

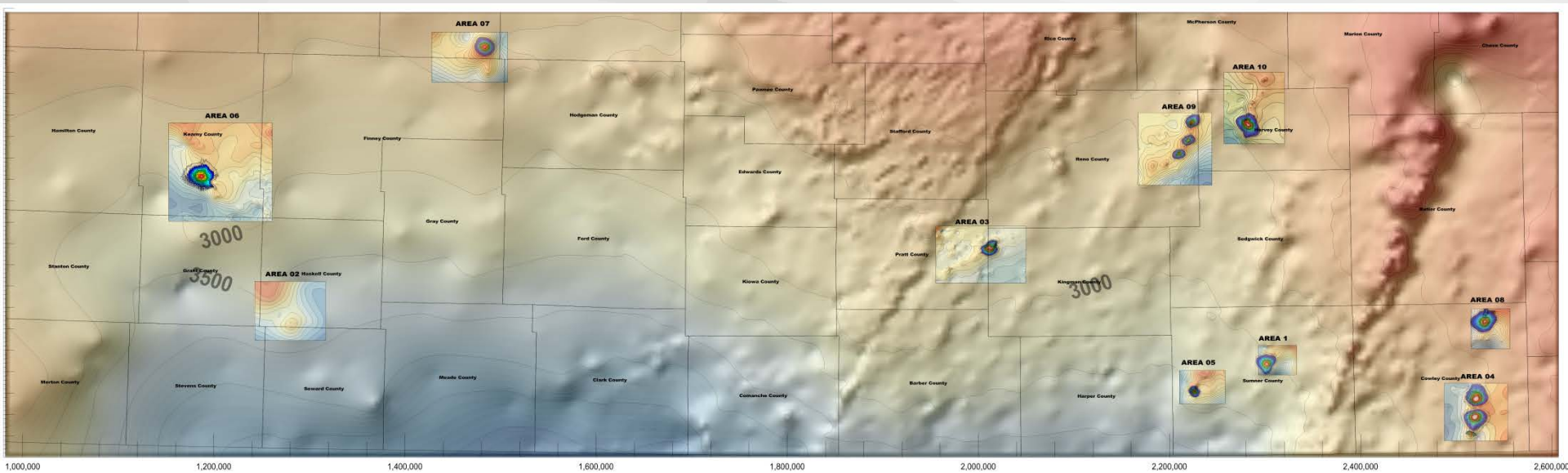
# CARBON CAPTURE, UTILIZATION & STORAGE CONFERENCE



**JUNE 14-16, 2016 | SHERATON TYSONS CORNER | TYSONS, VA**

[www.ccusconference.com](http://www.ccusconference.com)

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# Lessons Learned from Waste Water Disposal in Kansas: Applications for CO<sub>2</sub> Geological Storage

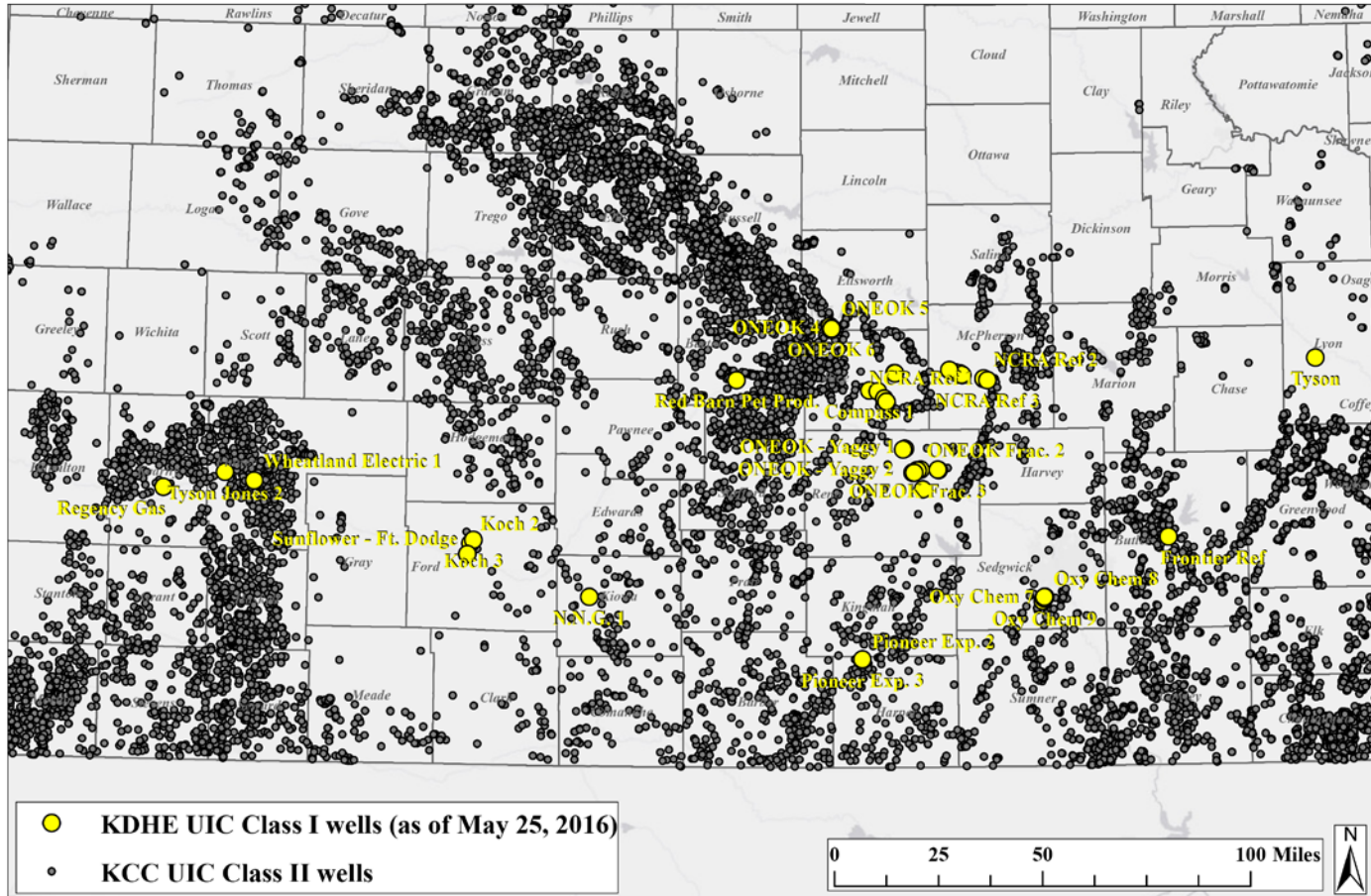
Yevhen Holubnyak, Lynn Watney, and Tandsis S. Bidgoli



# Outline

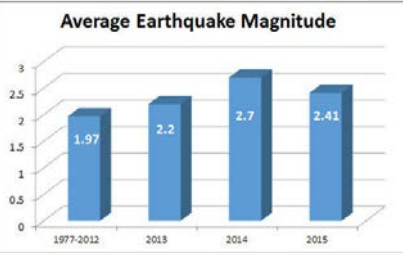
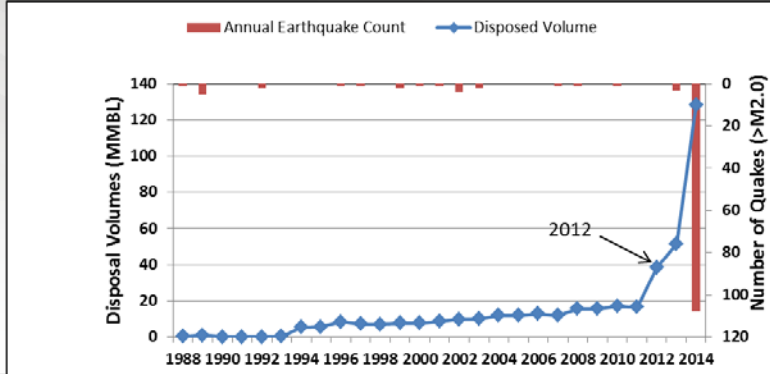
- Current state of seismicity and waste disposal in Sothern Kansas
- Waste disposal targets? Arbuckle group properties
- Modeling and observations

# Kansas Disposal Wells

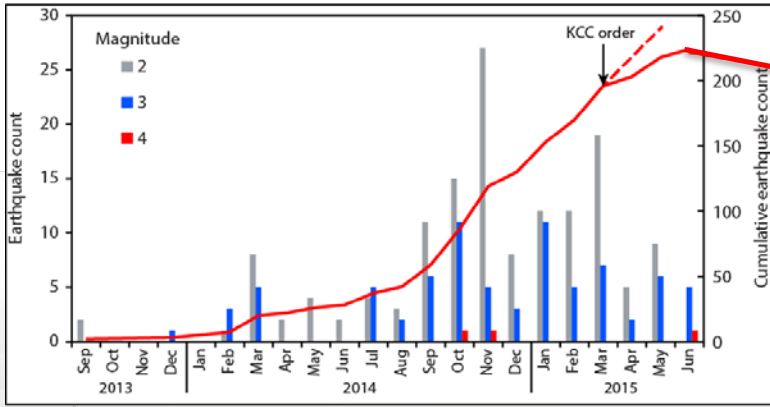
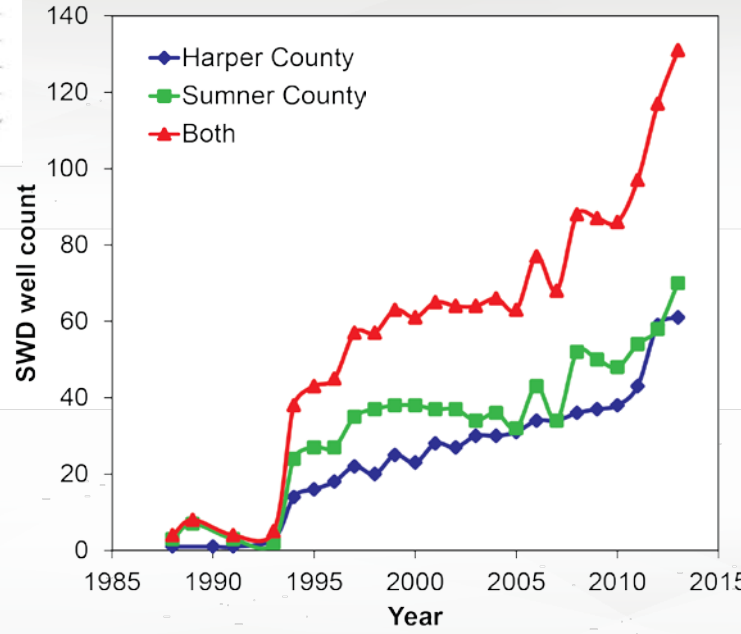


