Studying Seismicity in Kansas
Industry/Government Partnership

State Monitoring Networks
Consortium Monitoring Network
Active Earthquake Clusters and Observations

Dynamic Seismicity in Kansas

History of Seismicity

Current Statewide Network

Sub-Regional Network

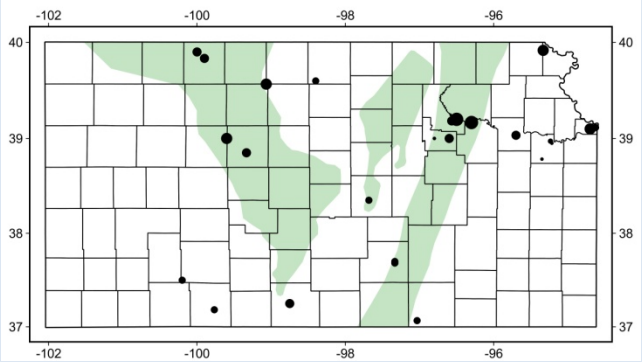
Consortium Network and Sensitivities

Interesting Clusters

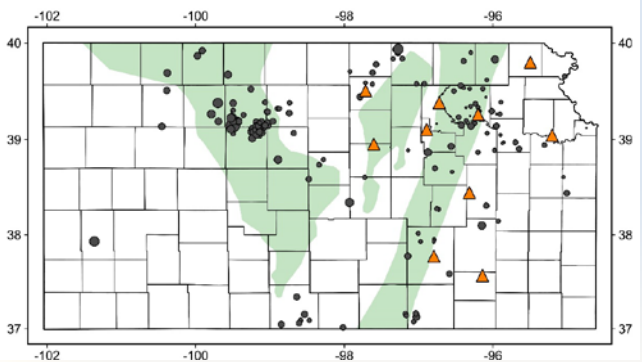
Current & Future Regional Network Funding

History Studying Earthquakes in Kansas

1867-1976 Historical Intensity Based on Documentation
110 years, 30 felt earthquakes, ~M2.5 to M5

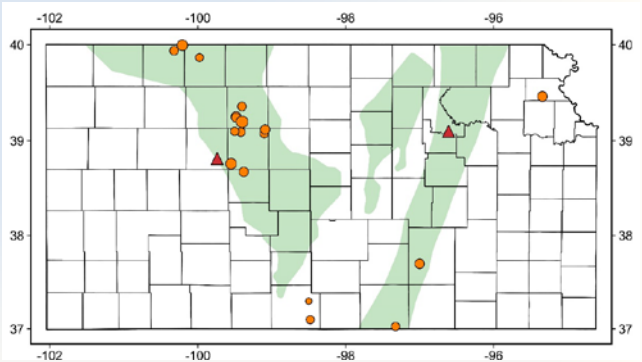


KGS Operated Network
1977-1989



13 years, 171 earthquakes, M0.5 to M4.0

USGS Operated Network
1990-2014

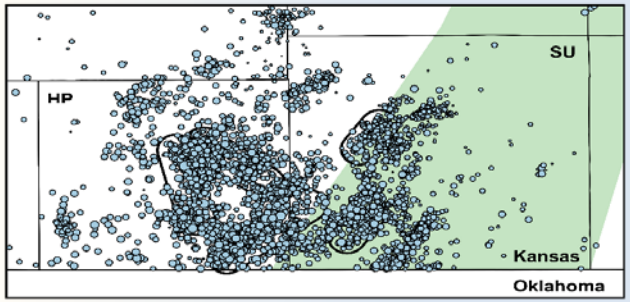


15 years, 18 earthquakes, M2.2 to M3.5

Ordered Reduction in Fluid Injection

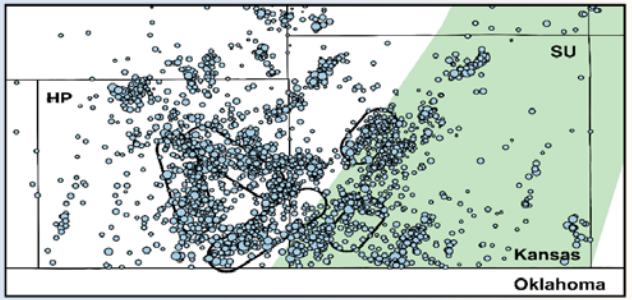
In 2015, the KCC ordered phased reduction in Arbuckle injection within 5 high seismicity zones

Vast potential of microseismic activity to understand and delineate sensitive structures

