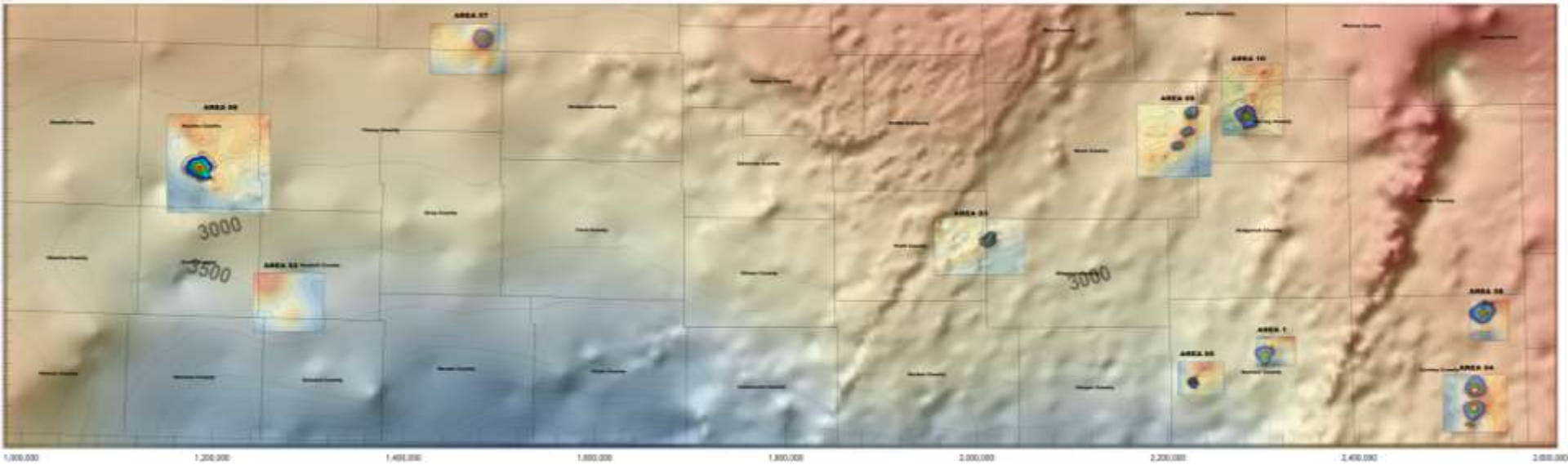



# SMALL SCALE FIELD TEST DEMONSTRATING $CO_2$ SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY $CO_2$-EOR AT WELLINGTON FIELD SUMNER COUNTY, KANSAS

Yevhen (Eugene) Holubnyak, W. Lynn Watney, Tiraz Birdie Jennifer Hollenbach, George Tsoflias, Tandis Bidgoli

12th $CO_2$ GeoNet Open Forum

8-9 MAY 2017, S.Servolo island, Venice

KANSAS GEOLOGICAL SURVEY
The University of Kansas

KSCO2

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

# Project Team

KANSAS GEOLOGICAL SURVEY
The University of Kansas

DOE-NETL Contract #FE0006821

NATIONAL ENERGY TECHNOLOGY LABORATORY

**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)***

BEREXCO

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

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

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

THE LINDE GROUP
Linde

**$CO_2$ supplier**

DEPARTMENT OF GEOLOGY
KANSAS STATE UNIVERSITY

**Saugata Datta, Ian Andree**
***(USDW monitoring)***

TBirdie Consulting, Inc
4705 McCormick Street • Lawrence • KS 66047 • 785 843 1085 • 785 865 0678 (fax) • tbirdie@sunflower.com

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

IRIS PASSCAL
Instrument Center
Program for Array Seismic Studies of the Continental Lithosphere


TRILOBITE TESTING, INC.

PARAGON
GEOPHYSICAL SERVICES, INC.

fairfieldnodal

Core Lab
RESERVOIR OPTIMIZATION

KU THE UNIVERSITY OF KANSAS — Department of Geology

Schlumberger

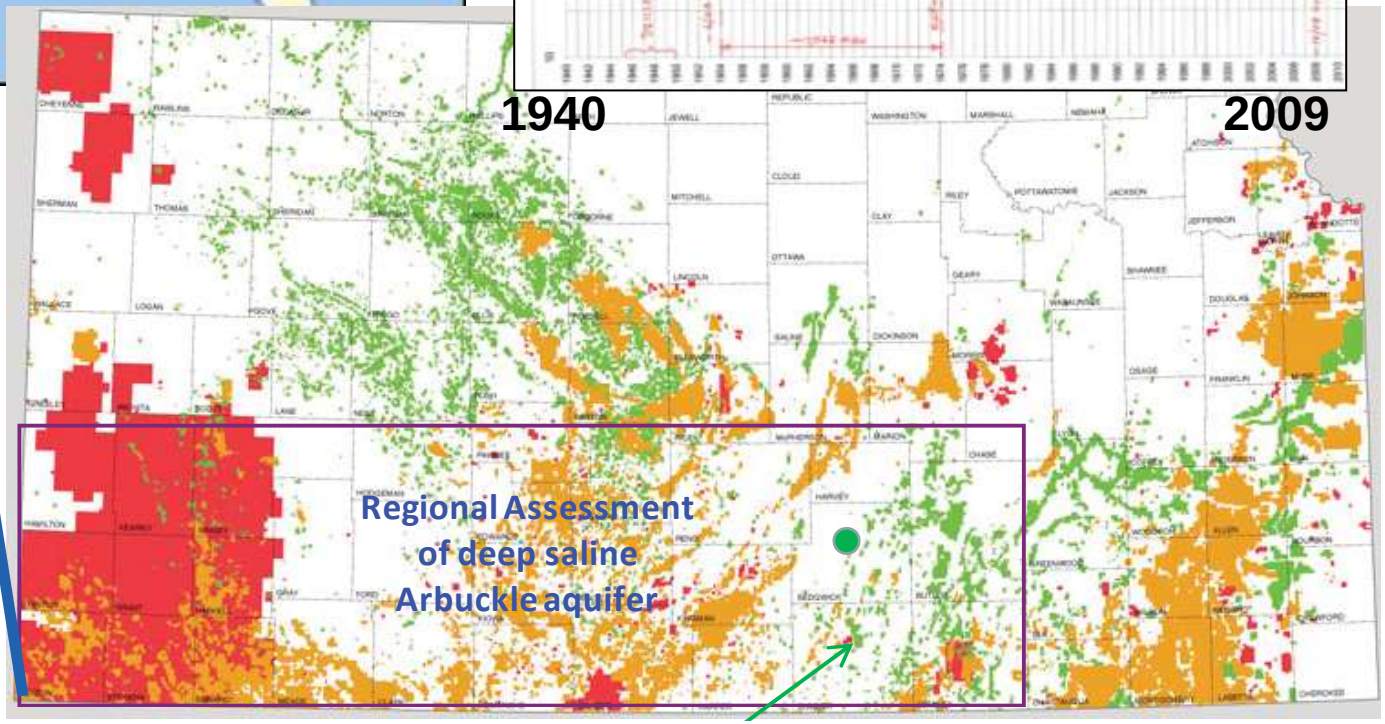
***Petrel***
***TechLog***

CMG COMPUTER MODELLING GROUP LTD.

HALLIBURTON

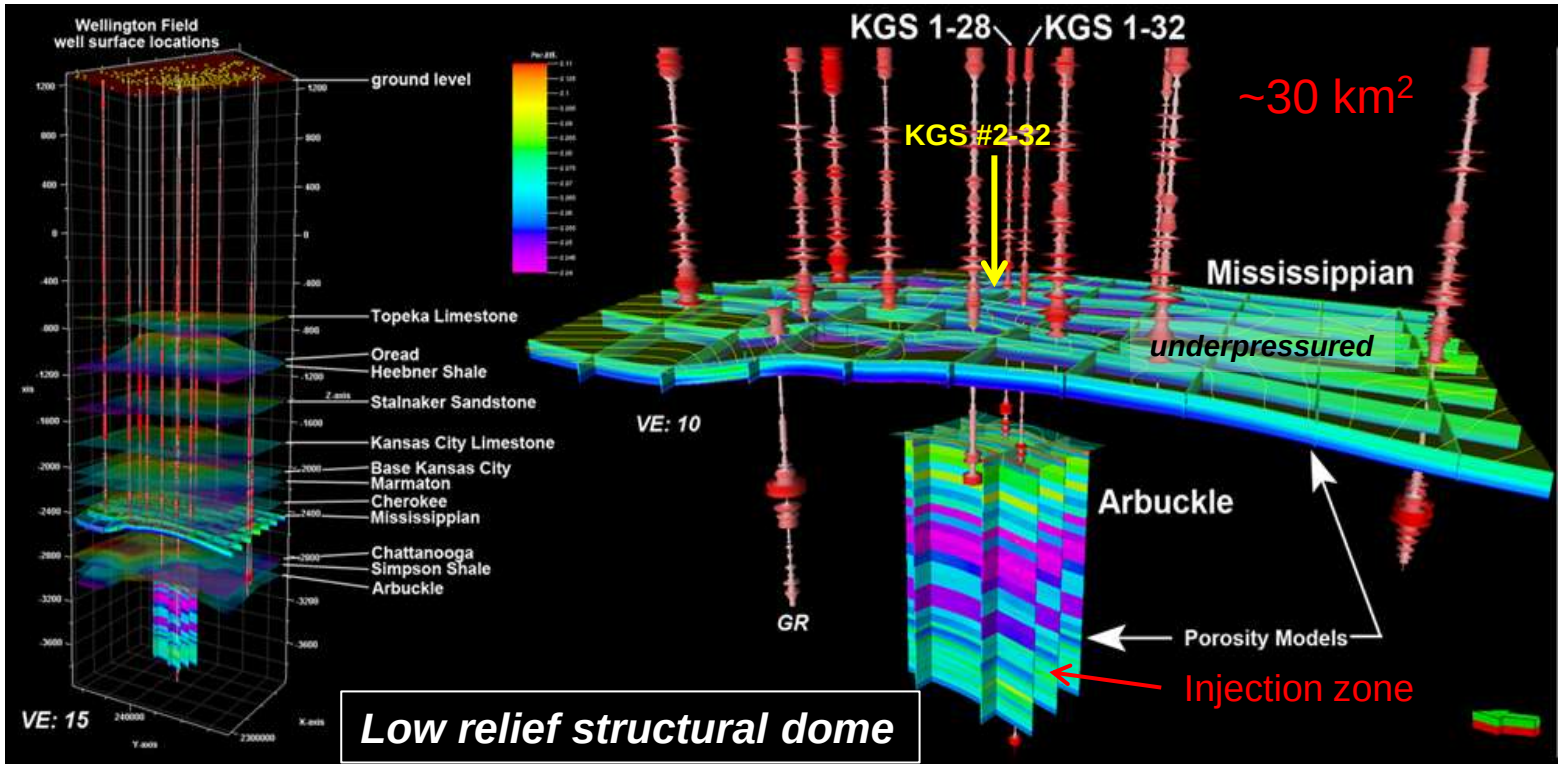
**Jennifer Roberts, Leigh Sterns, George Tsoflias, B. and K. Graham, A. Nolte, D. Schwab, B. Norwood**
***InSAR-cGPS, active and passive seismic, geochemistry***