Sources: Kansas Department of Health and Environment, ESRI, USGS, Kansas Corporation Commission, Kansas Geological Survey

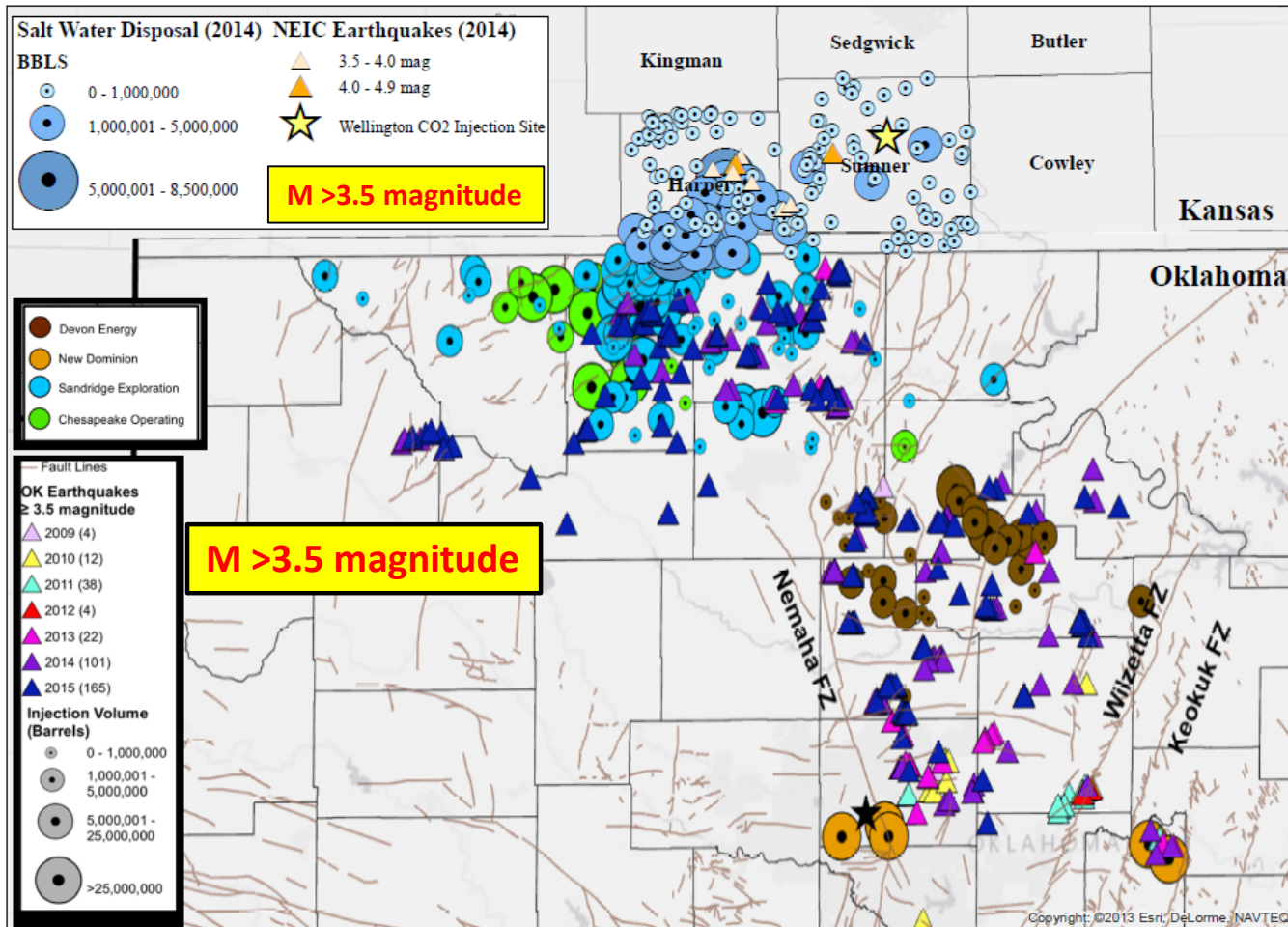
# Seismic and Waste Disposal Trends in Sothern Kansas



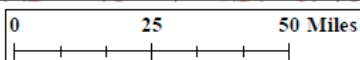
## Well count



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



Map printed by J. Hollenbach 12/8/2015



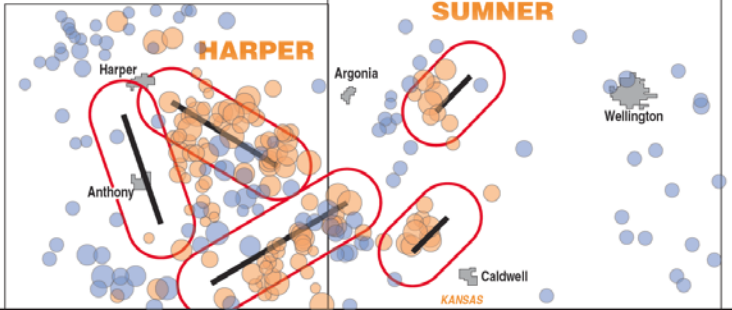
Sources: Kansas Geological Survey, Kansas Corporation Commission, NEIC, USGS, ESRI, Oklahoma Geological Survey, Oklahoma Corporation Commission  
Oklahoma map - Public Justice lawsuit on behalf of the Sierra Club dated 10/29/2015

## Earthquakes and geology in south-central KS and north-central OK

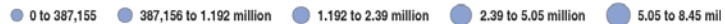
- Brine injection in Oklahoma in 2014 was ~2 billion barrels
- Earthquakes are larger and more numerous in Oklahoma.

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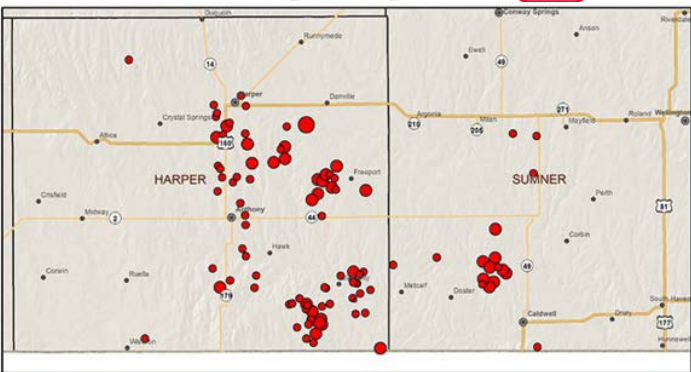
# Saltwater disposal wells in earthquake zones



## Disposal wells amount (in gallons)



## Earthquakes (in magnitude)



Kansas Geological Survey  
Data from USGS  
3 August 2015



Monitoring Earthquakes in Kansas

Conservation Division  
285 N. Main St., Ste. 220  
Wichita, KS 67203-1513

State Earthquake Chief  
Jay Scott Linka, Commissioner  
Pat Apple, Commissioner

**Kansas**  
Corporation Commission

Phone: 316.337.6200  
Fax: 316.337.6411  
http://kcc.ks.gov/

Steve Fair Abrick, Chair  
Tara Brownback, Governor

**News Release**

**For Immediate Release**  
March 19, 2015

**KCC ISSUES ORDER REDUCING DISPOSAL VOLUMES  
IN PORTIONS OF HARPER AND SUMNER COUNTIES**

**Contact Information**  
Amy Gilbert, (785) 271-3190

Wichita, KS – Today, the Kansas Corporation Commission (KCC) issued an Order requiring a reduction in volumes of saltwater injected into the Arbuckle formation in certain areas of Harper and Sumner counties.

The Order sets limits for Arbuckle injection wells located within five areas of seismic concern identified by the Kansas Geological Survey (KGS) in Harper and Sumner counties. The KGS determined areas of seismic concern by applying the Kansas-Induced Seismicity Task Force's Seismic Action Score (SAS) to the areas' earthquake activity recorded from January 2014 through February 2015. The recorded data is available from the U.S. Geological Survey's National Earthquake Information Center. The SAS used here is part of the Seismic Action Plan developed at the direction of Governor Brownback through the coordinated efforts of the KGS, the KCC, and the Kansas Department of Health and Environment.

The Order requires operators of Arbuckle saltwater disposal wells in these five areas to limit their injection wells to 16,000 barrels of saltwater per day within 10 days of the Order; to 12,000 barrels per day within 55 days; to 8,000 barrels per day within 100 days, for a total reduction of up to 60% on certain injection wells over this timeframe. These operators also will be required to regularly report data showing their compliance with the Order. The KGS will continue to measure the seismic activity in these areas. The Order directs KCC staff to work in conjunction with the KGS to review the data, with recommendation to the Commission for further action, if necessary.

