

**SMALL SCALE FIELD TEST DEMONSTRATING CO<sub>2</sub>  
SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND  
BY CO<sub>2</sub>-EOR AT WELLINGTON FIELD  
SUMNER COUNTY, KANSAS  
DE-FE0006821**

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Mastering the Subsurface through Technology Innovation, Partnerships and Collaboration:  
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

Sheraton Station Square  
Pittsburgh, Pennsylvania  
August 3, 2017



U.S. DEPARTMENT OF  
**ENERGY**



# Project Team



**DOE-NETL Contract  
#FE0006821**



**Project established November 2011**

David Cercone, P.M.

L. Watney (Proj. Manager, Joint PI), Y. Holubnyak (Joint PI),  
J. Hollenbach (Asst. Project Manager), T. Bidgoli, B. Campbell,  
J. Doveton, M. Fazelalavi, D. Newell, John Victorine  
*(static & dynamic modeling, petrophysics, well test analysis,  
install/maintain seismometer array, Structural, geochemical,  
geomechanical analysis, project management)*



Dana Wreath, Adam Beren  
*(field operator and operations)*



Tom Daley, Barry Freifeld  
*(CASSM, U-Tube for Arbuckle Class VI geosequestration)*



**CO<sub>2</sub> supplier**

DEPARTMENT OF GEOLOGY KANSAS STATE UNIVERSITY  
Saugata Datta, Ian Andree  
*(USDW monitoring)*



T. Birdie *(aquifer modeling, EPA Class VI permit)*

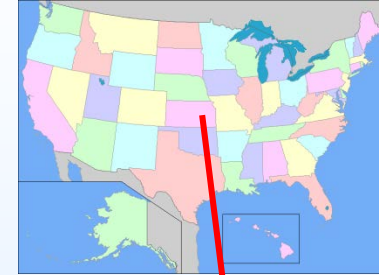


Jennifer Roberts, Leigh Sterns, George Tsoflias,  
B. and K. Graham, A. Nolte, D. Schwab, B. Norwood  
*InSAR-cGPS, active and passive seismic, geochemistry*



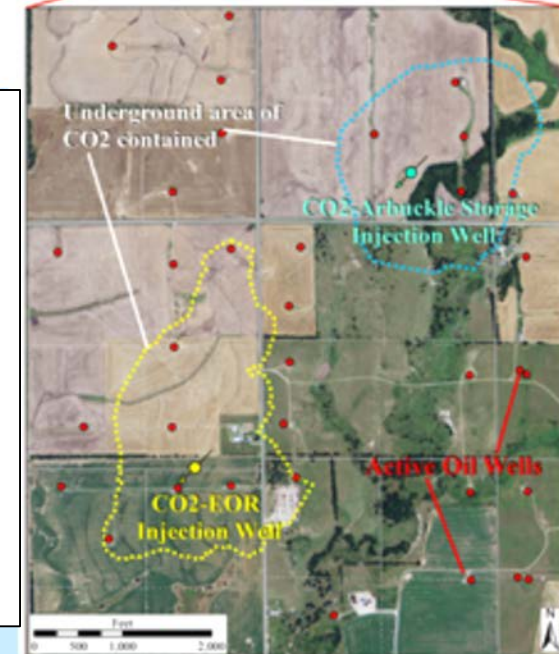
# Presentation Outline

1. Project Overview
2. Benefits to the Program
3. Technical Status
4. Future Plans and Expectations



## Wellington Field Sumner County Kansas

- Oil field in rural area operating since 1929
- 55 wells, 21 million barrels produced, 46,000 barrels annually
- Effective waterflood, ready for CO<sub>2</sub>-EOR
- **Phase I** – Completed June 21, 2016 → 20,000 tonnes CO<sub>2</sub> injected into Mississippian dolomite for EOR
- **Phase II** – 26,000 tonnes CO<sub>2</sub> into Arbuckle saline aquifer, pending Class VI permit (2017)



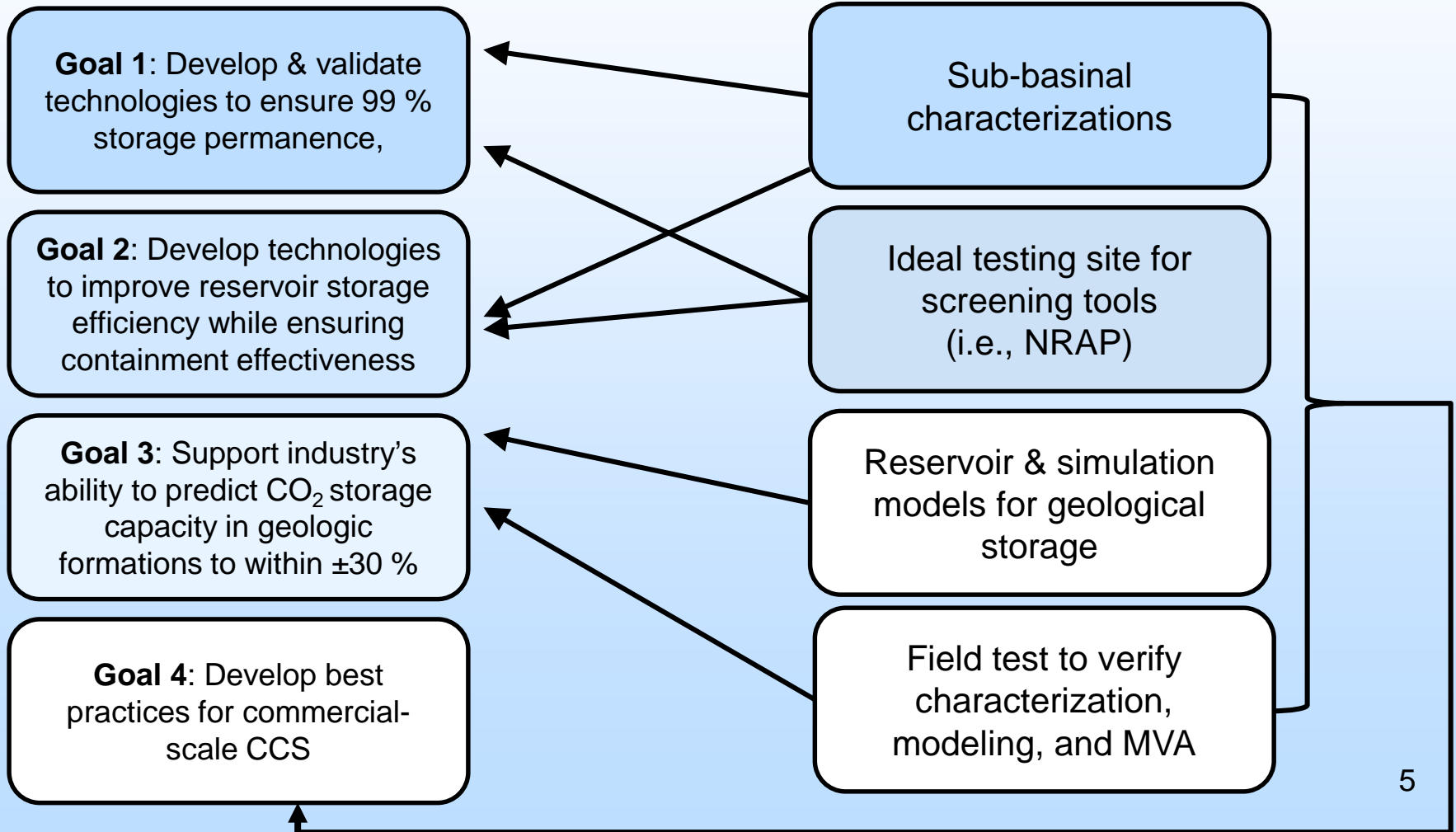
# Project Objectives

- Test Monitoring, Verification, and Accounting (MVA) technologies - partially addressed
  - National Labs tools:
    - U-Tube
    - Continuous Active-Source Seismic Monitoring (CASSM)
  - Other methods:
    - Surface and reservoir water analysis
    - 18- seismometer array for passive seismic
    - cGPS and InSAR
    - 2D and 3D Seismic
- CO<sub>2</sub> storage through EOR and saline aquifer
- Commercialization plan
- Technology transfer
- US EPA UIC Class VI permit application