Total Wellington Unit Waterflood


1940
2009
Regional Assessment
of deep saline
Arbuckle aquifer

# Project Goals

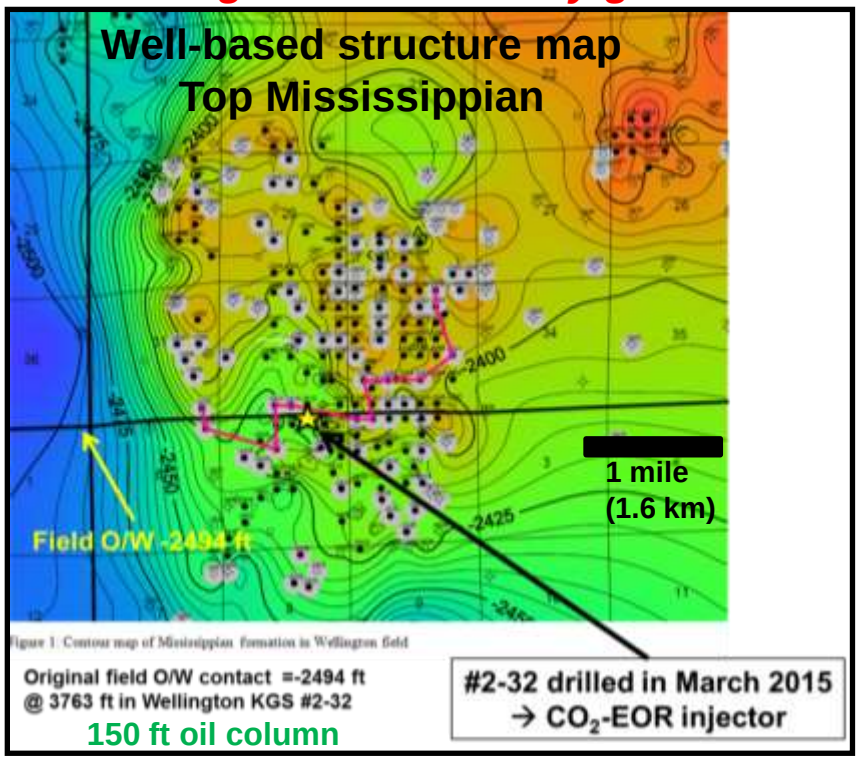
- **Demonstrate that 99 percent permanence of injected $CO_2$**
  - → 20,000 metric tons tonnes injected into KGS #2-32 into *Late Mississippian siliceous dolomite reservoir between January 9 and June 21, 2016* → *$CO_2$ plume and EOR response as forecast by model* ***(Class II UIC permit)***
  - → 20,000 metric ton injection into underlying *Lower Ordovician Arbuckle Group dolomitic saline aquifer* ***(Pendiing Class VI UIC permit)***
- **Demonstrate reliable and cost effective MVA (*monitoring, verification, and accounting*) tools and techniques**
- **Develop best practices for effective and safe $CO_2$-EOR and $CO_2$ saline storage**



# Technical Status

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

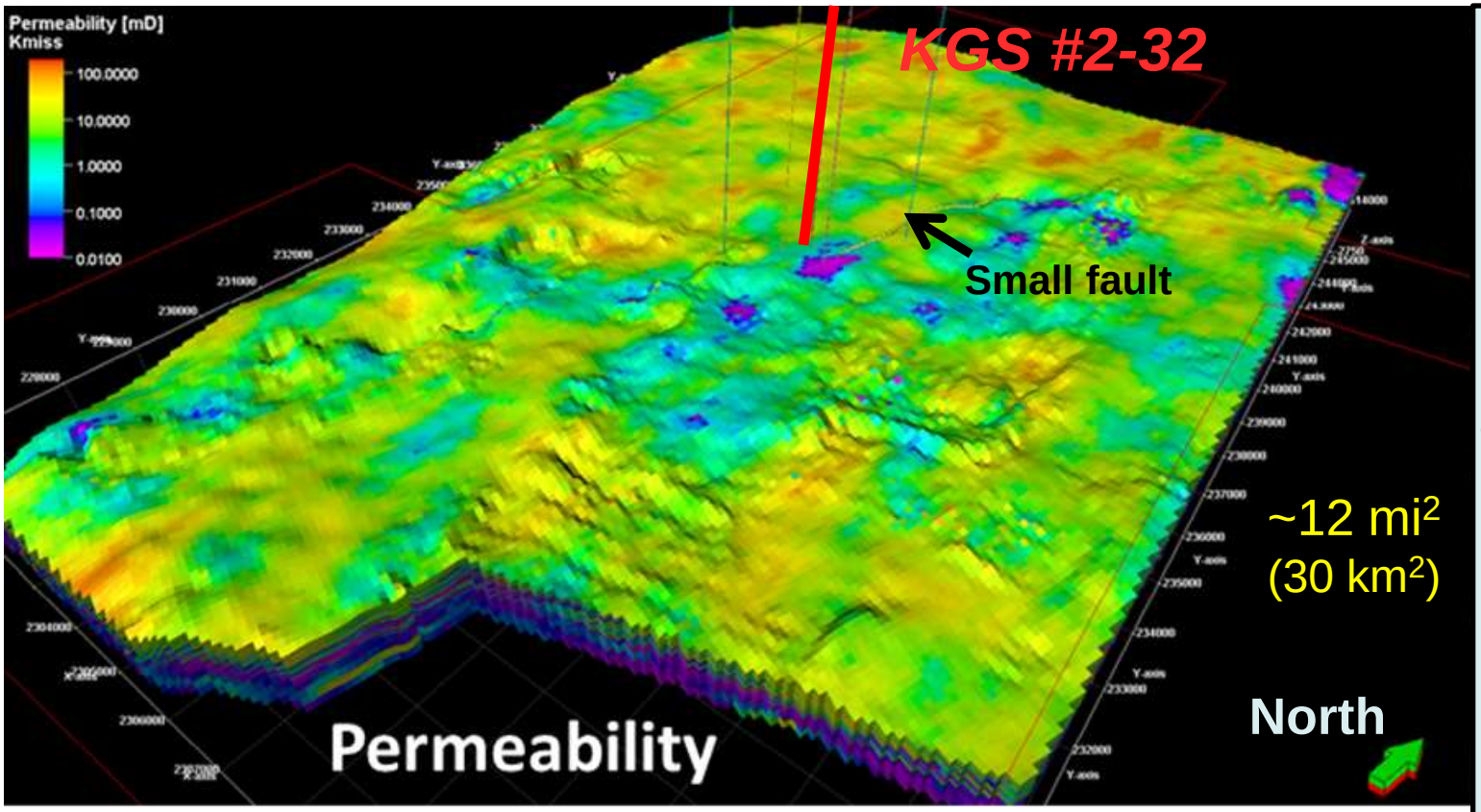
- Begin $CO_2$ injection into KGS #2-32 on January 9, 2016
- Completed injection on June 21, 2016
- 1,101 truckloads, 21,784 US tons, 19,803 metric tons, average of 120 tonnes per day, approximately 374,000 MCF of $CO_2$
- Total expenditures for purchasing $CO_2$ were $1,964,000. Our overall price for $CO_2$ was $90.16 per US ton from *Linde Group*
- ***Behaving as forecasted by gemodel/simulation***



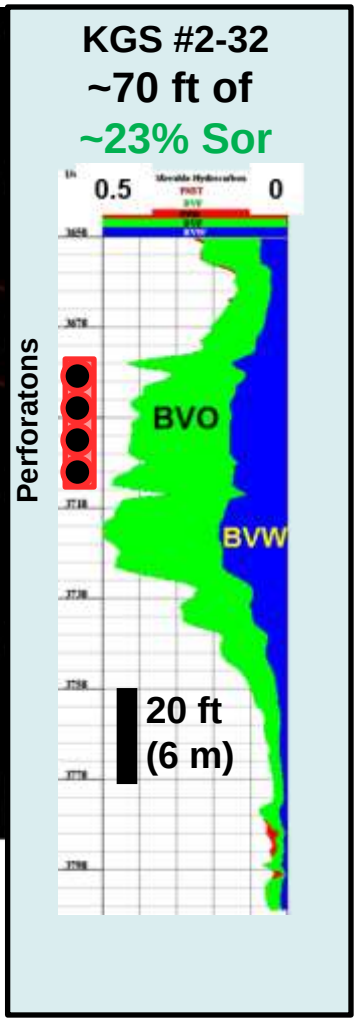

**Monitoring technologies during Class II injection**

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-$CO_2$ injection well performance around Class II well
7) Arbuckle pressure monitoring since April 2016

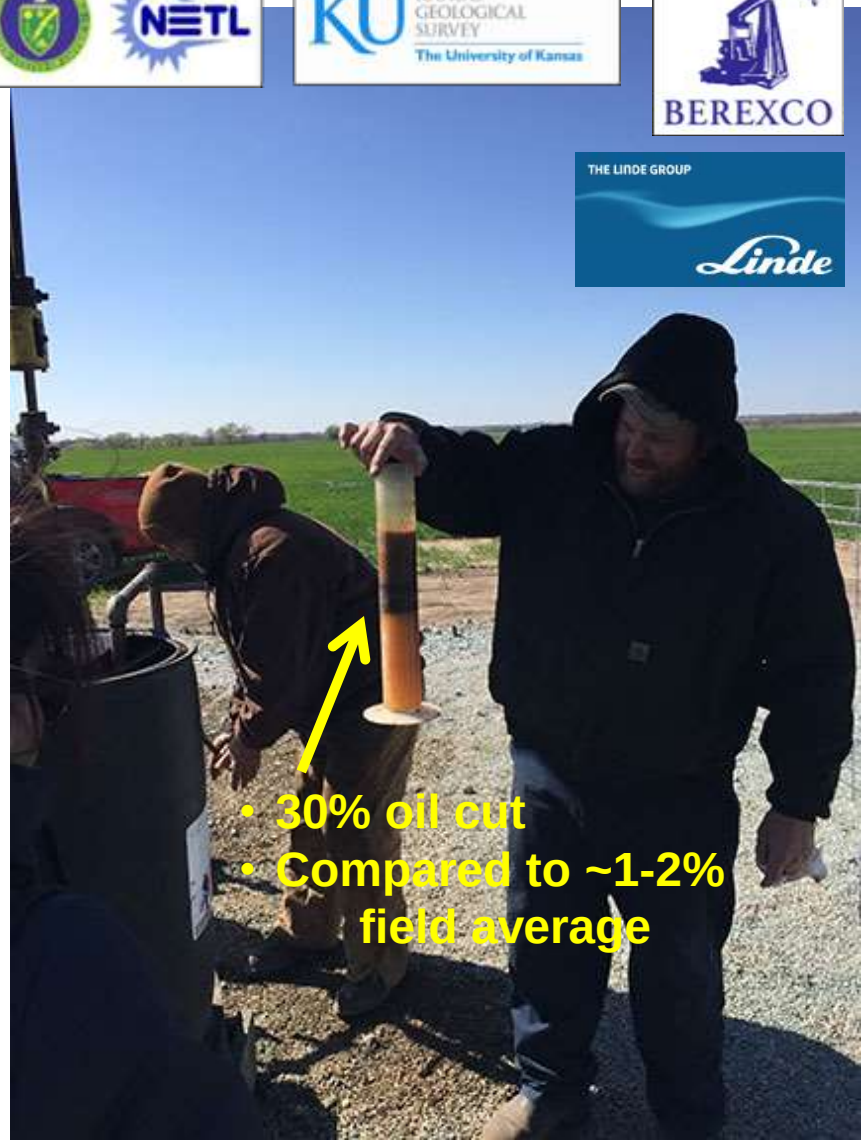
# Targeted area →High $CO_2$-EOR potential