**SPECIAL REPORT**  
The Hutchinson  
**NEWS**

# Kansas Quakes

[Kansas Quakes Home](#)
[Latest News](#)
[Quake Tracker](#)
[The Freshing Link](#)
[FAQs](#)
[Resources](#)

When earthquakes started rattling Kansas in 2013 they were met mostly with bemusement. But hundreds of earthquakes later the shaking earth has changed bemusement to concern. The Hutchinson News tracks earthquake activity each week, and investigates the questions that are leaving Kansas residents a little shaky.

**Quake Tracker**

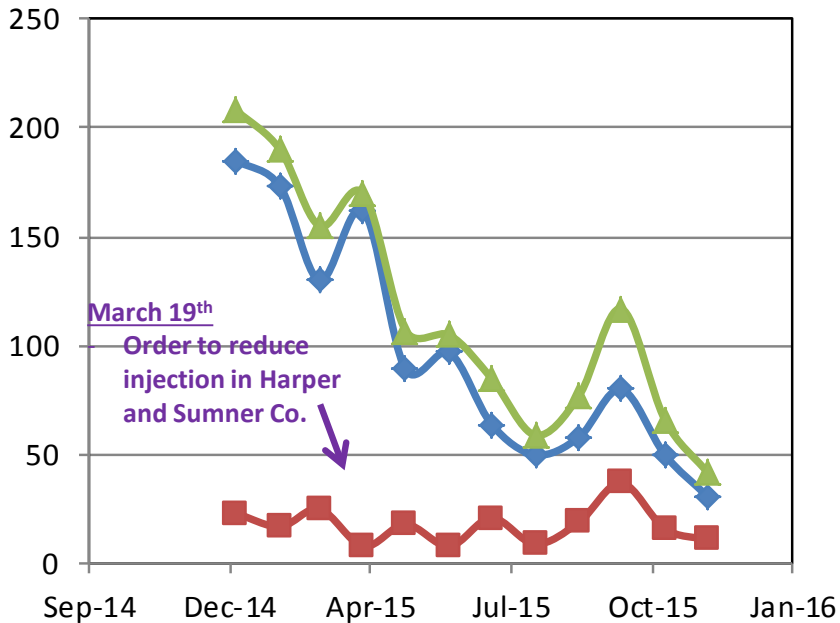
The map below plots all earthquakes recorded in south central Kansas and northern Oklahoma since 2013. Slide the magnitude control to filter the results by earthquake strength. Use the year checkboxes to show or hide data from various years. Hover over a point to see more detail about that earthquake.

**Latest Area Earthquakes**

M 2.2 - 14km SE of Perkins, Oklahoma  
15 hrs ago

**Latest Earthquake News**

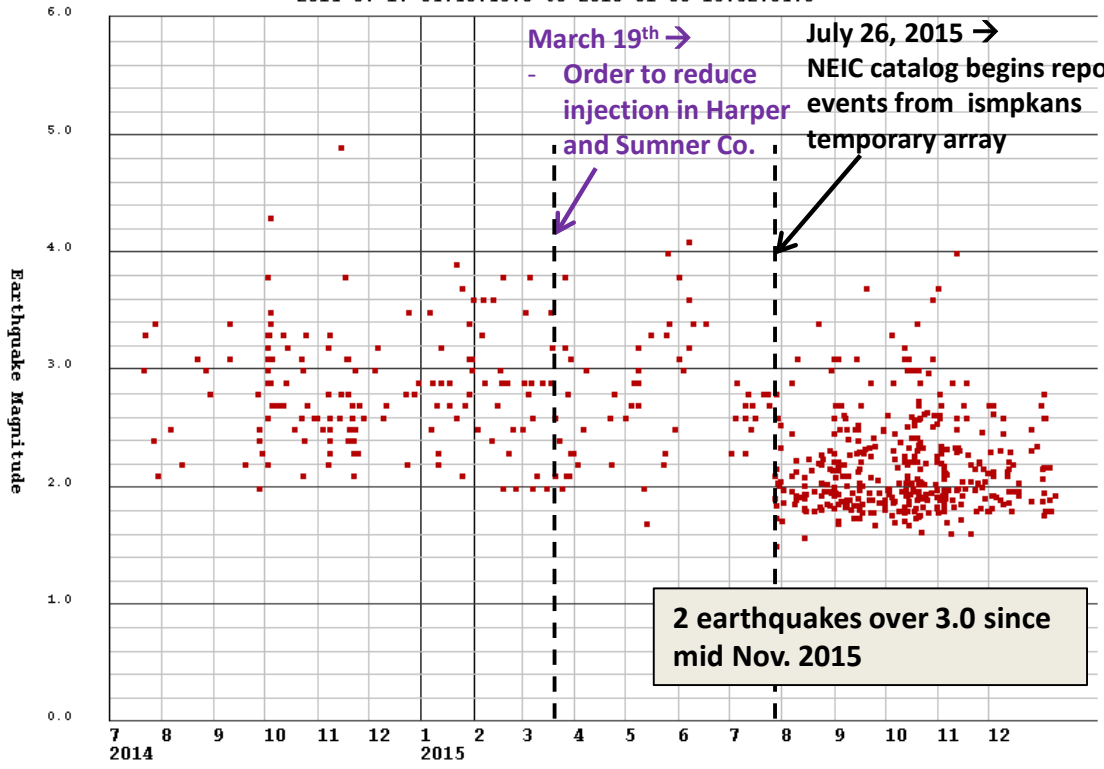
- Recent earthquake centered near Caldwell neighborhood
- Week-hours earthquake is upgraded to 4.7 magnitude
- Big earthquakes didn't stop after last week's 4.7 tremor
- Rainy residents among thousands who feel early a.m. earthquake originating in Oklahoma
- Quake numbers drop this week



- ◆ ismpkansas
- USGS without ismpkansas
- ▲ All sources

Kansas Geological Survey  
Kansas Earthquakes

2014-07-17 04:40:43.0 to 2016-01-06 13:32:04.0



[http://www.kgs.ku.edu/PRS/Ozark/Software/KS\\_Earthquake\\_2DPlot/applet.html](http://www.kgs.ku.edu/PRS/Ozark/Software/KS_Earthquake_2DPlot/applet.html)

# Kansas Earthquakes as Reported by NEIC

- First report on July 26, 2015 of new USGS temporary array "ismpkans" in Harper & Sumner counties

November 19, 2015

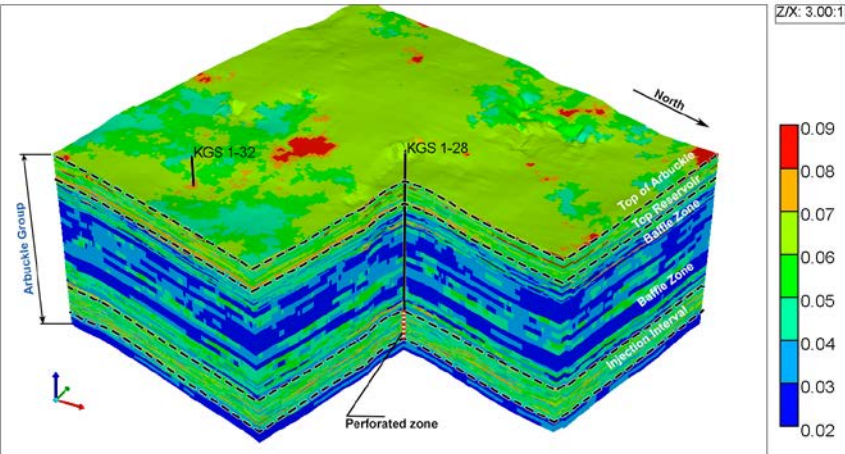




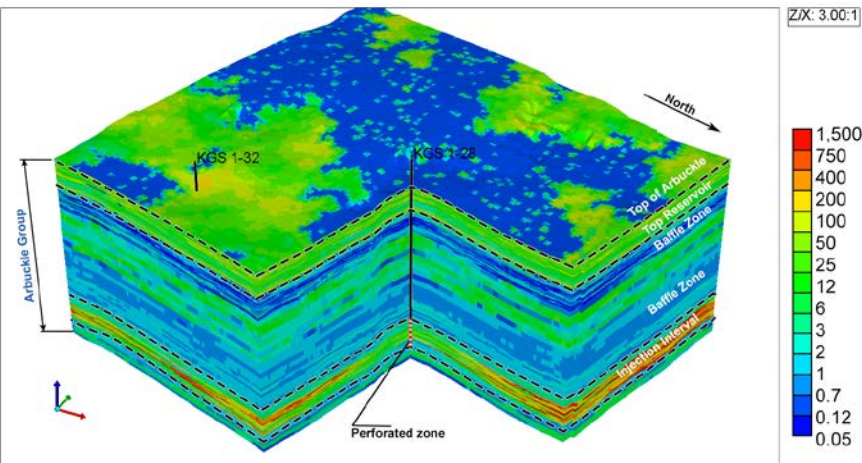
# What Do We Know About Arbuckle?