# Benefits to the Program

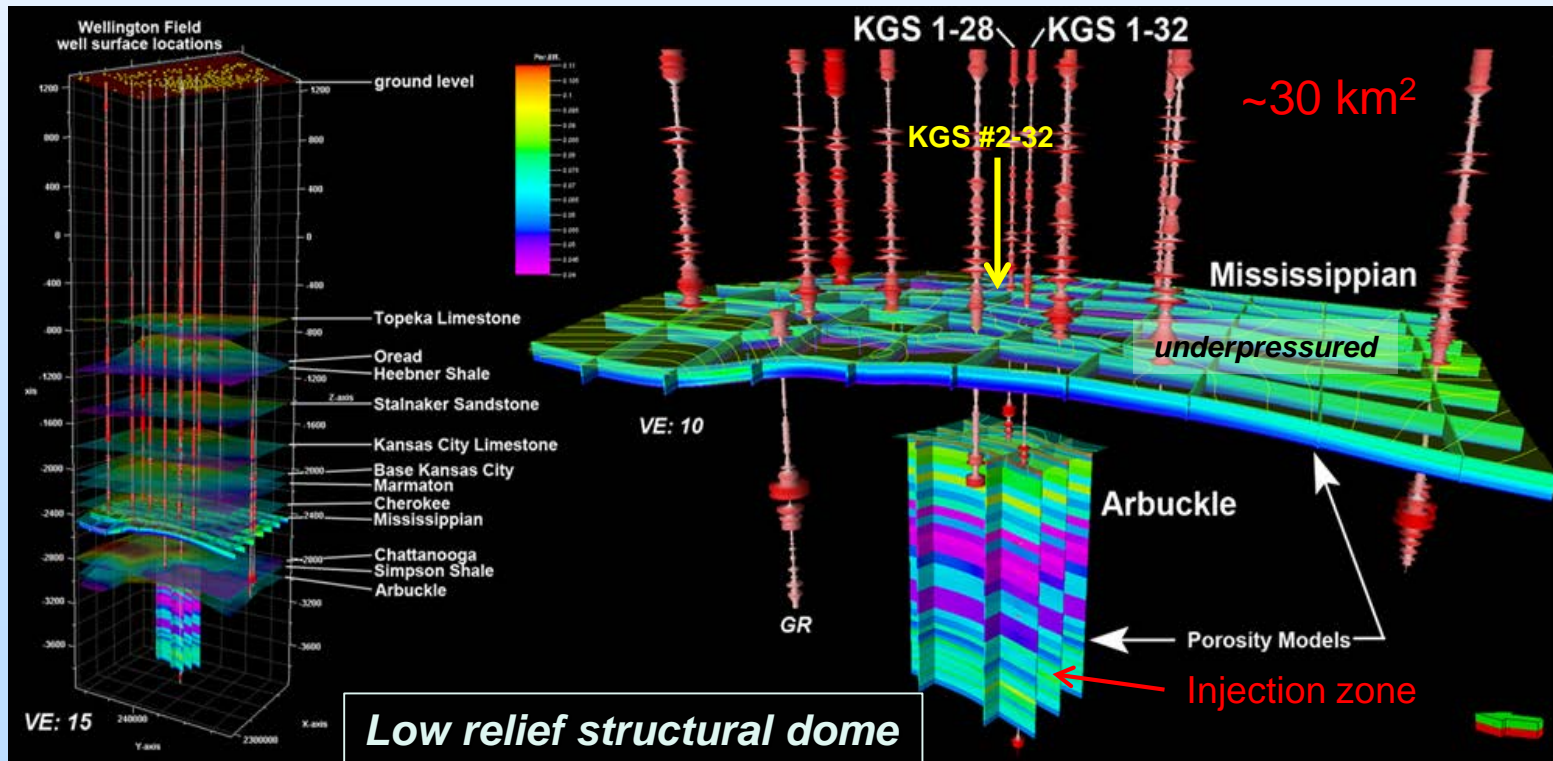
## DOE Program Goals

## This Study



# Benefits to the Program

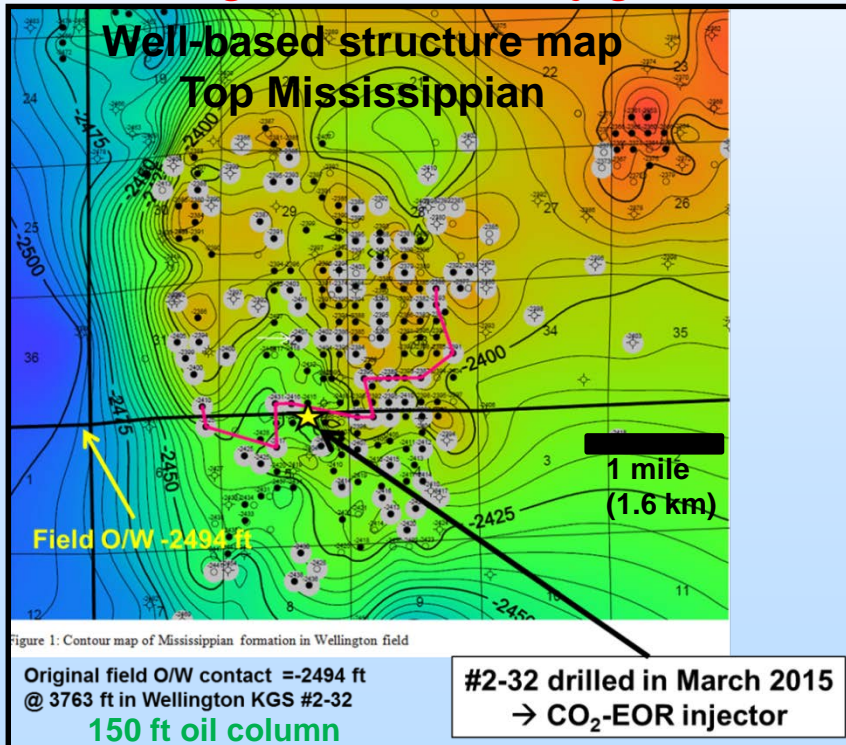
- **Demonstrate that 99 percent permanence of injected CO<sub>2</sub>**
  - 20,000 metric tons tonnes injected into KGS #2-32 into *Late Mississippian siliceous dolomite reservoir* between January 9 and June 21, 2016 → CO<sub>2</sub> plume and EOR response as forecast by model (**Class II UIC permit**)
  - 20,000 metric ton injection into underlying *Lower Ordovician Arbuckle Group dolomitic saline aquifer* (**Pending Class VI UIC permit**)
- **Demonstrate reliable and cost effective MVA (monitoring, verification, and accounting) tools and techniques**
- **Develop best practices for effective and safe CO<sub>2</sub>-EOR and CO<sub>2</sub> saline storage**



# Technical Status

## Task 15. Evaluate Potential to Move Oil and Optimize for Carbon Storage

- Begin CO<sub>2</sub> injection into KGS #2-32 on January 9, 2016
- Completed injection on June 21, 2016
- 1,101 truckloads, 21,784 US tons, 19,803 metric tons, average of 120 tonnes per day, approximately 374,000 MCF of CO<sub>2</sub>
- Total expenditures for purchasing CO<sub>2</sub> were \$1,964,000. Our overall price for CO<sub>2</sub> was \$90.16 per US ton from *Linde Group*
- **Behaving as forecasted by gemodel/simulation**

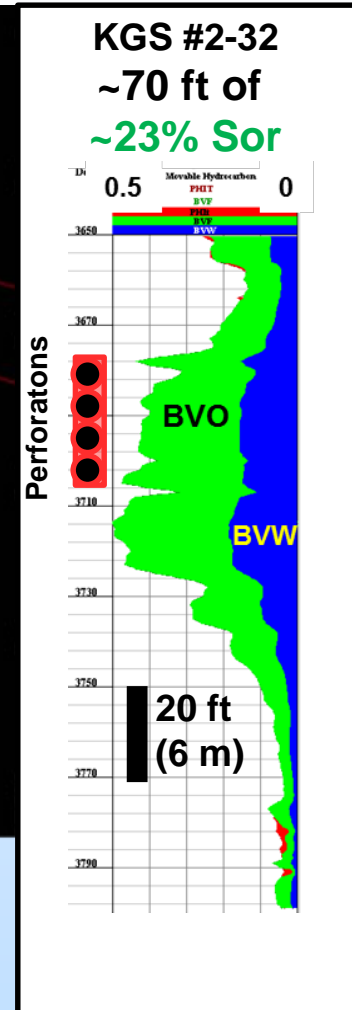
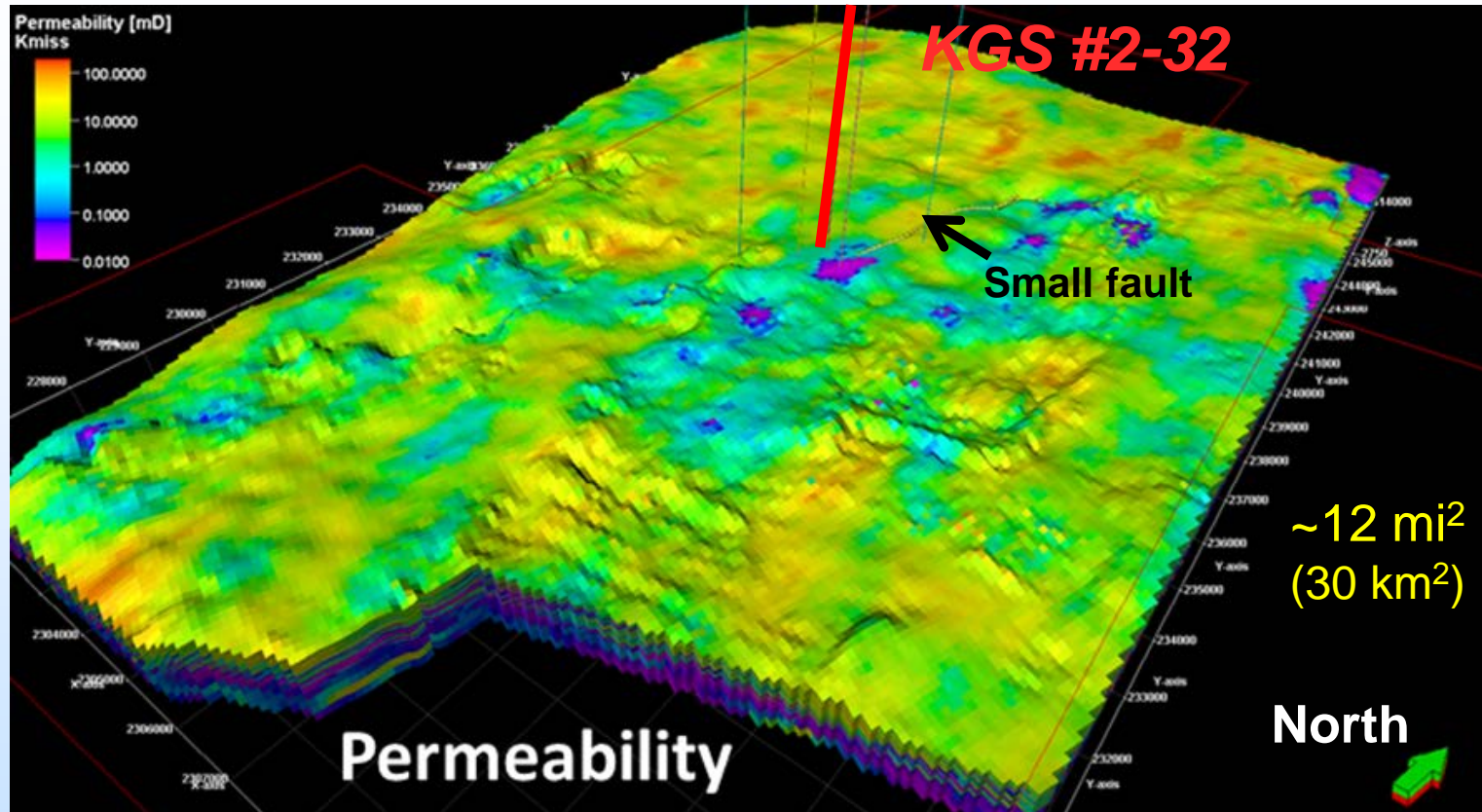