J. Rush




- Petrel map of permeability distribution in the Mississippian dolomite
- $CO_2$ injection well is red vertical line
- Lower permeability noted east and south of the injection well, <u>Berexco Wellington KGS #2-32</u>
- Residual oil saturation in cored injection well averages 23%



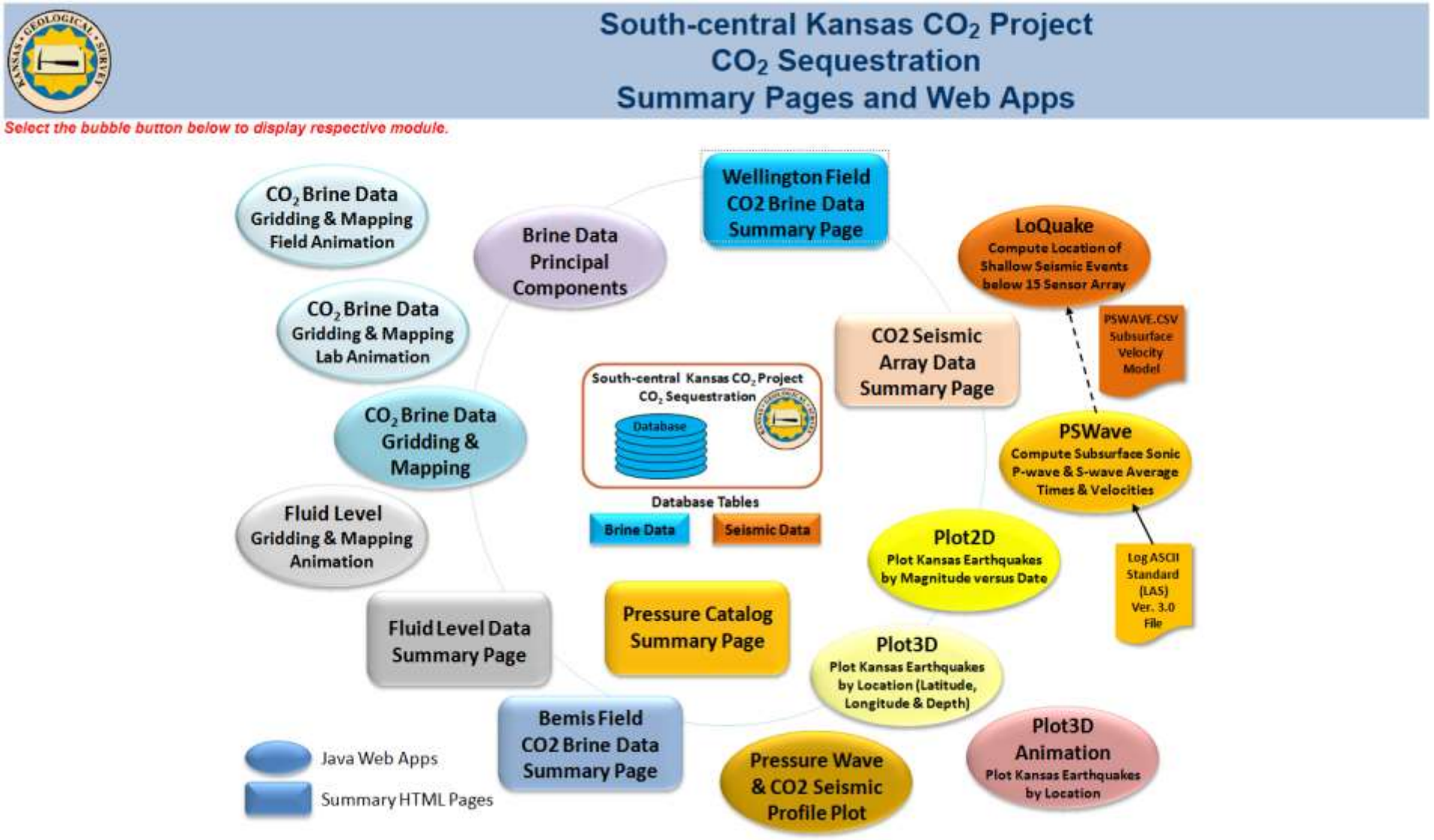

Wellington Field small scale $CO_2$-EOR Jason Bruns above (Caanon Well Services) and Dana Wreath upper right (VP *Berexco, LLC*) with KGS staff

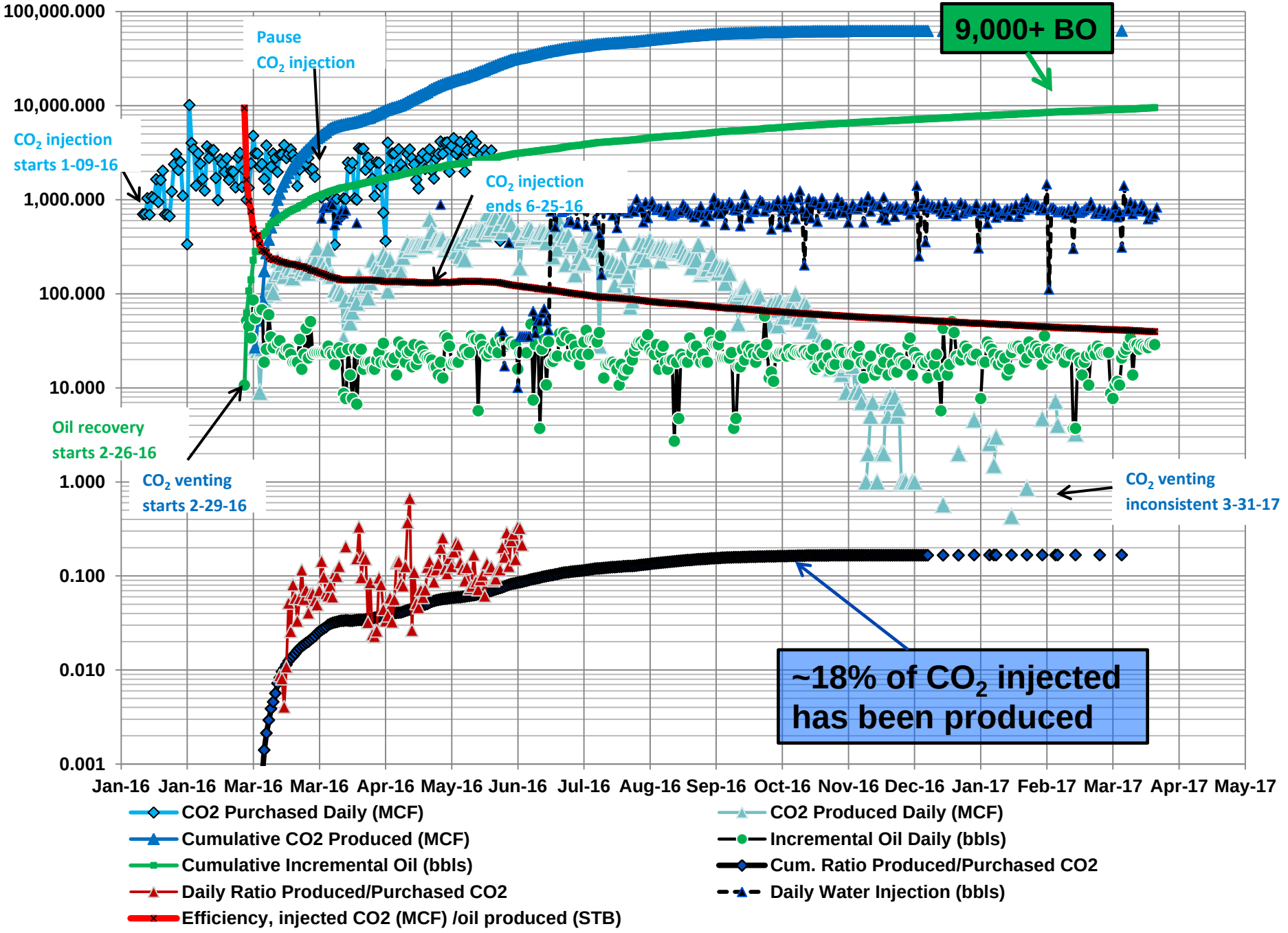


SCADA System installed on wells

# Web Applications Built to Display and Analyze Data "*in Real-Time*" by the Team During Monitoring →

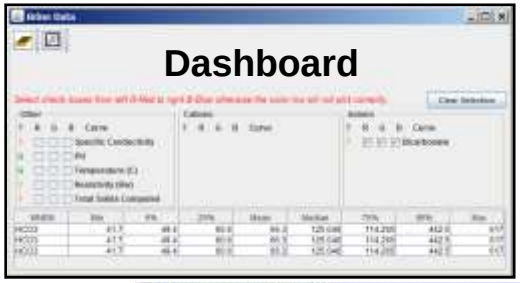
***time lapse maps, cross plots, analytical tools, csv download***



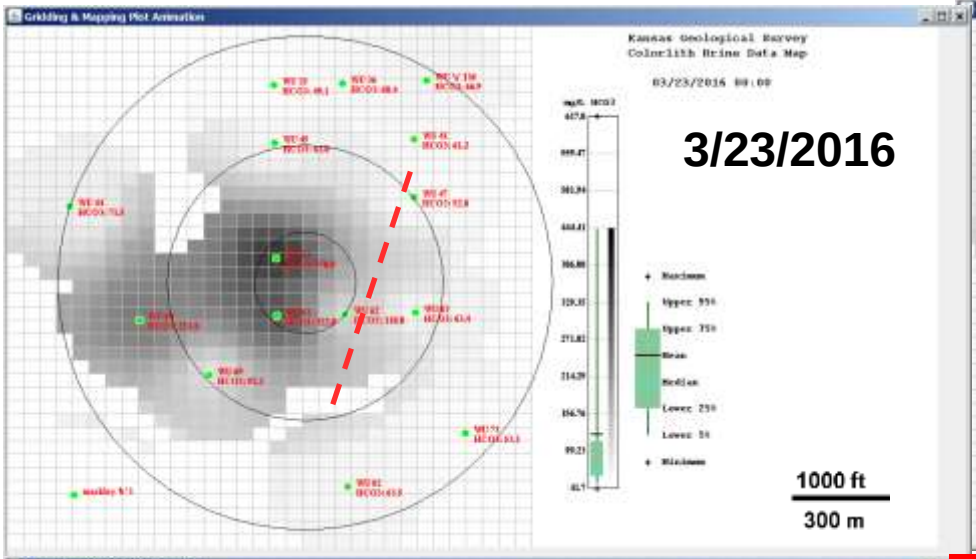

100,000.000
10,000.000
1,000.000
100.000
10.000
1.000
0.100
0.010
0.001
9,000+ BO
Pause
$CO_2$ injection
$CO_2$ injection
starts 1-09-16
$CO_2$ injection
ends 6-25-16
Oil recovery
starts 2-26-16
$CO_2$ venting
starts 2-29-16
$CO_2$ venting
inconsistent 3-31-17
~18% of $CO_2$ injected
has been produced
Jan-16 Jan-16 Mar-16 Mar-16 Apr-16 May-16 Jun-16 Jul-16 Aug-16 Sep-16 Oct-16 Nov-16 Dec-16 Jan-17 Feb-17 Mar-17 Apr-17 May-17
CO2 Purchased Daily (MCF)
CO2 Produced Daily (MCF)
Cumulative CO2 Produced (MCF)
Incremental Oil Daily (bbls)
Cumulative Incremental Oil (bbls)
Cum. Ratio Produced/Purchased CO2
Daily Ratio Produced/Purchased CO2
Daily Water Injection (bbls)
Efficiency, injected CO2 (MCF) /oil produced (STB)