- ~1000 ft thick carbonate
- ~5-7% porosity
- ~200 mD permeability
- Under-pressured (location dependent)
- Basement conditions? Faults?
- Waste disposal target for over 30 years

## Arbuckle Porosity Model



## Arbuckle Permeability Model



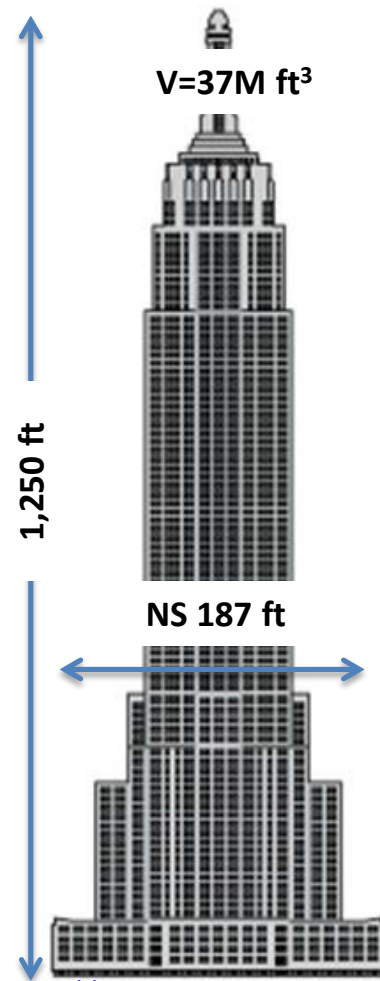
# Common Analogs

- What is the capacity?
- Empty Volume = 37M ft<sup>3</sup> = 6.6M bbls
- If  $\phi = 5-7\%$
- Volume <sub>$\phi$</sub>  = ~450K bbls
- If efficiency = 50 %
- Volume<sub>e</sub> = ~ 225K bbls
- High volume wells used to deliver up to 30K bbls/day
- Therefore

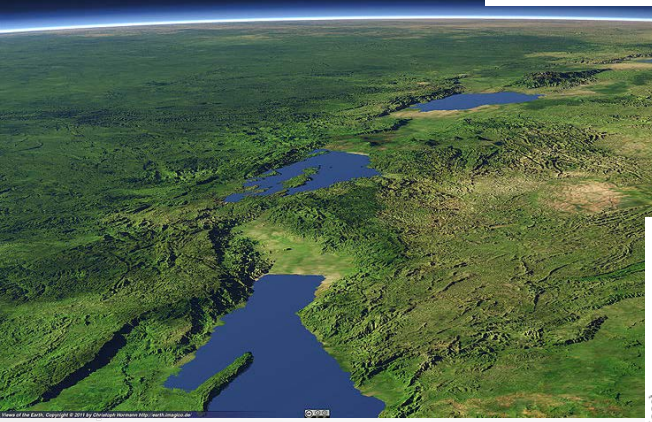
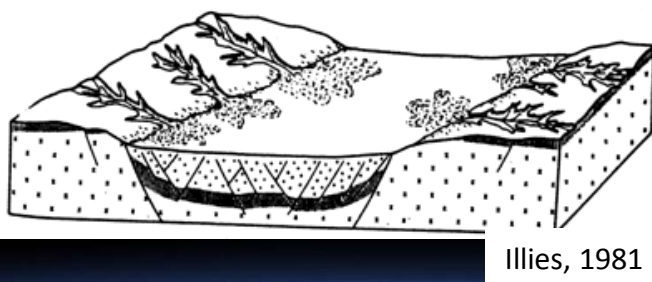
It would take up to 7-15 days to fill up this volume (without considering existing water)

- It would take 111-222 “ES units” to accommodate 50M bbls injected in 2014
- Translates into 3.9-7.8M ft<sup>2</sup>
- Harper Co. Area = 22.4B ft<sup>2</sup>
- “Plunging” system?

## Empire State Building

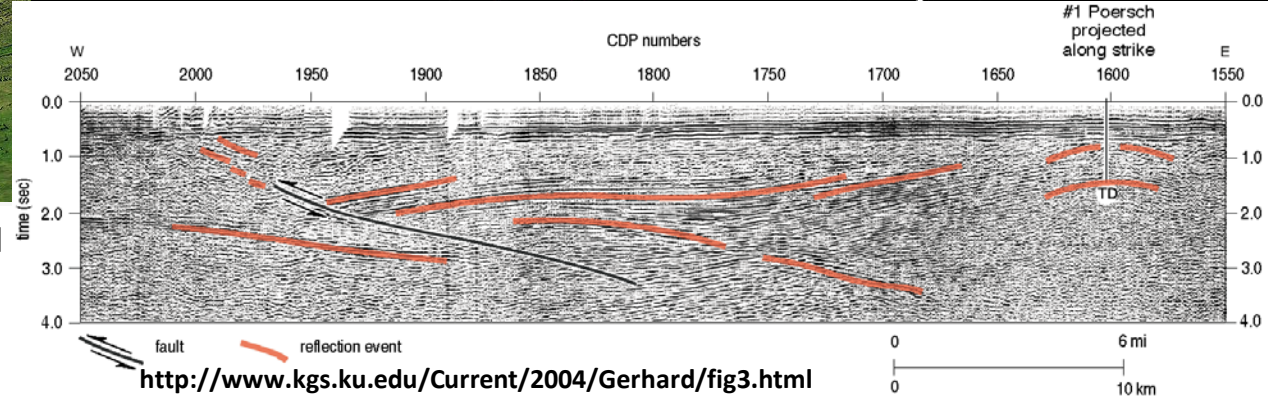
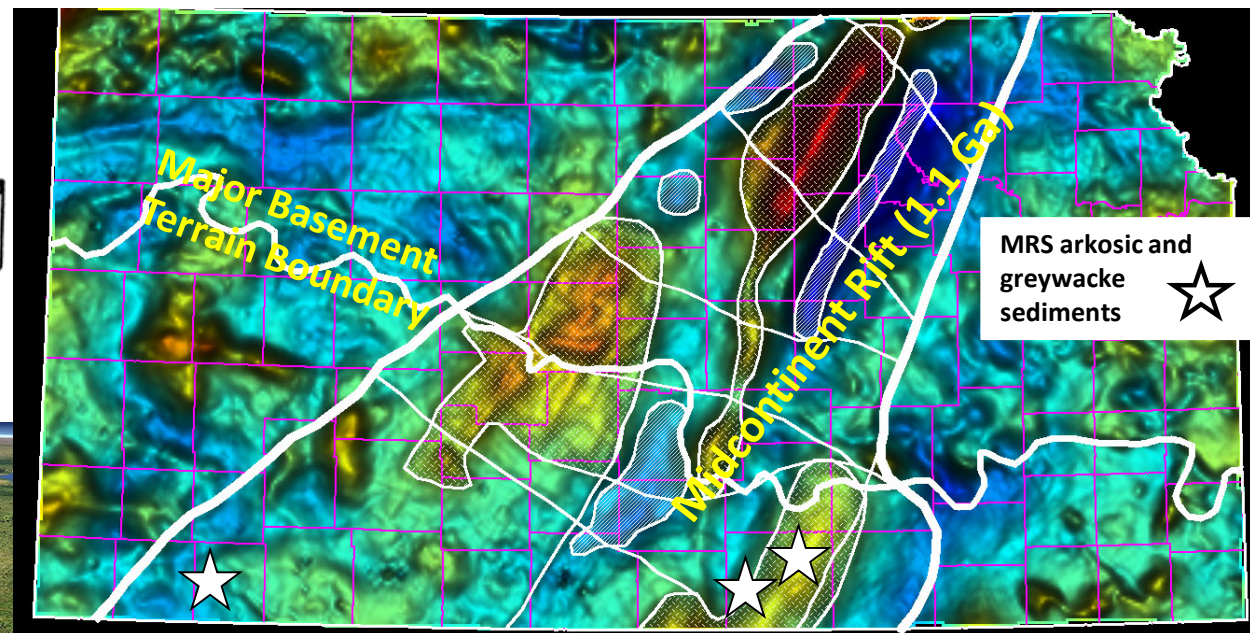


East African Rift is a Modern analog to the Midcontinent Rift System  
 → Both large graben systems

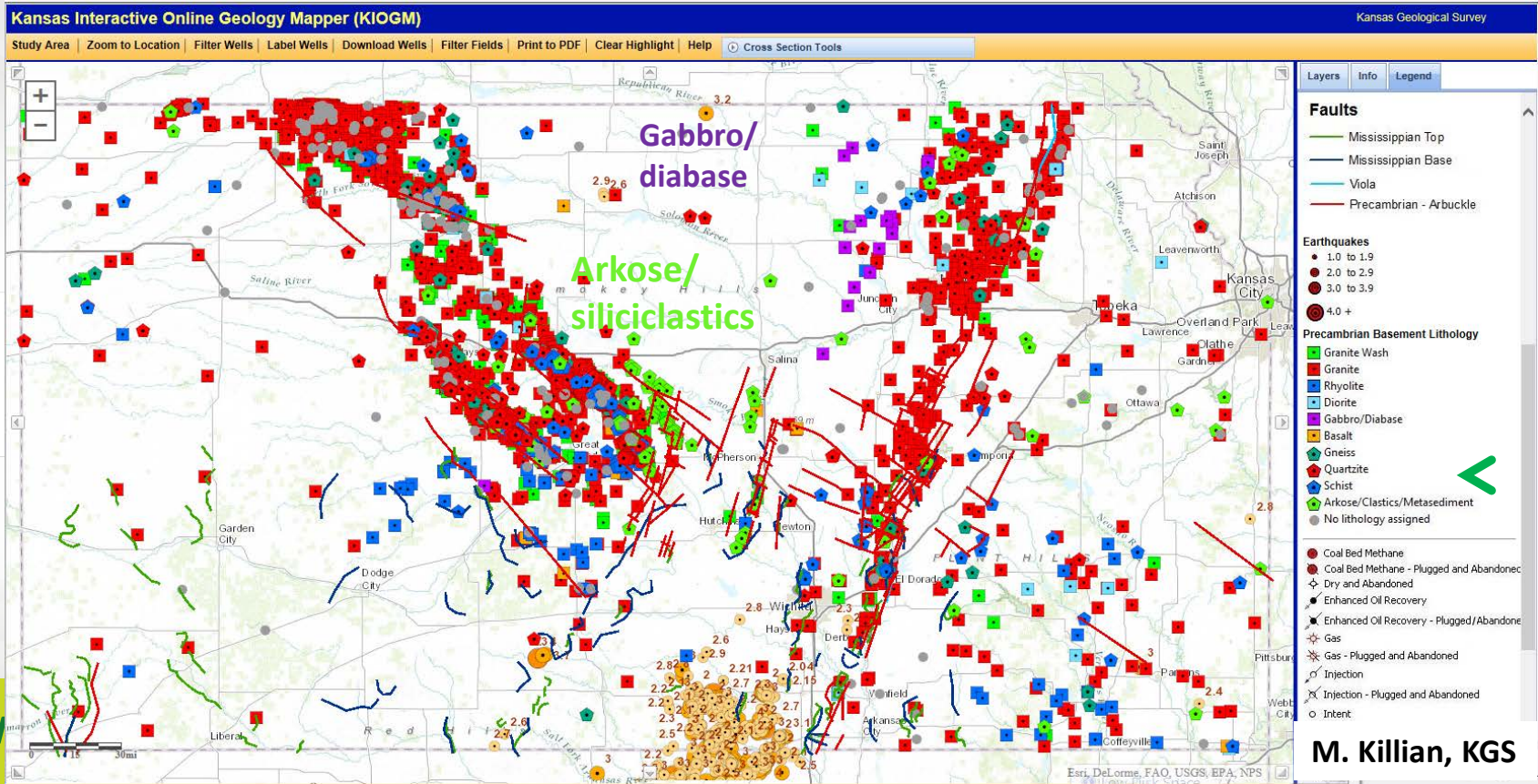


"Albertine Rift, East African Rift (artificial rendering)" by Christoph Hormann - <http://earth.imagico.de/view.php?site=rift2a>