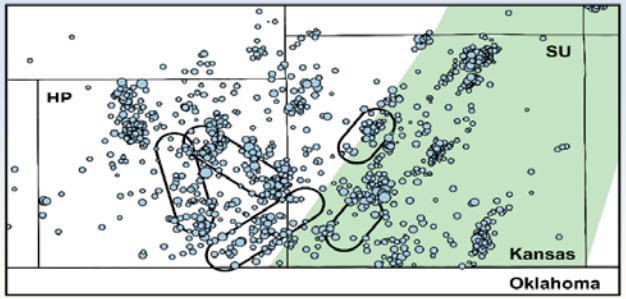


2015

Order fully in place

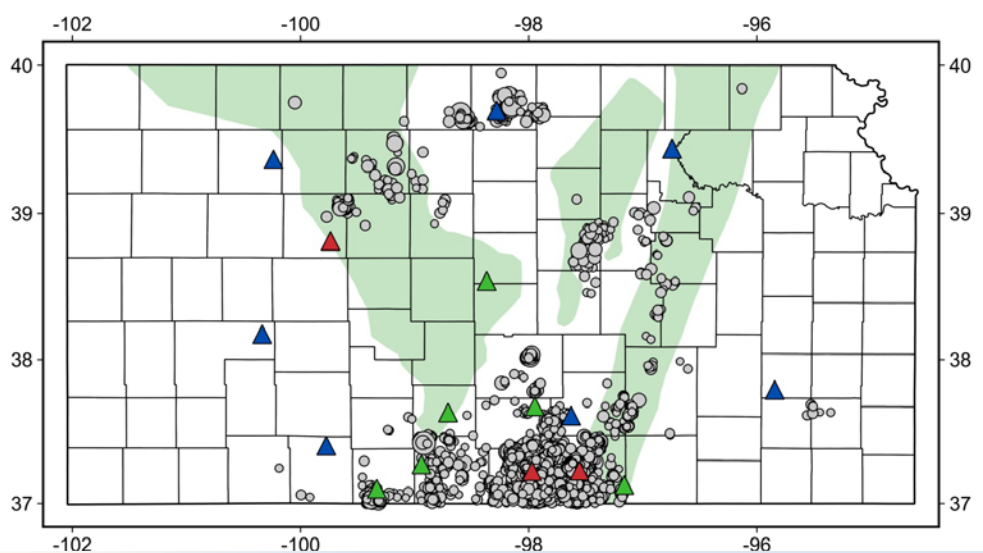


2016



2017

Earthquake Monitoring Restart at the KGS in 2015
Basic Make-up and Operations



- 7 KGS permanent stations—2 vertical & 2 horizontal
- 6 KGS temporary station—1 vertical & 2 horizontal
- 3 USGS stations occasionally used by KGS

2013-2016 Gov Task Force, KGS working with KS Dept of Health an Environment (KDHE) and KS Corp Commission (KCC)

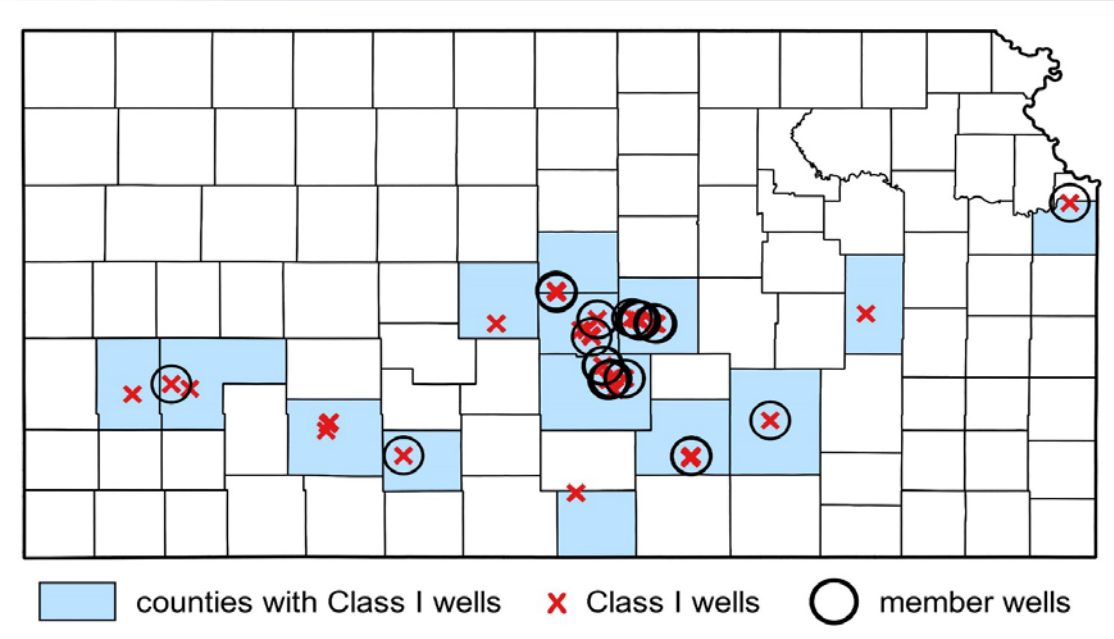
Real-time
- Earthworm system
- email alerts
- M ≥ 2

Near-real time
- Waveforms and preliminary catalog open access

Full catalog (1 week lag, currently 10,213 events)
- manual analysis of continuous data
- M ≥ 1.8 statewide (4,886 events, 2015 to present)
- M 1 in areas with enhanced network sensitivity

Since 2016 KGS working with KDHE & KCC developing online mapping & real time notifications, both in beta

Consortium Membership



Tier 1

Tier 2

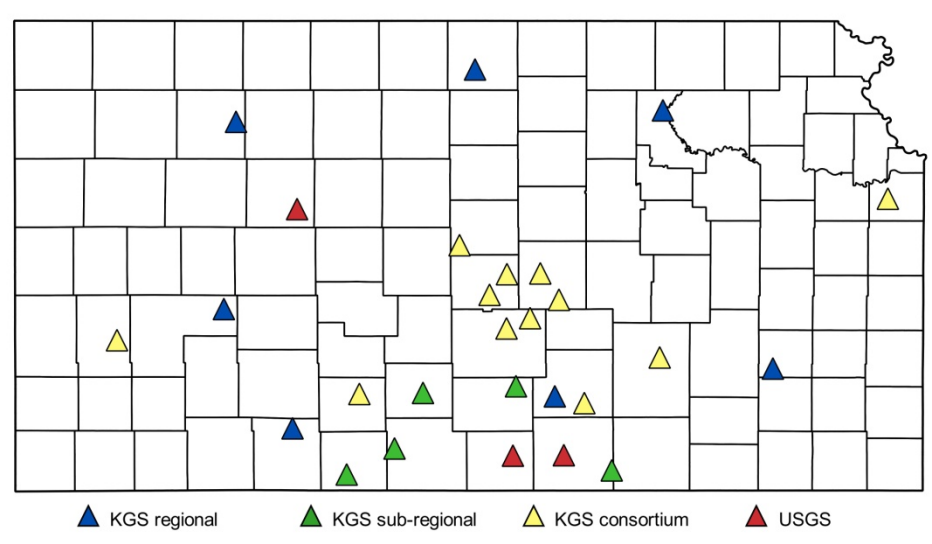
Combined Kansas Networks

Dense networks provide for enhance location accuracy and improves depth determinations

- USGS has more than 20 stations in Kansas, with all but two in southcentral Kansas focused on Harper and Sumner Counties
- Sub-regional initially sponsored by the KCC, but is currently operated and funded by KGS and designed to monitor for any expansion in the two county area where earthquakes were prominent during 2013-14
- Regional network designed to capture elevated seismicity that began occurring during 2014 and into 2015.