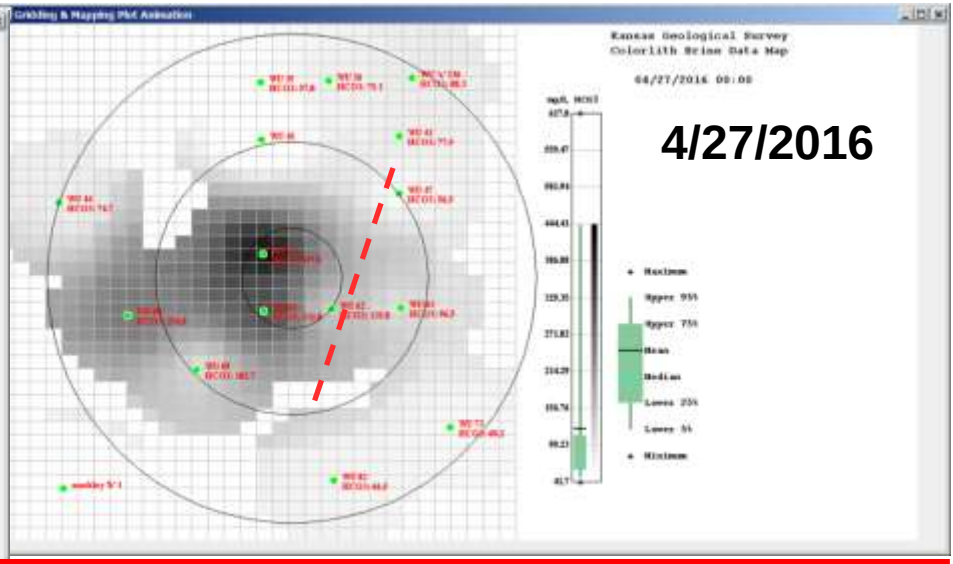
# Time Lapse Alkalinity

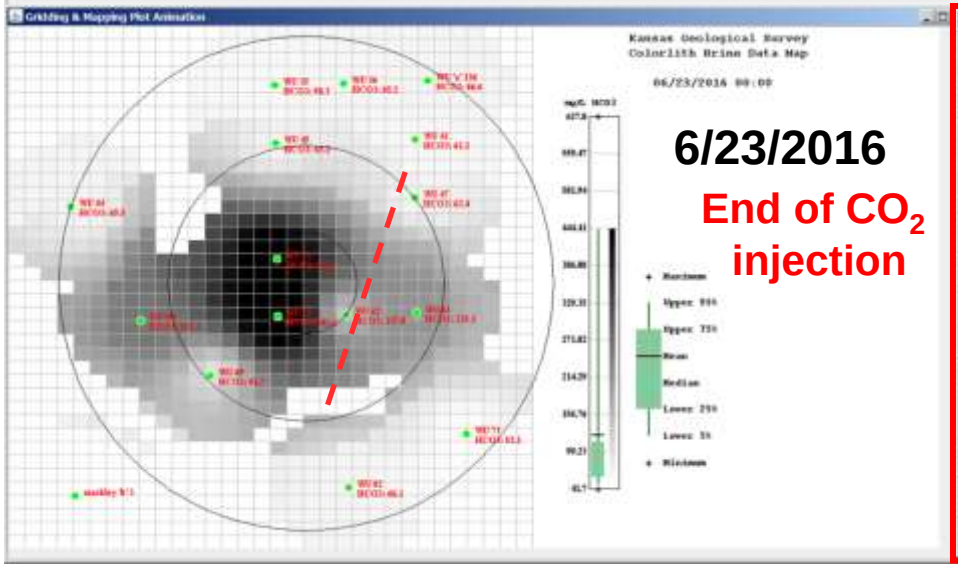
-- During and Post $CO_2$ Injection

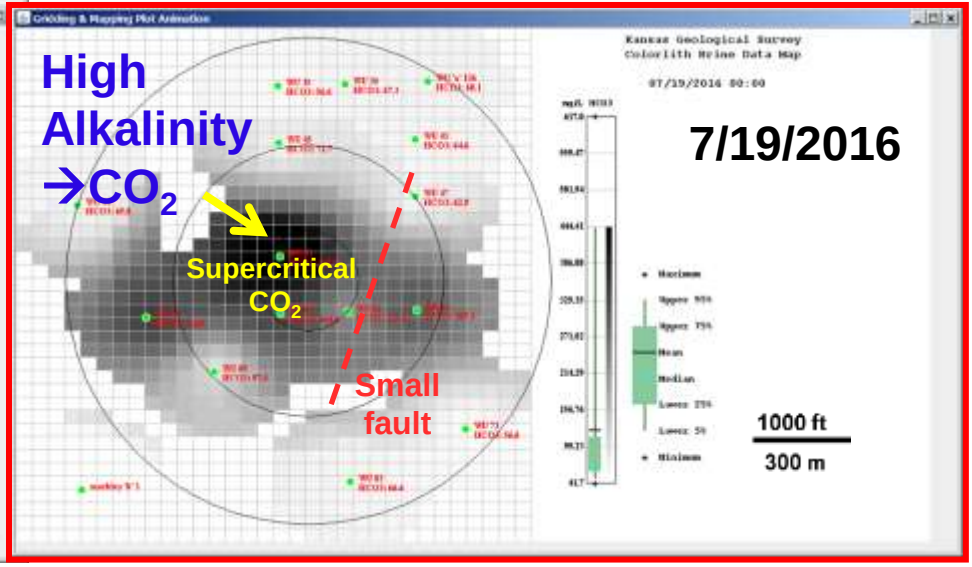






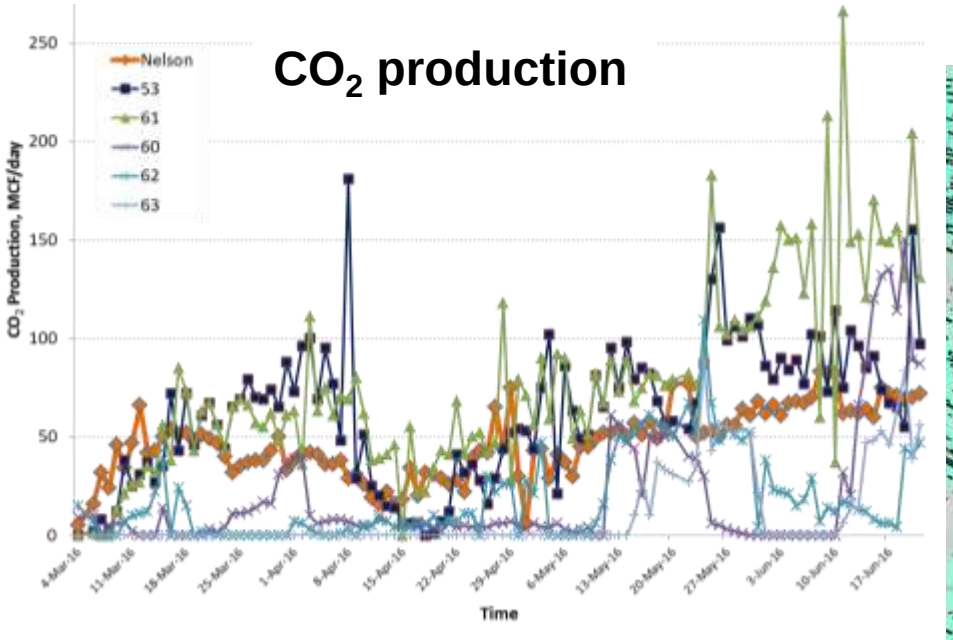



# Re-processed 3D seismic analysis: discrete fracture network vs. field $CO_2$ MVA data

$T_5$ = June 17, 2016

- KGS 2-32 Injection well
- Significant $CO_2$ production
- Detection of $CO_2$
- No detection of $CO_2$