Bouguer Gravity -- with rift and sub-elements, terrain boundary through Kansas (Kruger, 1999)



# Basement geology from sample rock types in the area of the induced seismicity → thick arkosic sediment fill indicative of the Midcontinent Rift System (MRS)





# Small Scale CO<sub>2</sub> Injection Project

- Very limited data on Arbuckle group existed
- Several wells drilled, cored, logged, etc.
- Well tests performed
- 3D and Seismic

# Core from Lower Arbuckle Injection Interval

5089-92 ft



5080-83



5053-56



4995-97.7 ft

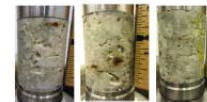


## Lower Arbuckle Injection Zone

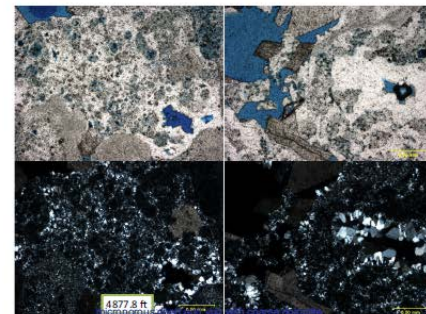
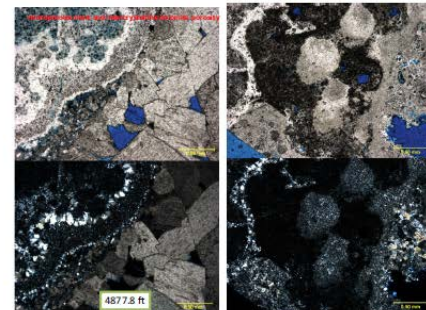
Lower Arbuckle  
(Gasosade)  
Lower hydrostratigraphic unit  
Flow unit -  
Proposed injection unit

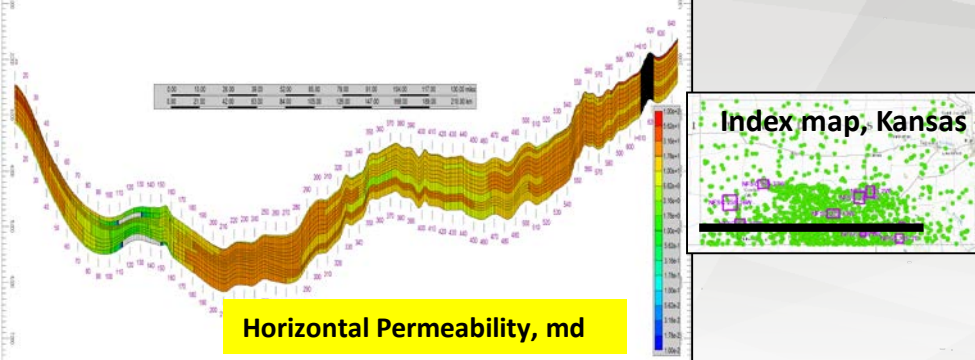


31-19  
4977.8'

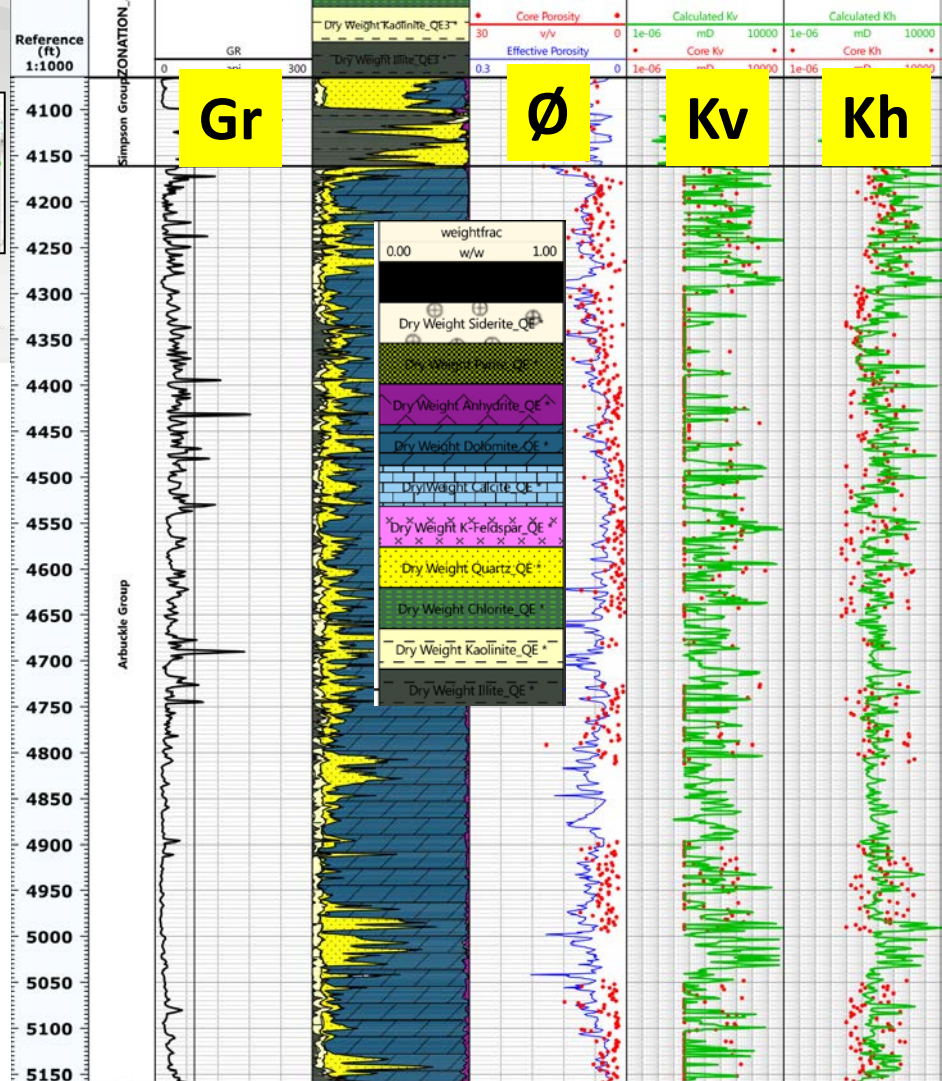
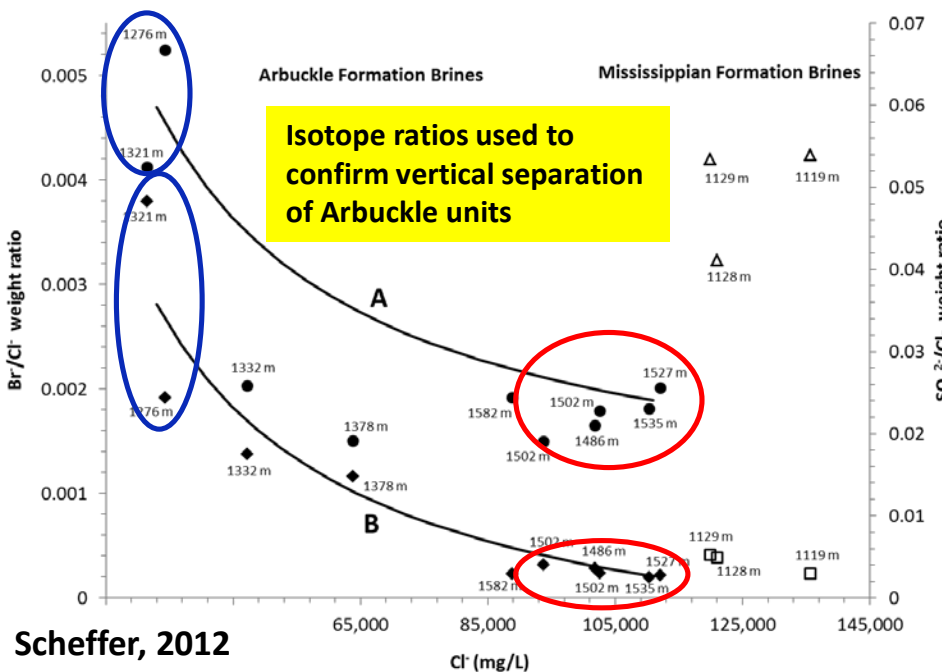