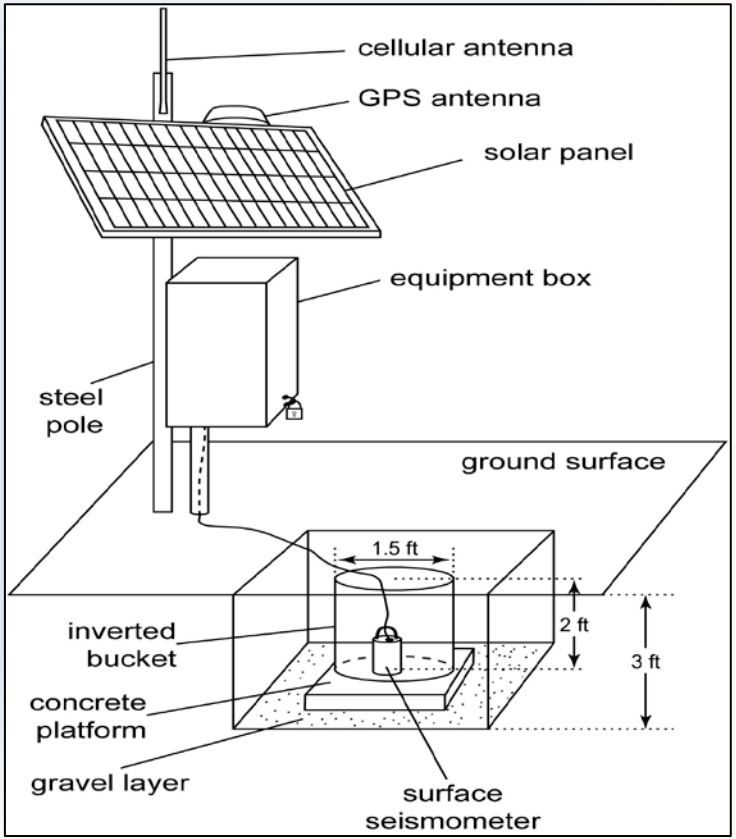
Continued escalation in several earthquake clusters is providing the catalyst for expanding the regional network further

- Consortium stations are complemented by the other networks, which increase the accuracy and allow for smaller earthquakes to be located than with consortium stations alone.

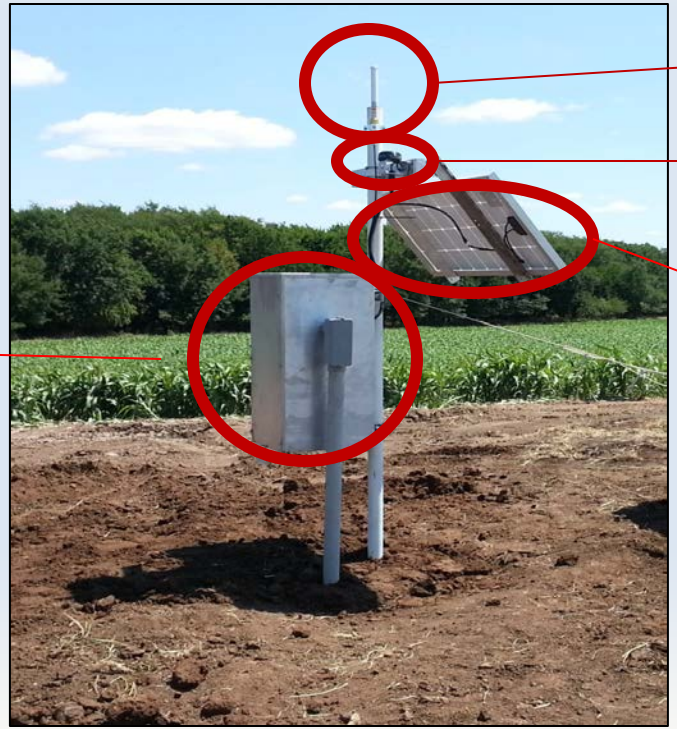


Seismic Station Installation

- Seismic sensor
  - Seismometer
  - Digitizer
- Real-time communications
  - cellular modem
  - cellular antenna
  - RTP server
- Power
  - 120 watt 12 V solar panel
  - charge controller
  - two deep-cycle marine batteries