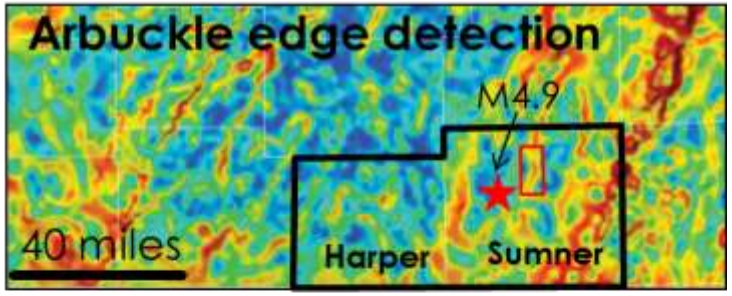


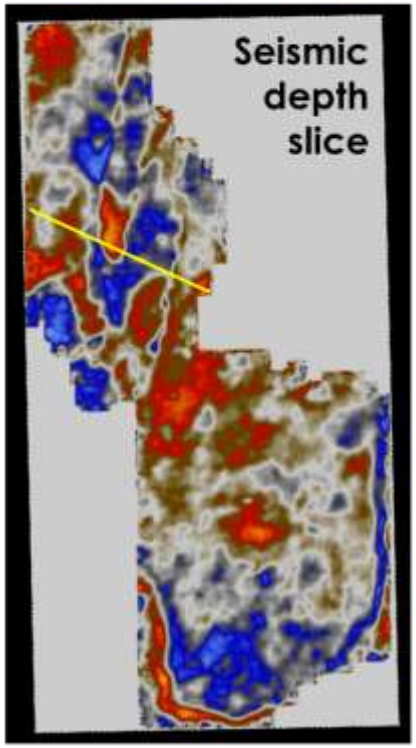


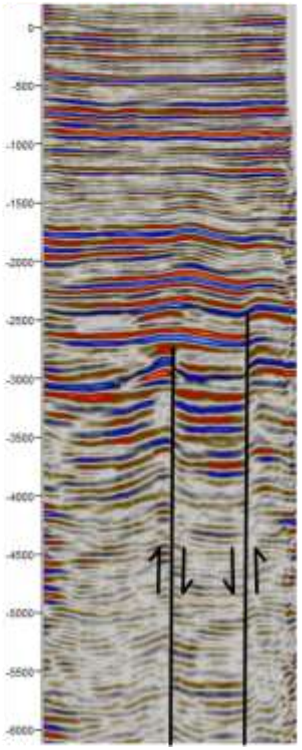


G. Tsoflias &
B. Graham

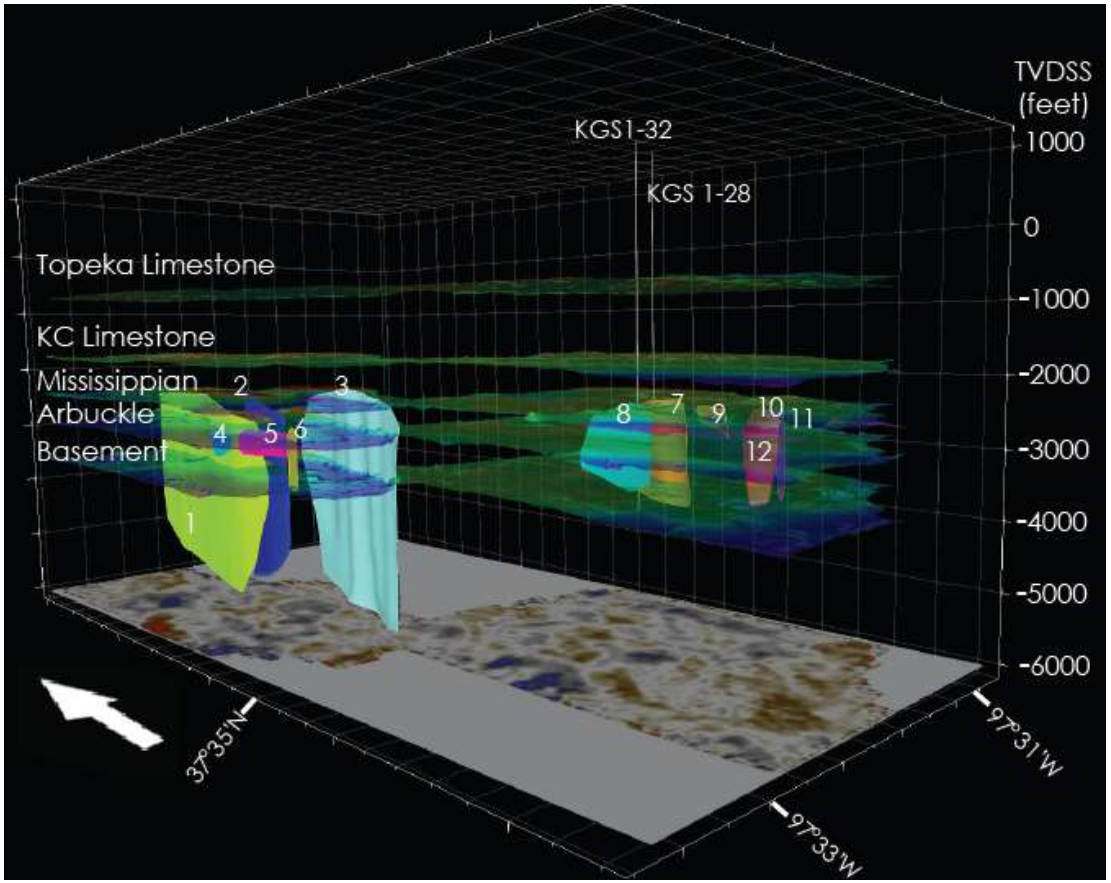
# Faults cut Mississippian, Arbuckle, and basement



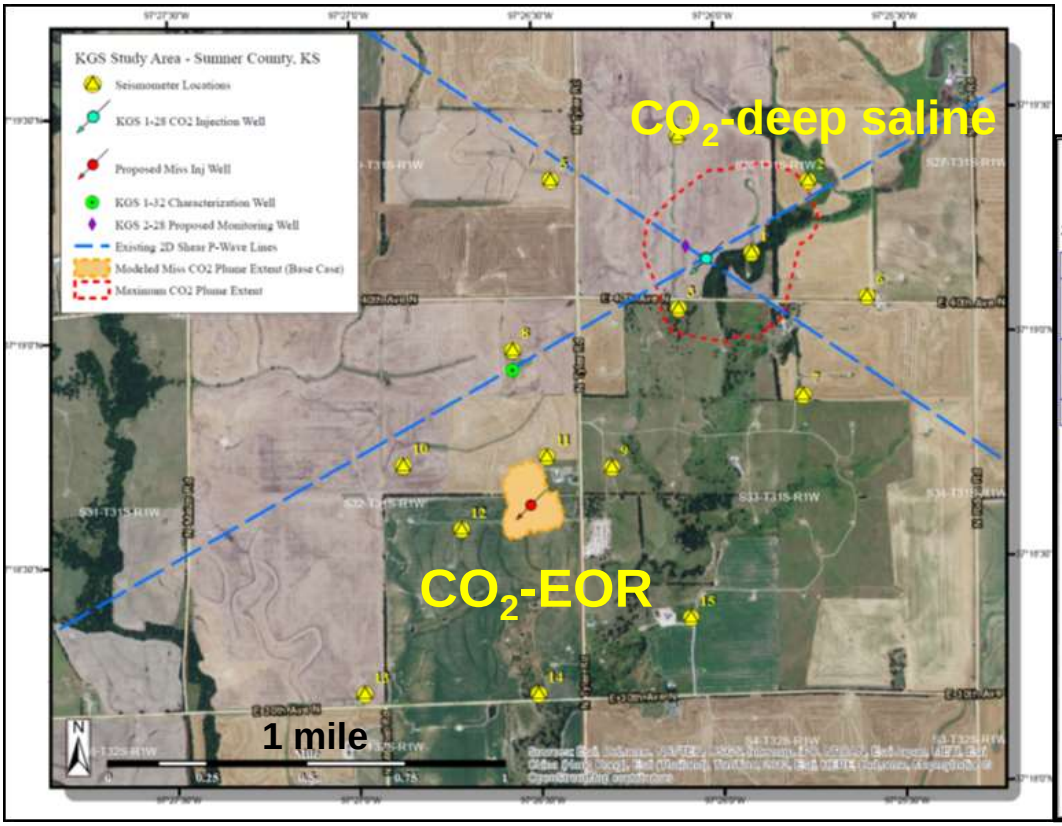
Wellington-Anson Bates Fields, Sumner Co.

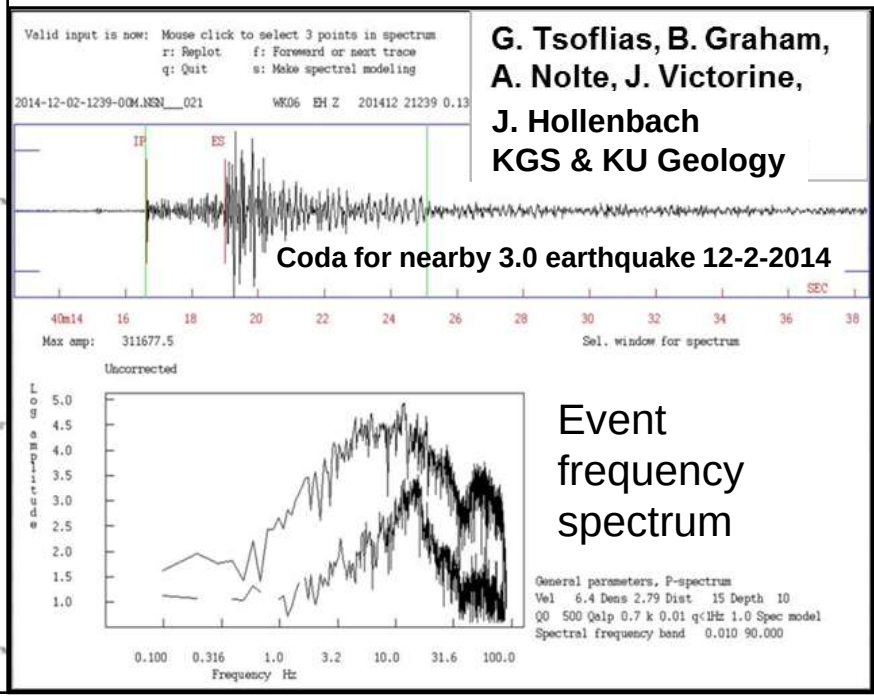



**T. Bidgoli & D. Schwab**

# • 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 $CO_2$-EOR
- ❑ Static bottom hole pressure in lower Arbuckle from KGS #1-28 since April 2016

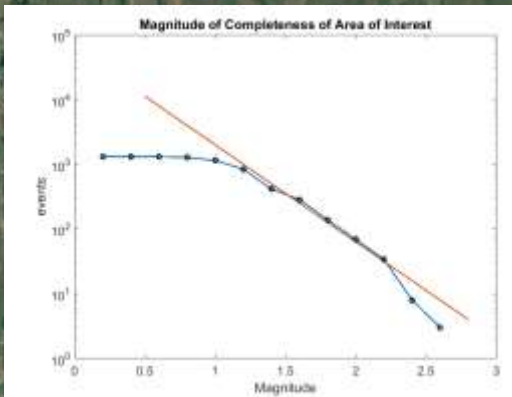



# Earthquake Catalog

No earthquake has been detected within Wellington field in association with the $CO_2$ injection in KGS #2-32


Milton
Conway Springs
Belle Plaine
STN01
WK05 WK07
WK08
WK13
WK14
KS21
Argonia
Mayfield
STN02
Wellington
KAN06
Sumner
KS20

