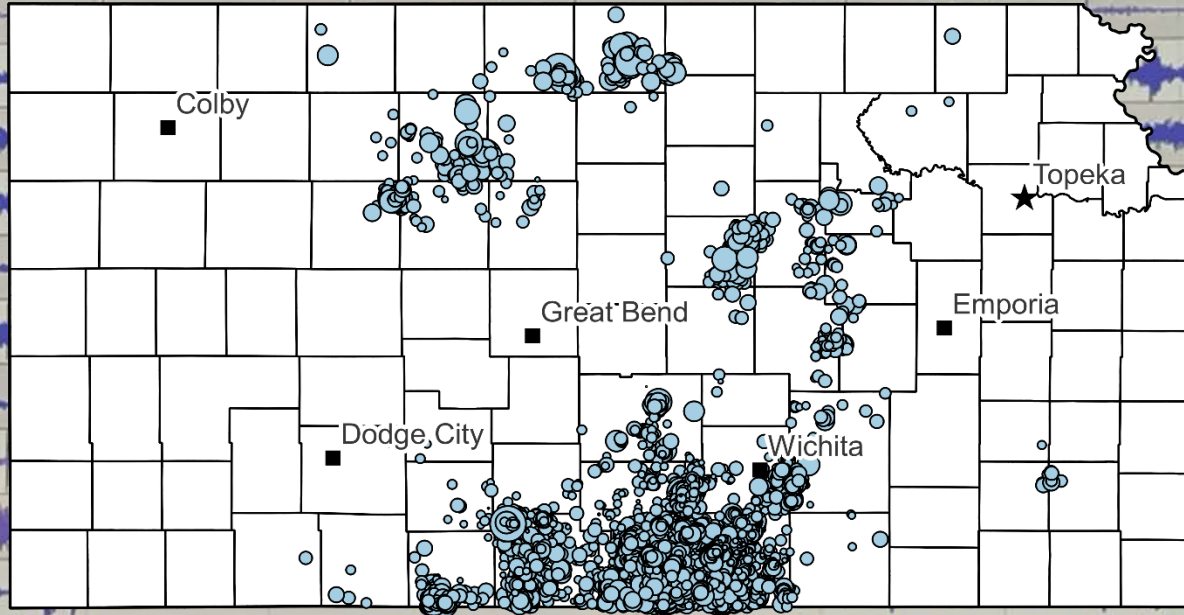


Kansas Seismicity: Monitoring to Define Earthquake Trends and Characteristics



Exploration Services Participants:
Shelby Peterie, Julio Gonzales, Brett Bennett, Brett Wedel, Joe Anderson, Anthony Hoch, John Intfen, Rex Buchanan, Rick Miller, and bucket load of undergraduate students coming and going.

Dynamic Seismicity in Kansas

History of Seismicity

Current Statewide Network

Sub-Regional Network

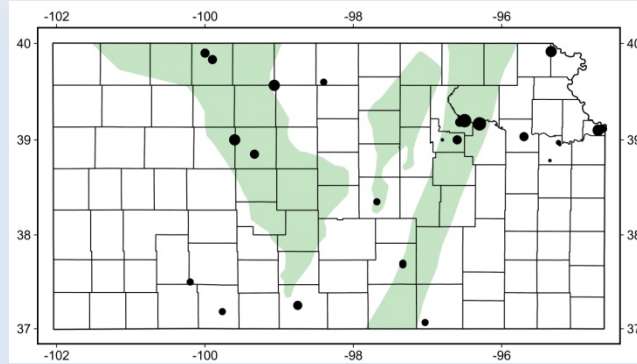
Interesting Clusters

What Does It All Mean?

