26th Annual CO_2 Conference

Presented Both Live and Virtually

Kansas Case Histories of Permitting and CO_2 Projects

Eugene Holubnyak, Franciszek Hasiuk, Jenny Meng, Jennifer Hollenbach, George Tsoflias, Alex Nolte

Presented at the 26th Annual CO_2 Conference

Tuesday - Thursday Dec 8th-10th, 2020

Bush Convention Center

Midland, Texas

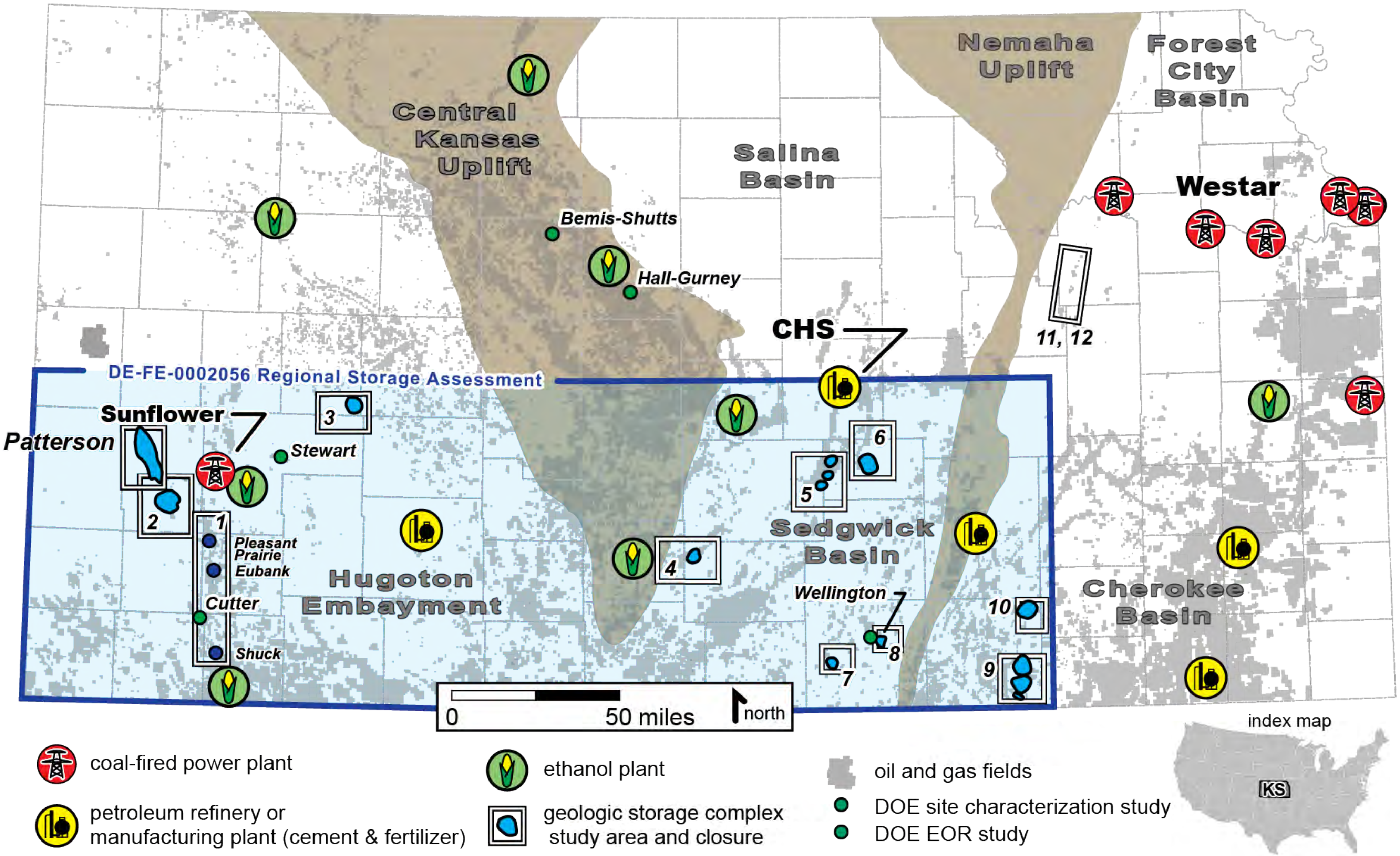
2020 CO_2 Conference
December 8-10

Why CCUS in Kansas?

Large point sources of CO_2 → Rapid development of renewable energy (#2 in % wind) → ***How do we avoid junking expensive investments?*** → Abundant subsurface data *Abundant Reservoirs* → Mature oil and gas industry *EOR Potential* → Mature underground injection industry *Saline Storage Potential*

Evergy's Lawrence Energy Center
Often shut down due to low demand for coal-fired power

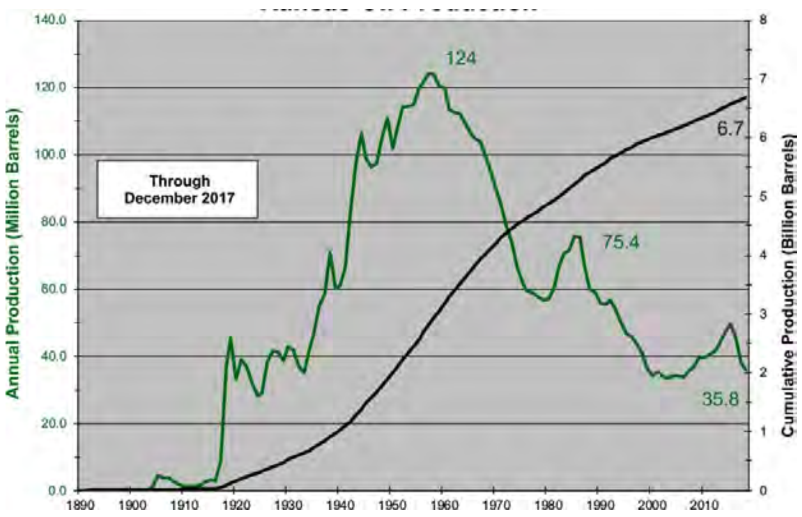
KGS CarbonSAFE Projects Phase I and II



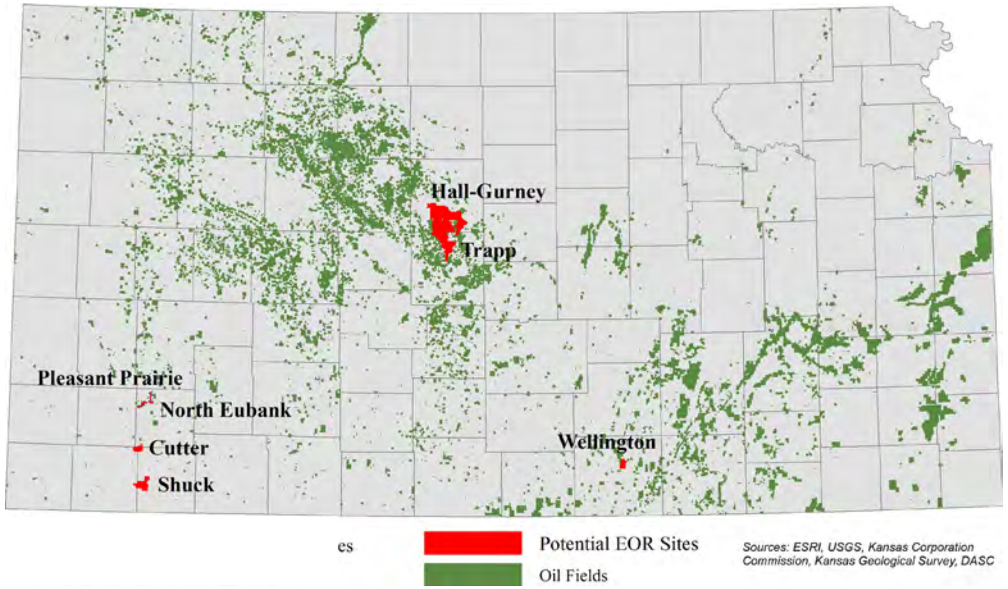
CO_2-EOR Potential in Kansas

- Kansas oil production has been in decline since 1960s
- Uptrends happened due to technological innovation
- A few commercial and pilot CO_2-EOR projects exist
- Several fields are characterized, with geologic and simulation models developed
- KGS is creating a database with waterflood information that will be available soon to CUSP

Kansas Oil Production is Falling



Numerous Potential Sites for EOR



Basin	EOR Potential (mill bbl)	Net CO_2 Demand (MMT)	Direct Jobs Created
Illinois-Indiana	500	160-250	1550-3100
Ohio	500	190-300	1550-3100
Michigan	250	80-130	800-1800
Kansas	750	240-370	2300-4600
	2000	**670-1050**	**3200-12400**

	Injection Rate (Mt/yr)	CO_2 Storage (Mt)	Primary and Secondary (MMBO)	CO_2 EOR (MMBO)	Basis for Estimate
Shuck	0.4	1.5	7.9	3.6	DE-FE000256
Cutter	0.5	1.3	5.4	2.8	DE-FE000256
N Eubank	0.6	1.5	7.4	4.6	DE-FE000256
Pleasant Prairie	0.3	0.5	4.7	2.2	DE-FE000256
Hall-Gurney	1	11.3	62.5	26.8	DE-AC26-00BC15124 and Pilot C12 Energy
Trapp	0.5	4.3	31.3	10.3	KGS reports
Wellington	0.6	2.2	16.2	5.3	DE-FE0002056 and Pilot
	3.9	**22.8**	**135.4**	**55.7**	

What 45Q credits could be captured?

Hypothetical Scenario

- Construction in 2020, injection in 2022
- Tax credits
  - $33/tonne CO_2 stored (for EOR) over 12-yr period
  - $47/tonne for saline storage

	Ethanol Plant	Oil Field	Large Pipeline
CO_2 Injection Volume (Mt/yr)	0.15	0.5	4.3
Annual Tax Credits	$5M	$17M	$142M
12-years of Credits	$59M	$198M	$1,703M

Estimates are based on $60 per bbl of oil

	Pipeline	Ethanol	Total
CapX ($/T)	$17.92	$7.81	$25.73
OpX ($/T)	$4.77	$8.58	$13.35
Total ($/T)	$22.69	$16.39	$39.08
Total ($/mcf)	$1.19	$0.86	$2.06
	With 45Q		
Total ($/T)	$5.00	$8.68	$13.68
Total ($/mcf)	$0.26	$0.46	$0.72

Kansas Field Candidate Guidelines

1. Relatively **large fields**
   - >20 million barrels recovered
   - Or close fields in aggregate > 20 mmbo

2. **High recovery rates** on per-acre basis are most ideal

	MBO/Acre	MBO/Section
SW KS Study (Chester/Morrow)	4-5	3
Hall-Gurney (L-KC)	8	5
Arbuckle (Geneseo-Edwards)	15	9.5

3. **Good waterfloods** and >3000 ft
   - Hall-Gurney - (63 Mbo from L-KC waterfloods)
   - Others possible (to name a few) – Huffstutter, Fairport, Trapp, Wellington

CO_2 Source Economics

Facility	Capture Rate (Mtonnes/ annum)	Best Case ($/t$CO_2$)	Worst Case ($/t$CO_2$)
Jeffrey Energy Center	2.70	$45	$67
Holcomb Station, Case 1a	1.70	$46	$72
Holcomb Station, Case 1b	1.20	$50	$79
Holcomb Station, Case 2	1.70	$35	$61
Holcomb Station, Case 3	1.70	$46	$71
CHS SMR refinery	0.80	$60	$94

Integrated CCS for Kansas (ICKan); Award Number: DE-FE0029474
DUNS NUMBER: 076248616 Final Technical Report

Westar Energy Jeffrey Energy Center, Eastern Kansas

- 3 separate 800 MWe coal-fired units
- Annual CO_2 emissions – 12.5 million tonnes
- Units were built in the 1980s but fitted recently with selective catalytic reduction (SCR) based NOx removal, activated carbon sorbent-based Hg removal and scrubber-based flue gas desulfurization (FGD)

Sunflower Electric Power Corporation's Holcomb Station

- Single subcritical 348 MWe unit (387 MVA; 0.9 PF)
- Annual CO_2 emissions – 1.5-2 million tonnes
- Began operation in 1983; uses low sulfur, sub-bituminous coal from Wyoming
- Plant is fitted with environmental controls including low-NO_X burners, over-fire air (OFA), a powdered activated carbon (PAC) injection system, a dry scrubber, and baghouse

CHS Refinery, South-Central Kansas

- 2 steam methane reformer (SMR) hydrogen plants
- Annual CO_2 emissions – 0.76 + 0.62 million tonnes

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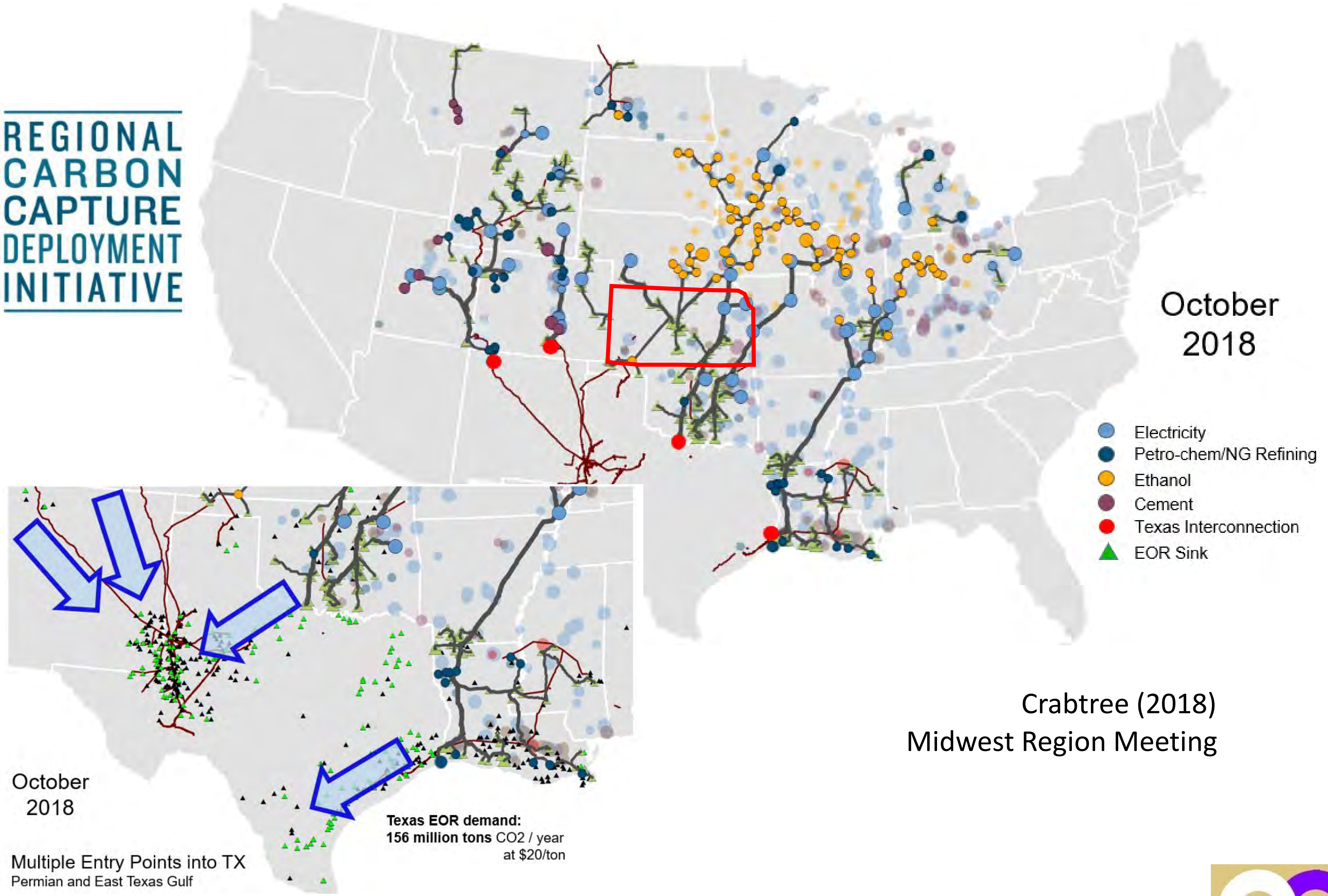
Many Potential Pipeline Routes Cross Kansas

- Potential pipeline scenarios RCCDI
- Several commercial operators expressed interest in building pipelines connecting CO_2 sources in Upper Midwest and KS, OK, TX, and NM
- Kansas can become a CCUS hub with multiple businesses and communities benefiting from this technological breakthrough

REGIONAL CARBON CAPTURE DEPLOYMENT INITIATIVE



Crabtree (2018)
Midwest Region Meeting

Kansas Legal and Regulatory Framework

Challenge		CO_2 EOR	Storage/ Sequestration	Possible Remedies
Statutory framework		Adequate	Not developed	Statutes for Sequestration
Pore Space	Ownership	Minerals owner	Surface owner	Statute to make definitive
	Aggregation (pooling / unitization)	Covered (KSA 1301-1303), but is rather weak	Needs to be addressed	Make less difficult to unitize (EOR). Expand for Sequestration. Eminent domain under a utility model (Sequestration).
Regulatory	Well permitting	Class II; State primacy; no issues	Class VI; EPA primacy; Tough to get permitted	States may file for Class VI primacy
CO_2 ownership	During operations	Determined by contracts	Determined by contracts	Sequestration - utility model would simplify
	Post-closure, long-term liability	No issue?	Long-term liability	Sequestration - utility model could pass liability to State

Source: Mostly condensed from results from ICKan legal and regulatory studies (Steincamp, Schremmer, et.al.)