### Monitoring technologies during Class II injection

- 1) Surface water analysis
- 2) 18- seismometer array for passive seismic
- 3) cGPS and InSAR
- 4) Weekly analysis of 17 wells surrounding injector
- 5) Repeat 2D seismic survey (July 2016)
- 6) Post-CO<sub>2</sub> injection well performance around Class II well
- 7) Arbuckle pressure monitoring since April 2016



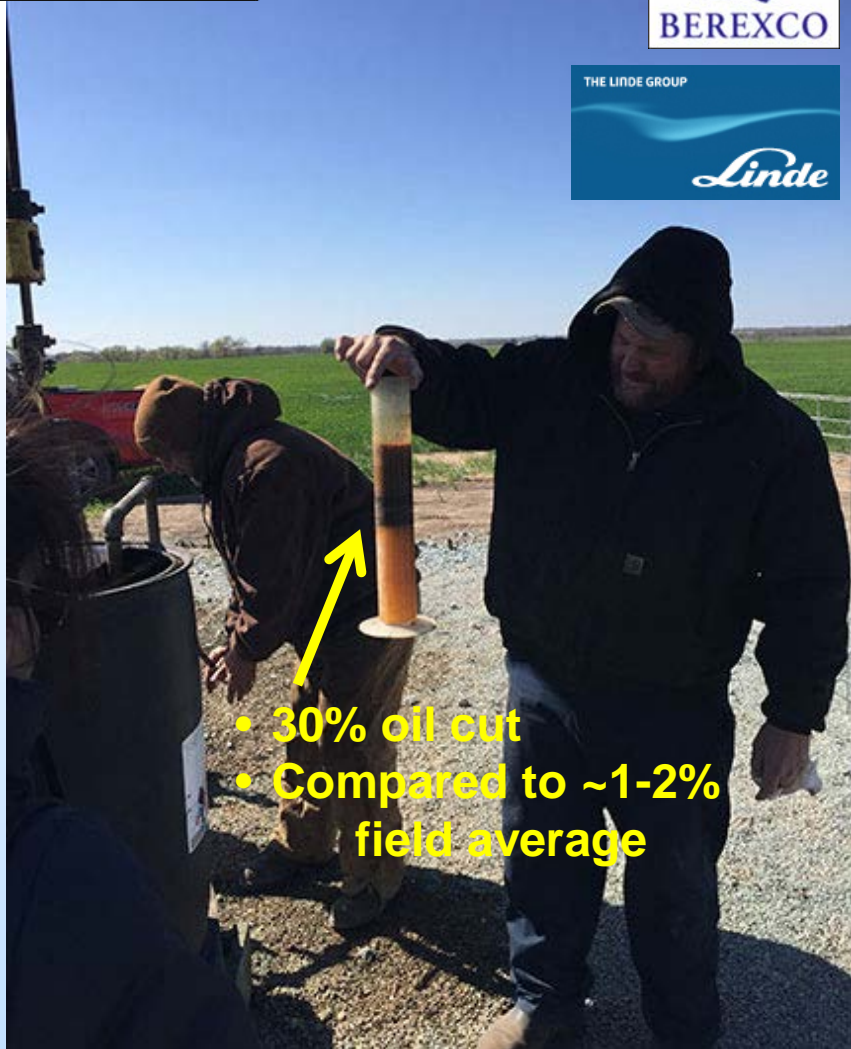
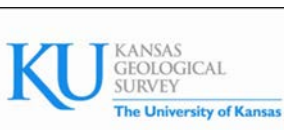
# Targeted area → High CO<sub>2</sub>-EOR potential



J. Rush

- Petrel map of permeability distribution in the Mississippian dolomite
- CO<sub>2</sub> injection well is red vertical line
- Lower permeability noted east and south of the injection well, Berexco Wellington KGS #2-32
- Residual oil saturation in cored injection well averages 23%





- 30% oil cut
- Compared to ~1-2% field average

**Wellington Field small scale CO<sub>2</sub>-EOR**  
**Jason Bruns above (Caanon Well Services) and Dana Wreath upper right (VP Berexco, LLC) with KGS staff**



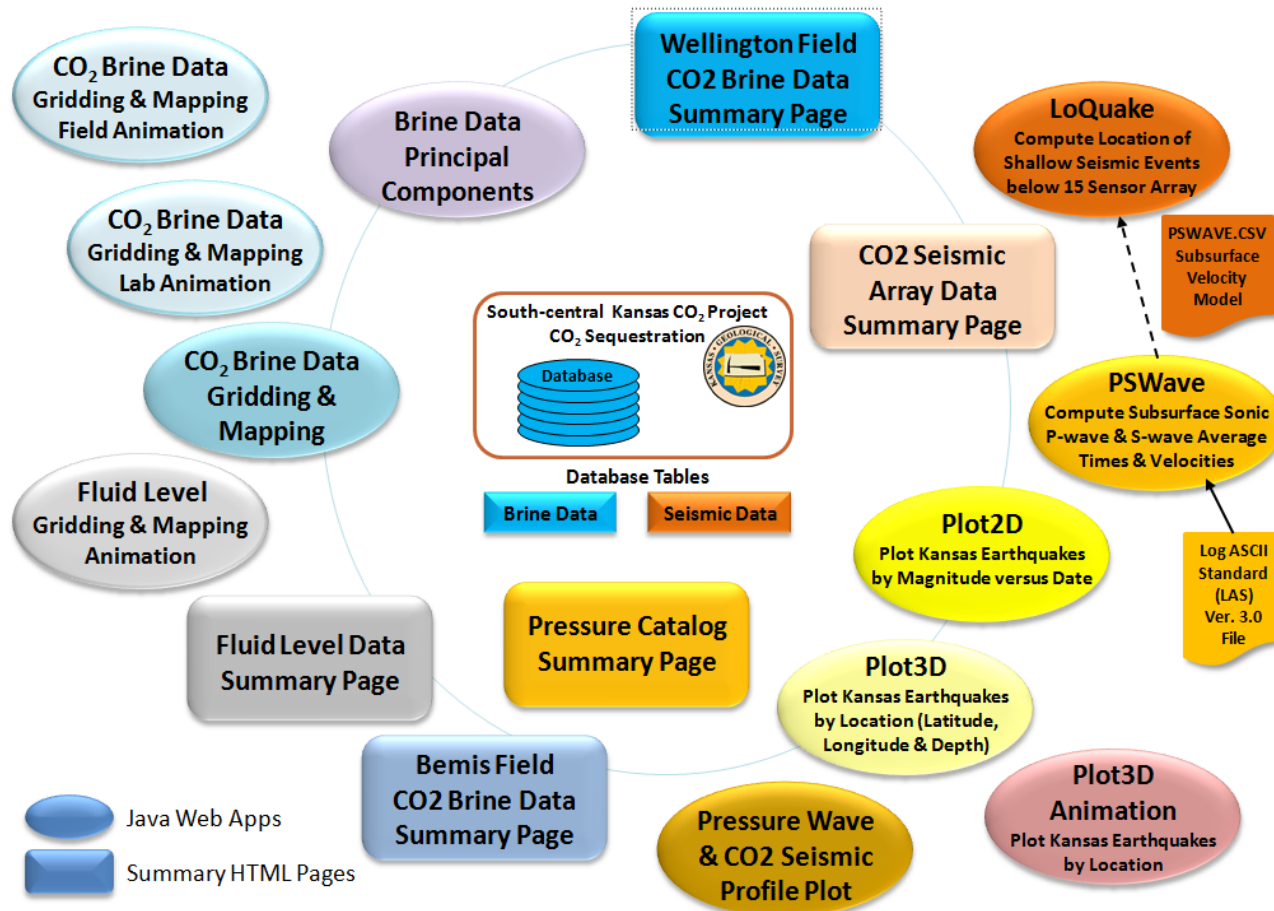
**SCADA System installed on wells**

# Web Applications Built to Display and Analyze Data “in Real-Time” by the Team During Monitoring → time lapse maps, cross plots, analytical tools, csv download

