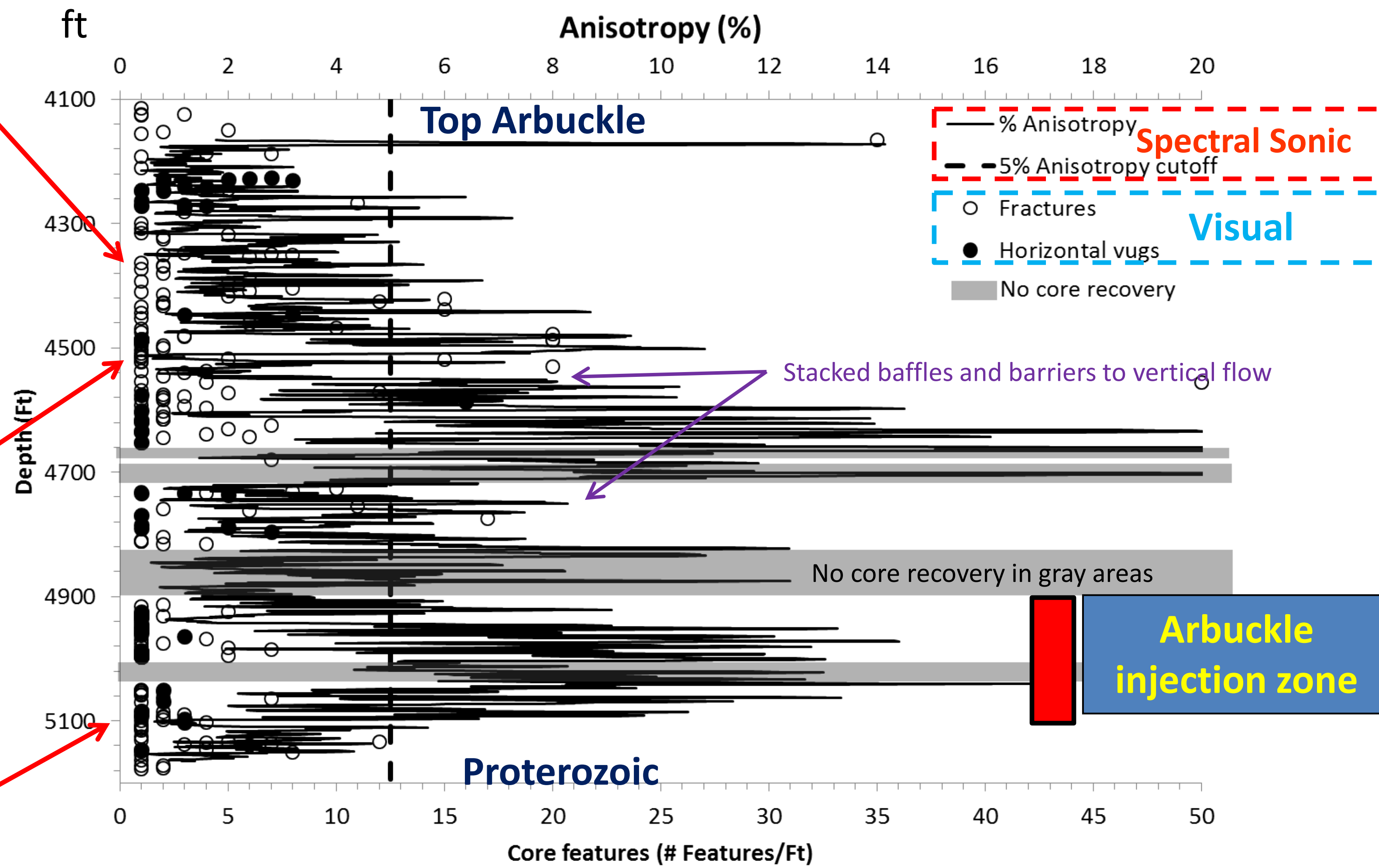


Scheffer, 2012

Variable Zonal Fracturing Through the Arbuckle