Few issues for EOR

Multiple challenges with saline aquifer storage

KGS has been central in CCUS Outreach in Kansas

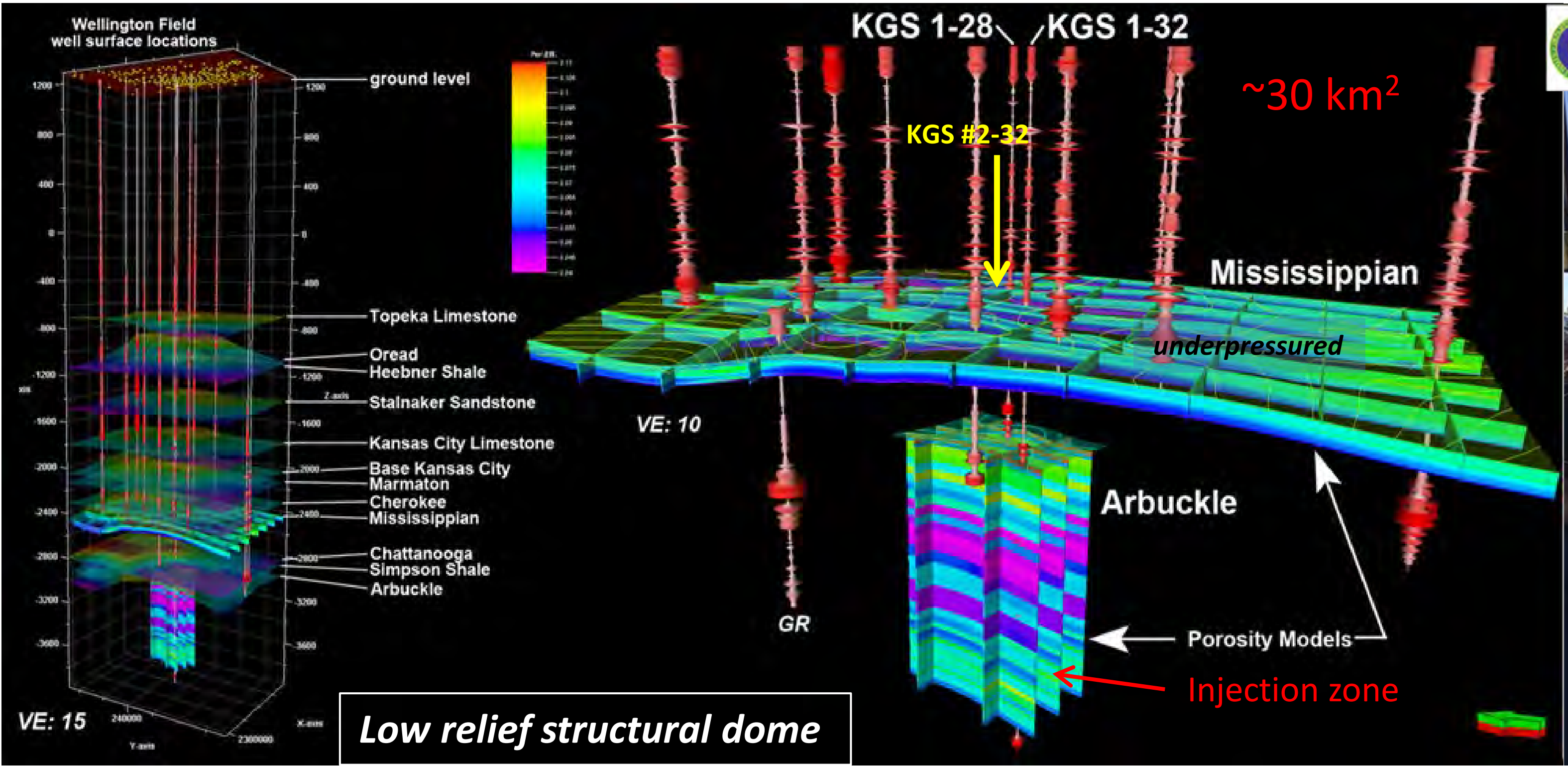
- **Effective public outreach is critical to support state regulatory changes and for public acceptance**
  - Induced seismicity
  - Infrastructure development
  - Economic impact and opportunity

- **3rd Annual Kansas CCUS Conference**
  - October 14-15, 2019, Lawrence, KS
  - More than 70 participants from industry, regulators, and academia
  - Main conclusion of a conference: economic opportunity is there but legal/regulatory framework is not ready
  - Next event is **January 27th, 2021**

- **Kansas CCUS Task Force**
  - 2 Meetings in September and October 2019
  - Infrastructure bill: http://kslegislature.org/li/b2019_20/measures/sb395/

CCUS Pilots in KS: Wellington EOR and UIC Class VI project

- **Successful CO_2-EOR project and attempted UIC Class VI**
  - ➢ 20,000 metric tonnes injected into KGS #2-32 into *Mississippian siliceous dolomite reservoir between January-June 2016*
  - ➢ *CO_2 plume and EOR response as forecast by model* ***(Class II UIC permit)***
  - ➢ 20,000 metric ton injection into underlying *Arbuckle Group dolomitic saline aquifer* ***(attempted Class VI UIC permit)***
- **Demonstrated reliable and cost effective MVA (monitoring, verification, and accounting) tools and techniques**
- **Developed best practices for effective and safe CO_2-EOR and CO_2 saline storage**



NETL | KU Kansas Geological Survey, The University of Kansas | BEREXCO | The Linde Group, Linde

KGS Experience with UIC Class VI Permitting

Constructed 3 shallow wells at EPA's request to prove absence of USDW

Installed Wellington Seismic Array

Prepared Opinion on Induced Seismicity in Kansas

Wellington Seismic Action Plan prepared in response to EPA's concern about induced seismicity

Conducted analytical studies to demonstrate absence of USDW at site

Conducted modeling for 26,000 tons and prepared new report

Prepared Site Structure and Induced Seismicity Report

Permit application submitted April 2014

Work with EPA to prepare permit documents

Apr 14	Aug 14	Dec 14	Apr 15	Aug 15	Dec 17	Apr 16	Aug 16	Dec 16	Mar 17

Respond to Request For Information on all sections of permit

Permit reformatted, resubmitted using new GS Tool

Kickoff meeting in August 2014

Water Quality Testing and Analysis at shallow wells

Prepares Quality Assurance and Surveillance Plan (QASP)

Operation Plan for Safe and Efficient Injection (OPSEI) prepared as a monitoring response plan.

Conducted STOMP simulations to assist EPA in AoR evaluations

At EPA's request, prepare plan for monitoring pressures in Mississippia n reservoir

Address Financial Responsibility requirements – Lower cost estimate

EPA Class VI Permit Application – Required Elements

1. **Site characterization (geologic) information**
   - **Maps/cross sections, structure, lithology, faults/fractures, geochemistry, hydrology/hydrogeology, USDWs, seismic history**
2. **AoR delineation and proposed corrective action**
3. **GS Project Plans**
   - **AoR and Corrective Action, Testing and Monitoring, Well Plugging, Post- injection Site Care (PISC) and Site Closure, Emergency and Remedial Response**
4. **Well construction/specifications**
5. **Operating plan and pre-injection testing plan**
6. **Financial responsibility demonstration (i.e., cost estimates and instruments)**
7. **Injection depth waiver application and aquifer exemption expansion (if necessary)**

40 CFR 146.82(a) and (c)

Class VI Requirements and Main Challenges

- Site characterization
- AoR Delineation
- GS Project Plans
  - AoR and Corrective Action
  - Testing and Monitoring
  - Well Plugging
  - PISC and site closure
  - Emergency and Remedial Response
- Well construction
- Operating plan and pre-injection testing
- Financial Responsibility demonstration

- Key Challenges:
- Seismicity
  - KGS Findings on Seismicity in Kansas
  - Seismic Action Plan
- Modeling
- Financial Assurance
  - USDW delineation
  - Emergency and Remedial Response
  - PISC reduction
  - **KGS reduced FA by over $60 million**

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Initial EPA Financial Assurance Cost Requirement

Amount Needed to Show Financial Responsibility (2012$)

Project Task	Low End Cost Estimate ($/Project; includes 20% G&A)	Middle Cost Estimate ($/Project; includes 20% G&A)	High End Cost Estimate ($/Project; includes 20% G&A)
Performing Corrective Actions on Deficient Well(s) in AoR			
Maintenance Rig Rental (Clean Out Deficient Wells)	$ -	$ -	$ -
Flush Deficient Wells	$ -	$ -	$ -
Plug Deficient Wells	$ -	$ -	$ -
Log Deficient Wells	$ -	$ -	$ -
Subtotal: Corrective Actions Cost	**$ -**	**$ -**	**$ -**
Plugging Injection Well			
Maintenance Rig Rental (Clean Out Injection Well)	$ 31,000	$ 67,000	$ 76,000
Perform Mechanical Integrity Test Before Plugging Injection Well	$ 31,000	$ 31,000	$ 31,000
Flush Injection Well with a Buffer Fluid Before Plugging	$ 300	$ 2,600	$ 7,000
Plug Injection Well	$ 15,000	$ 20,000	$ 89,000
Log Injection Well	$ 4,000	$ 4,000	$ 18,000
Subtotal: Injection Well Plugging Cost	**$ 81,000**	**$ 125,000**	**$ 221,000**
Post-Injection Site Care (assume 0% discount rate)[1]			
Post-Injection O&M for Monitoring Wells Post-Injection Seismic Survey Post-Injection Groundwater Monitoring Post-Injection Monitoring Reports to Regulators	**$ 176,000**	**$ 246,000**	**$ 293,000**
Site Closure			
Maintenance Rig Rental (Clean Out Monitoring Wells)	$ 52,000	$ 114,000	$ 130,000
Perform Mechanical Integrity Test Before Plugging Monitoring	$ 87,000	$ 87,000	$ 87,000
Flush Monitoring Wells	$ -	$ 3,000	$ 8,000
Plug Monitoring Wells (occurs at end of PISC; use 0% discounting)	$ 73,000	$ 90,000	$ 377,000
Log Monitoring Wells (occurs at end of PISC; use 0% discounting)	$ 18,000	$ 22,000	$ 90,000
Remove Surface Equipment and Restore Vegetation for Injection Wells	$ 19,000	$ 35,000	$ 50,000
Remove Surface Equipment and Restore Vegetation for Monitoring Wells (occurs at end of PISC; use 0% discounting)	$ 97,000	$ 173,000	$ 249,000
Document Plugging and Closure Process	$ 19,000	$ 19,000	$ 19,000
Subtotal: Site Closure Cost	**$ 366,000**	**$ 544,000**	**$ 1,010,000**
Emergency and Remedial Response, Scenario B: Remediate Underground Source of Drinking Water (USDW) Contamination			
Stop CO2 Injection	$ 1,000	$ 1,000	$ 3,000
Create Hydraulic Barrier	$ 3,924,000	$ 4,462,000	$ 5,610,000
Install Chemical Sealant to Stop CO2 Leaks	$ 11,000	$ 24,000	$ 32,000
Treat Contaminated Water from USDW	$ 3,254,000	$ 14,419,000	$ 62,841,000
Subtotal: Scenario B	**$ 7,190,000**	**$ 18,906,000**	**$ 68,486,000**
Responsibility	**$ 7,812,000**	**$ 19,822,000**	**$ 70,010,000**

Note: Results may not add due to independent rounding.

- **$70 million financial obligation with 50 yr default monitoring period**
- **Absence of USDW demonstrated with 5 separate reports**

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EPA Financial Responsibility Requirement

FR Category	EPA Estimate
Performing Corrective Action	$0
Plugging the Injection Well	$86,000 - $221,000
PISC and Site Closure	$743,000 - $1,447,000
Emergency and Remedial Response	$4,288,000 - $6,115,000

Cost related to constructing hydraulic barrier (sealing breach of confining zone)

EPA Class VI Review Process

Completeness Review

Technical Review and Decision Making

- RAI Tables
- Ad hoc reports
  - USDW Waiver
  - Seismicity
- Requests through GS Tool

Finalization

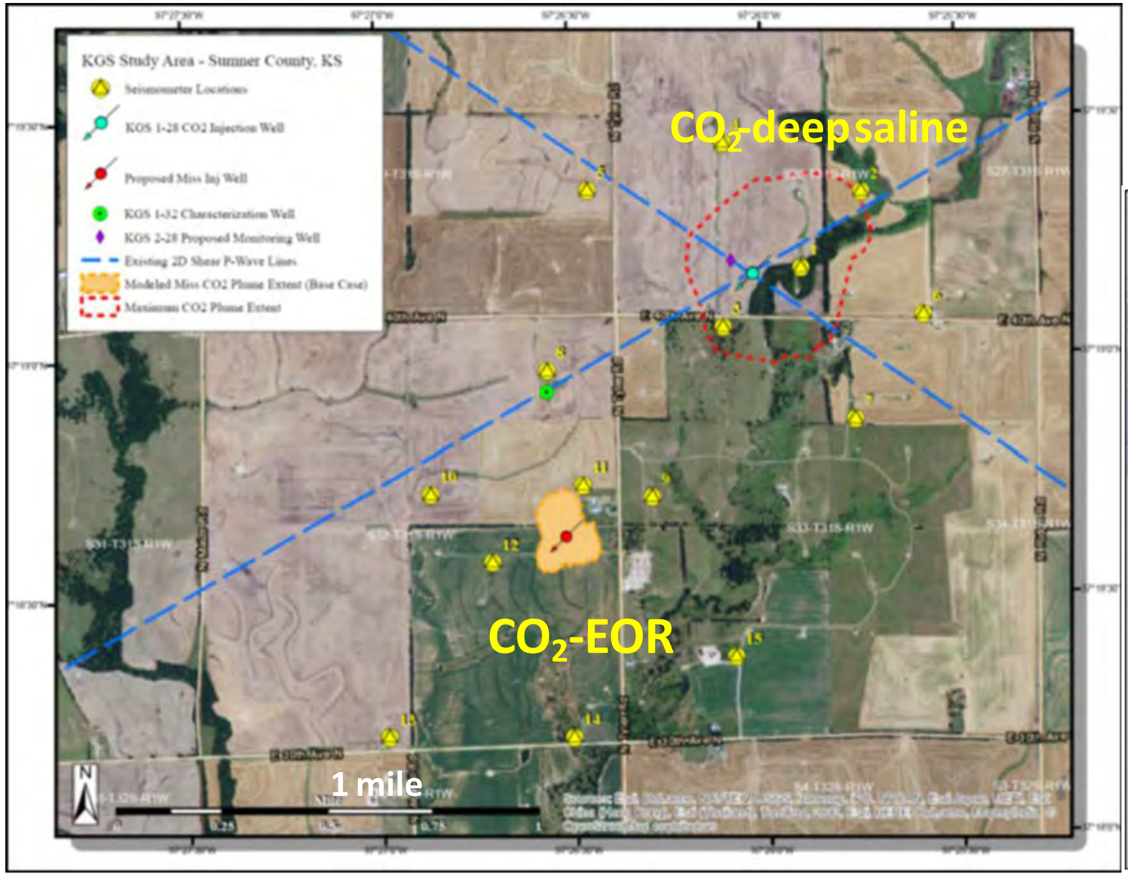
- Draft Permit
- Public Comments
- Public Outreach
- Town Hall Meeting

Class VI Guidance documents: https://www.epa.gov/uic/class-vi-guidance-documents

The GS Data Tool and the Input Advisor: https://epa.velo.pnnl.gov/

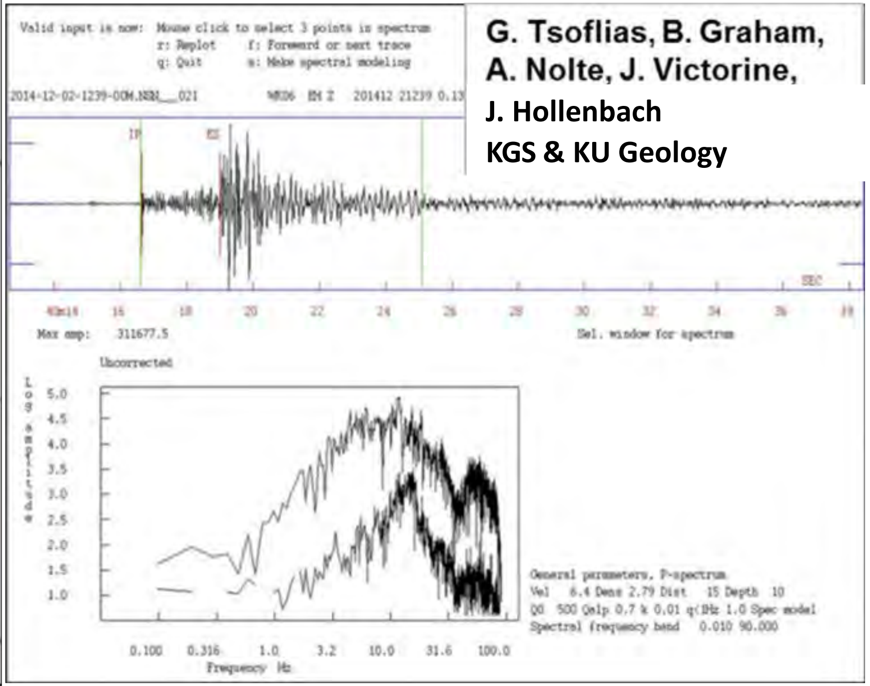
Pre-injection MVA Baseline Recording

- 18 seismometer array since Fall 2014 (and Patterson in 2019)
- cGPS and inSAR for processing since August 2014
- Five shallow monitoring wells around KGS #1-28 and domestic wells in vicinity
- Weekly baseline geochemistry and production data from 17 oil wells during CO_2-EOR
- Static bottom hole pressure in lower Arbuckle April 2016 – 2018