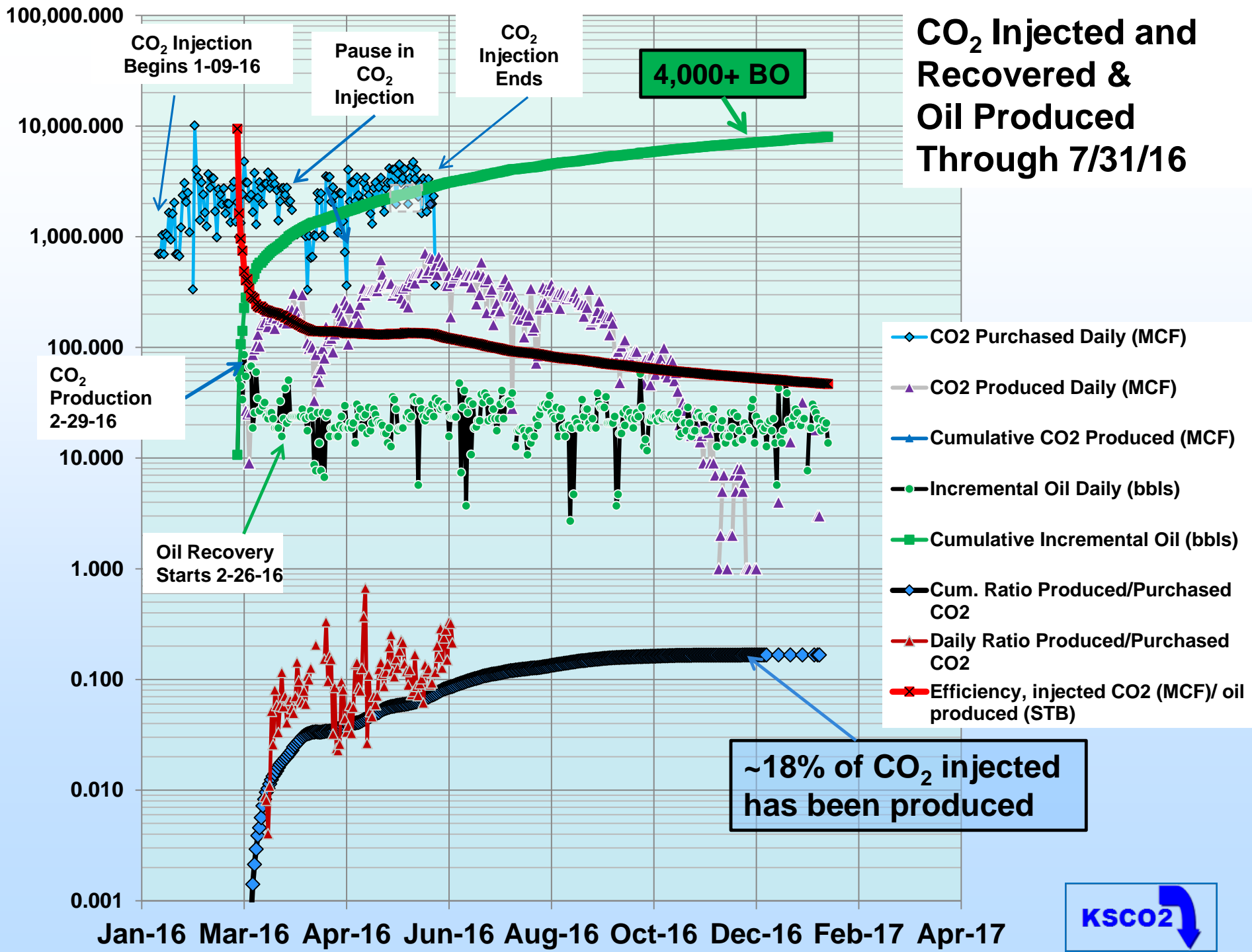


## South-central Kansas CO<sub>2</sub> Project CO<sub>2</sub> Sequestration Summary Pages and Web Apps

Select the bubble button below to display respective module.

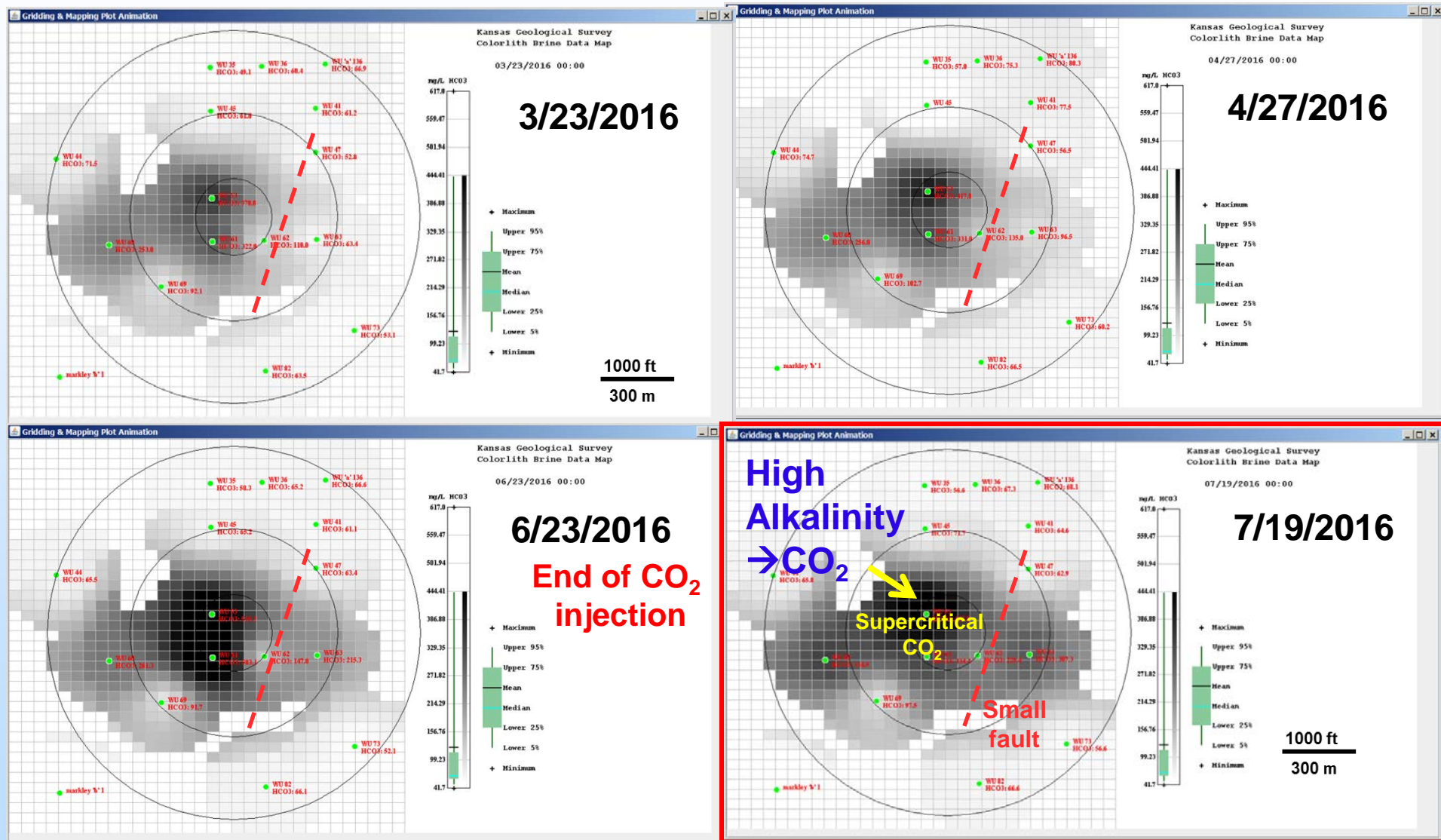
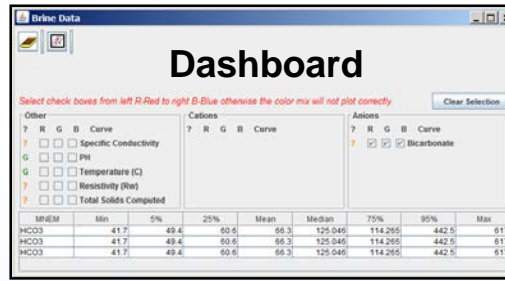