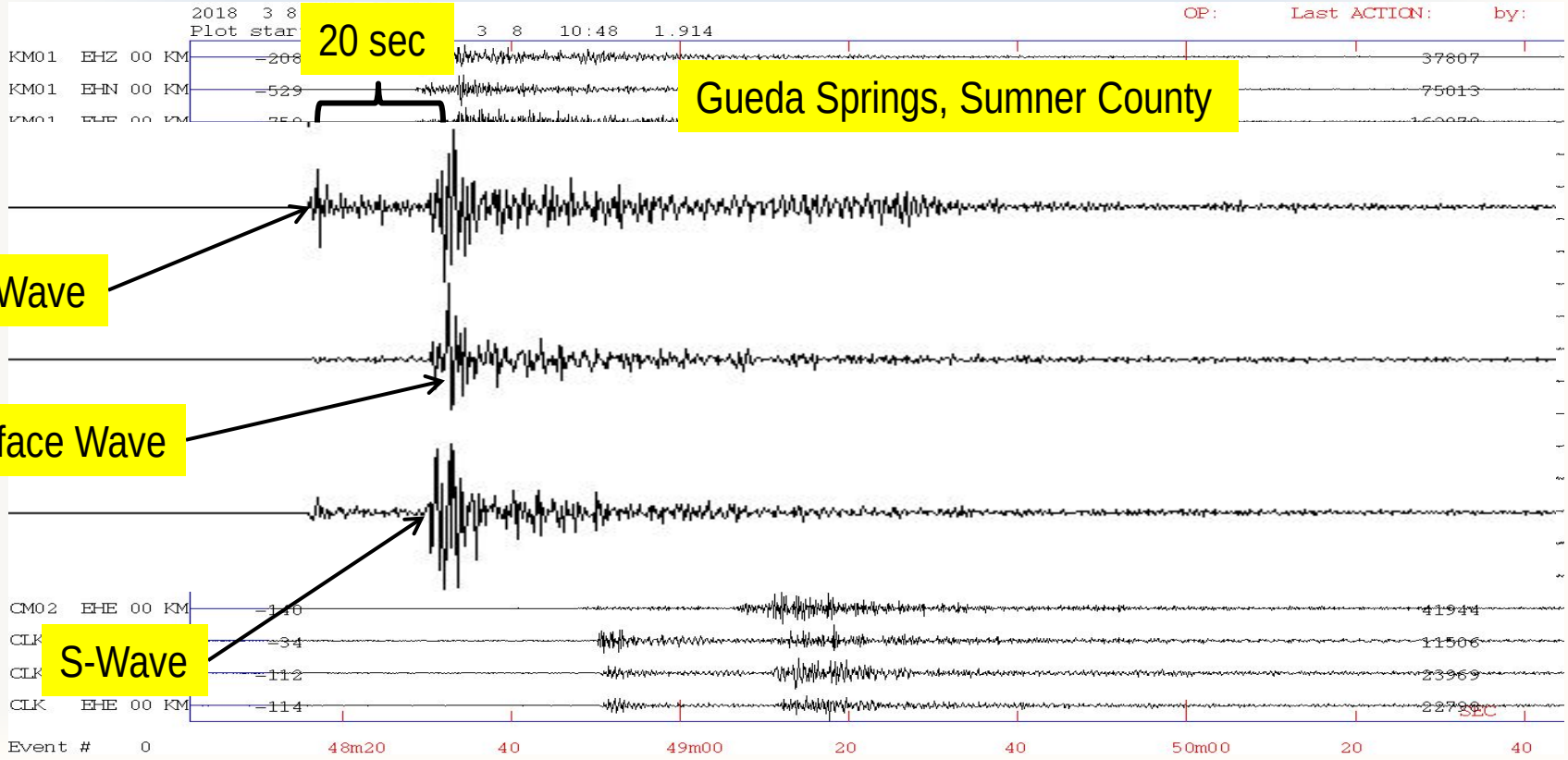
Seismic Station Installation



Seismic Station Installation

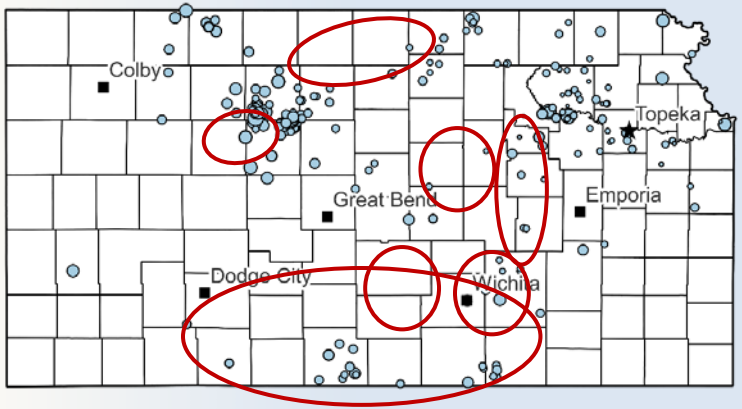
Seismic Station Installation

Hutchinson Cluster M3.6 Earthquake
March 8, 2018 4:48 AM

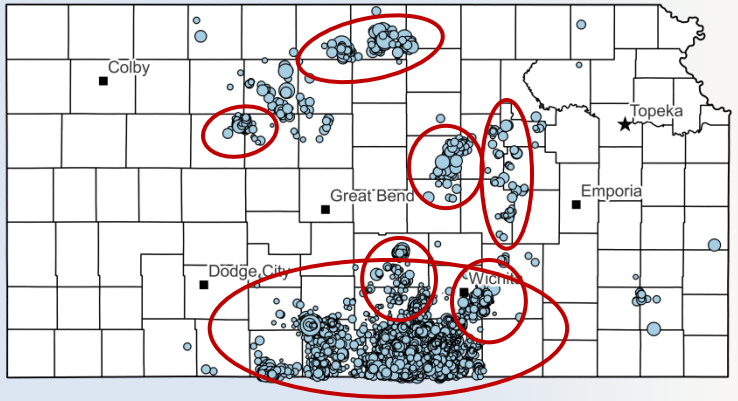


Historical Compared to New Normal

Nearly 150 years of consistent seismicity began
abruptly transitioning in 2013



1867 - 2012

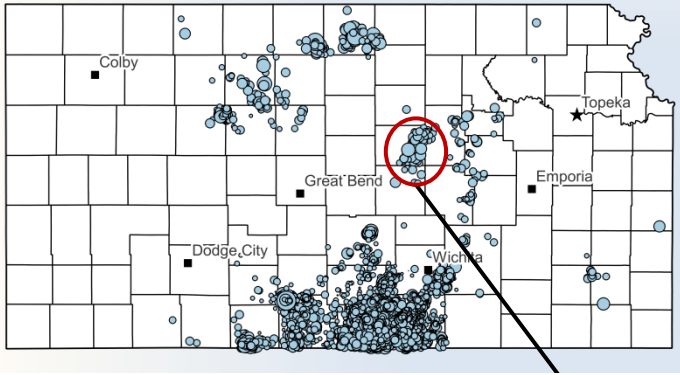


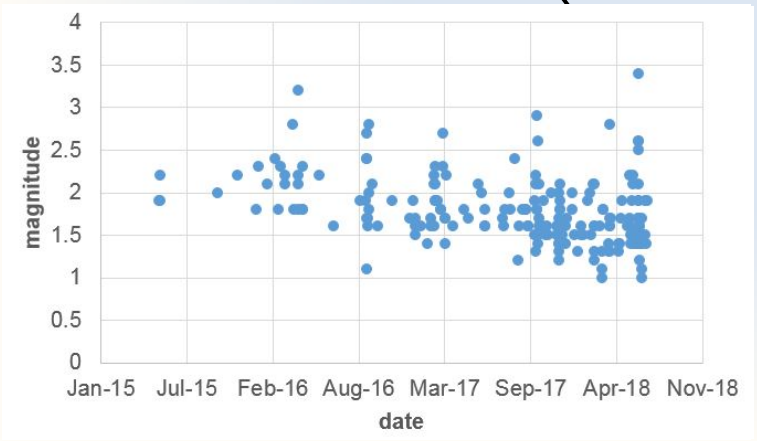
2013 - Today