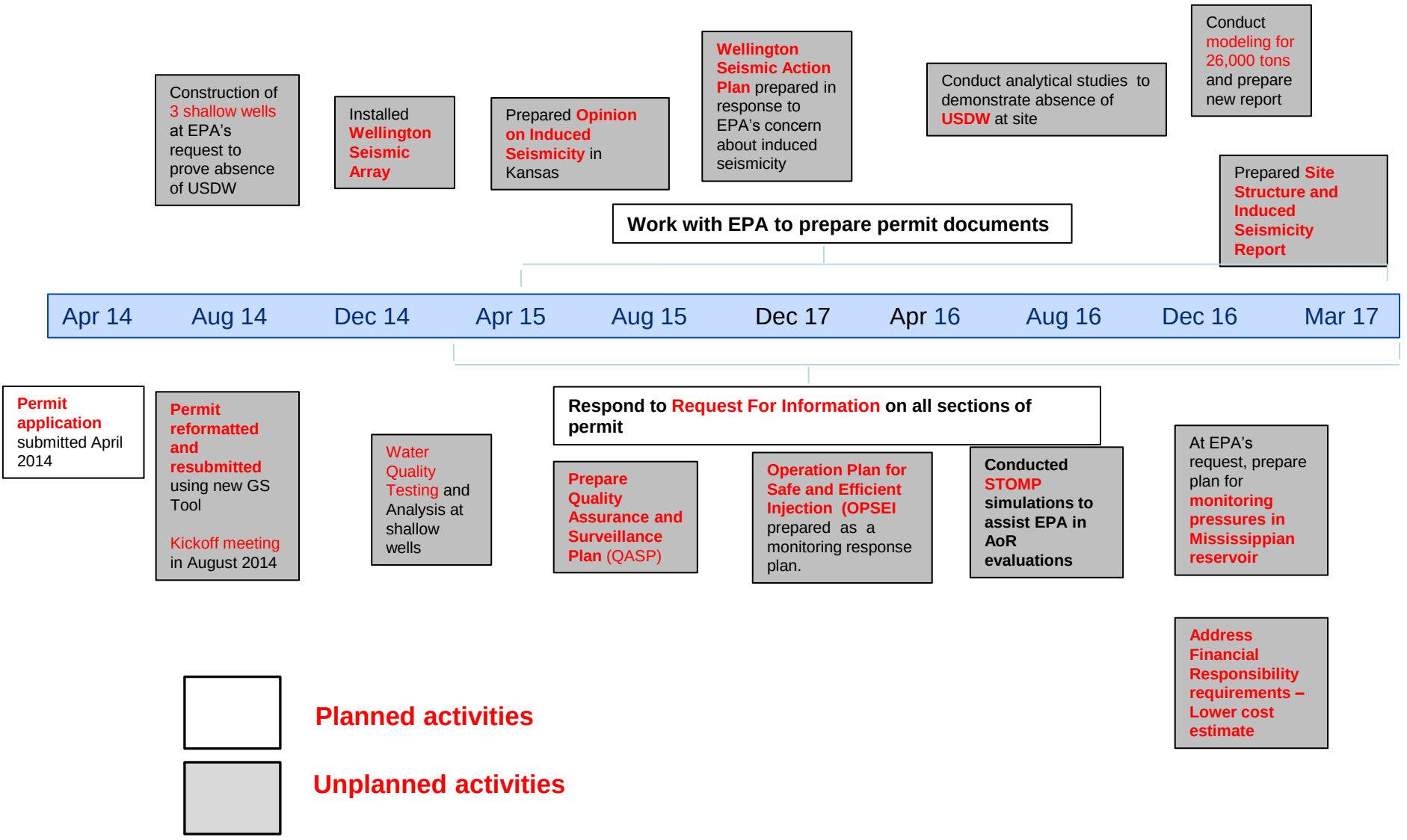
- 1905 total earthquakes:
  April 2015 - December 2016
- Mc ~1.2
- Smallest earthquake $M_w$ 0.4



# Class VI Permit Application

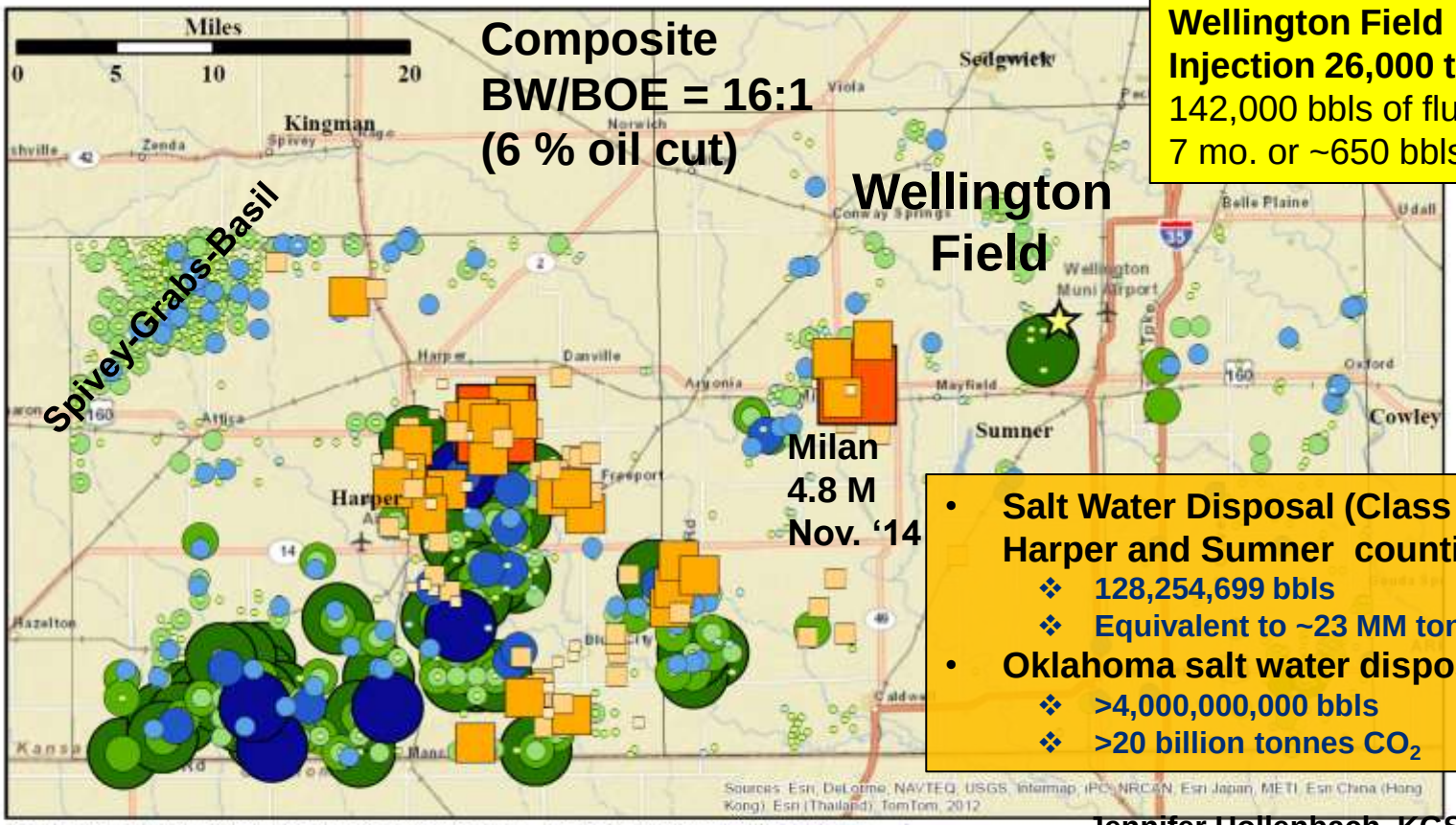
- **Submitted to EPA in April 2014**
- **1468 page document**
- **EPA requested reformatting and resubmission of permit in June 2014 in order to conform with new Geologic Sequestration (GS) Tool**

# Permitting Timeline



# 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**




**Wellington Field Arbuckle Injection 26,000 tonnes** = 142,000 bbls of fluid over 7 mo. or ~650 bbls per day

- **Salt Water Disposal (Class II) in Harper and Sumner counties in 2014**
  - **128,254,699 bbls**
  - **Equivalent to ~23 MM tonnes $CO_2$**
- **Oklahoma salt water disposal in 2014**
  - **>4,000,000,000 bbls**
  - **>20 billion tonnes $CO_2$**

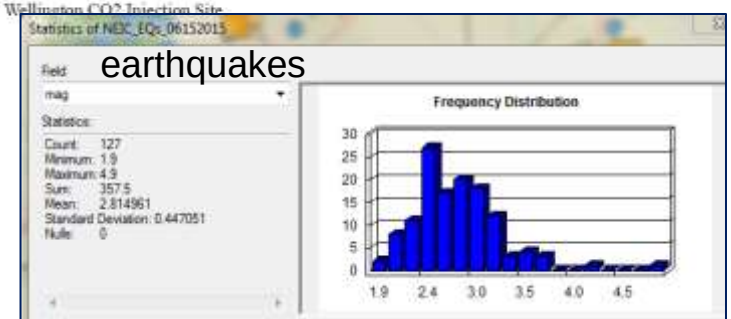
**NEIC Earthquakes (2014)**
Magnitude
1.9 - 2.5
2.5 - 3.0
3.0 - 4.0
4.0 - 5.0

**Salt Water Disposal (2014)**
Million BBLS
0.1
1.5
5.0
8.5

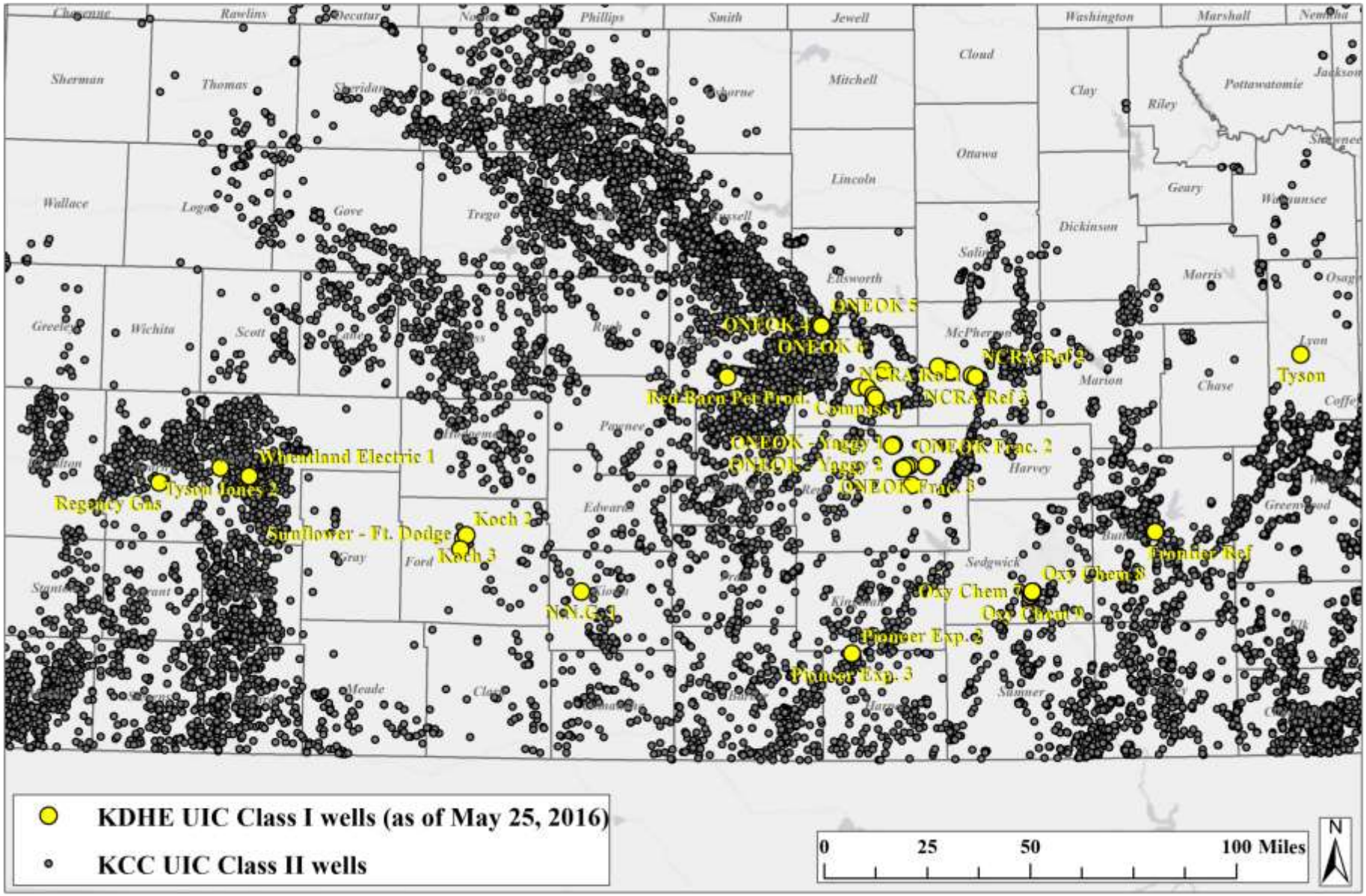
**Total Oil & Gas Production (2014) (BOE)**
Bbls
0 - 2,000
10,000
20,000
200,000