# CO<sub>2</sub> Injected and Recovered & Oil Produced Through 7/31/16



# Time Lapse Alkalinity

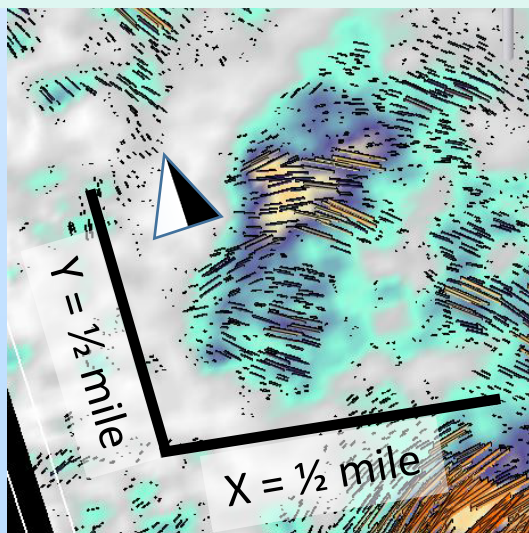
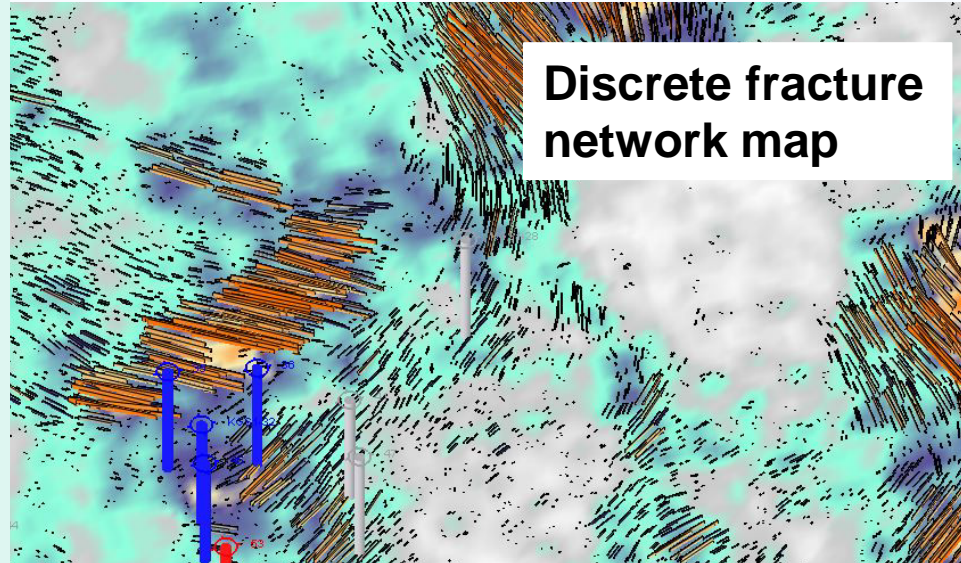
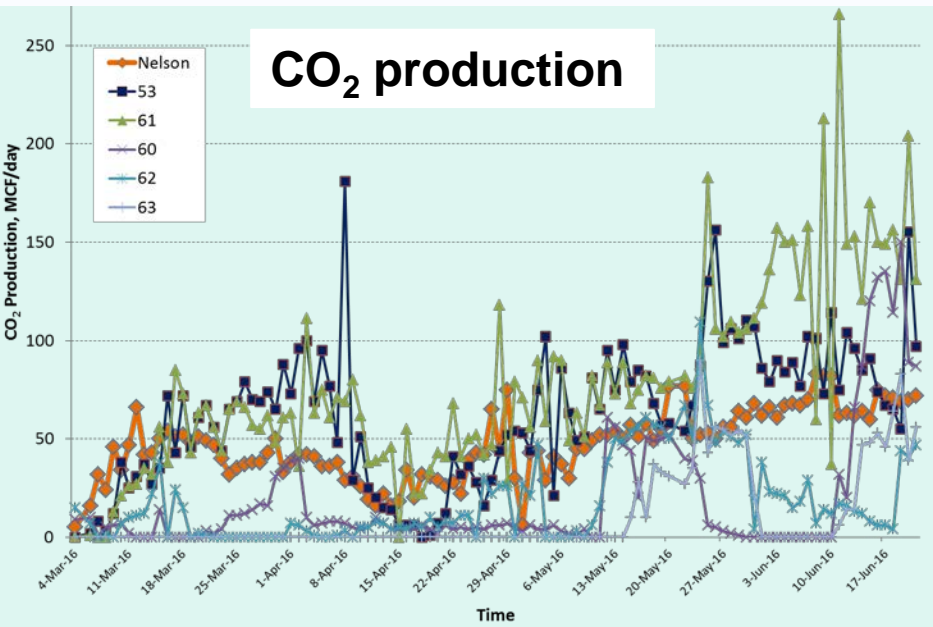
-- During and Post CO<sub>2</sub> Injection



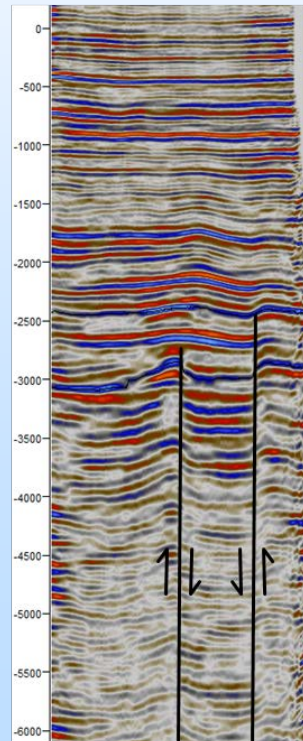
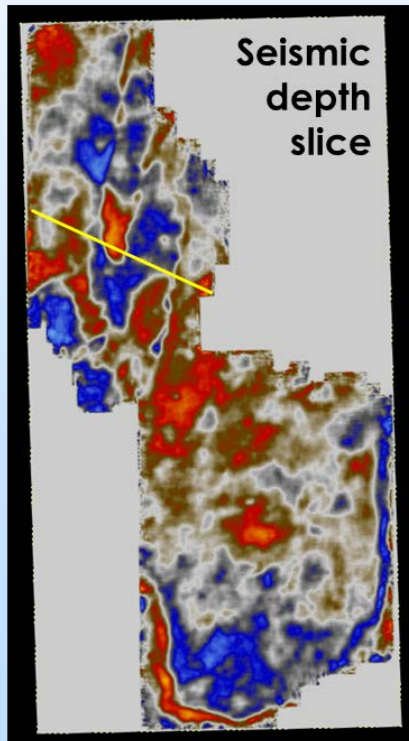
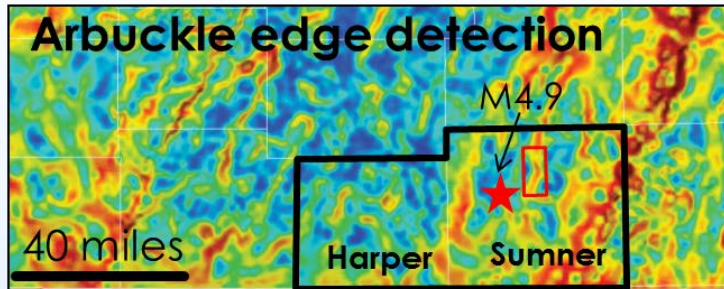
# Re-processed 3D seismic analysis: discrete fracture network vs. field CO<sub>2</sub> MVA data