A key indicator of an induced catalyst for earthquake activity is changes
in recursion and occurrences in area previously considered aseismic

Trends Along Structures: Some Known, Some Not

Earthquakes can only occur on faults w/displacement and aligned w/regional stress field





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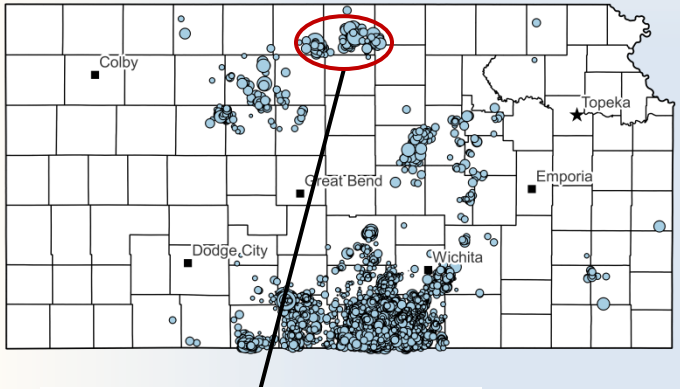

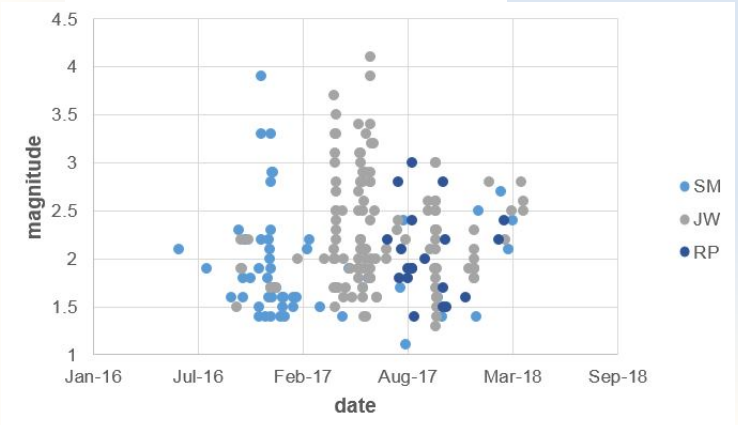

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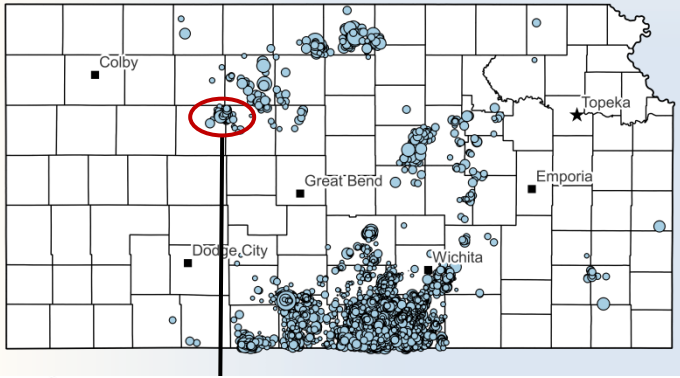