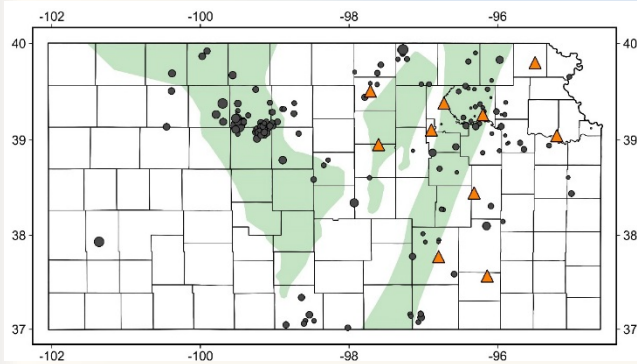


History Studying Earthquakes in Kansas

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

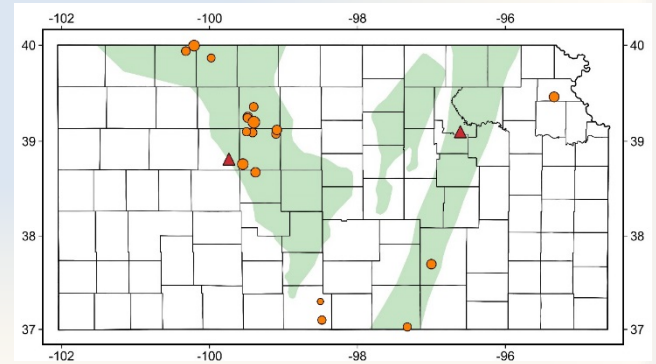


KGS Operated Network
1977-1989



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

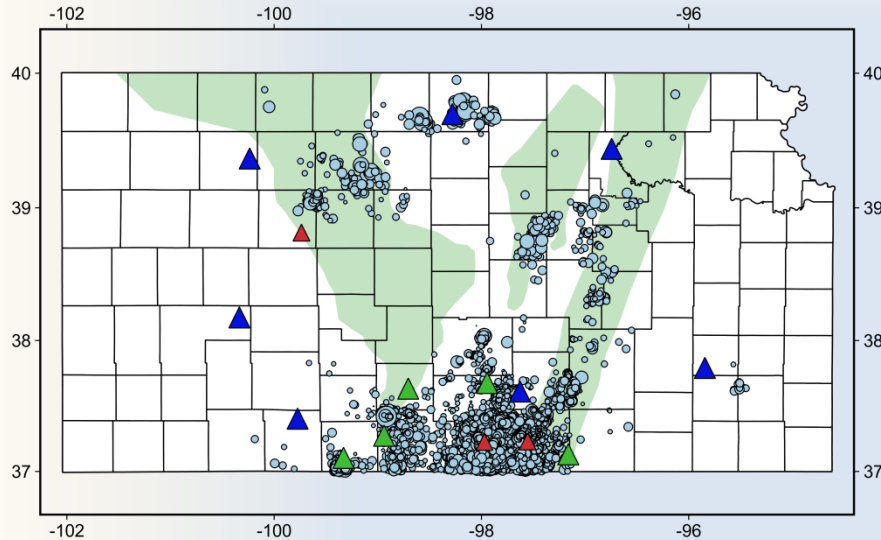
USGS Operated Network
1990-2014



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

Earthquake Monitoring Restart at the KGS in 2015

Basic Make-up and Operations



- ▲ 7 KGS permanent stations—2 vertical & 2 horizontal
- ▲ 5 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 and Environment (KDHE) and KS
Corp Commission (KCC)

2015-2017 Installed temporary & permanent networks

Real-time

email alerts

$M \geq 2$

Near-real time

Waveforms and preliminary catalog open access

Full catalog (1 week lag, currently 10,213 events)

manual analysis of continuous data (M1 locally)

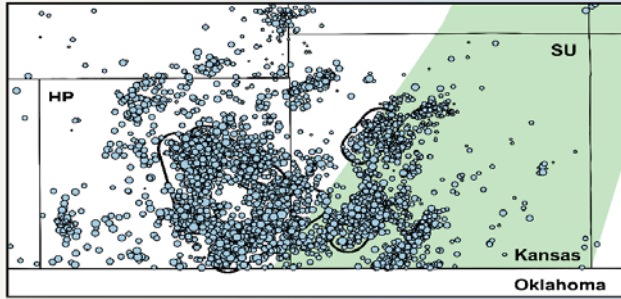
$M \geq 1.8$ statewide (4,886 events, 2015 to present)