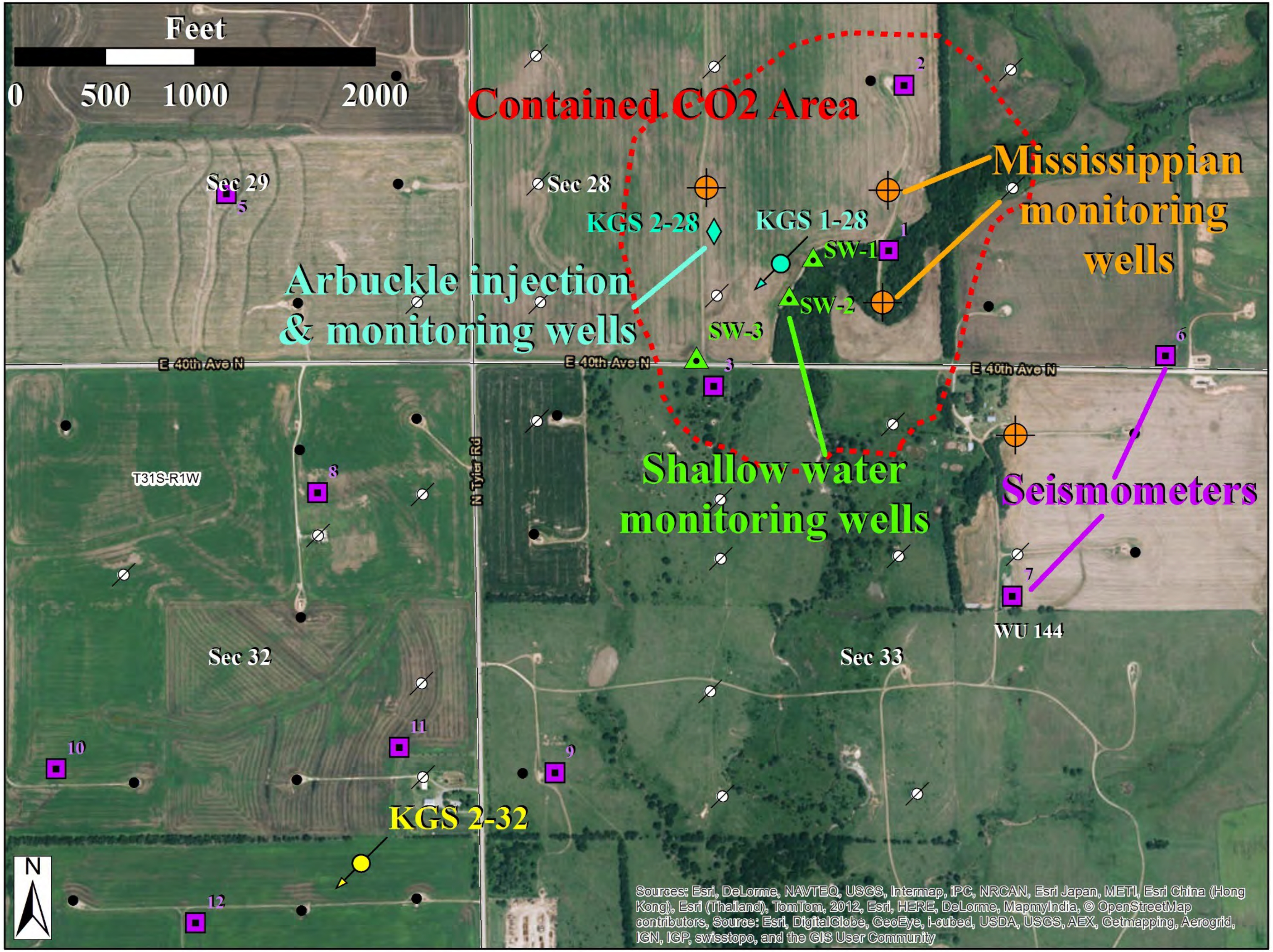


Housing setup for Sercel (Mark Products) L-22D-3D sensors, ~5 ft below surface to minimize surface noise; installed below frost line in bedrock

R. Miller & S. Petrie, KGS installation



G. Tsoflias, B. Graham, A. Nolte, J. Victorine, J. Hollenbach
KGS & KU Geology



Edited 10-5-2015

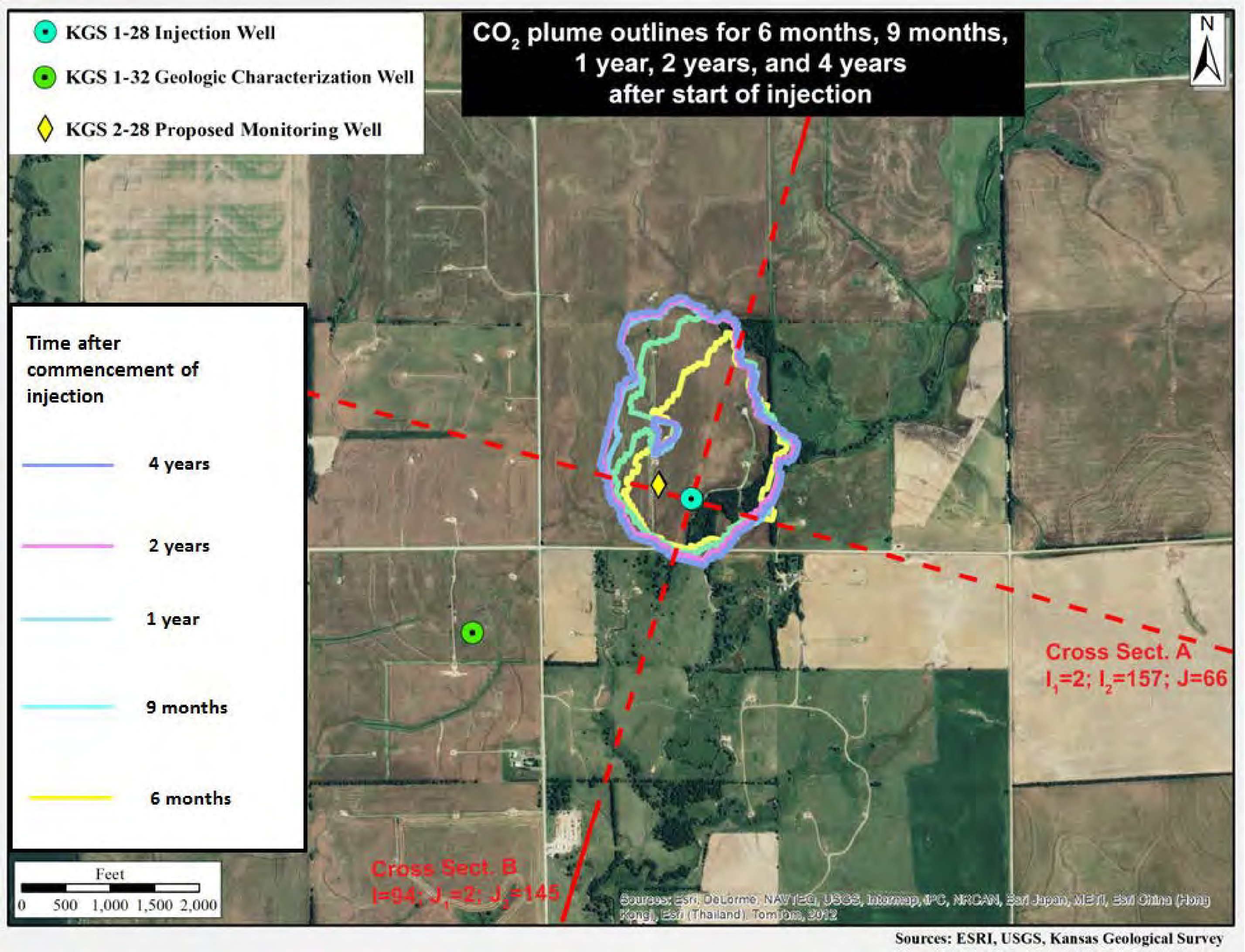
Sampling event at SW-3

Wellington Rapid Response Plan

Monitoring Activity	Frequency of Evaluation	Monitoring Objective	Expected Range	Deviation Triggering Reevaluation	Potential Causes of Deviation	Level 1 Response Action(s)	Level 2 Response (Actions)	Notes
CASSM - Early detection of plume at KGS2-28	weekly	Determine plume front/validate CO2-brine model	Plume expected to arrive at KGS 2-28 within 45-60 days	Plume arrival at KGS 2-28 within 15 days of commencement of injection	Presence of preferential flow pathway(s)/	• Validate plume detection with U-Tube sampling • Conduct Hall Plot analysis • Recalibrate model • Make projections new plume and pressure front • Recalculate AoR • Determine if any Corrective Action (CA) required • Report finding to EPA Director.		
CASSM – Non-detection of plume at KGS2-28	weekly	Determine plume front/validate CO2-brine model	Plume expected to arrive at KGS 2-28 within 45-60 days	Plume not detected within 90 days of commencement of injection	Non-radial migration of CO_2 through preferential pathway(s), escape into basement, breach of caprock, well integrity failure	• Conduct Hall Plot analysis • Review annulus pressure data • Sample Mississippian and shallow well • Conduct MIT • Recalibrate model • Make projections new plume and pressure front • Recalculate AoR • Determine if any Corrective Action (CA) required • Report finding to EPA Director.		Procedure to be repeated every 30 days if breakthrough at KGS 2-28 not achieved.
Sudden loss of downhole and/or wellhead pressure at injection well	Continuous	Monitor for leakage from well or caprock	Near steady pressures, increasing mildly with injection (except during start and stoppage of injection)	> 20% drop in pressure (over average of past 5 minutes)	Potential leakage from well or caprock, escape into basement, or formation of new fracture	• Pause injection • Review downhole, wellhead, and annulus pressure data. • Determine if loss of pressure due to CO_2 supply. If positive, rectify problem, report findings to EPA Director and resume injection. • Conduct Hall Plot analysis. • Sample and test water quality in the Mississippian and shallow monitoring wells • Conduct MIT • Utilize other monitoring technology to predict and calibrate model • If necessary, implement Level 2 response • Report finding to EPA Director.	• Conduct Pressure Fall-Off Test (to determine if loss of pressure due to formation enhancement • Conduct seismic survey • Obtain InSAR scene and analyze for caprock breach (if deemed feasible)	
Unexpected increase of downhole wellhead pressure at injection well	Continuous	Monitor for interception of barrier boundary and well	Near steady pressures, increasing mildly with	Unexpected increase in pressure gradient	Interception of barrier boundary, well plugging, reduced formation permeability due to chemical reactions, reduction of permeability due lower downhole temperature	• Review downhole and wellhead temperature and pressure data. • Conduct Hall Plot analysis. • Determine if increase in pressure due to cooling effect of CO_2 or supply, formation		

Cost Reduction Strategy - Early Site Closure

- EPA required monitoring for 4 years after injection
- Re-modeled AoR with various CO_2 volumes
- Demonstrated multiple scenarios
- Demonstrated plume stabilization
- Developed risk mediation and response action plans
- Optimized monitoring program to provide reliable data with minimal investment



Quality Assurance and Surveillance Plan

Wellington Oil Field Small Scale Carbon Capture and Storage Project
Wellington, KS

Class VI Injection Well: Quality Assurance and Surveillance Plan

Prepared by:
Kansas Geological Survey
Lawrence, KS

September 2015

TITLE AND APPROVAL SHEET

This Quality Assurance and Surveillance Plan (QASP) is approved for use in implementation of the Wellington Oil Field Small Scale Carbon Capture and Storage Project, Wellington, Kansas. The signatures below denote the approval of the document and intent to abide by the procedures outlined within it.

Willard Lynn Watney — Aug 25 20
Lynn Watney — Date
Kansas Geological Survey
Senior Scientific Fellow

Aug 25, 2015
Dana Wreath — Date
Berexco LLC
Vice President

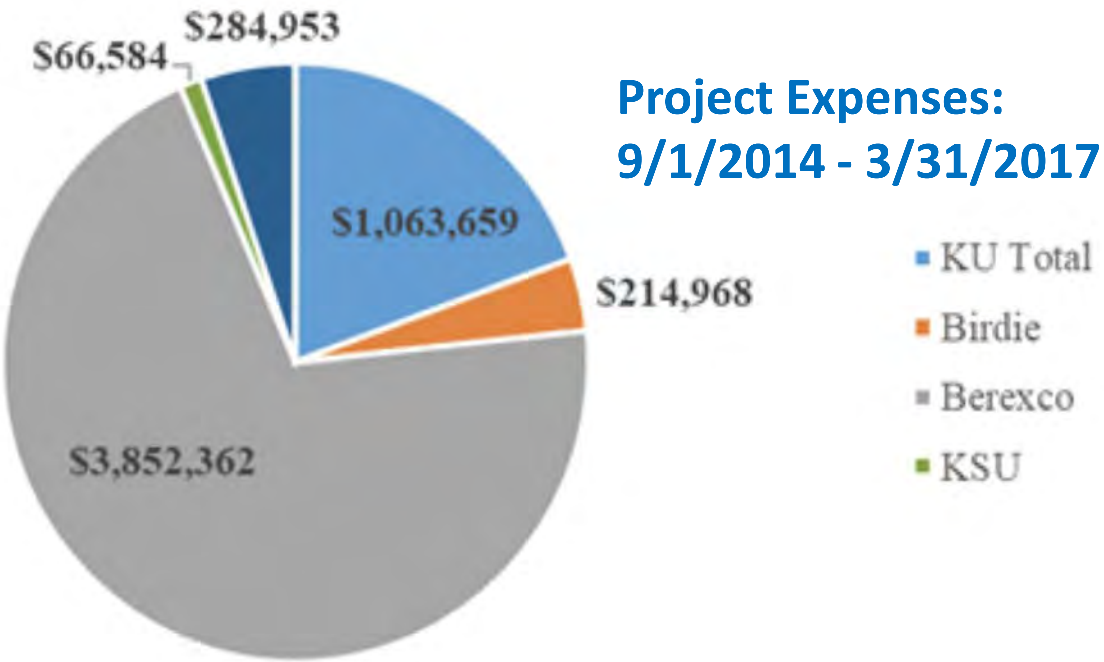
Aug 25, 2015
Tiraz Birdie — Date
TBirdie Consulting Inc.
President

9/3/15
Kurt F. Hildebrandt — Date
U.S. Environmental Protection Agency, Region VII
UIC Director

(approved w/condition) 09/03/2015
Diane Harris — Date
U.S. Environmental Protection Agency, Region VII — 2015214
Quality Assurance Coordinator

QASP finalized and signed by DOE, Berexo, KGS, EPA Region 7 and Washington D.C. offices

Expenditures & Cost Estimates



Project Expenses:
9/1/2014 - 3/31/2017

Class VI MVA Cost Estimates from QASP

- **Total PISC costs estimated between $250K - $500K per year**
- **Labor was underestimated**
- **Geochemistry = $2K per event**
- **Approx. $60K for all well sampling and geochemical analysis**

Mississippian CO_2 – EOR Injection (Fieldwork + well construction = ~75% of costs)

Estimated annual MVA costs based on finalized QASP:

Cost Estimate based on QASP	During injection	PISC	total wells	sample	total # events	Vendor estima
Shallow groundwater wells	Quarterly	Semiannually	18		6	$36,000
Miss wells	Quarterly	Semiannually	8		8	$16,000
KGS 2-28	Quarterly	Semiannually	4		4	

US UIC Class VI - List of Problems
Financial Assurance (FA) costs

Problems and examples

- Financial model used to determine financial assurance costs is not open to the applicant and general public - it is unclear how some financial responsibilities are calculated
- FA costs for certain items are unreasonably and unsustainably high, for example, the hydraulic barrier costs were grossly exaggerated for our pilot scale project
- Suggested FA costs and instruments are generally geared towards large corporations and are mostly prohibitive for smaller businesses
- FA in general is not equivalent to existing risks associated with CO_2 injection - CO_2 is not a hazardous waste, CO_2 pipeline operations in general deemed less risky than oil, natural gas, etc. pipelines and CO_2 underground injections for EOR purposes have more than 50 years of operational history without major operational failures
- US UIC Class II wells for CO_2 EOR do not require equivalent FA although these wells and operations are equivalent in nature to US UIC Class VI wells
- Pilot and small-scale projects (less than 150,000 tonnes a year), that definitely do not pose the same level of risk and are not of the same commercial magnitude are being penalized

Solutions

- Clarify FA models and make them transparent;
- Reduce FA costs where appropriate consulting standard practices for US UIC Class II CO_2 EOR wells;
- Reduce requirements for small-scale projects.