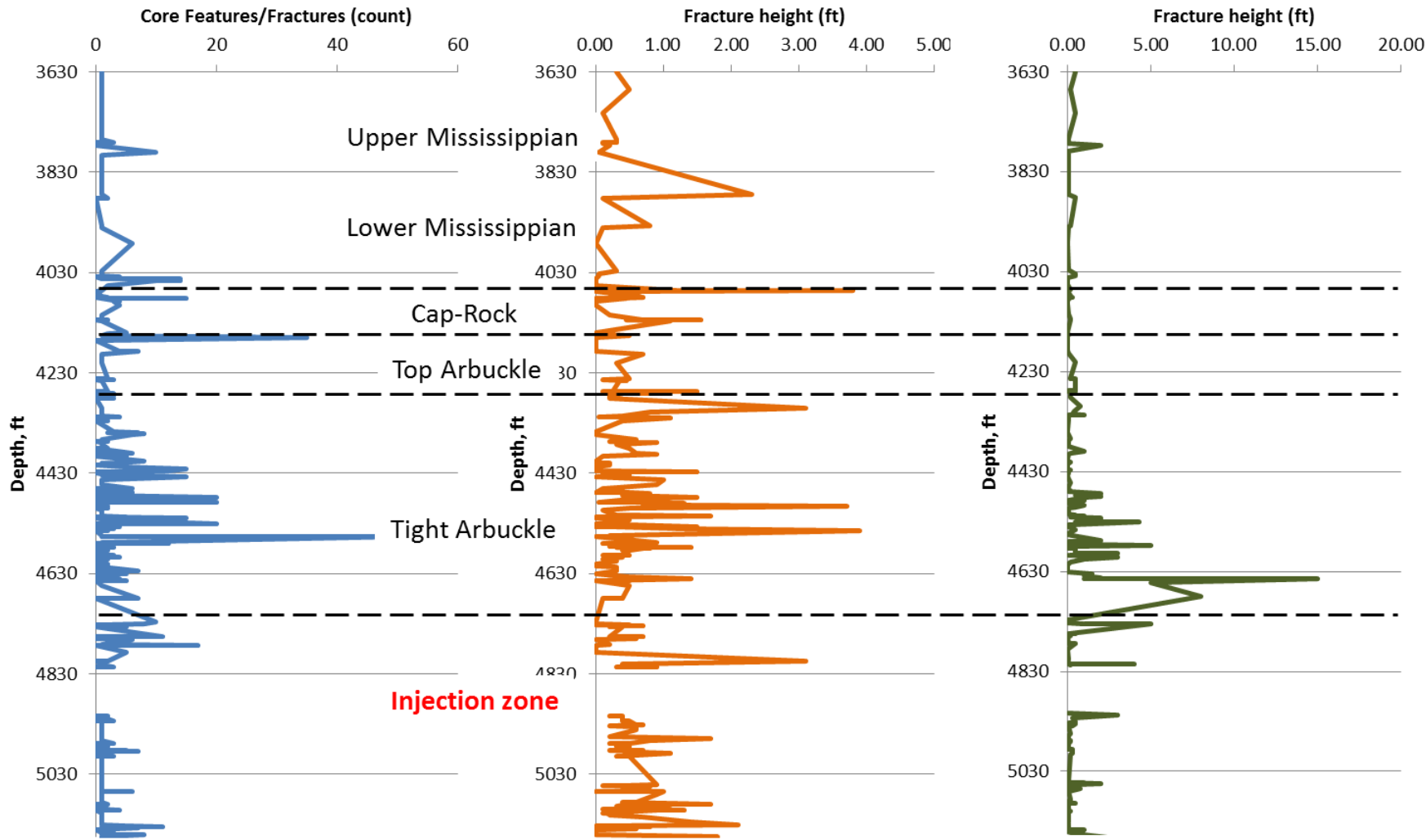
whole core: phi 8.8% 4 md



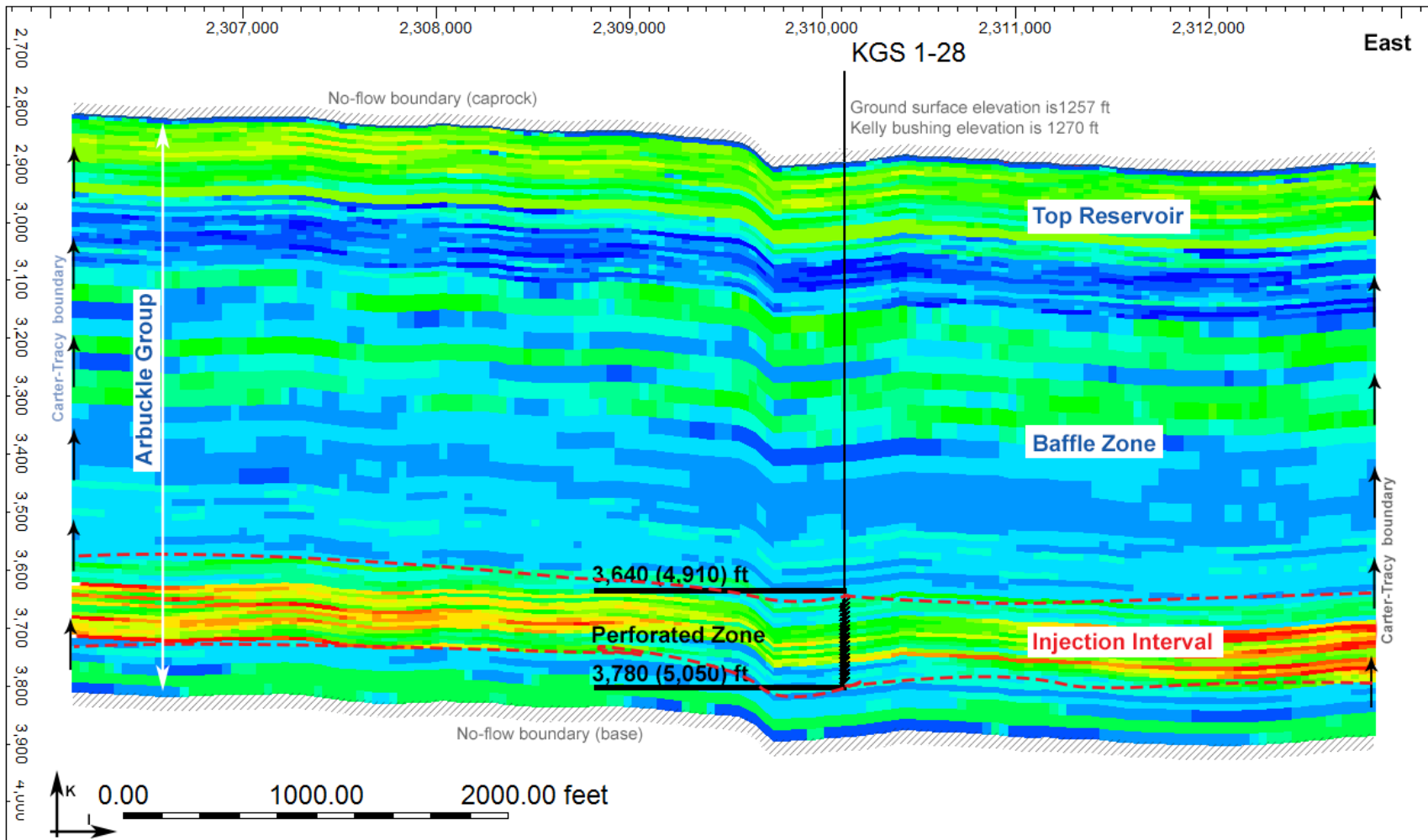


● Arbuckle Br/Cl<sup>-</sup> — Hypothetical Mixing Curve ▲ Mississippian Br/Cl<sup>-</sup> ◆ Arbuckle SO<sub>4</sub><sup>2-</sup>/Cl<sup>-</sup> □ Mississippian SO<sub>4</sub><sup>2-</sup>/Cl<sup>-</sup>