T<sub>5</sub> = June 17, 2016

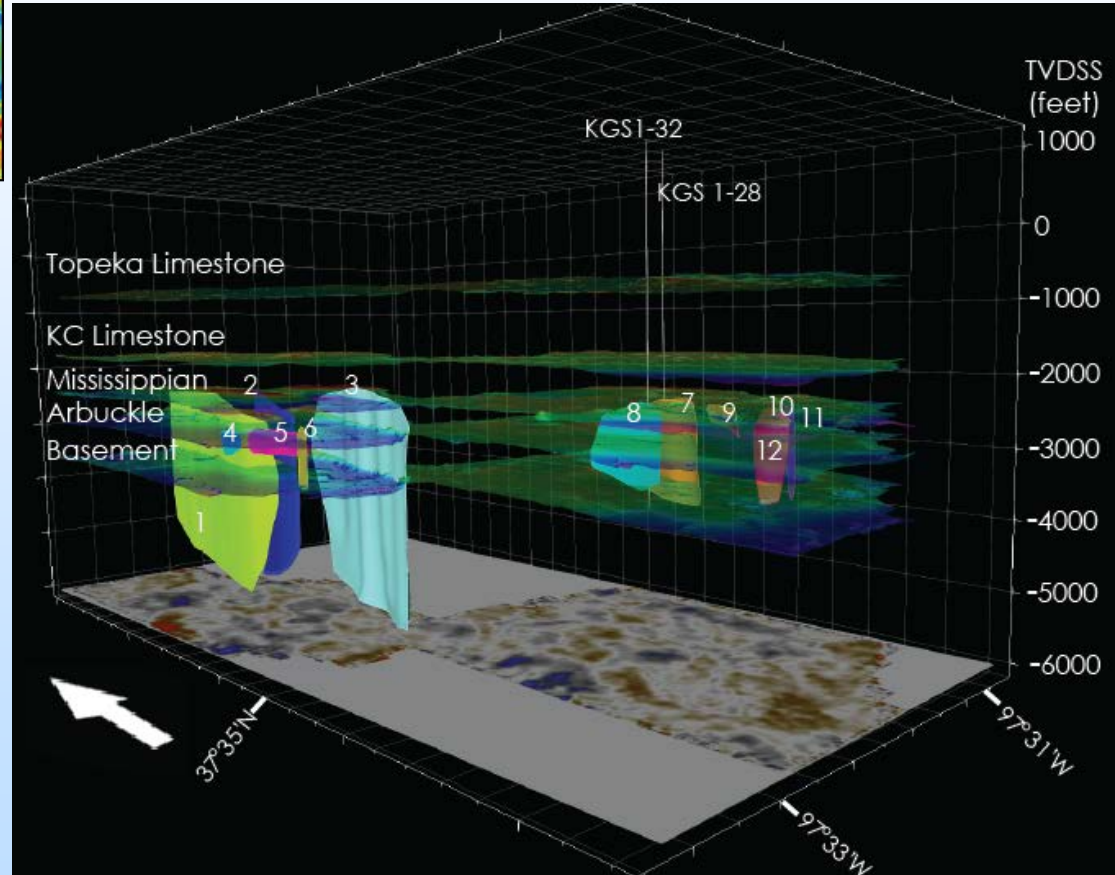
- █ KGS 2-32 Injection well
- █ Significant CO<sub>2</sub> production
- █ Detection of CO<sub>2</sub>
- █ No detection of CO<sub>2</sub>



# Faults cut Mississippian, Arbuckle, and basement



Wellington-Anson Bates Fields, Sumner Co.



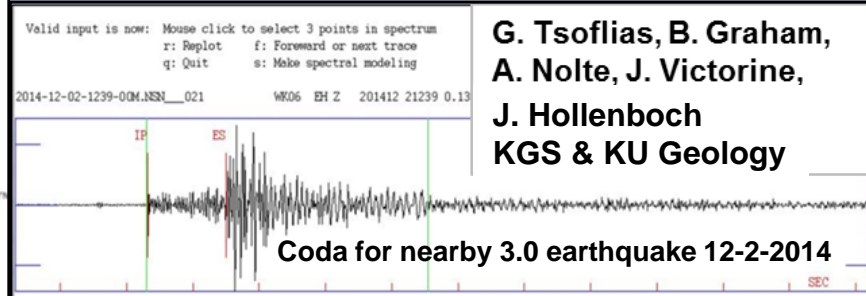
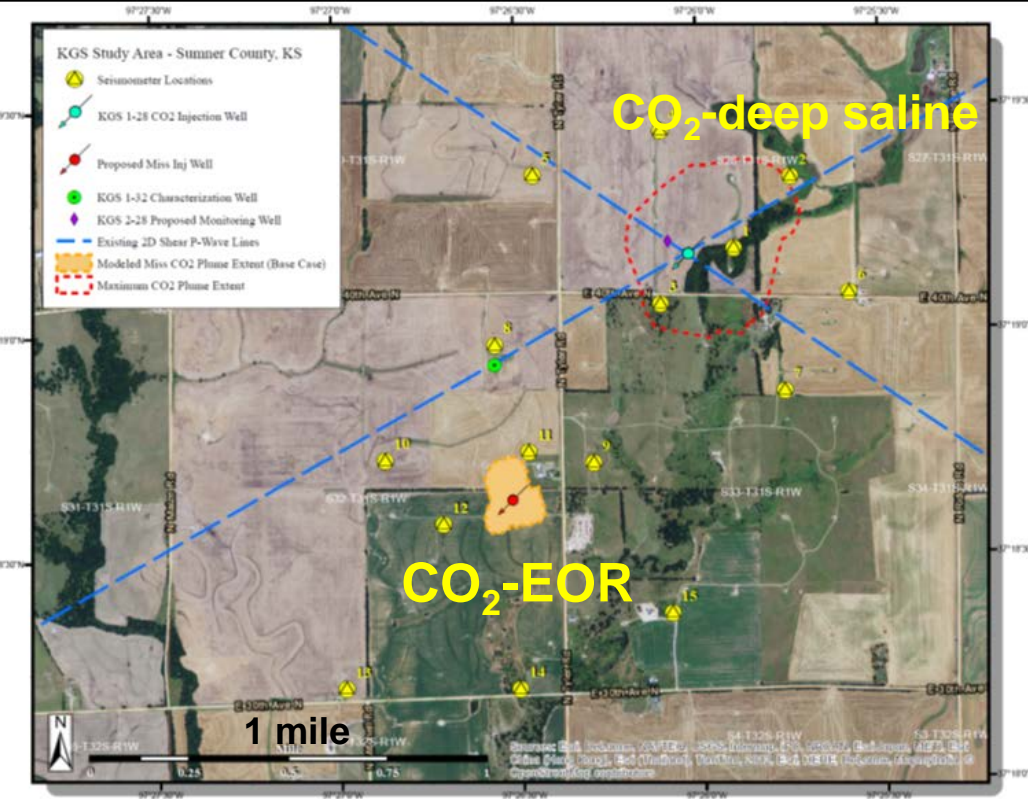
# Milestone 3. Pre-injection MVA baseline recording

- ❑ 18 seismometer array since Fall 2014
- ❑ 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 wells during CO<sub>2</sub>-EOR
- ❑ Static bottom hole pressure in lower Arbuckle from KGS #1-28 since April 2016

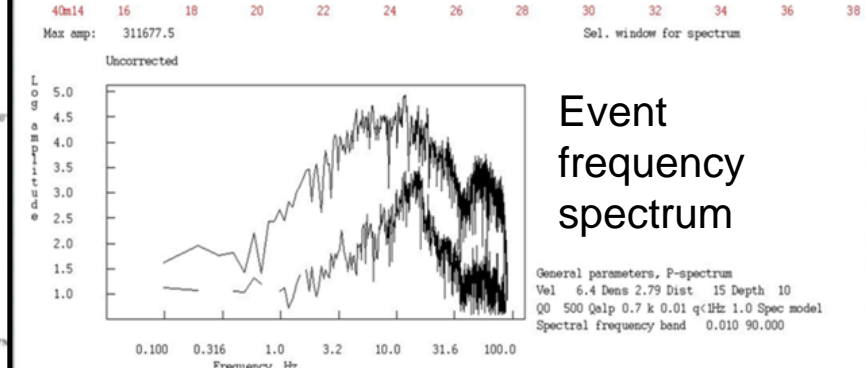


Housing setup for Sercel (Mark Products) L-22D-3D sensors, ~5 ft below surface to minimize surface noise; installed below frost line in bedrock