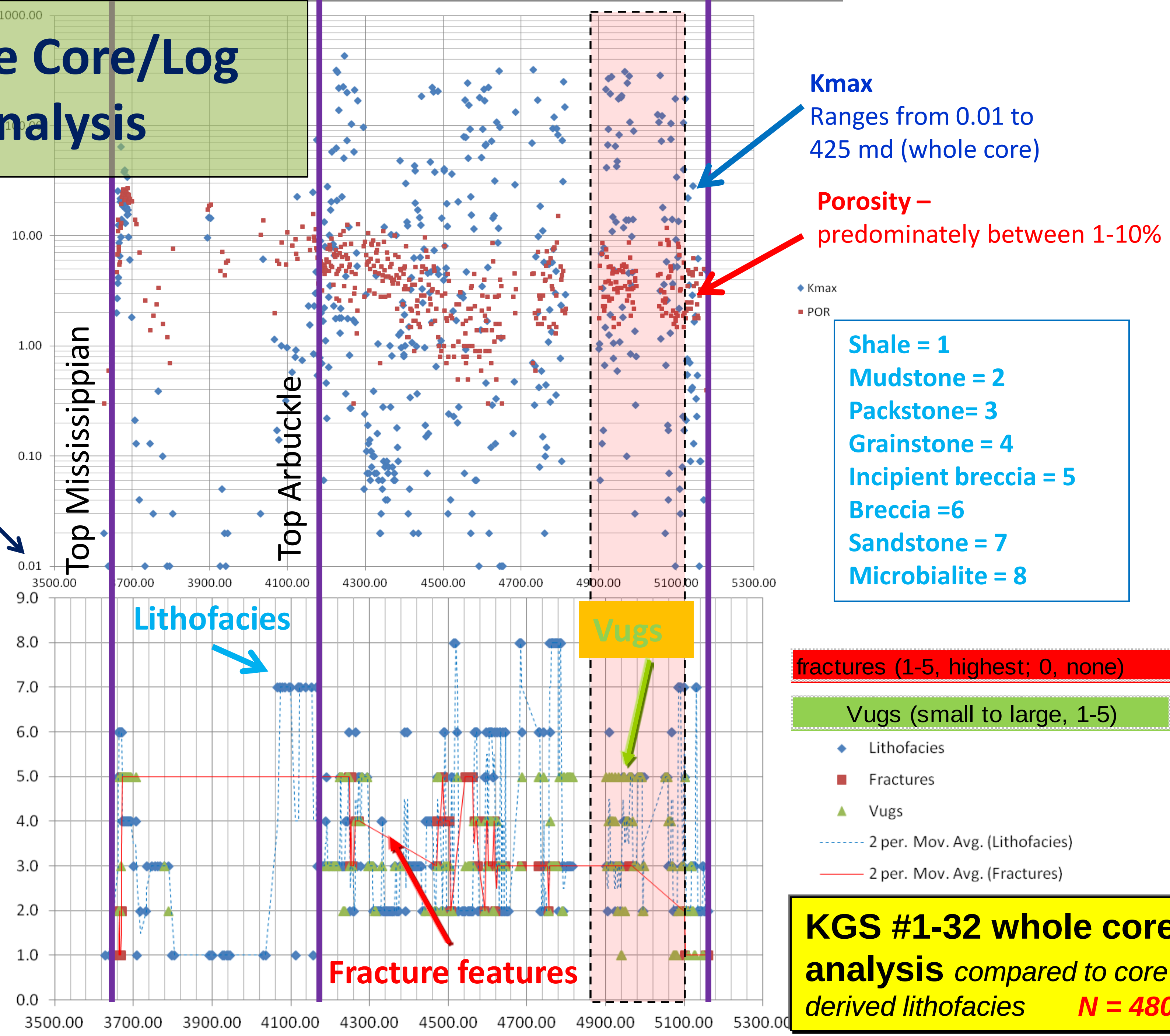
Spectral (dipole) acoustic log and visual core description