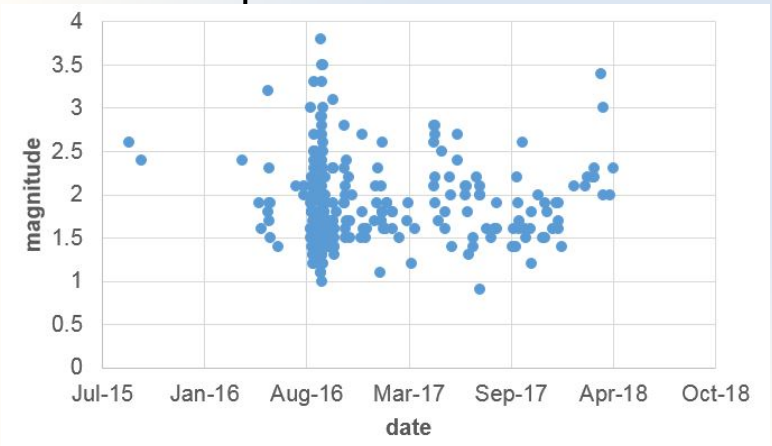

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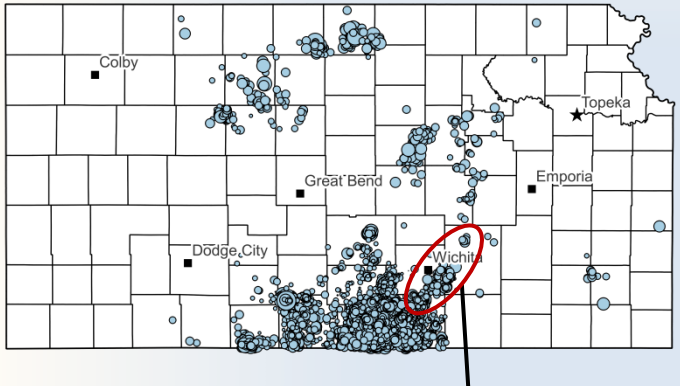

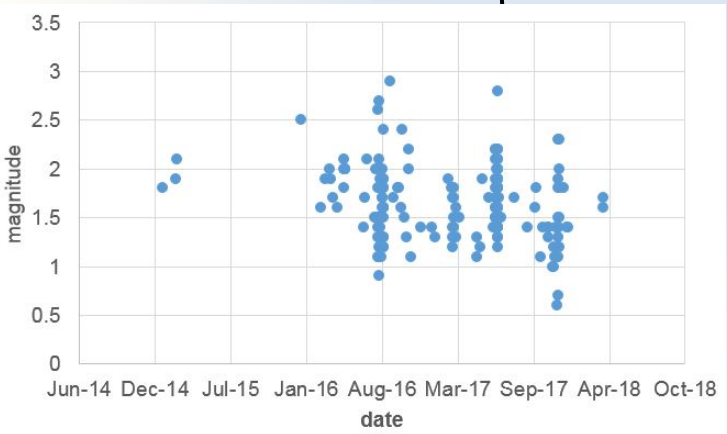

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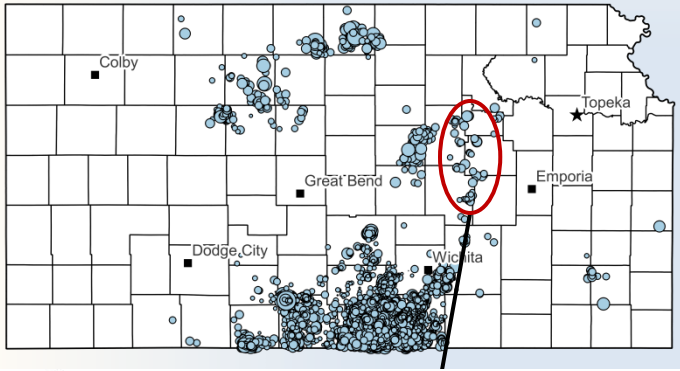