US UIC Class VI - List of Problems
Application Timeline

Problems and examples

- Typical timeframe for the application is beyond 3 years, at the same time it would take about two months to get US UIC Class II wells for CO_2 EOR in Kansas;
- Some hazardous waste injection permits (Class I wells) could take longer and a comparable to Class VI effort; however, most Class I applications are not that difficult to obtain and the amount of geological and engineering effort to obtain these permits is not comparable;
- Pilot studies that often funded by research organizations often could not continue research projects due to long and unclear timelines;
- Lack of clarity on general milestones for the application and vagueness of criteria for qualifications.

Solutions

- Reduce the timeline to two years for general projects;
- Reduce the timeline to 6 months for pilot/small scale projects;
- Make applications review timelines comparable to other non-hazardous injection wells

US UIC Class VI - List of Problems
Post Injection Site Care (PISC)

Problems and examples

- The Class VI rule states that the applicant can request closure when the plume and pressures have stabilized but does not specify what the stabilization criteria are;
- Open-endedness and long term projections for PISC are unrealistic for many projects

Solutions

- Specify plume stabilization criteria and reduce;
- Determine clear criteria and reduce PISC requirements according to existing standards for other non-hazardous injection well

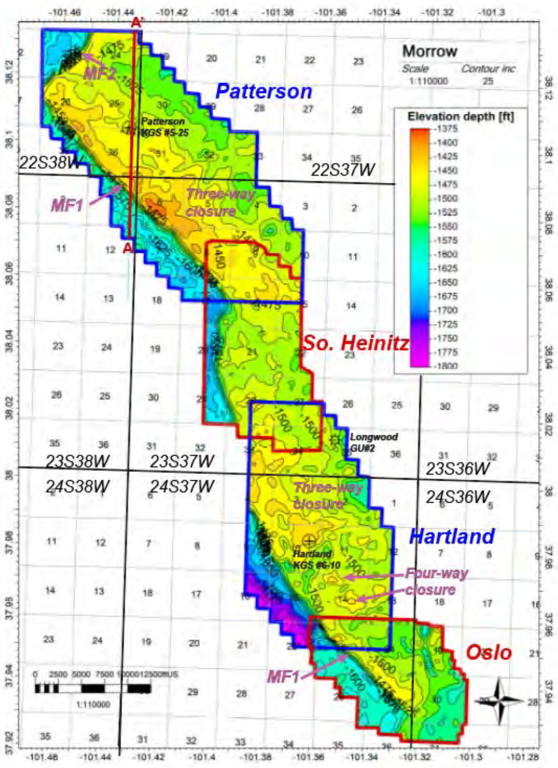
What is New?
Current Projects and Future Plans

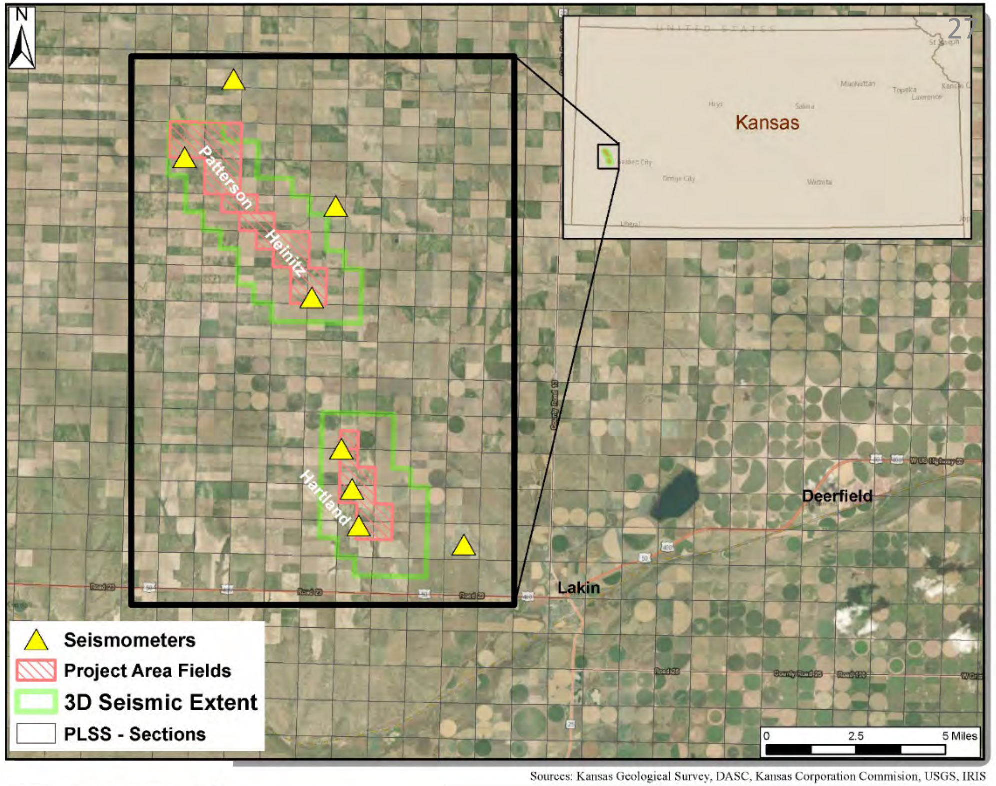
- Patterson Field near Lakin, KS
- Wellington field advanced EOR?
- Pipeline network?

Hartland-Patterson 4D Seismic Shoot, May 2019

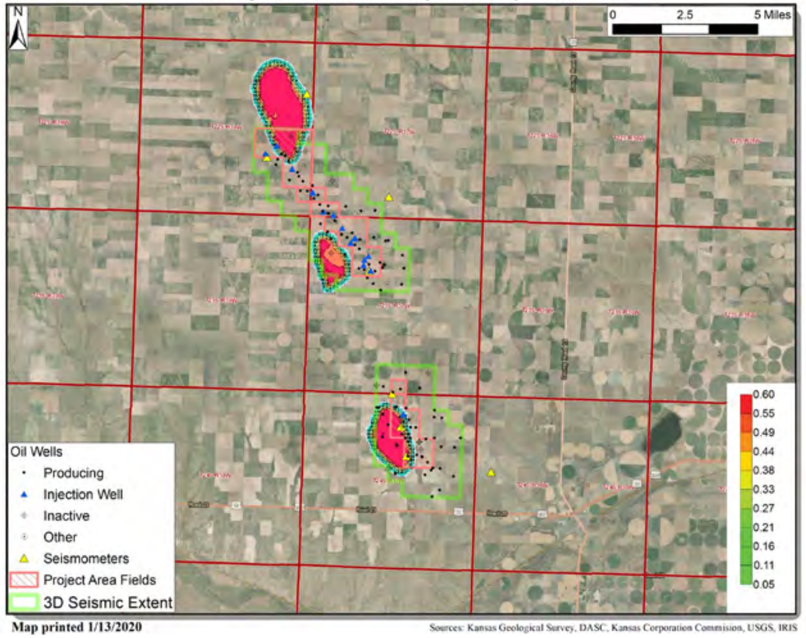
Patterson Site Characterization and preparation for UIC Class VI

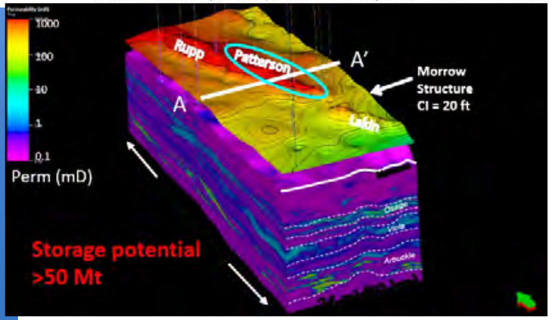
- Stacked storage concept: multiple saline formations + potential CO_2-EOR
- 26 square miles of new 3D seismic data were acquired in July 2019
- 2 new wells were drilled and logged
- ~800 ft of core recovered
- Advanced well testing program is planned summer 2020
- Close proximity to several CO_2 sources

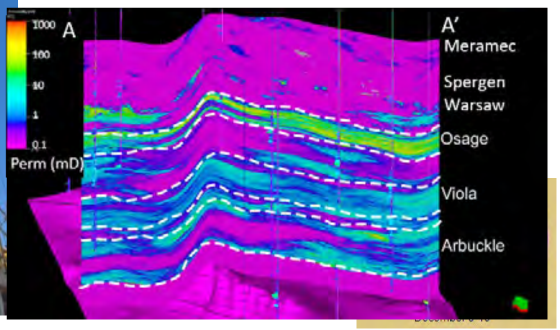




Osage Saturation Plume - 50 years after injection

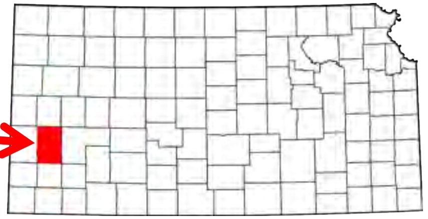


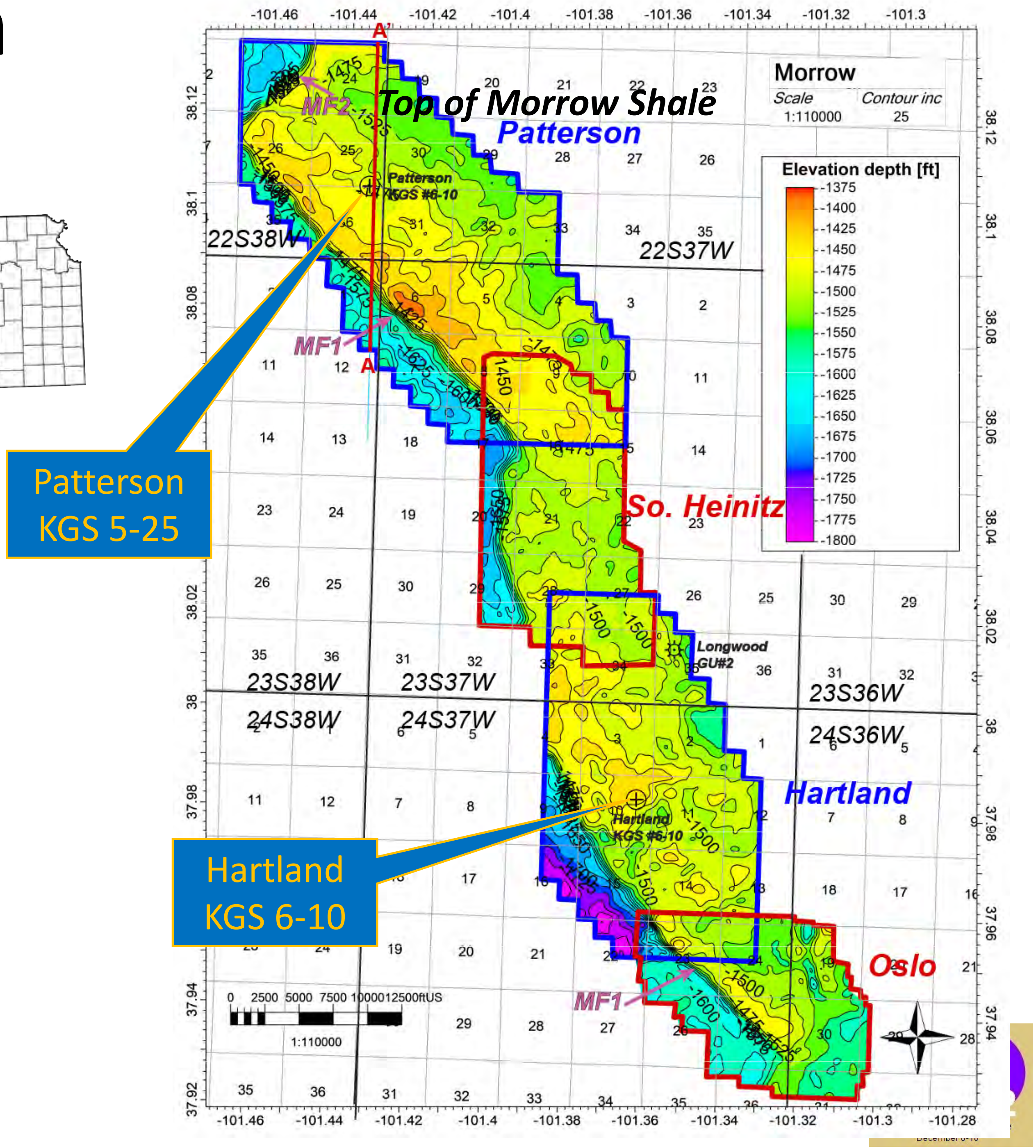




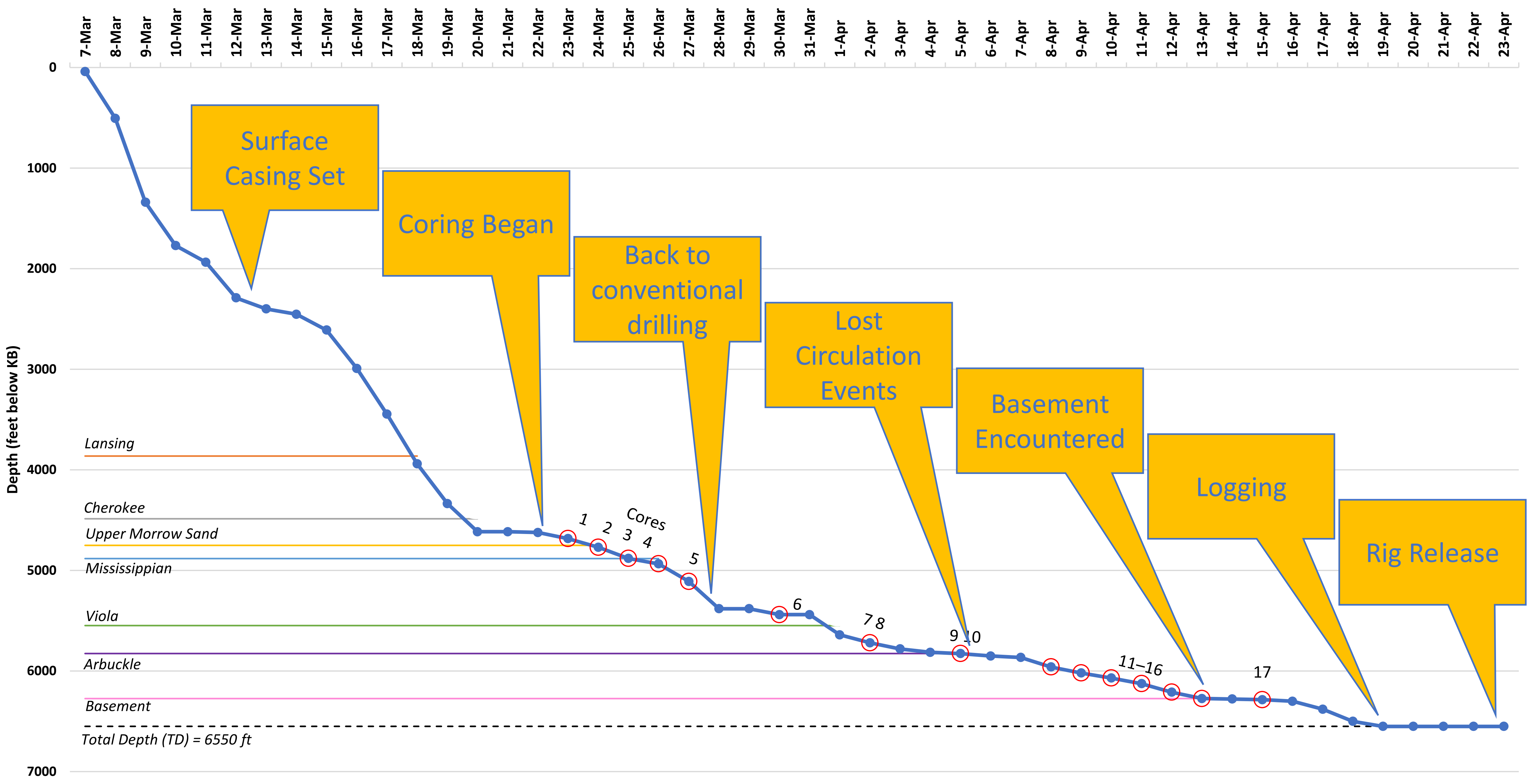
Drilling/Coring Program

- KGS 5-25 (API 15-093-21979)
- Patterson Field (Berexco)
- Kearny County, KS
- Drilled March-April 2020
- The goals for the well were to
  - Collect core samples from several stacked reservoirs and seals
  - Collect well logs from the Precambrian basement up through the Pennsylvanian
  - Conduct drill stem tests in prospective reservoirs
- Drilled during onset of global COVID19 pandemic