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

**Jennifer Hollenbach, KGS**

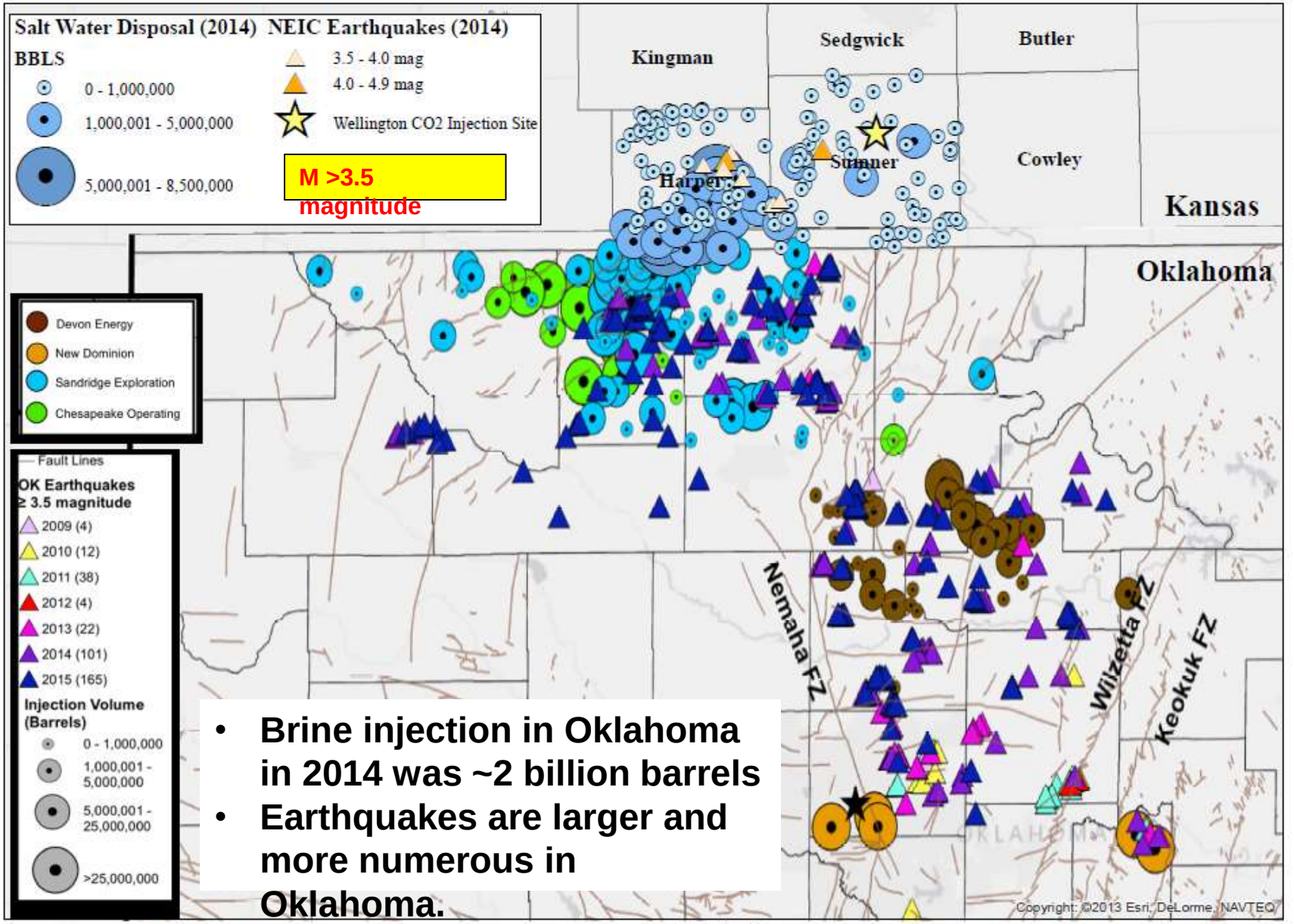


# Kansas Disposal Wells




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

# Earthquakes and geology in central KS and OK




- **Brine injection in Oklahoma in 2014 was ~2 billion barrels**
- **Earthquakes are larger and more numerous in Oklahoma.**

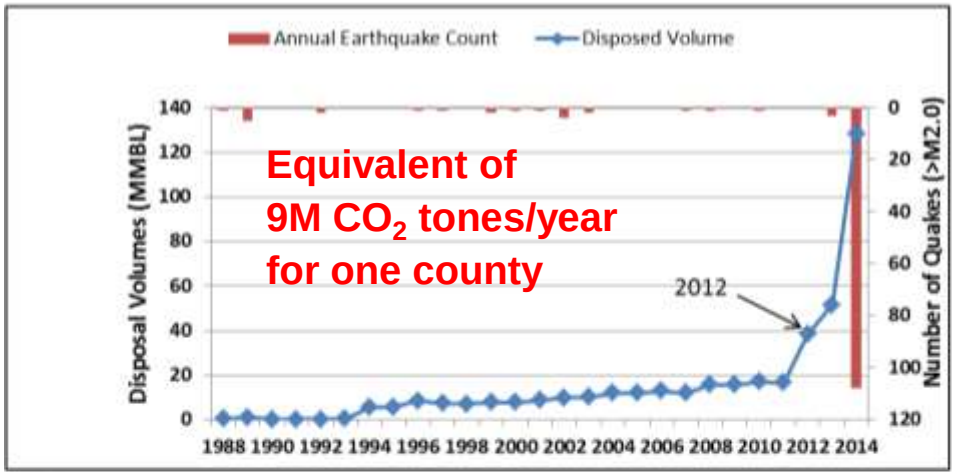
Map printed by J. Hollenbach 12/8/2015

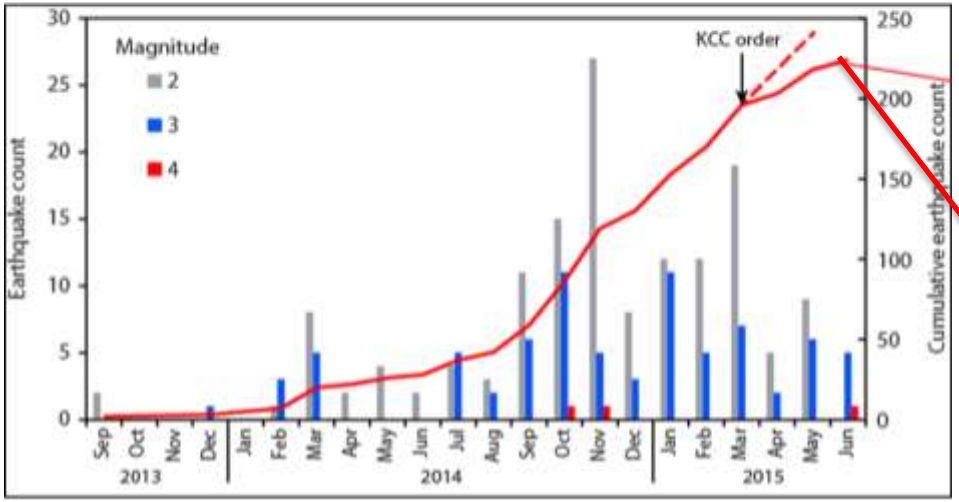
0 25 50 Miles

N

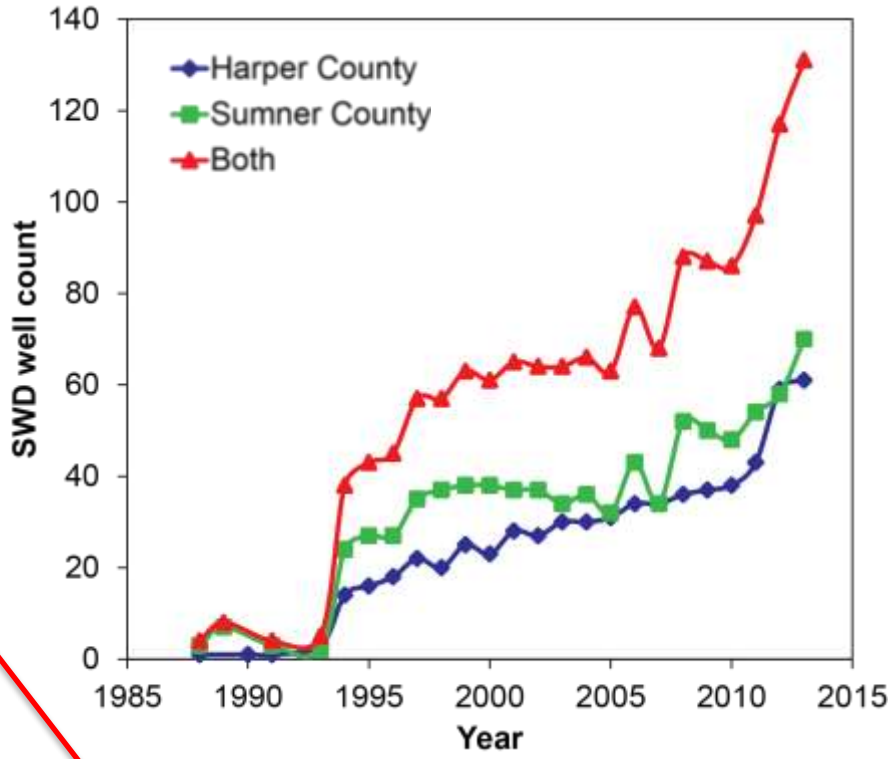
Sources: Kansas Geological Survey, Kansas Corporation Commission, NEIC, USGS, ESRI, Oklahoma Geological Survey, Oklahoma Corporation Commission
Oklahoma map - Public Justice lawsuit on behalf of the Sierra Club dated 10/29/2015