Scheffer, 2012; Lorenz and Cooper, 2011

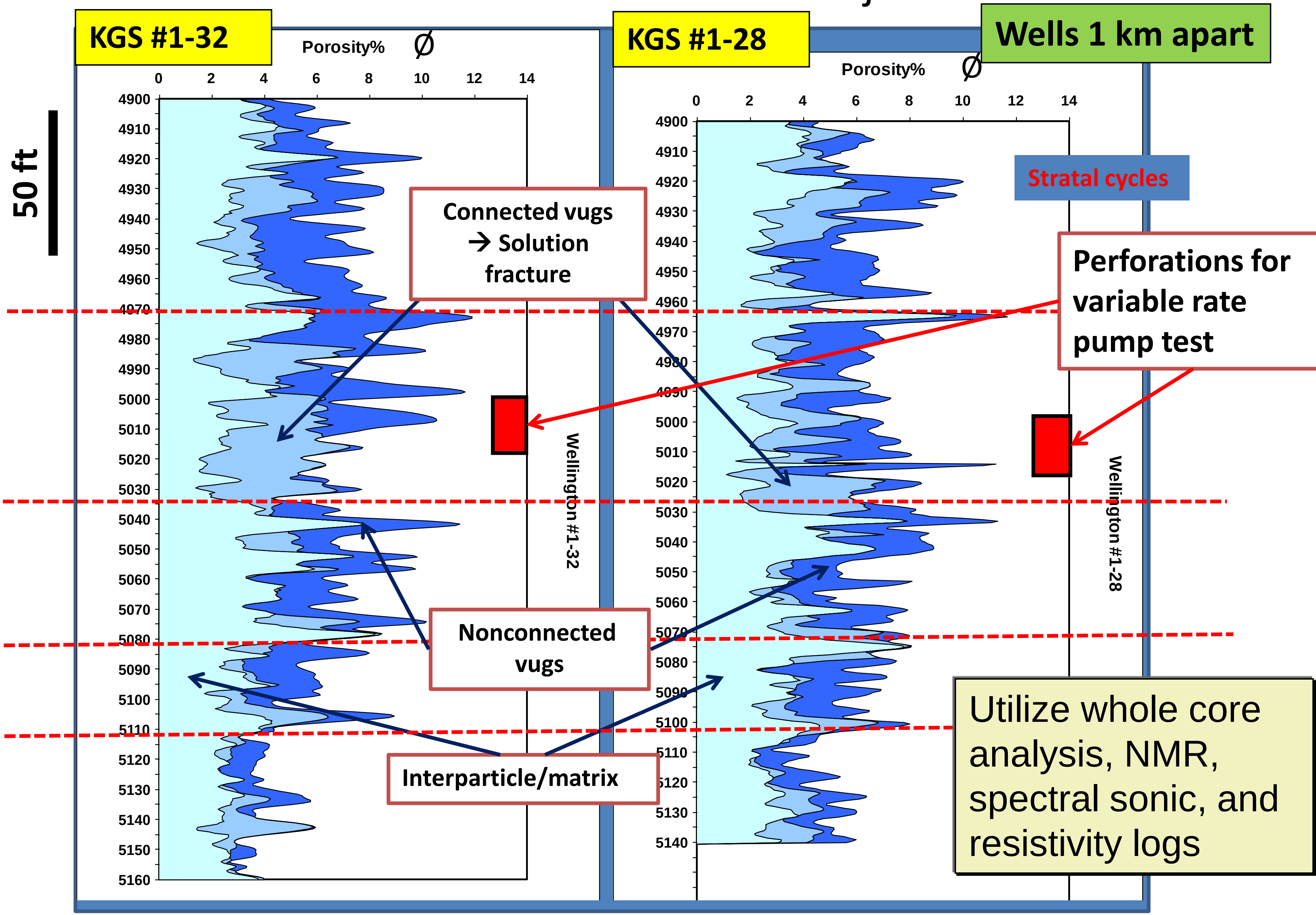
Whole Core/Log Analysis



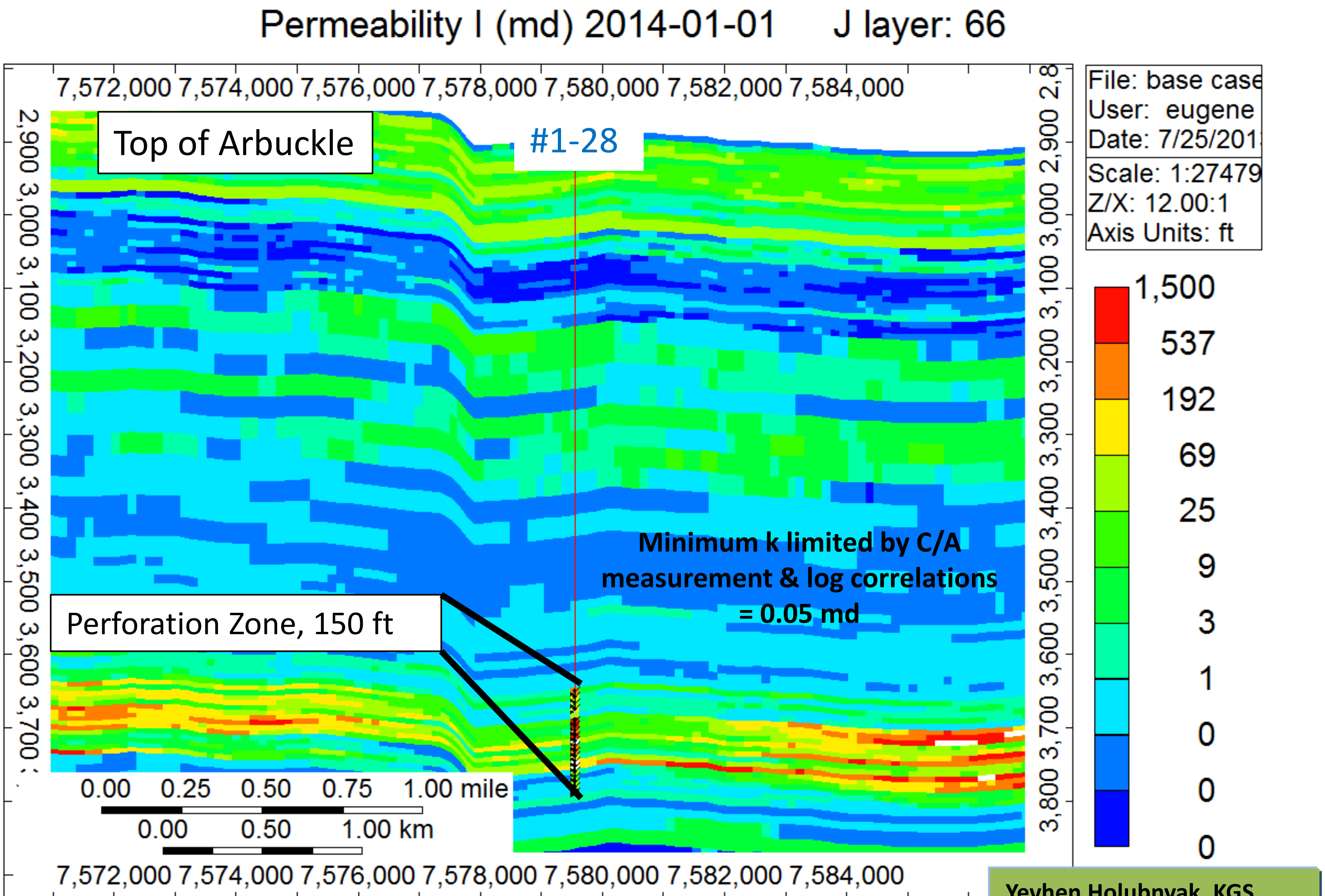
Minimum k reported as <0.01 md, but accuracy of measurement down to 0.005 md (Weatherford)

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

Stratigraphic Cyclicity and Corresponding Lithofacies Define Flow units Lower Arbuckle Injection Zone