R. Miller & S. Petrie, KGS installation

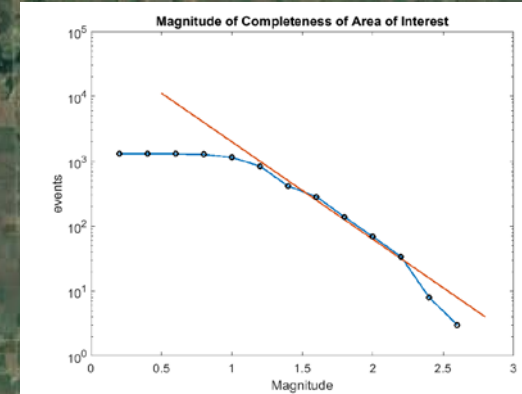
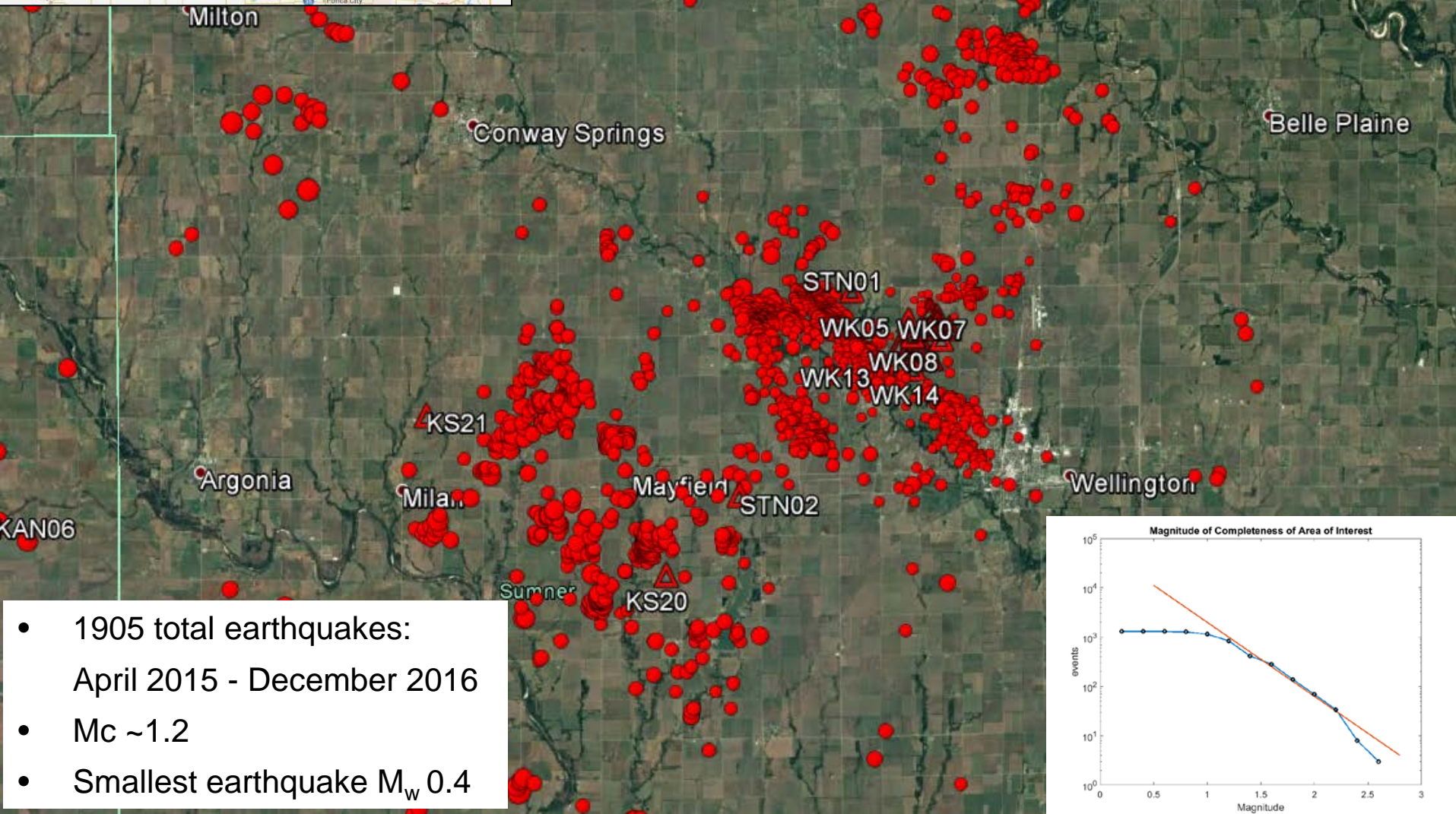



G. Tsoflias, B. Graham,  
 A. Nolte, J. Victorine,  
 J. Hollenboch  
 KGS & KU Geology



# Earthquake Catalog

No earthquake has been detected within Wellington field in association with the CO<sub>2</sub> injection in KGS #2-32

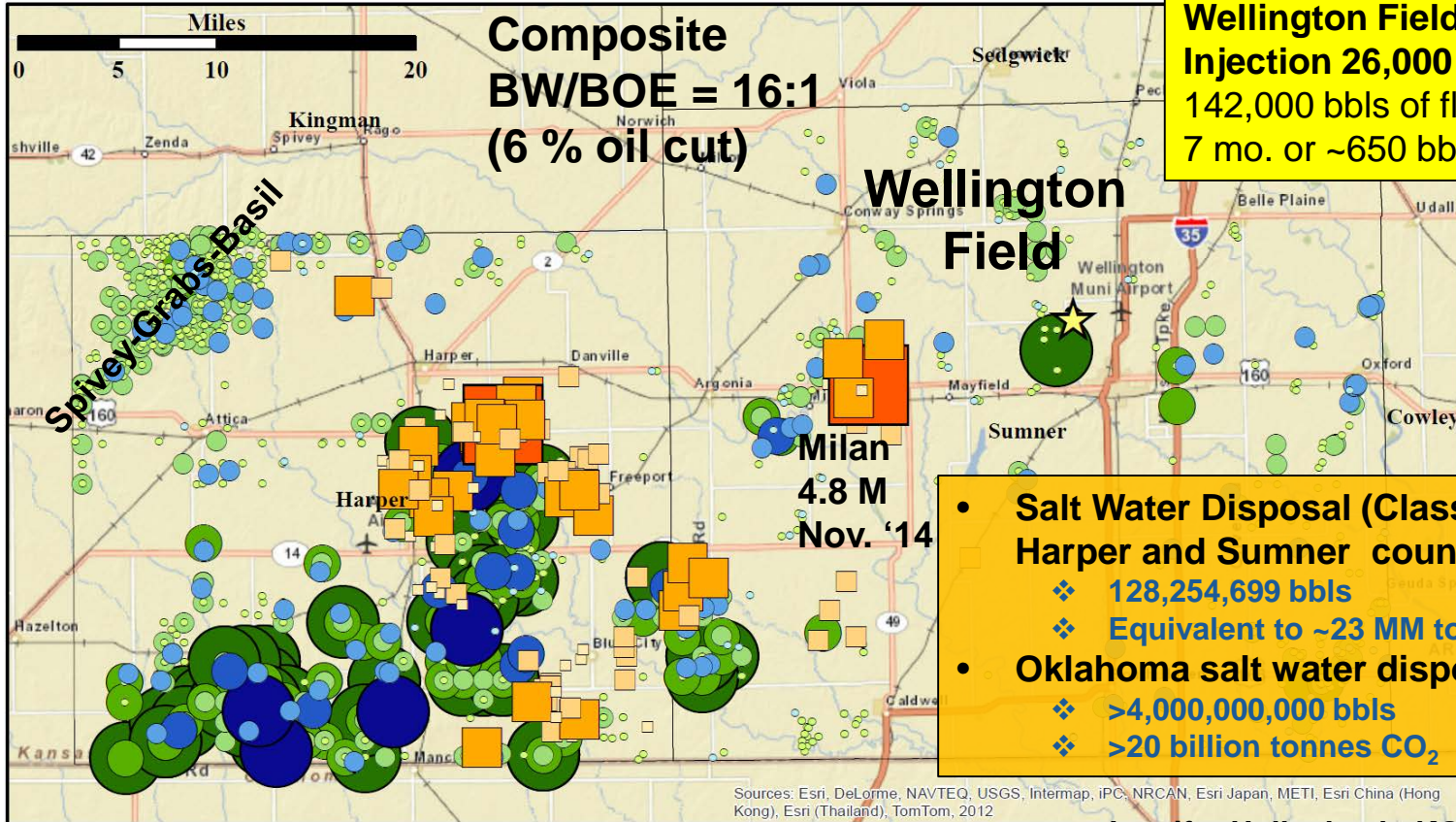


- 1905 total earthquakes:
- April 2015 - December 2016
- $M_c \sim 1.2$
- Smallest earthquake  $M_w$  0.4



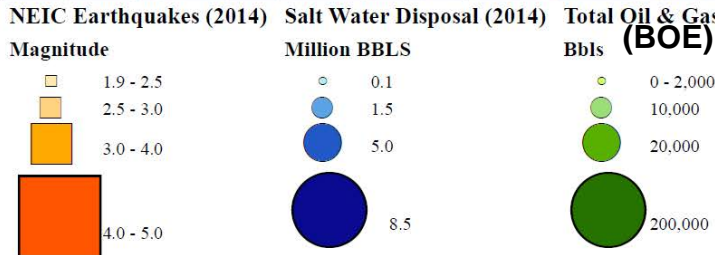
# Induced Seismicity Southwest of Wellington Field

Total salt water injected by well (●), BOE produced by oil lease (●) and earthquakes (■) in 2014, Harper and Sumner Counties, Kansas

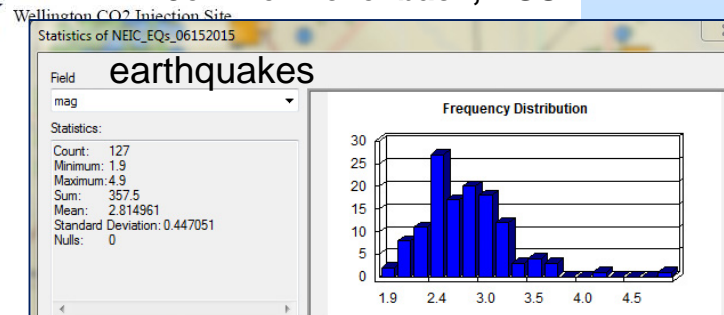


- **Salt Water Disposal (Class II) in Harper and Sumner counties in 2014**
  - ❖ 128,254,699 bbls
  - ❖ Equivalent to ~23 MM tonnes CO<sub>2</sub>
- **Oklahoma salt water disposal in 2014**
  - ❖ >4,000,000,000 bbls
  - ❖ >20 billion tonnes CO<sub>2</sub>