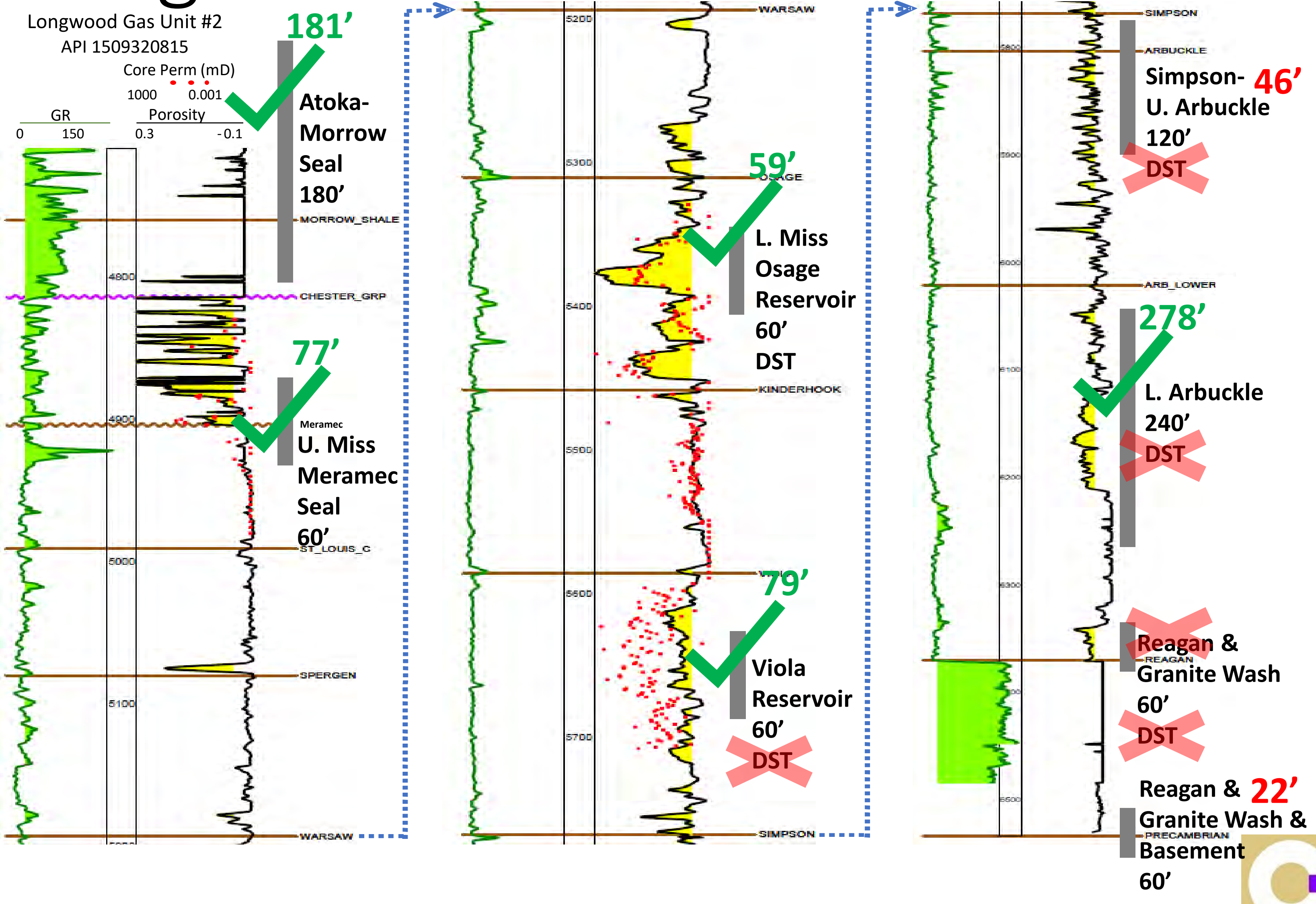


Day-Depth Progress

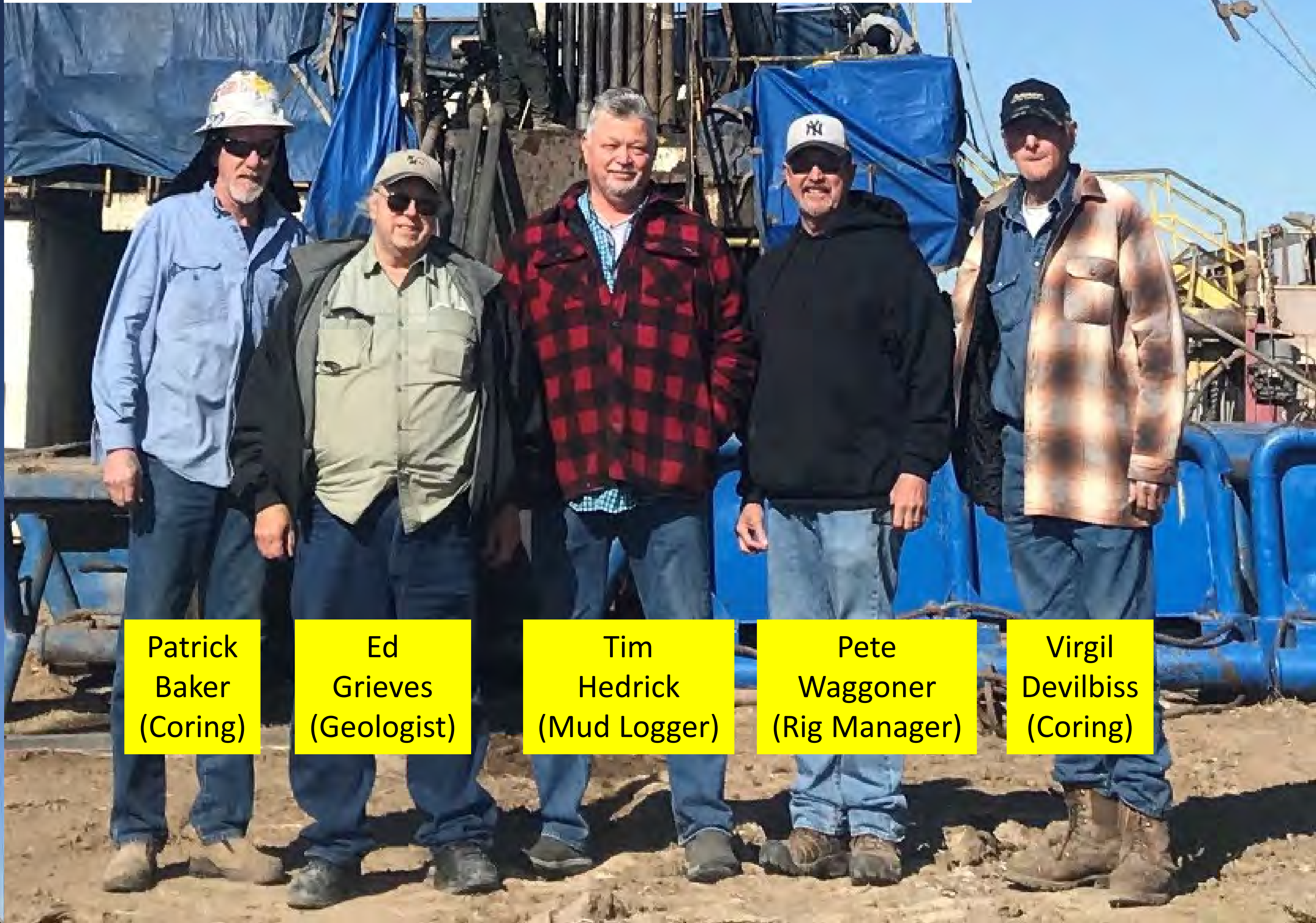


Coring Plan vs. Results

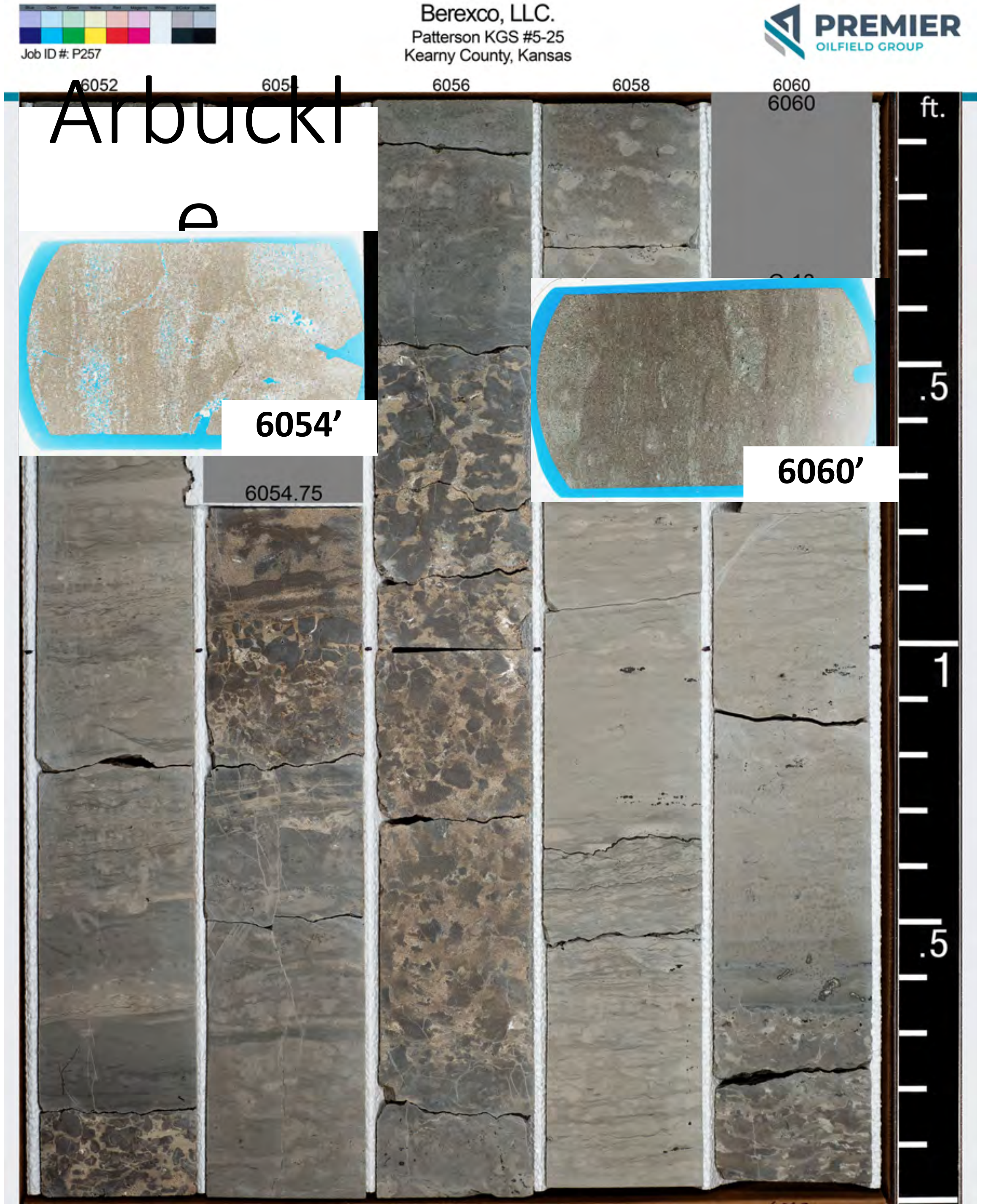
- Type log for Longwood Gas Unit #2
- 8 intervals chosen to recover 840 ft of core
- Coring proceeded without incident across first four intervals
- Coring in Simpson-Upper Arbuckle was truncated by lost-circulation events
- Coring in the Lower Arbuckle proceeded without incident…until basement was reached
- No Reagan Sand and only a short Granite Wash interval were observed
- Only 22 ft of basement were recovered due to slow ROP