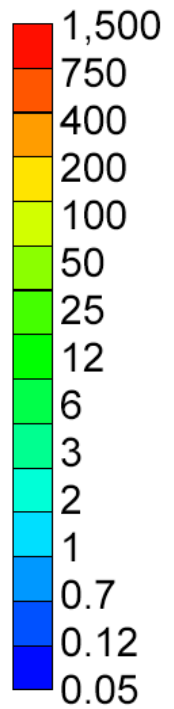








Scale: 1:8682  
Z/X: 3.00:1  
Axis Units: ft

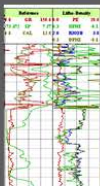


# Workflow for reservoir simulation and geomechanical analysis

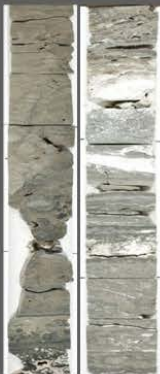
Data

Well logs

Tops



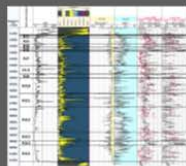
Core data



Dynamic data

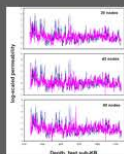
Reservoir  
Characterization

Multi-mineral FE

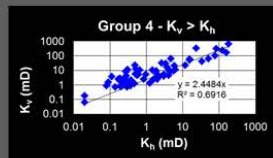


FZI-SWPHI

K prediction via ANN



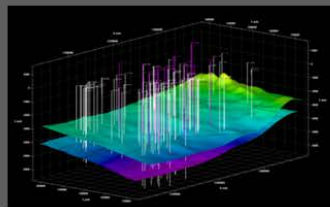
$K_h$  and  $K_v$  relations



Flow units

Static model

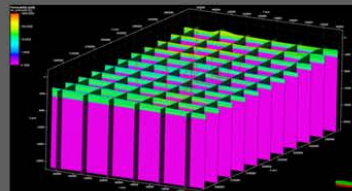
Structural model



Upscale logs

Statistical analysis

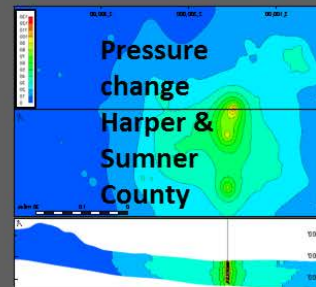
Property models



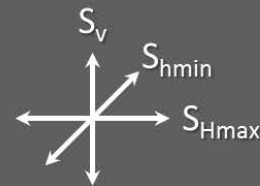
Geomechanical  
model

Dynamic  
model

Reservoir  
simulations

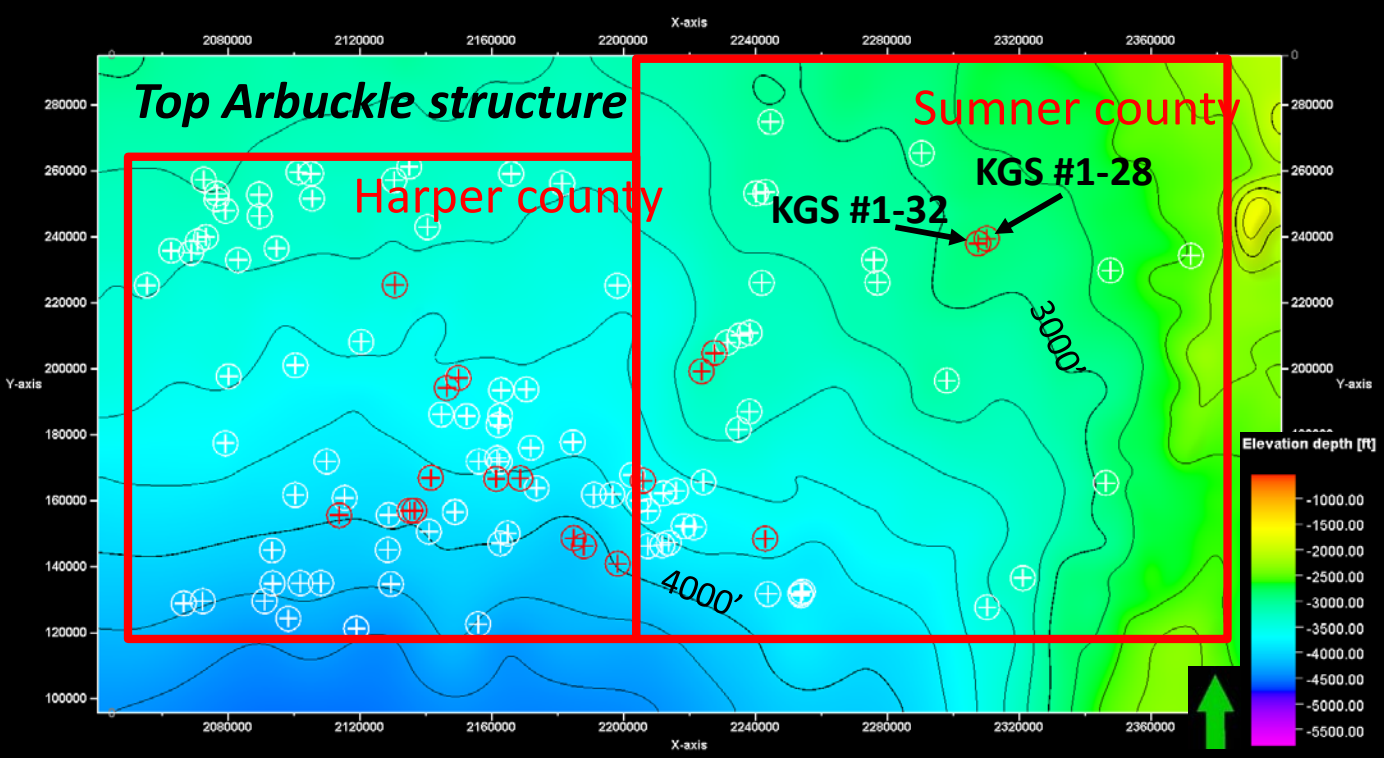


Geomechanical  
simulations



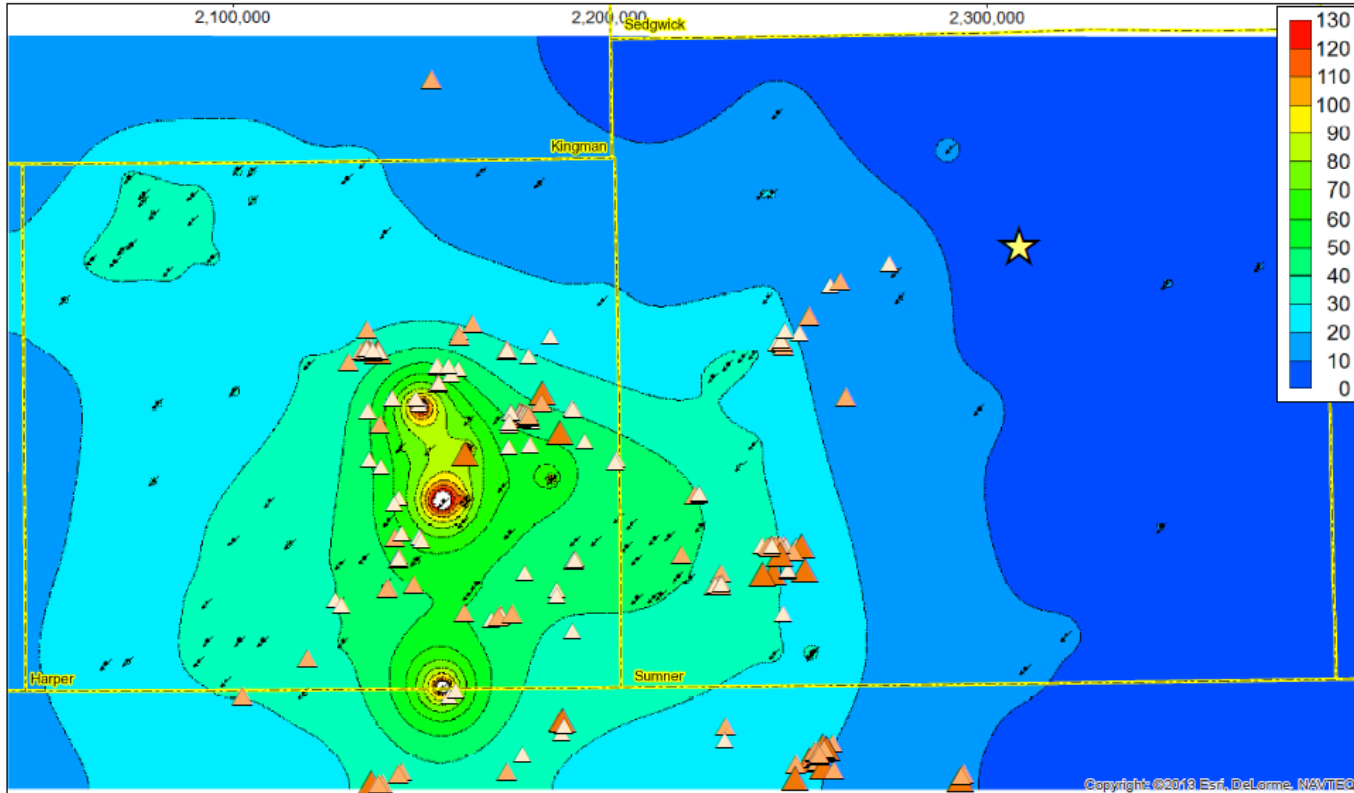


# Model Area



- 18 wells for property analysis
- 4 complete penetrations with log data
- 103 SWD wells with yearly injection data