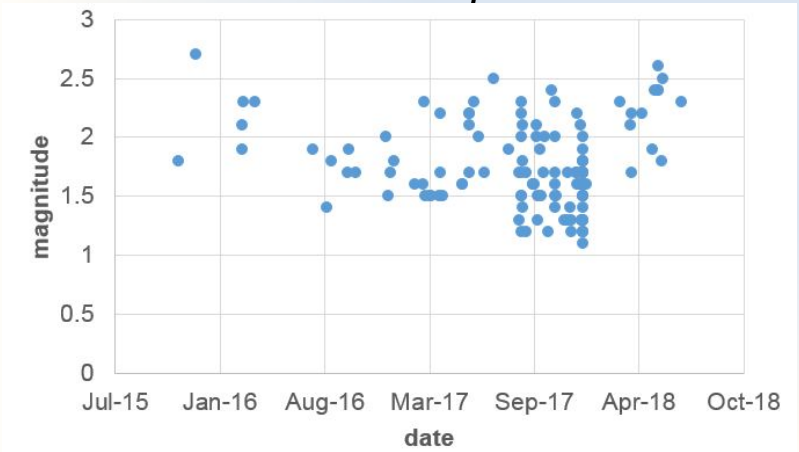

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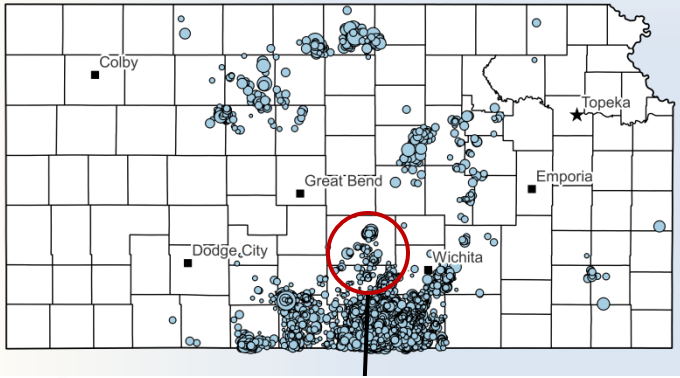
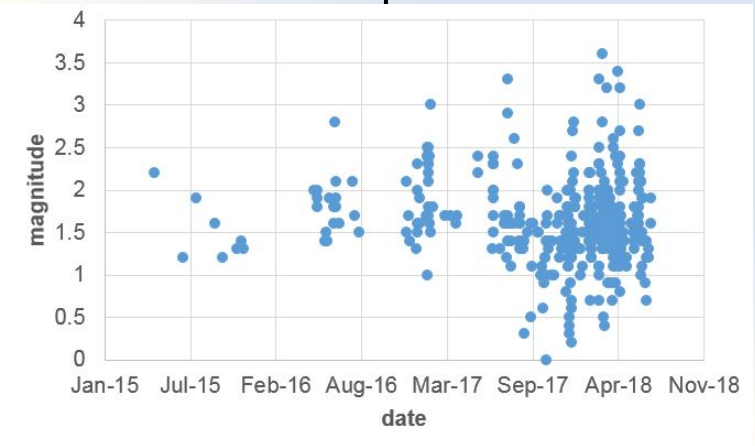
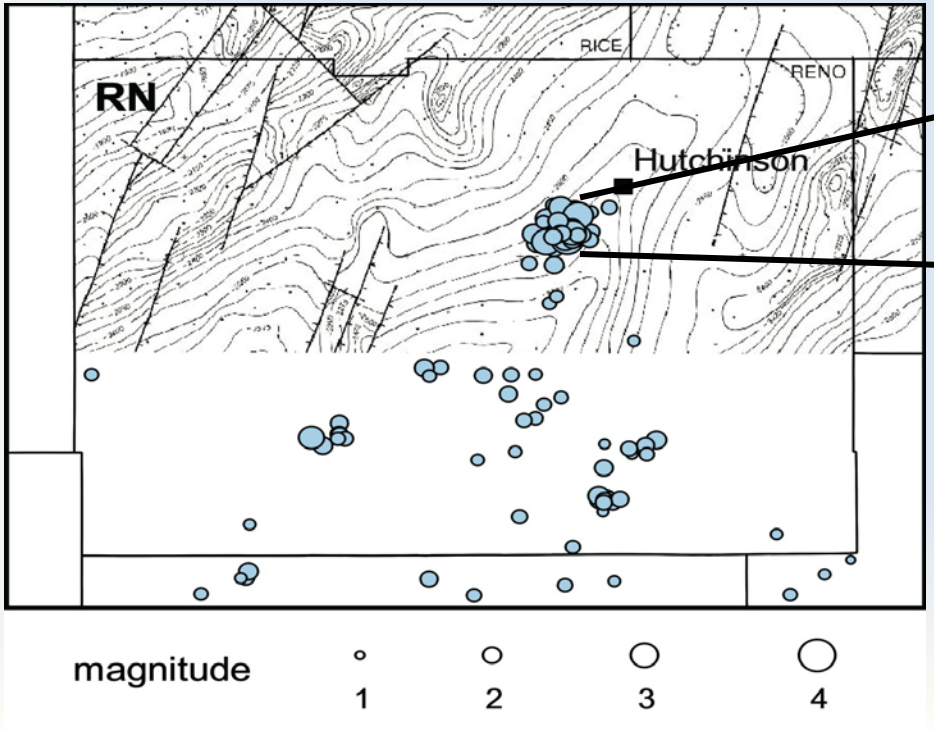


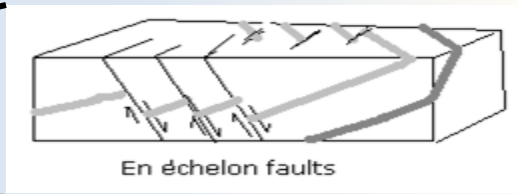


Trends Along Structures: Some Known, Some Not

Earthquakes can only occur on faults w/displacement and aligned w/regional stress field

structural contours (Arbuckle Group)

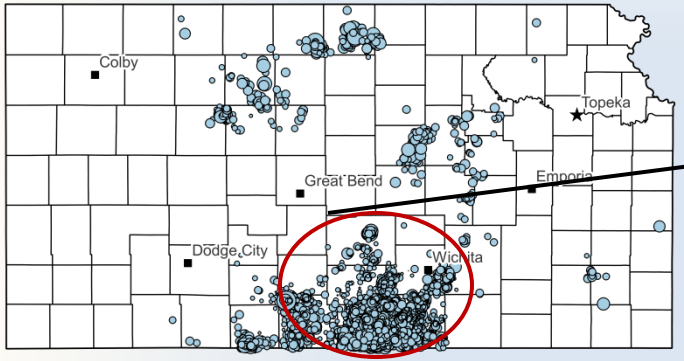


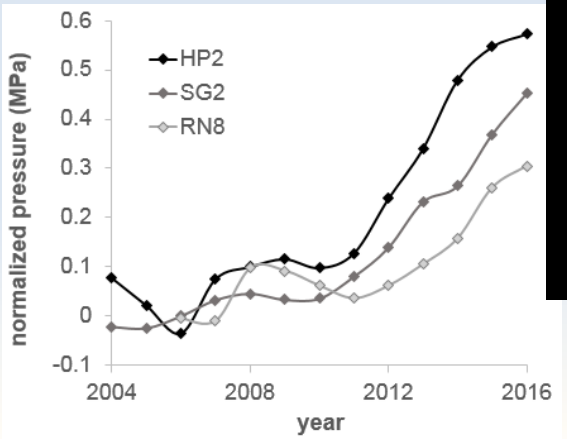


Northward migration of earthquakes across Reno County from January 2017 to July 2018

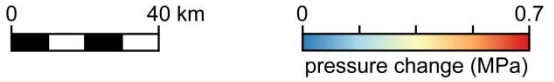
Arbuckle Fluid Pressure Influence on Seismicity

Earthquakes can only occur on faults w/displacement and aligned w/regional stress field