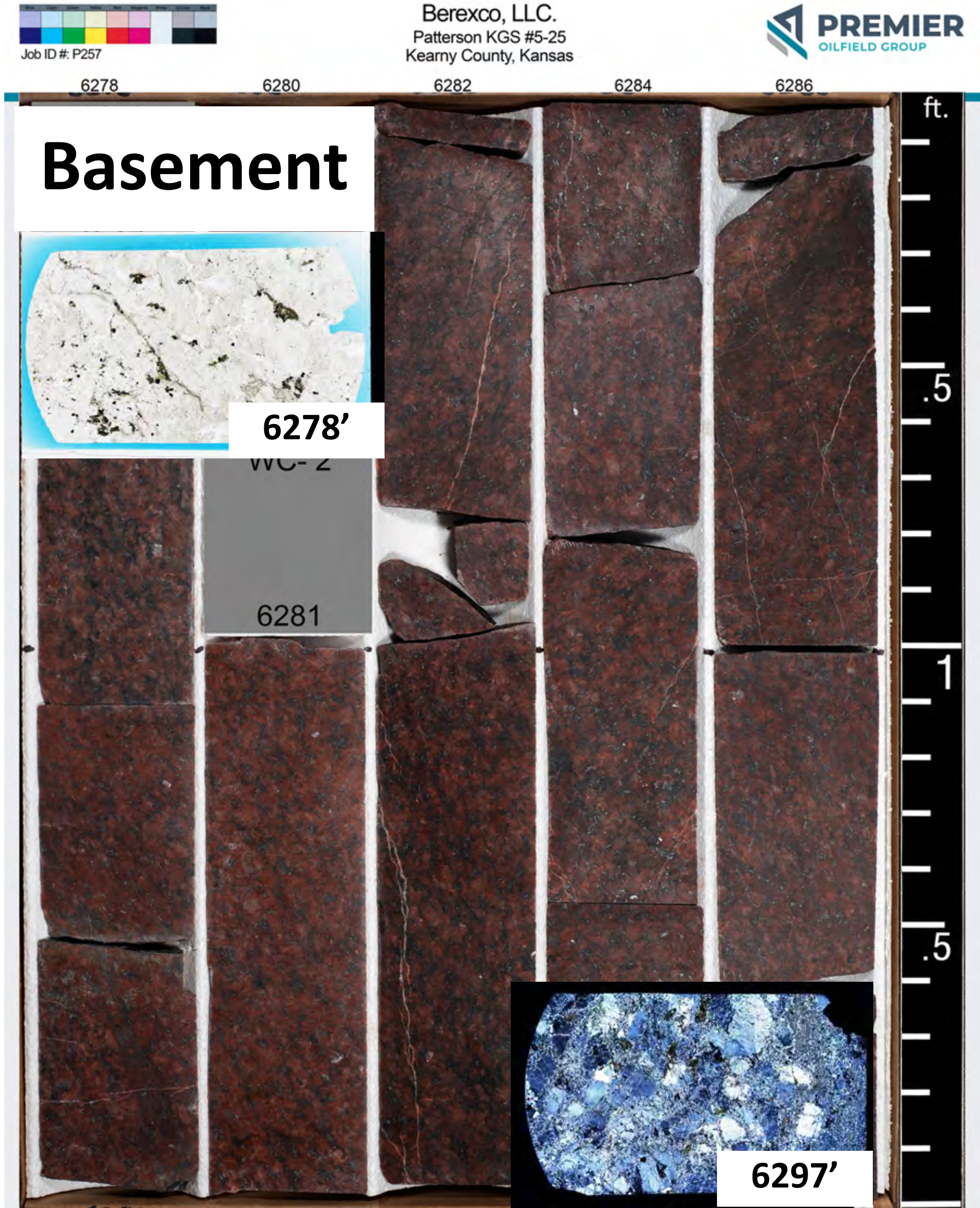


Drilling/Coring Crew

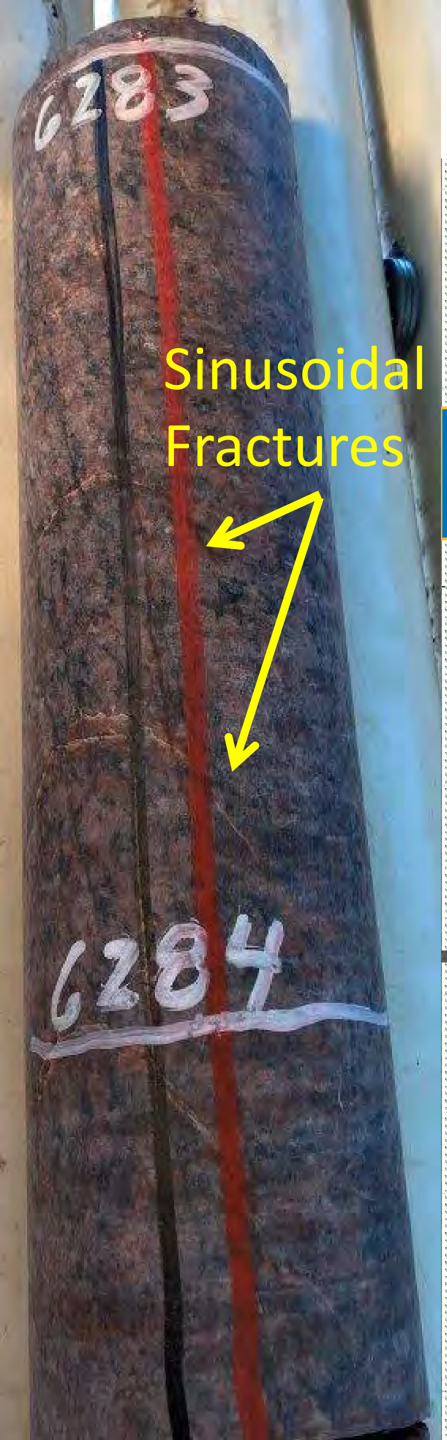


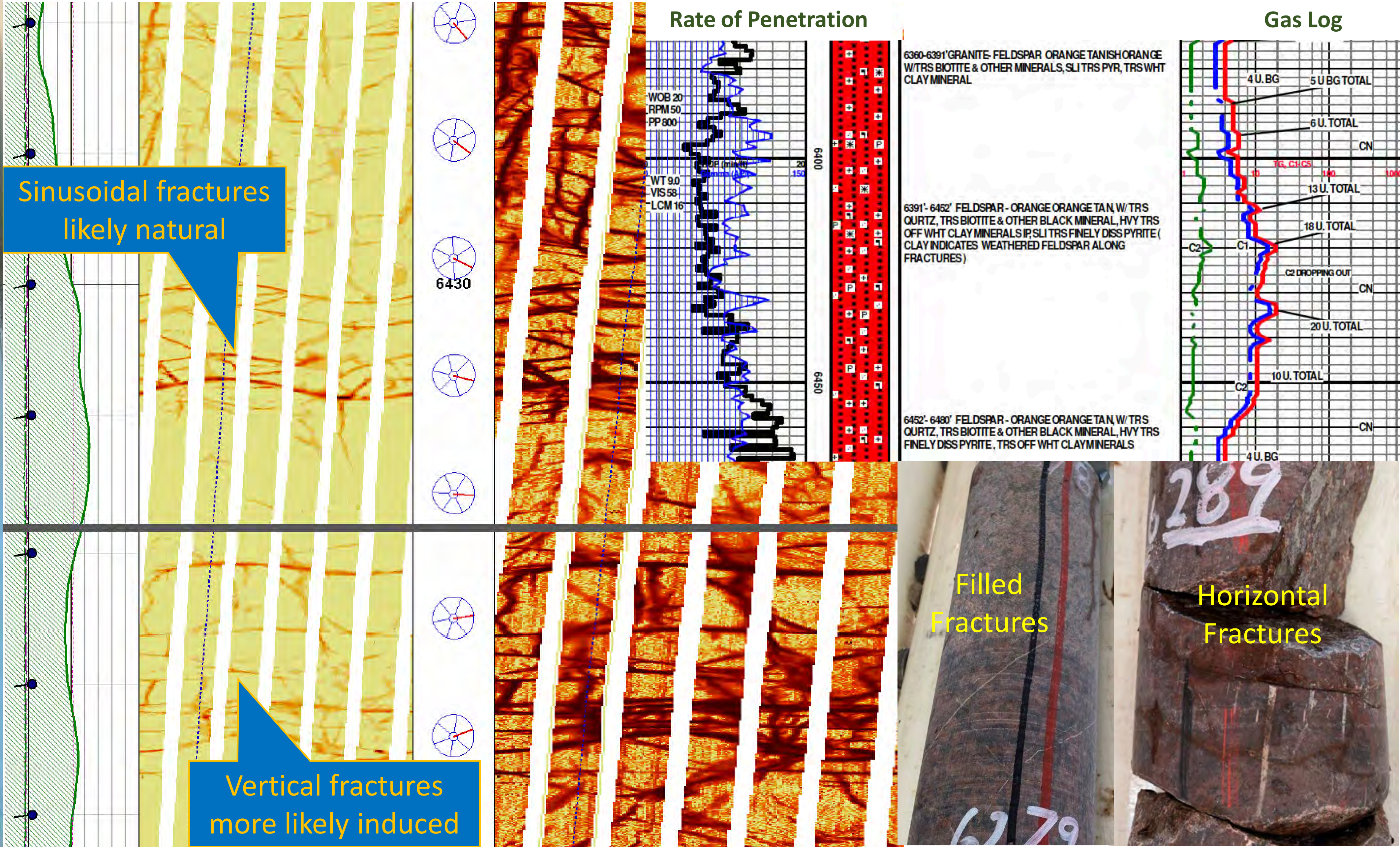
Core Analysis in Progress





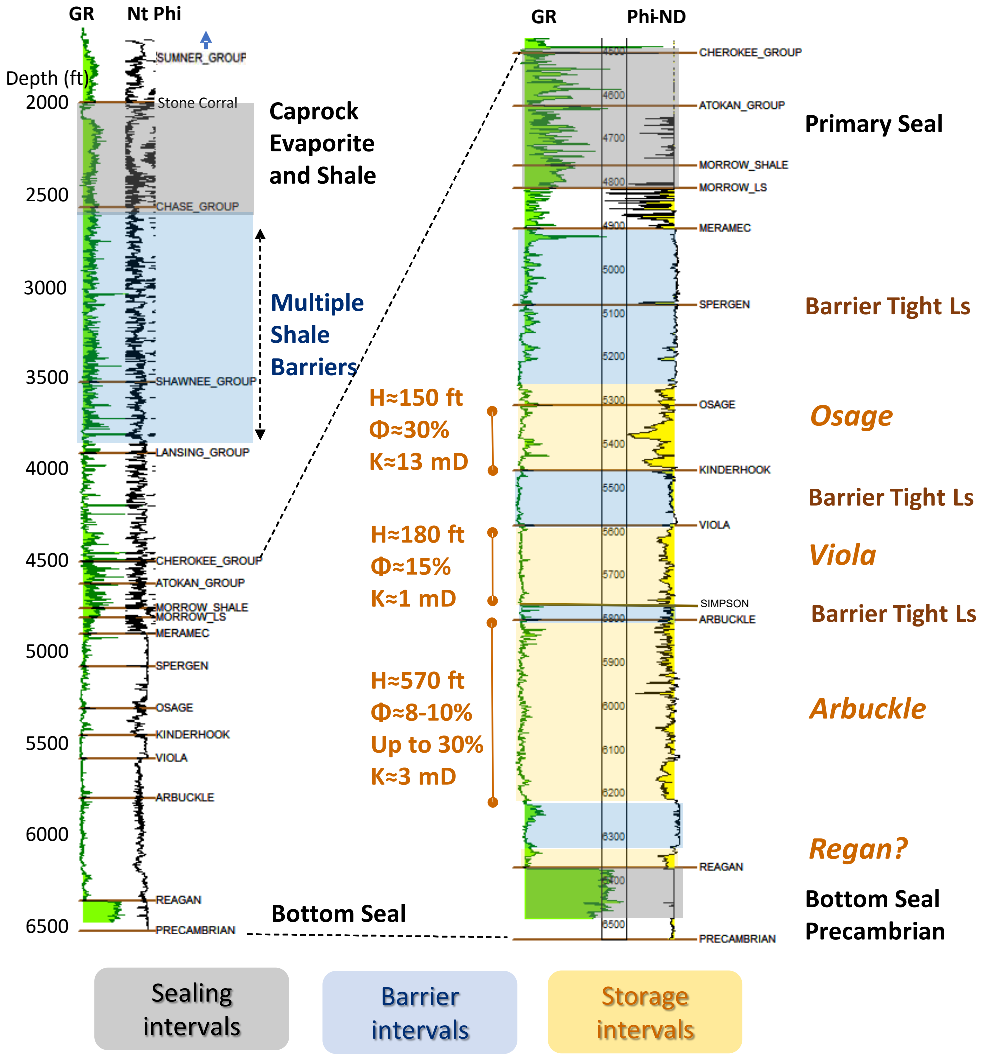
Basement: Fractures and Methane Kick





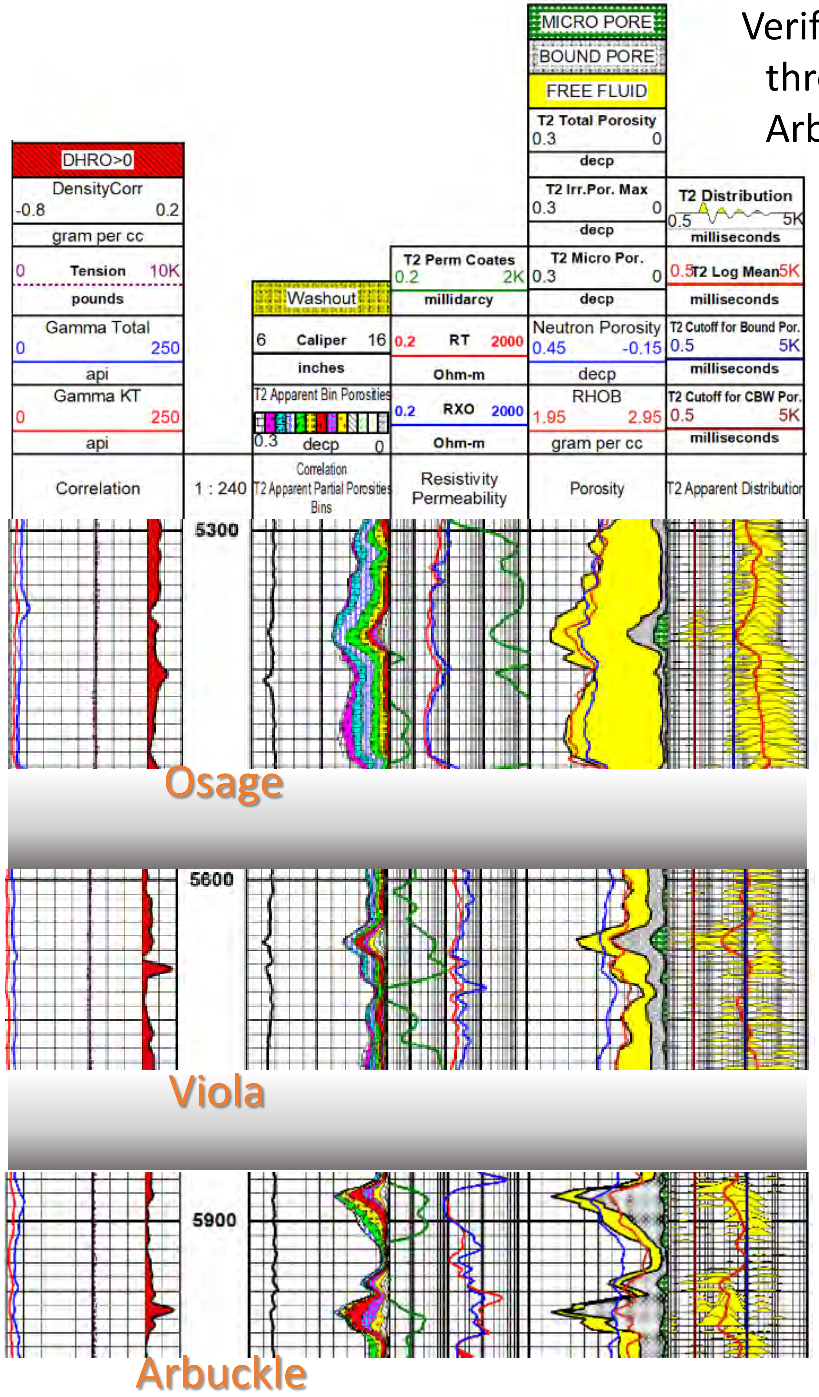
Storage Complex

Verified ~**15 bbl/min** flow in all three potential sink formations: Arbuckle, Viola, and Osage



Stratigraphy illustrated by wireline log from a key well in the Patterson Site (Longwood Gas Unit #2 well).

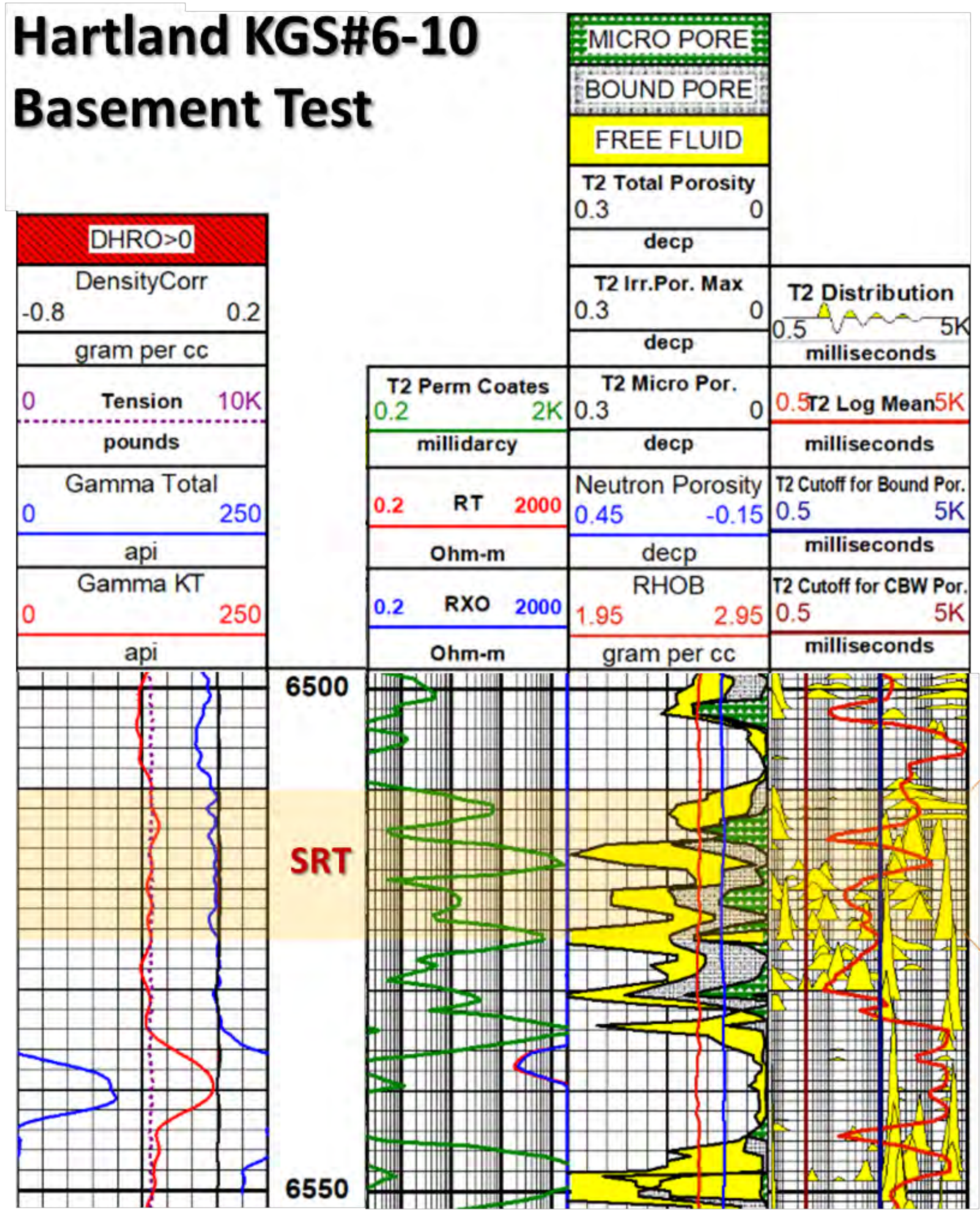
Meng et al., 2020

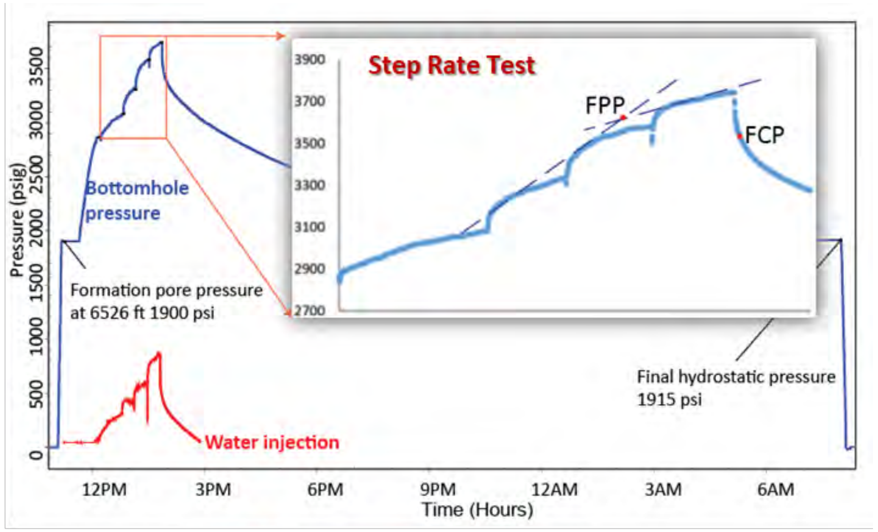


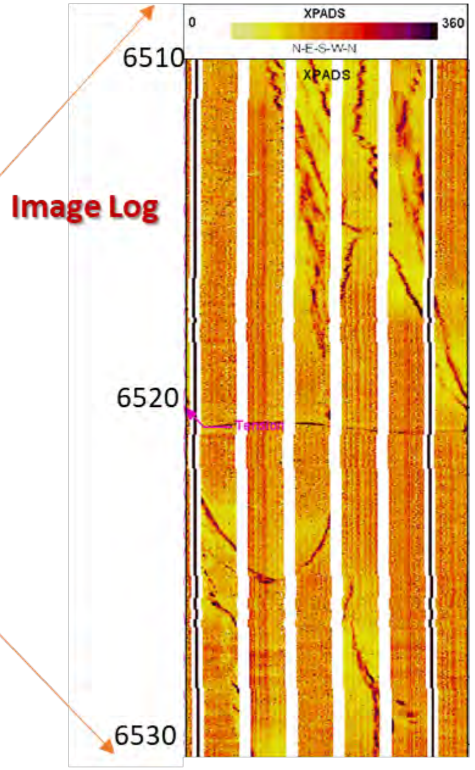
Vuggy porosity of Arbuckle reservoir

Hartland-Patterson Well-Testing Program

- Total of 14 cased-hole intervals tested
  - Basement-2
  - Arbuckle-3
  - Viola-1
  - Osage-1
- SRT, falloff, interference
- One successful deep basement flow test 12bbls/min
- **<u>~15bbls/min</u>** flow all others