# January 2015 Delta Pressure (psi)



## January 2015 Events

### magnitude

- ▲ 1.5 - 2.0
- ▲ 2.0 - 3.0
- ▲ 3.0 - 3.7



Wellington CO2 Injection Site

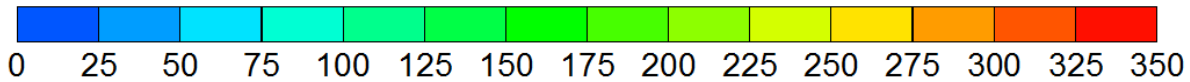
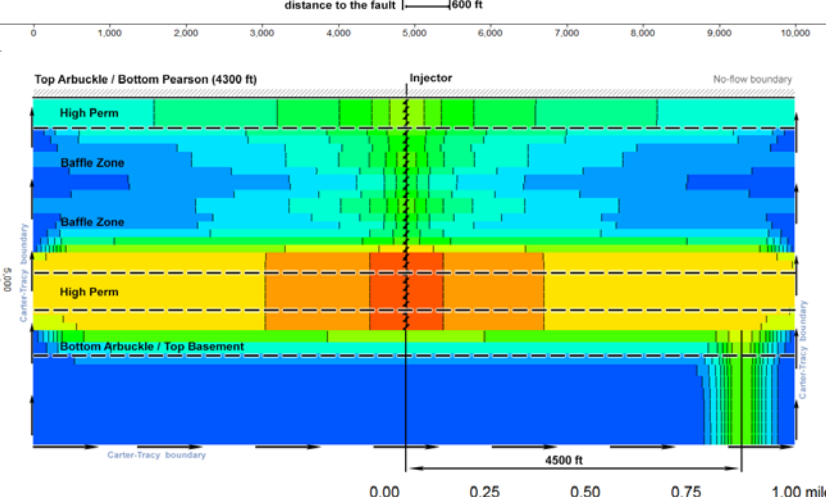
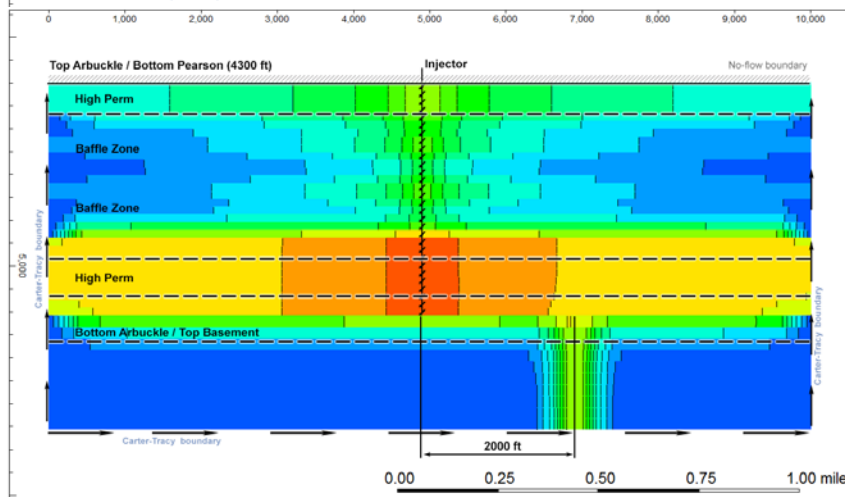
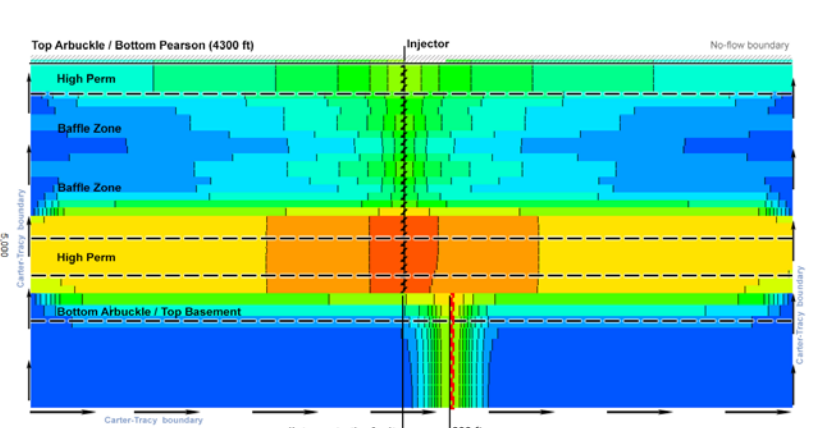
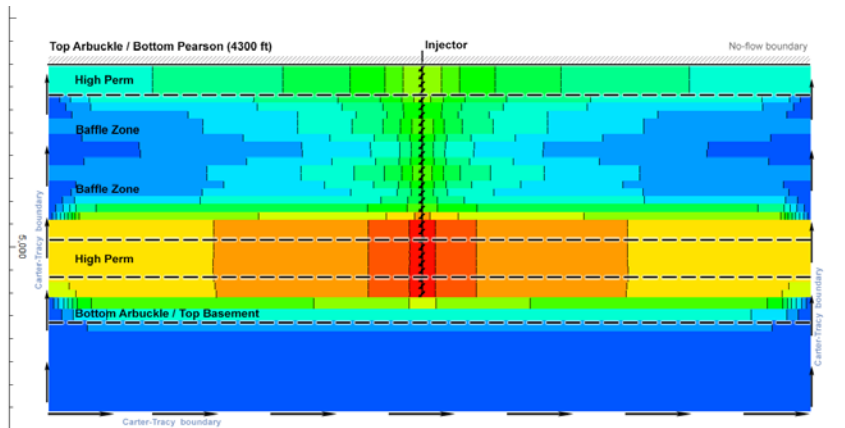
Kansas Geological Survey, Kansas Corporation Commission, NEIC, USGS, ESRI, Oklahoma Geological Survey, Oklahoma Corporation Commission

Map printed by J. Hollenbach 12/8/2015

# Modeled Delta Pressure for Harper and Sumner Counties in South Kansas

#CCUS

# Delta Pressure at a Basement Fault



# PRESSURE VS TIME

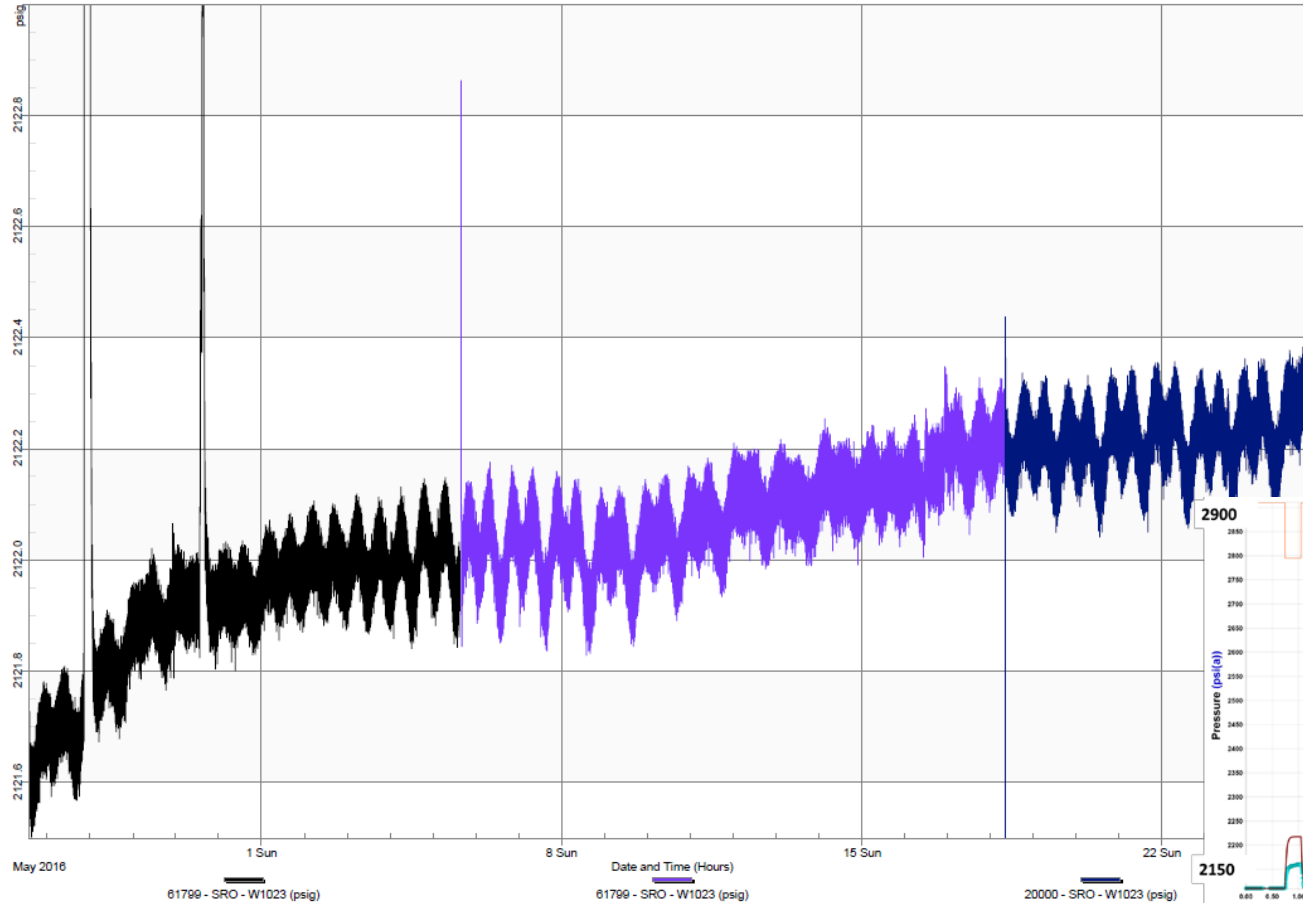
Company: KGS

Location: Wellington 1-28

Test Description: Monitoring induced seismicity near the Wellington oil field CO2 injection in the Mississippian and Arbuckle reservoirs

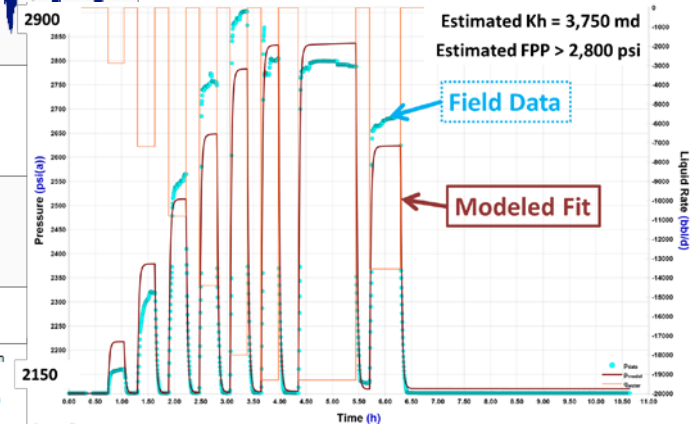
Serial# 61799

Comments: 3 runs merged into one



## Downhole Pressure Monitoring

- ~ 30 psi increase since 2011
- 16 psi pressure spikes





# Summary

- Arbuckle/basement interface?
- Injection management strategies
- Production strategies and water cut improvements
- Produced water treatment?

# Acknowledgements

- Bittersweet Energy – Tom Hansen with Paul Gerlach and Larry Nicholson; Dennis Hedke, Martin Dubois and SW Kansas CO<sub>2</sub>-EOR industry consortium, John Youle, George Tsoflias and students at KU, Gene Williams, and KGS staff supporting the acquisition of data, stratigraphic correlation, regional mapping, and interpretations for the DOE-CO<sub>2</sub> project
- Dana Wreath, Berexco, LLC for access and participation in drilling and testing at Wellington and Cutter fields and small scale field test at Wellington
- Rick Miller and Shelby Petrie, Wellington seismometer array, high resolution seismic
- Justin Rubinstein, USGS
- Induced Seismicity Task Force -- Rex Buchanan, Chair





# Acknowledgements & Disclaimer

## Acknowledgements

- *The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant DE-FE0002056 and 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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