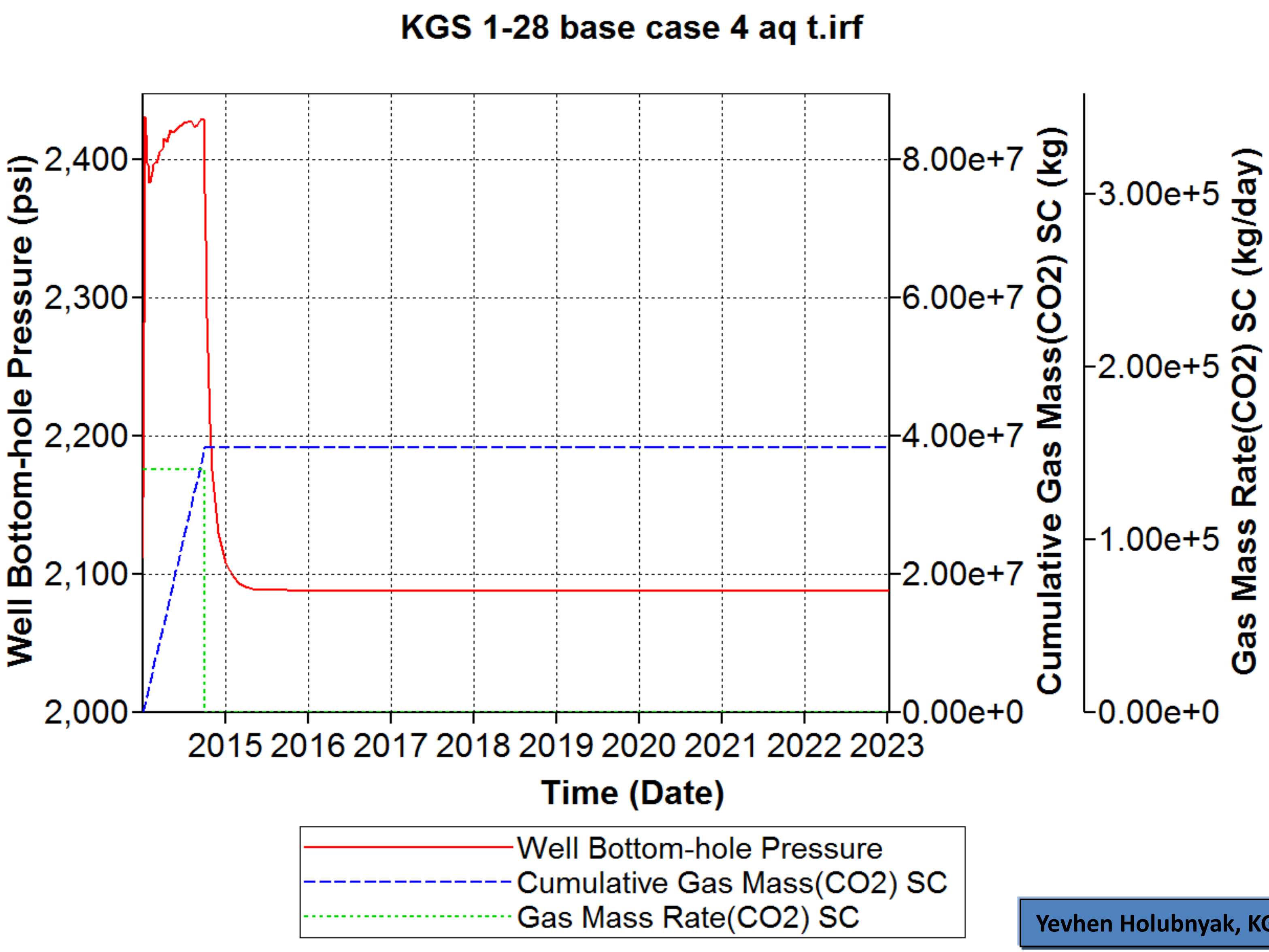


Upscaled Horizontal Permeability in CMG Dynamic Model

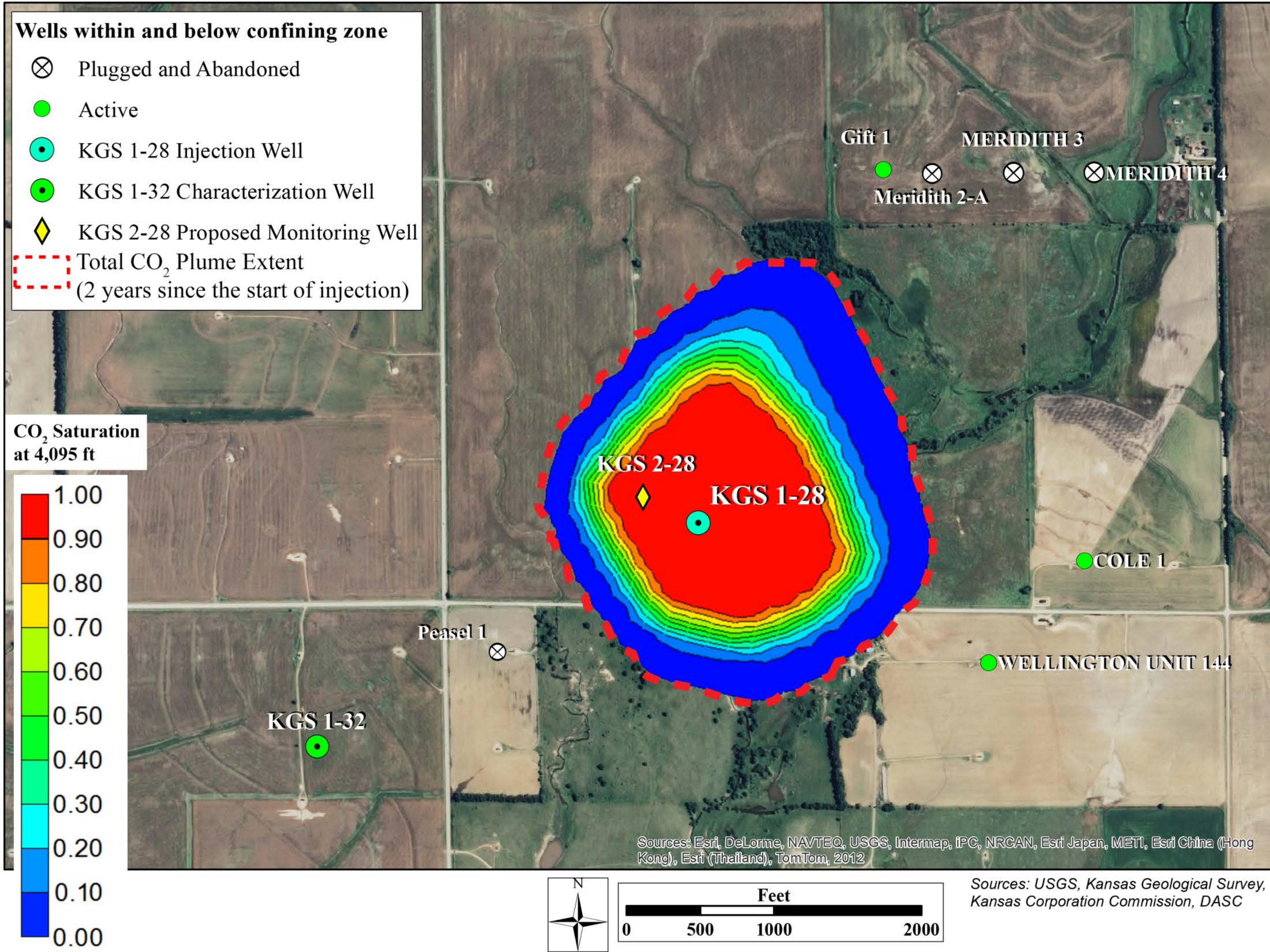


Yevhen Holubnyak, KGS

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



Yevhen Holubnyak, KGS



Wells within and below confining zone
Plugged and Abandoned
Active
KGS 1-28 Injection Well
KGS 1-32 Characterization Well
KGS 2-28 Proposed Monitoring Well
Total CO_2 Plume Extent
(2 years since the start of injection)
Gift 1
MERIDITH 3
MERIDITH 4
Meridith 2-A
CO_2 Saturation at 4,095 ft
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
KGS 2-28
KGS 1-28
COLE 1
Peasel 1
WELLINGTON UNIT 144
KGS 1-32
Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, 2012
N
Feet
0
500
1000
2000
Sources: USGS, Kansas Geological Survey, Kansas Corporation Commission, DASC

Summary

Key Findings

– Suitable injection zones, caprock, and isolation from USDW
  - Arbuckle highly stratified three distinct hydrostratigraphic units
  - Significant amounts of the scCO_2 are 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

Lessons Learned

– Water geochemistry and biogeochemistry have proved extremely useful

– Multiple independent means required to assess permeability in complex carbonate aquifer system requires

Future Plans

– Submit application for Class VI injection permit in May 2014

– 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 (Fall 2014), followed by saline aquifer (mid 2015)