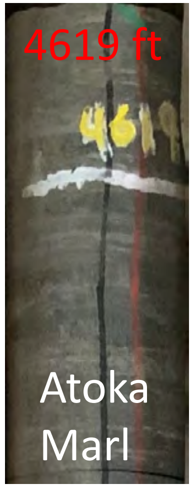


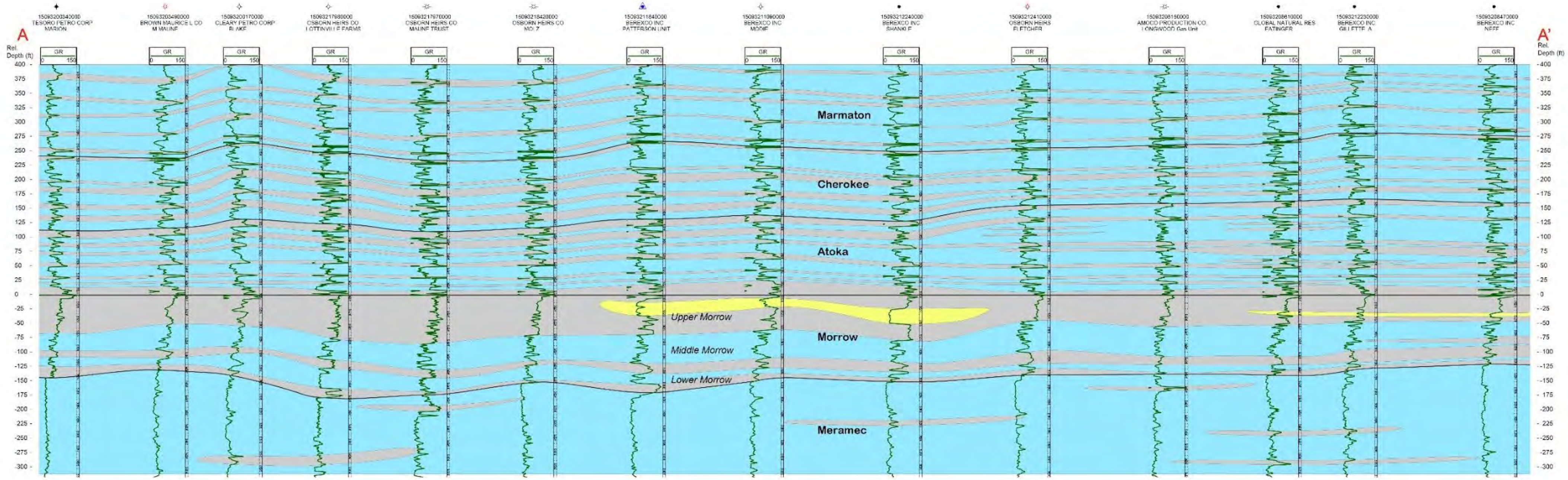


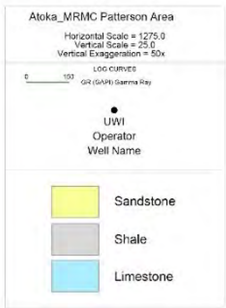


Primary Seal Distribution

- >400 ft primary seal with laterally continuous shale
- Upper Morrow shale (up to ~100 ft);Lower Morrow shale (up to ~25 ft)
- Interbedded shale-nonporous limestone in Atoka-Cherokee Group
- Core permeability, MICP, and threshold entry pressure tests are performed to confirm seal capacity (e.g., permeability, capillary pressure, CO_2 column height)







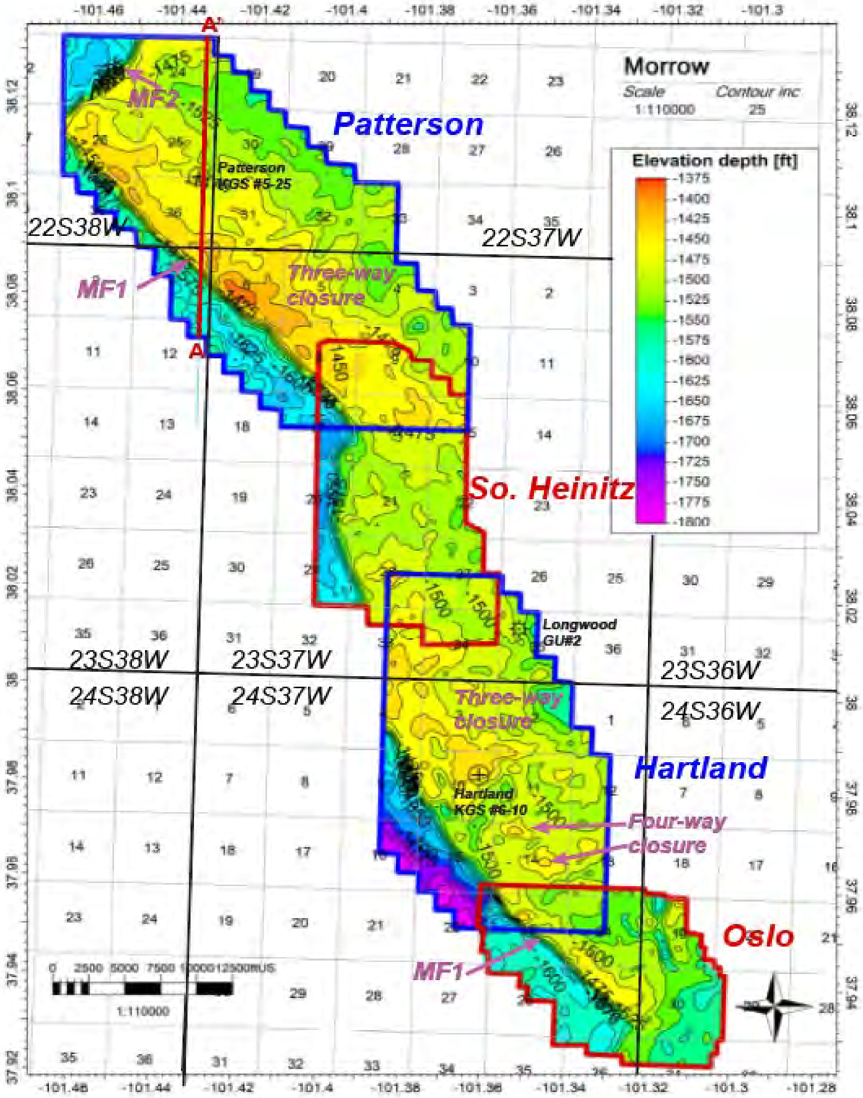
0 4 mi
0 5 km

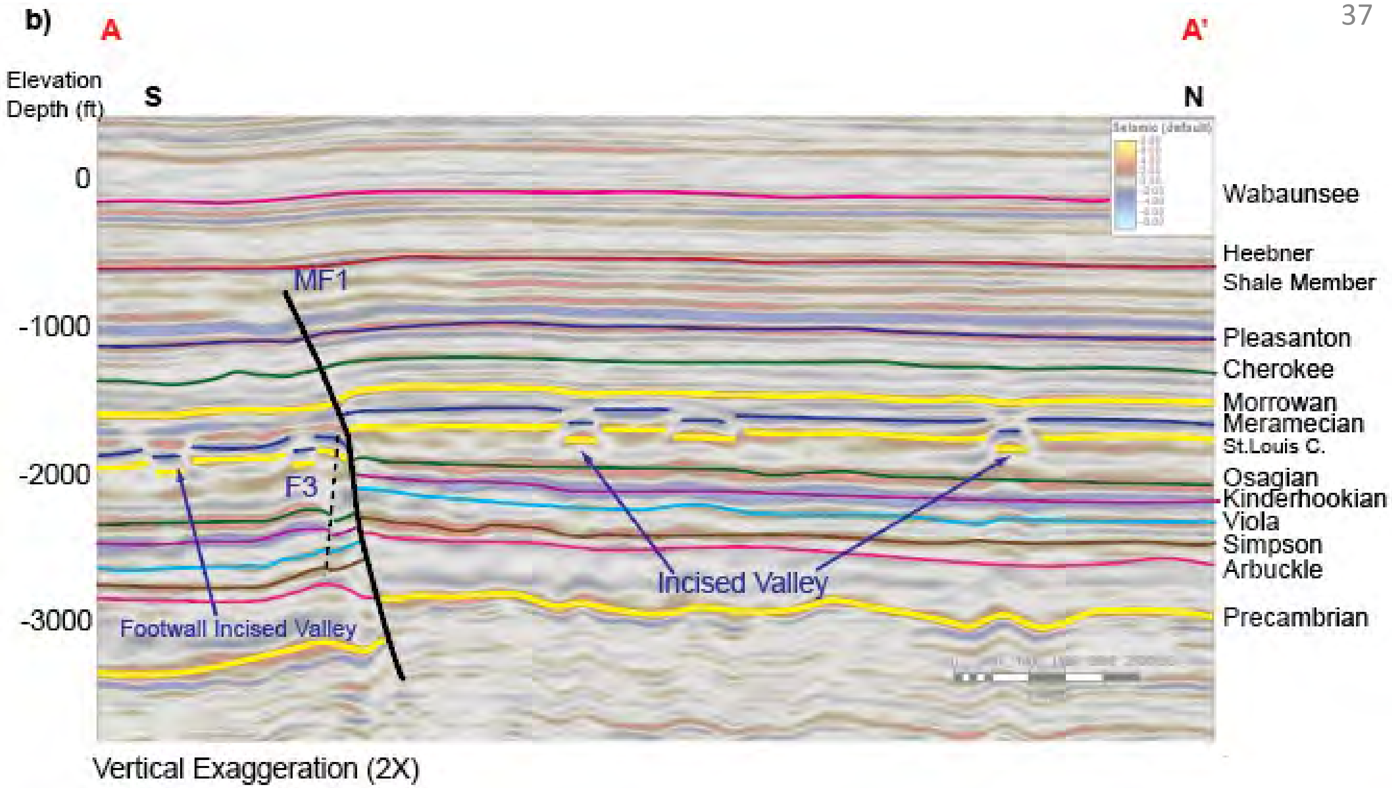
Cross-section (A-A’) in the study area show the seal distribution of the potential reservoirs.

Meng et al. 2020 AAPG ACE

(Meng et al., 2019)

Structural Framework



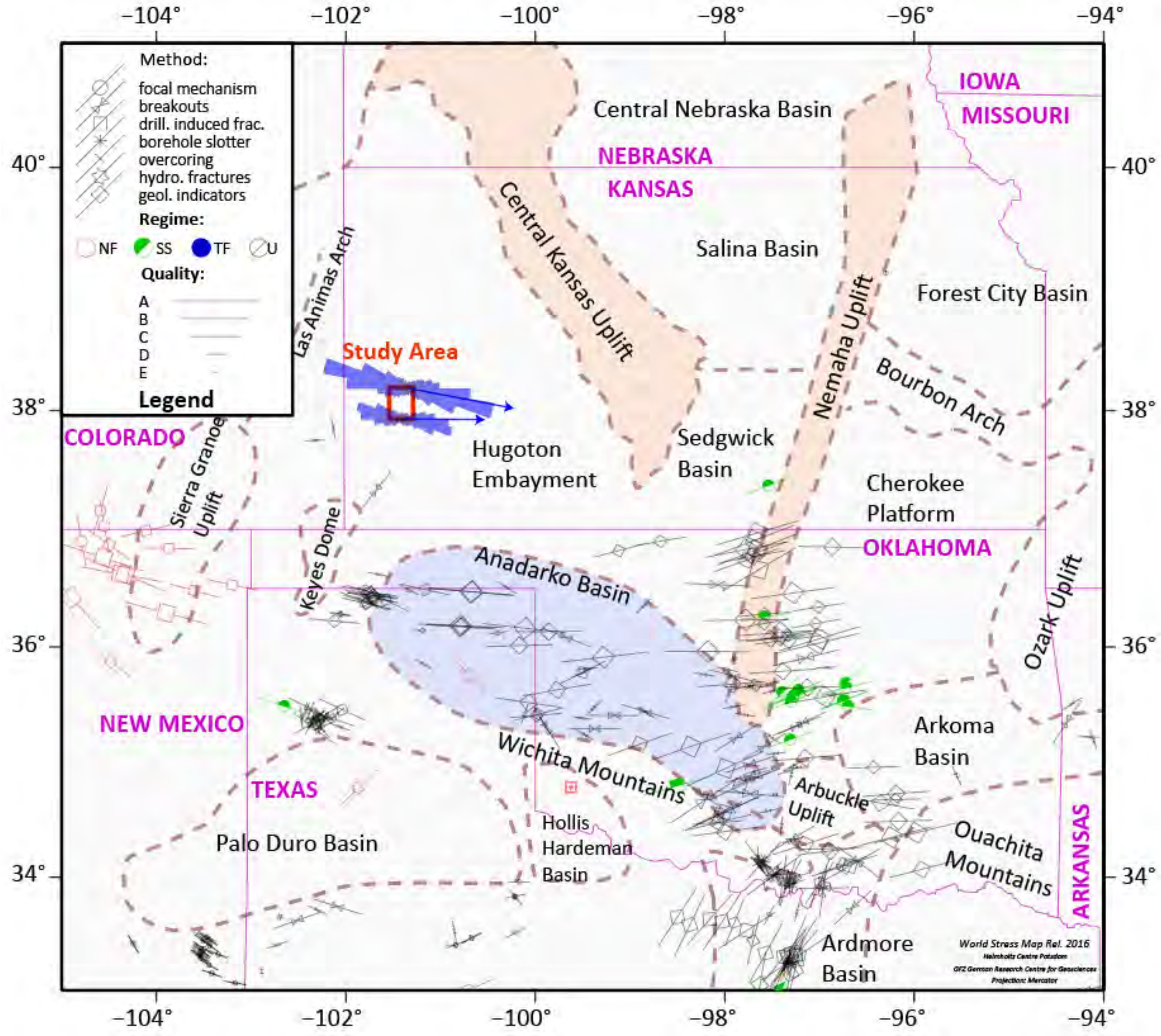


- Two major reverse faults exist at the Patterson Site that offset the reservoir and seal intervals and constitute an uplifted block in the Patterson Area. Fault displacements are maximum at the Precambrian basement and decrease upward
- Identified three- and four-way structural closures at the Patterson Site can assist trapping CO_2 in the Arbuckle-Osage reservoirs
- 150-600 ft stacked saline reservoirs are overlapped by ~800 ft seal rocks