Jennifer Hollenbach, KGS

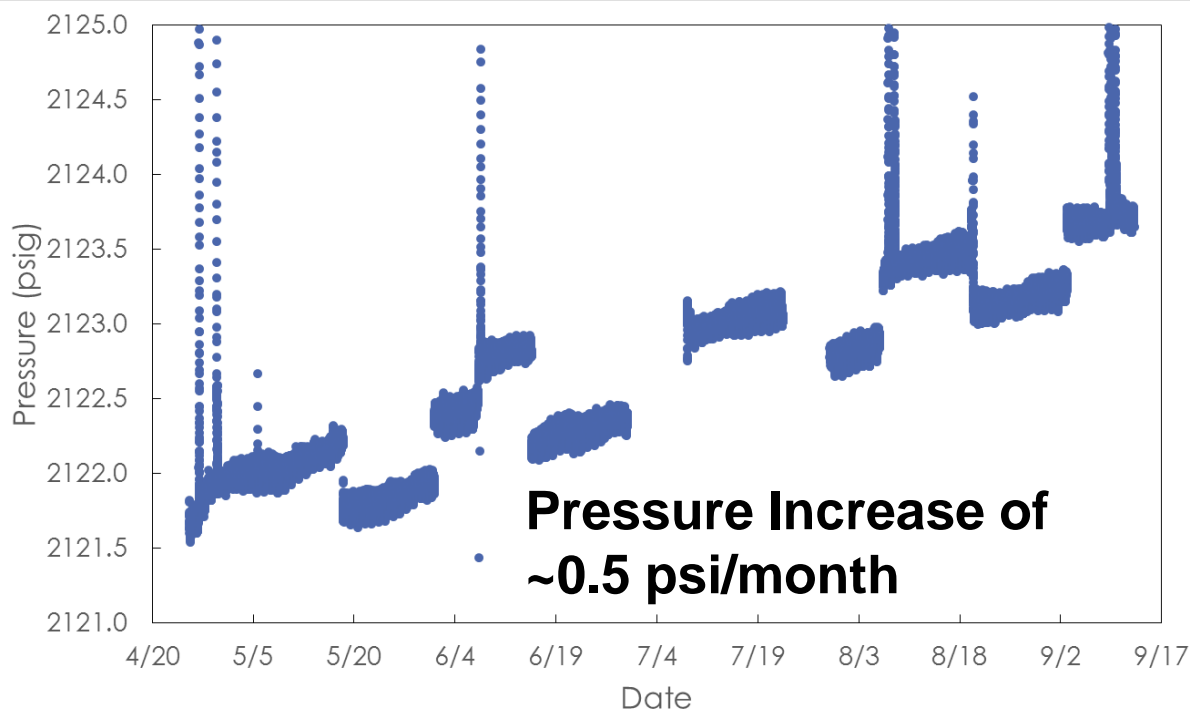


★  
**Min 1.9**  
**Max 4.8**  
**Mean 2.8**  
**127 earthquakes in 2014**

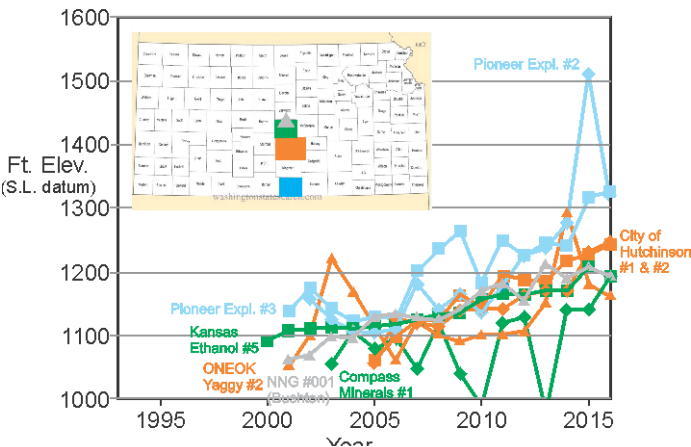


# Kansas Regional Pressure Increase

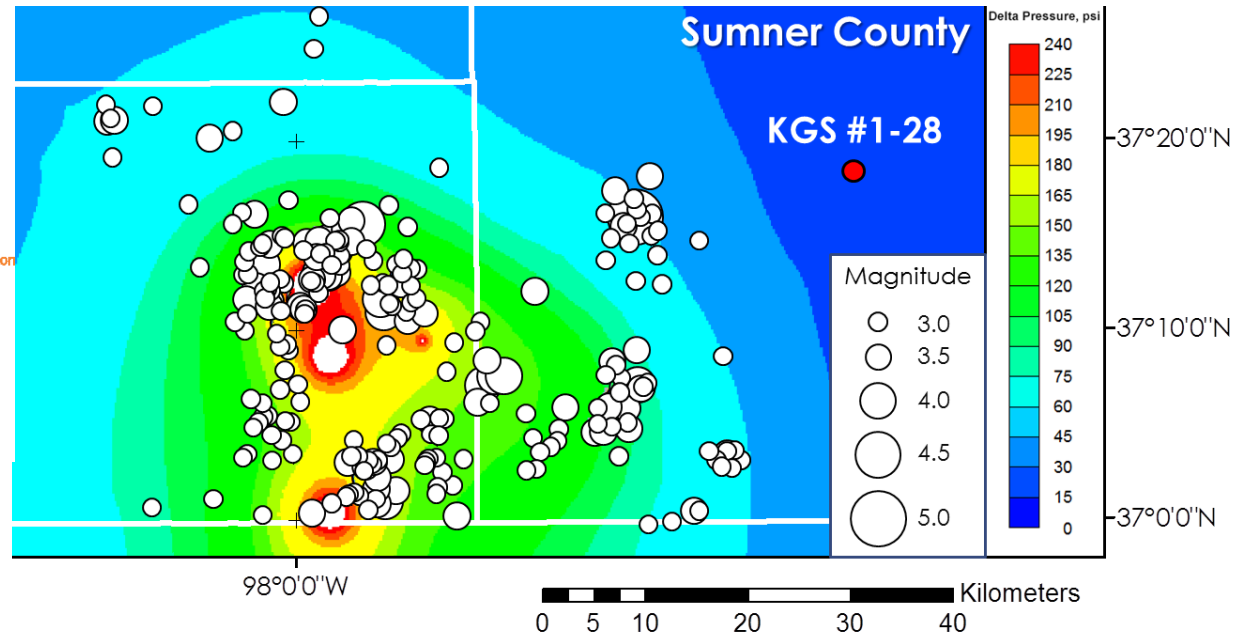
- On 4-25-16, BHP in lower Arbuckle was **+31.4 psig** higher than what was recorded on 8/23/11.
- Since April, 2016 the pressure has risen to **+32.9 psi** → 1.5 psi (0.0147 psi/day or **0.44 psi/mo**).
- Increase in pressure forecast by simulation of 2-county brine disposal
- Regulators express concerns about storage capacity



## CLASS-I-WELL FLUID LEVELS central KS, north-south comparison



## Simulation model: $\Delta$ pressure (psi)



- Pressure increase without changes to injection rate

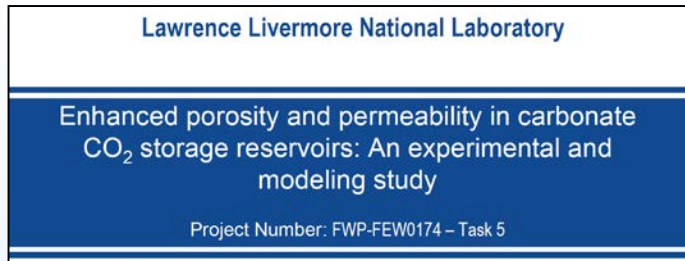
# Accomplishments of the Wellington Project during BP2

## ACTIVITIES CARRIED OUT TO DATE BY THE KANSAS TEAM

- Successful CO<sub>2</sub> injection in the Mississippian carried out by Berexco, LLC, Wichita, KS
- Injection done in a highly controlled and monitored environment
- Linde Group, a leader in CO<sub>2</sub> capture and supply, an excellent partner for the project, provided steady supply of CO<sub>2</sub>
- Assisting in defining safe disposal and economic potential for Kansas reservoirs
- Rapid-response detection & mitigation procedures being tested are as part of a comprehensive operation & risk management plan
- Advanced monitoring technologies
- Wellington Field is proving to be a viable field laboratory

# Synergistic Activities

- Collaboration with Susan Carroll, PI, LLNL



- Task addition → *Experimental calibration of NMR well logs to determine pore connectivity in the injection zone at the Wellington CO<sub>2</sub> storage demonstration site, Kansas*
- Site twinning at ENOS and UK MEMOIR projects
- Data rich site with considerable data sharing with all data publically available
  - Carbonate and caprock cores, modern wireline logs, tests -> KU, KSU et students and faculty; industry consortium
  - Water and oil samples
  - Multicomponent 3D → new processing techniques → KU, KSU, BEG
  - Earthquake catalog being built from operating IRIS/KGS 18-seismometer array
  - Monitoring and risk analysis from operational plan for safe and effective injection and adaptation by EPA for this project
  - Test NRAP tools
- Extensive Web (Java) application tools and development, petrophysical application focus, data archiving
  - Need more users and explore incorporation into NATCARB

# Acknowledgements & Disclaimer

## Acknowledgements

- *The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant DE-FE0006821, W.L. Watney and Jason Rush, 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.*

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