# Seismic and Waste Disposal Trends in Sothern Kansas




**Well count**

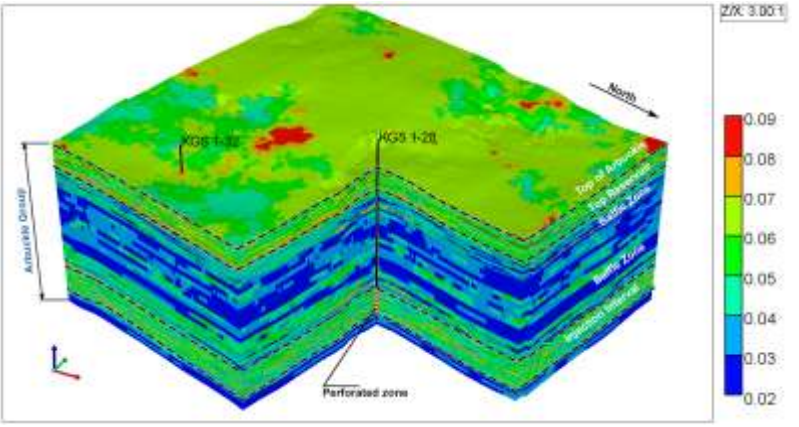



Slight reduction in seismic activity following state restriction order on injection volumes and other factors

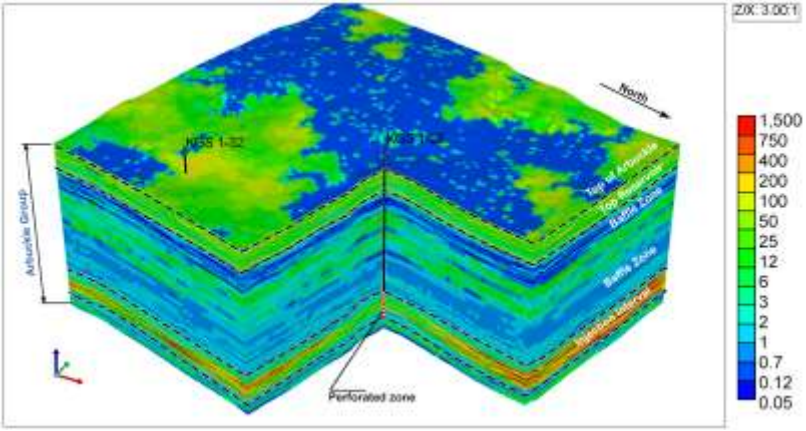
**T. Bidgoli**

# Common Analogs?

**Arbuckle Porosity Model**



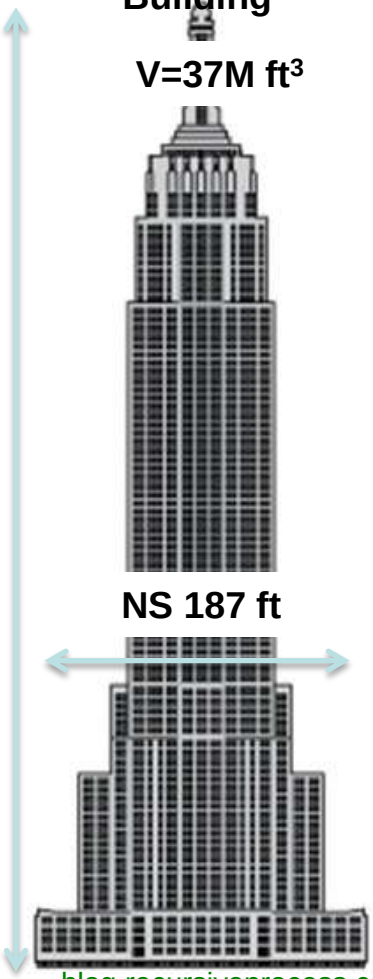

**Arbuckle Permeability Model**




- What is the capacity?
- Empty Volume = 37M $ft^3$ = 6.6M bbls
- If Ø = 5-7 %
- $Volume_{Ø}$ = ~450K bbls
- If efficiency = 50 %
- $Volume_e$ = ~ 225K bbls
- High volume wells used to deliver up to 30K bbls/day
- Therefore

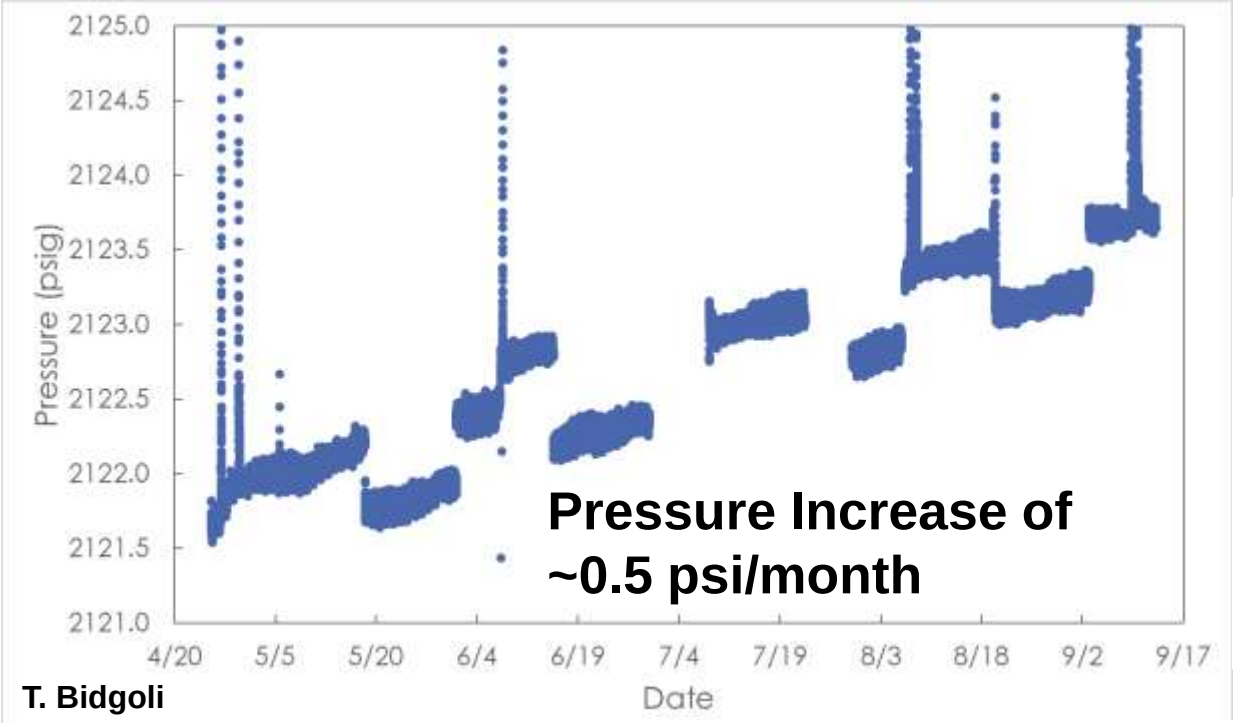
  It would take up to 7-15 days to fill up this volume (<u>without considering existing water</u>)
- It would take 111-222 “ES units” to accommodate 50M bbls injected in 2014
- Translates into 4-8M $ft^2$
- Harper Co. Area = 22B $ft^2$
- “Plunging” system?

**Empire State Building**



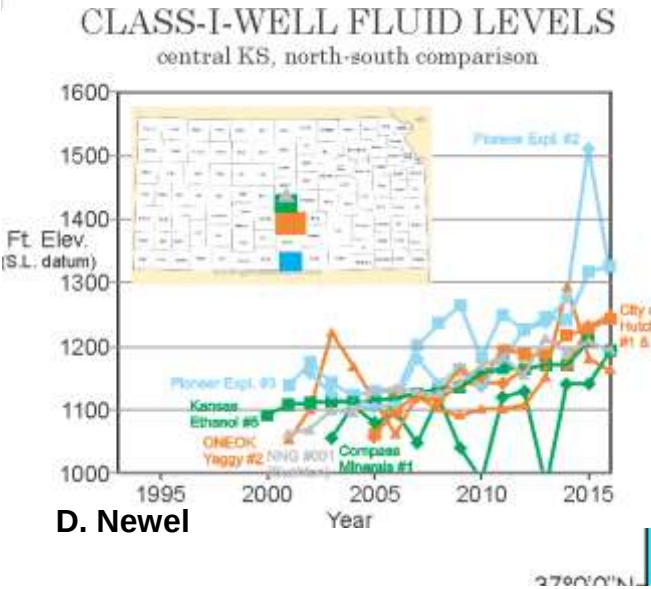

blog.recursiveprocess.com

# Kansas Regional Pressure Increase



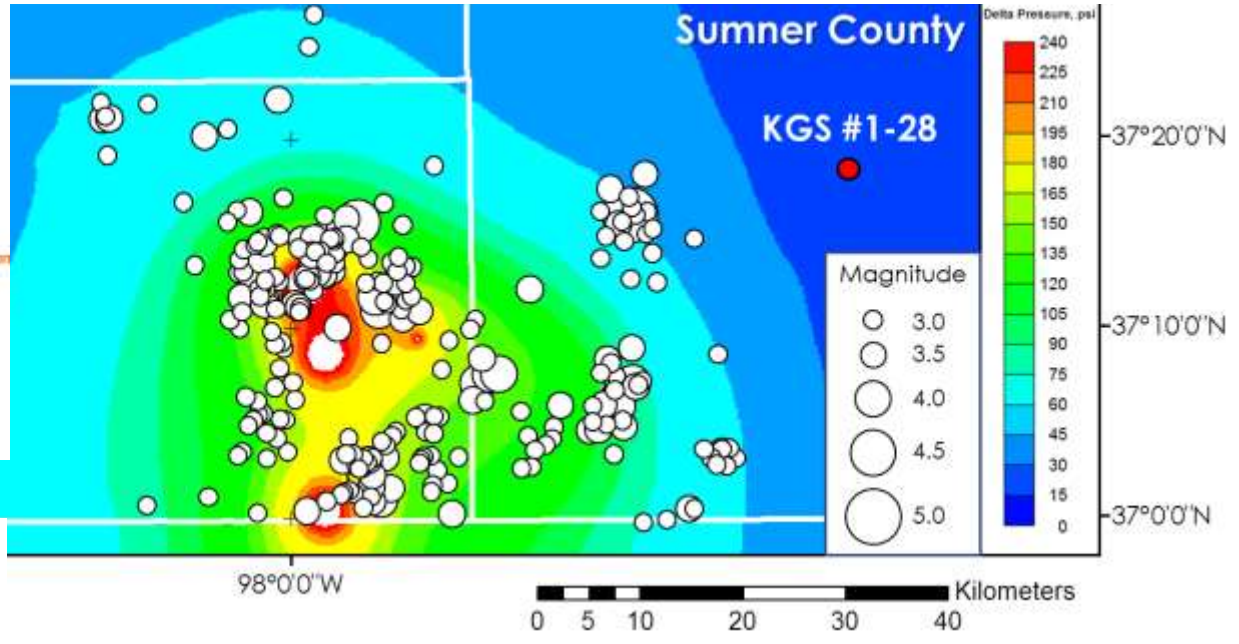

T. Bidgoli

- 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**




D. Newel

## Simulation model: Δ 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 $CO_2$ 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 $CO_2$ capture and supply, an excellent partner for the project, provided steady supply of $CO_2$
- 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

# 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 Yevhen Holubnyak, 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.*