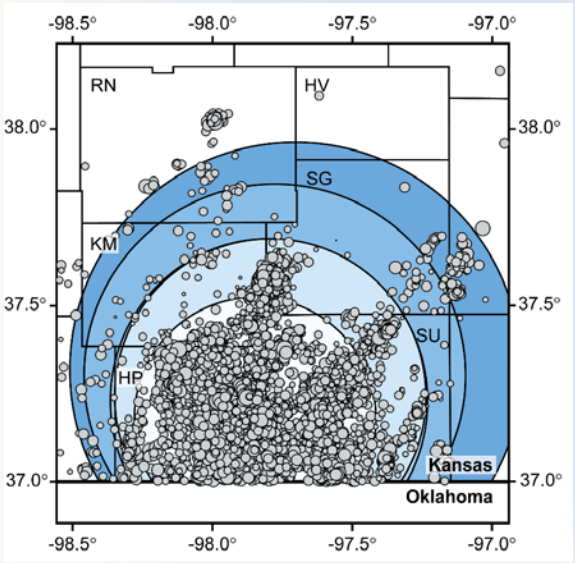


- regionally elevated pressure
- correlate with high volume SWD
- suggest fluid migration

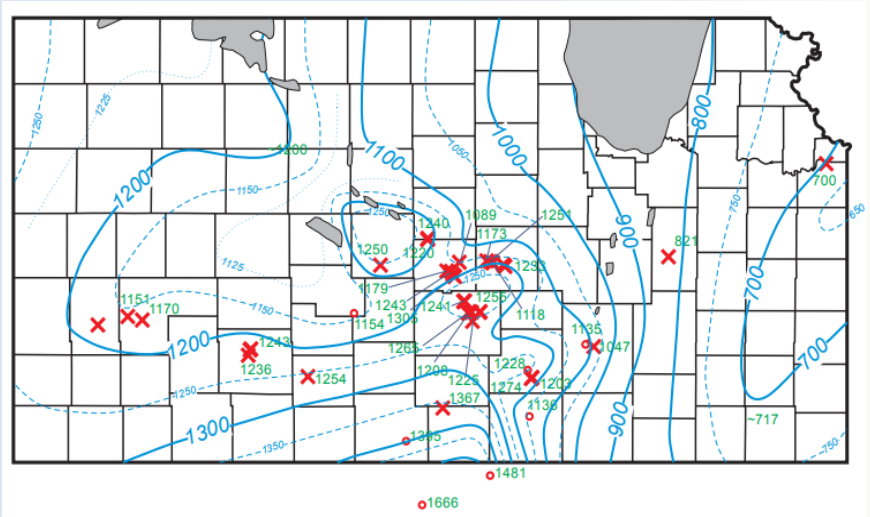


Areas of research with focus on seismicity

Spatio-temporal progression of seismicity into central Kansas (Peterie, et al 2018)



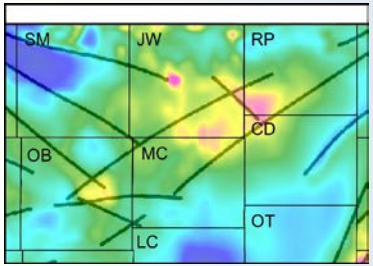
Mapping Arbuckle Group hydrostatic surface and pressure



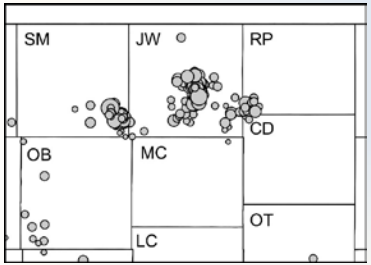
Arbuckle Working Group is a multiagency effort to more completely characterize the Arbuckle by working across all UIC classes. KGS is lead working with KDHE and KCC

Areas of research with focus on seismicity

aeromag w/lineaments interpreted in 1983

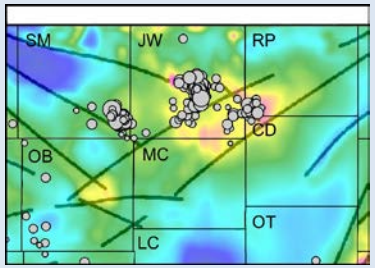


Data Integration



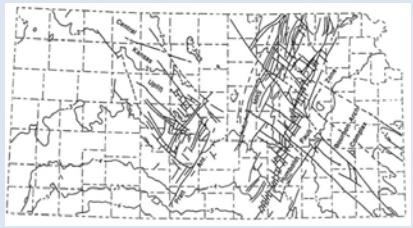
earthquakes (2015-present)

Seismicity in the Salina Basin

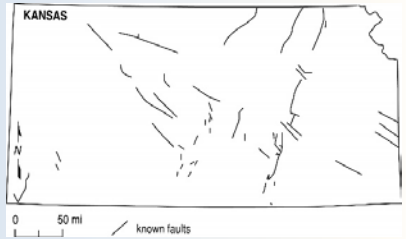


2015-present earthquakes
1983 aeromag w/lineaments

Comprehensive Fault Mapping from Published Data

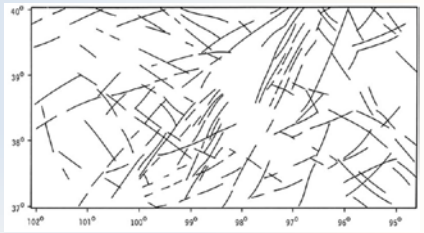


Baars and Watney, 1991



Cole 1976

Berendsen and Blair, 1986



Yarger 1983

Summing Up and Setting Up Shelby

Seismicity in Kansas has dramatically changed since 2013 and continues to change

Clusters and swarms can have a range of characteristics: linear, irregular circles/ellipses, systematic migration, random scattering, temporal relationships, etc, not clear there is a relationship to magnitude

Seismicity in Kansas (measured by number of earthquakes above 2.5) spiked in 2015 and has been on the decline since that time.

Seismicity spike in Kansas was consistent with measured increase in pore pressure in the Arbuckle

Seismicity has declined with the decrease in injection volumes, while the pore pressure in the Arbuckle seems to have stabilized. Suggesting faults with triggering thresholds below these pressures have already slipped and produced earthquakes.

Sub-magnitude 1 earthquakes within 20 miles of member injection facilities are both on historical trends and are in areas with no history of seismicity