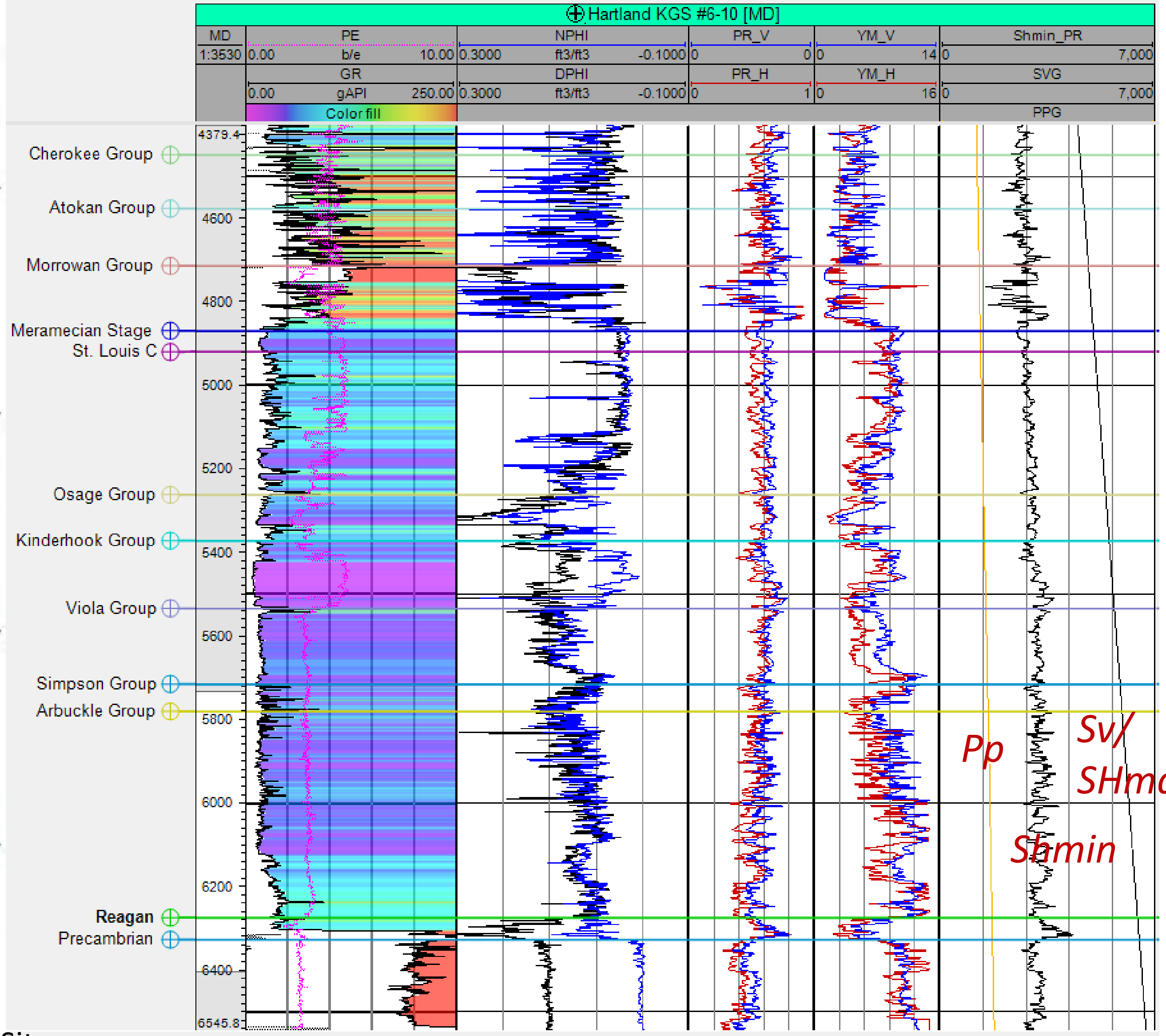
Left: Depth structural contour map of the top of the Morrow Shale; Right: uninterpreted a) and interpreted b) seismic line of A-A’

Meng et al., 2020

Patterson Stress Field



Underpressured Reservoir at Patterson Site
Evidence of regional compartmentalization



Left: General regional structural province and present-day stress in Patterson Site;
Right: 1D Geomechanical model of the Hartland KGS#6-10 well

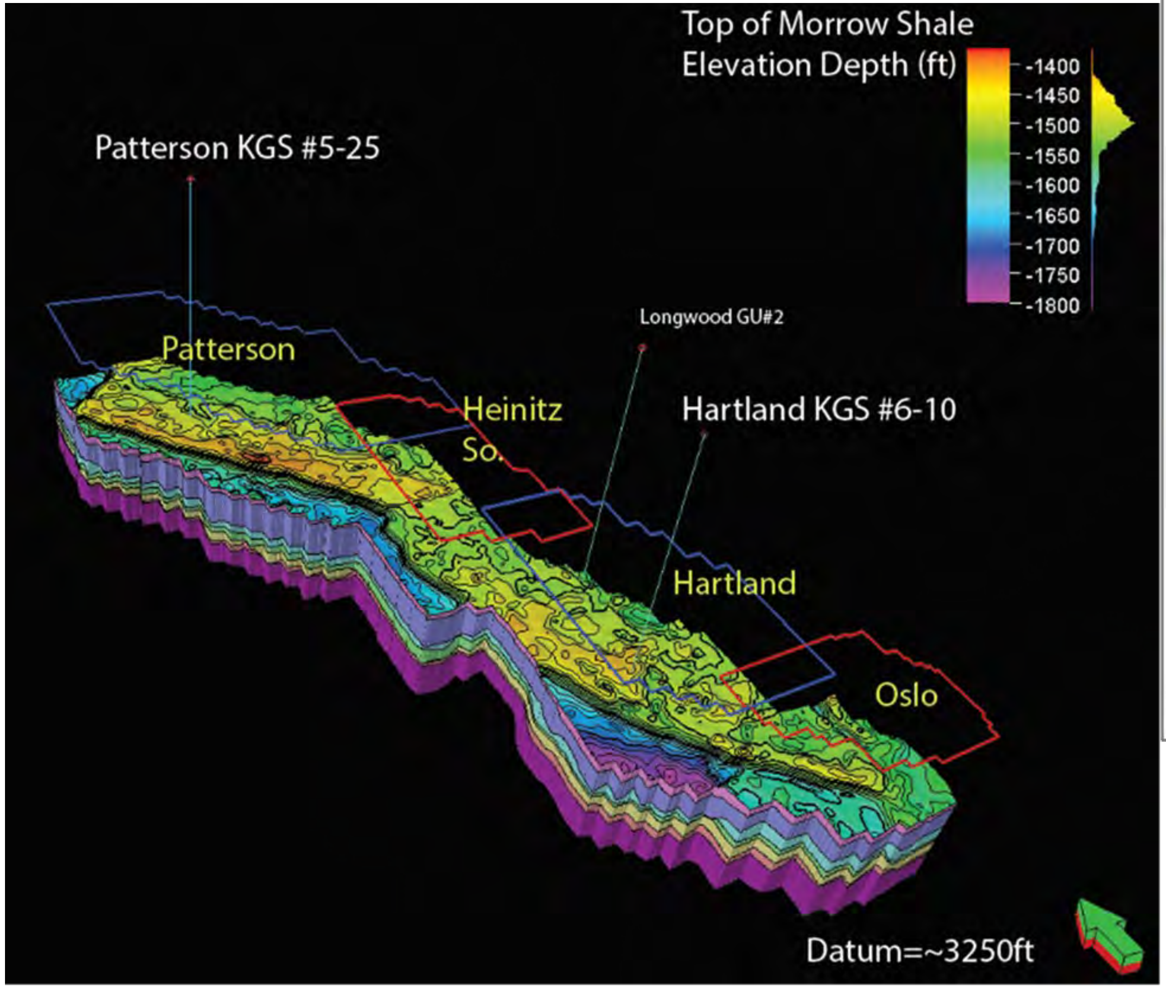
Meng et al., in preparation

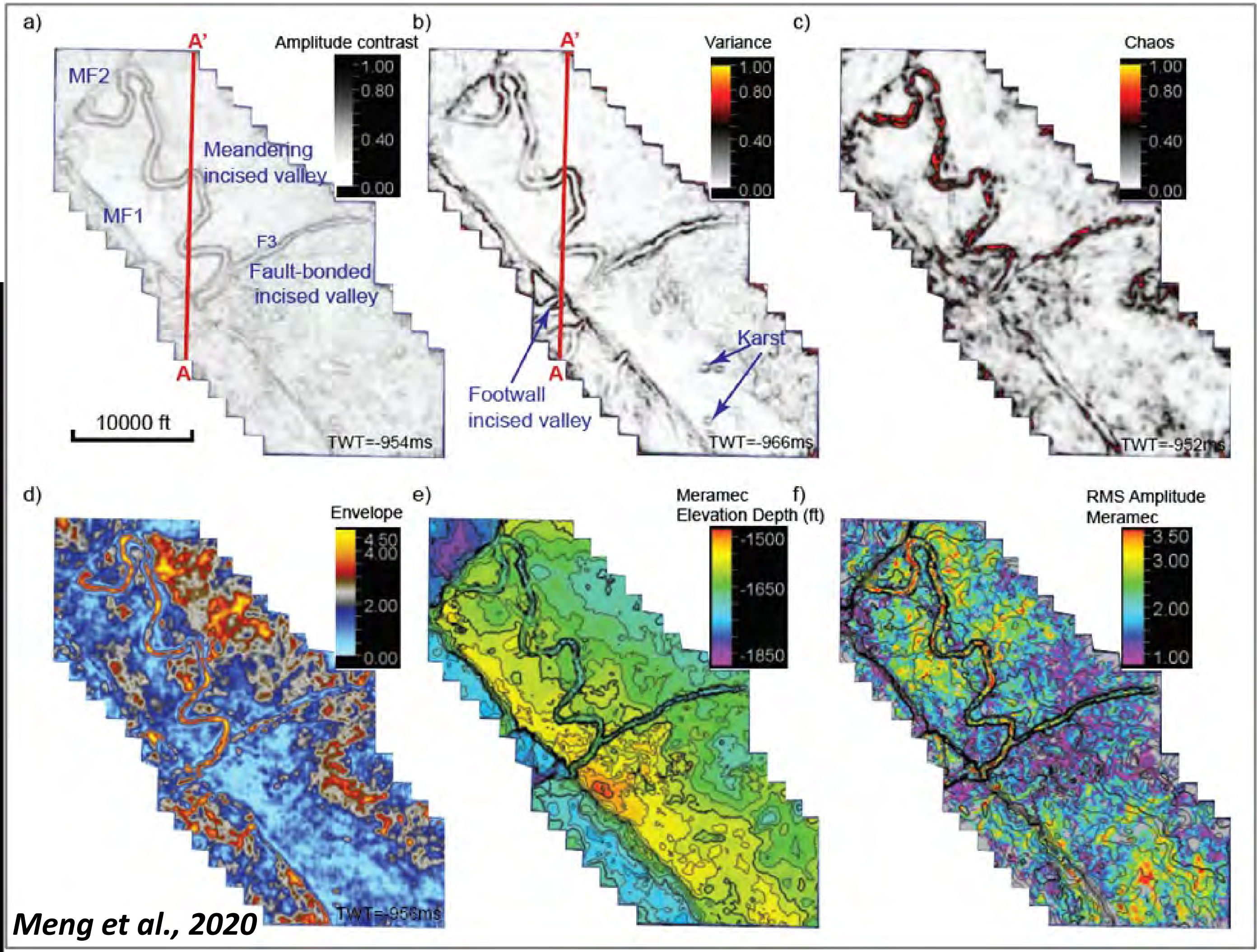
PpG: ~0.3 psi/ft
Normal Hydrostatic: 0.465 psi/ft

2020 CO_2 Conference
December 8-10

Static Earth Model Updates

- Newly acquired 3D seismic reflection surveys allowed for more accurate definition of the structural model (i.e., traps and seals) for at the PHH Site.





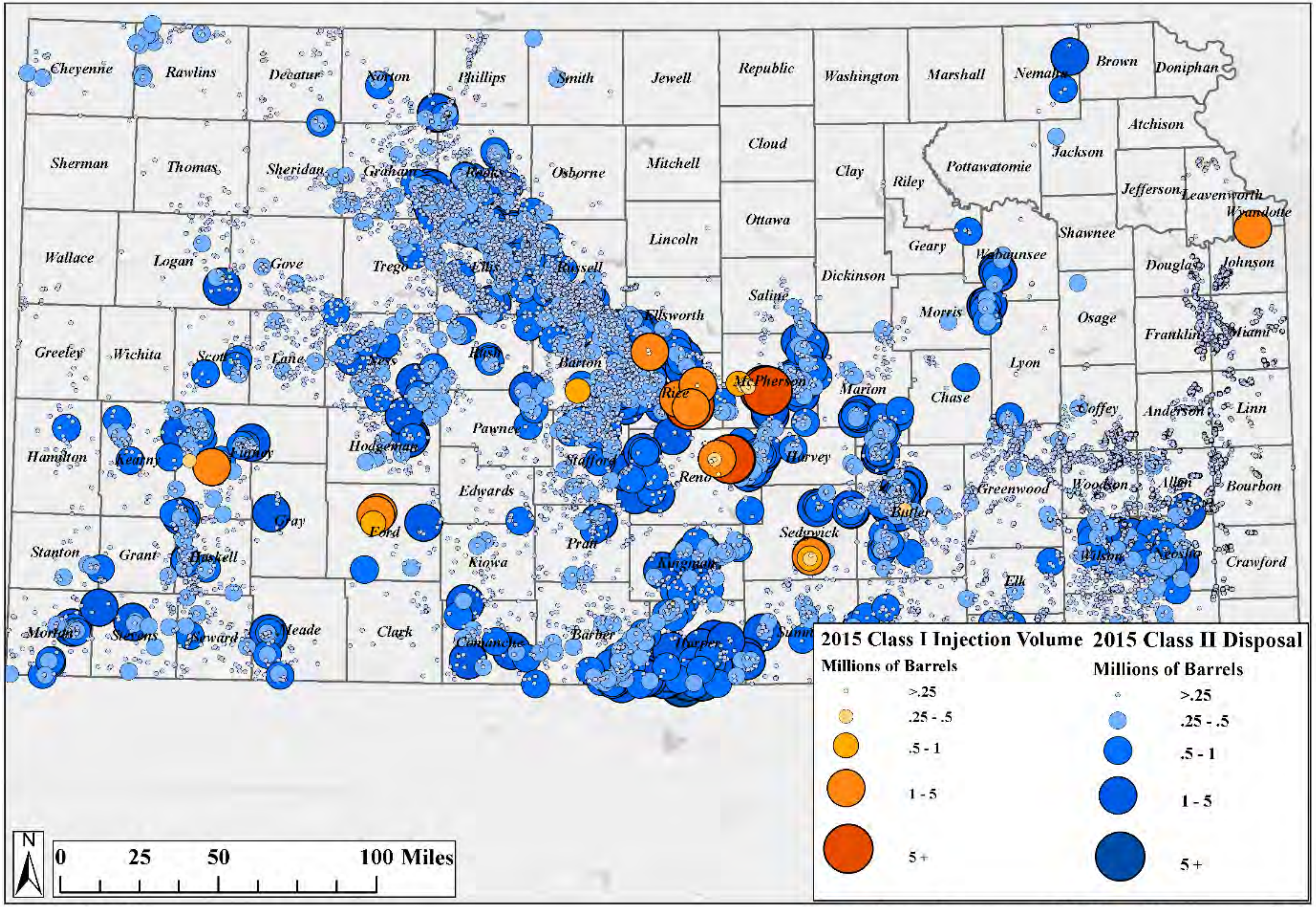
Meng et al., 2020

- A new element of the stratigraphic model: meandering valley system incised into the Meramecian surface was discovered through seismic attribute analysis

2020 CO_2 Conference
December 8-10

Fluid Disposal History in Kansas

- 49 Class I and 2381 Class II Arbuckle wells across Kansas
- Volumes increase in 2005, peak in 2013-2014 to >750 million barrels, and drop to 500 million barrel in 2015
- Equivalent of 9M CO_2 tones/year for one county
- Class I wells show increase in pressure and SFL
- Class II would show similar tendencies if data is available



Map printed 3/1/2017

Sources: Kansas Department of Health and Environment, ESRI, USGS, Kansas Corporation Commission, Kansas Geological Survey

Summary & Conclusions

- CCUS is rapidly developing and becoming commercially viable technology thanks to 45Q and other incentives. There is a strong momentum building in many industrial sectors to use CCUS, hydrogen generation, energy storage, and other technologies as an alternative to "business as usual".
- KS is a strategic region due to available resources
  - Geographic position
  - Developed power generation, ethanol, agriculture, infrastructure, and oil & gas
  - Geological resources: available and accounted
- If positioned correctly, KS could become a HUB platform for many future sustainable energy projects
- CCUS R&D projects performed by KGS and partners are strategic resource:
  - Industry connections
  - Geology and engineering know-how
  - Regulatory and policy issues: UIC Class VI, 45Q, etc.
  - Economics
- Characterization, assessments, data, and analysis performed for CCUS projects could be used as leverage for other industries including other waste-fluid injection operations

Summary & Conclusions

- Arbuckle Group is an excellent resource for waste-fluid disposal and a lot of data and knowledge was generated with DOE NETL CCUS program at KGS
- Previous studies determined that Arbuckle group is
  - Heterogeneous, fractured, suggested vertical isolation
  - High permeability and porosity only in select intervals
  - Basement and horizontal communication is unclear
- Additional Arbuckle/Basement characterization was performed with CarbonSAFE program and new data is being analyzed and published as a result
  - 4D Seismic
  - Well logs and core
  - Well testing: Step-Rate, falloff, interference tests in cased and perforated well
- CCUS resource assessment methodologies and know-how could help to select and manage pore-space
  - Suggest alternative injection strategies
  - Suggest and characterize additional injection targets

CUSP Partnership

REGIONAL INITIATIVE PROJECTS

-Addressing Key Technical Challenges

-Facilitating Data Collection, Sharing, and Analysis

-Evaluating Regional Infrastructure

-Promoting Regional Technology Transfer

Why are the RI projects so important?

- ➢ Established stakeholder network
- ➢ Long history on best practices development
- ➢ Wealth of data to support further research
- ➢ Experienced in public outreach and education

The RI's know how to get projects started!

Acknowledgements & Disclaimer

Acknowledgements

The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grants DE-FE0006821, DE-FE076248616, DE-FE0002056, DE-FE726904, Willard Watney, Eugene Holubnyak, Jason Rush, Marty Dubois, Tandis Bidgoli Joint PIs. Project is managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners.

Questions?

http://www.kgs.ku.edu/PRS/petroProj.html

Jeffrey Energy Center, KS, 2.16 gigawatts, ~12Mt CO_2