Since 2016 KGS working with KDHE & KCC

developing online mapping & real time
notifications, both in beta

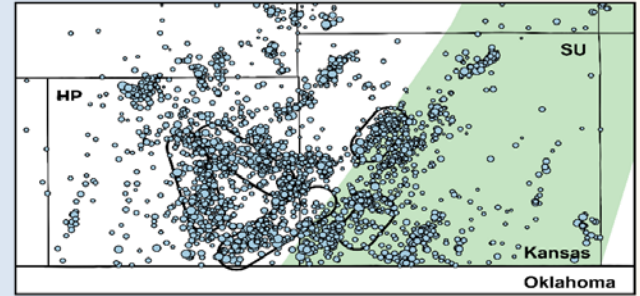
Ordered Reduction in Fluid Injection

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

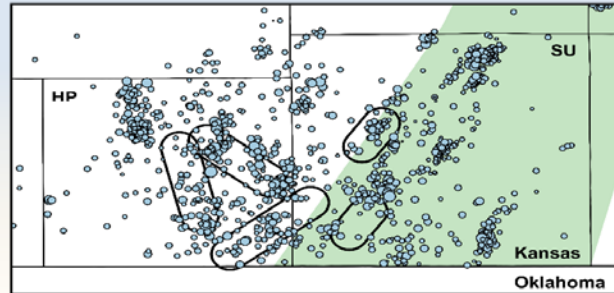


2015

Order
fully in
place



2016

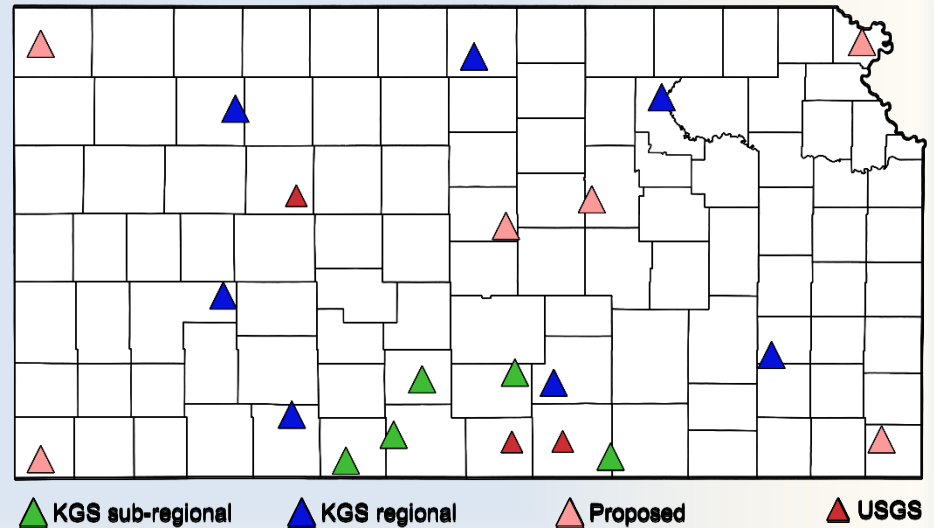


2017

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 (5) 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 (7) designed in 2015 to capture elevated seismicity occurring during 2014 and into 2015
- ▲ Continued escalation in several earthquake clusters is providing the catalyst for expanding the regional network further with 6 more permanent stations in under sampled areas



Seismic Station Installation

Seismic sensor (\$15,000)

Seismometer

Digitizer

Real-time communications (\$4,000)

cellular modem

cellular antenna

RTP server

Power (\$1,200)

120 watt 12 V solar panel

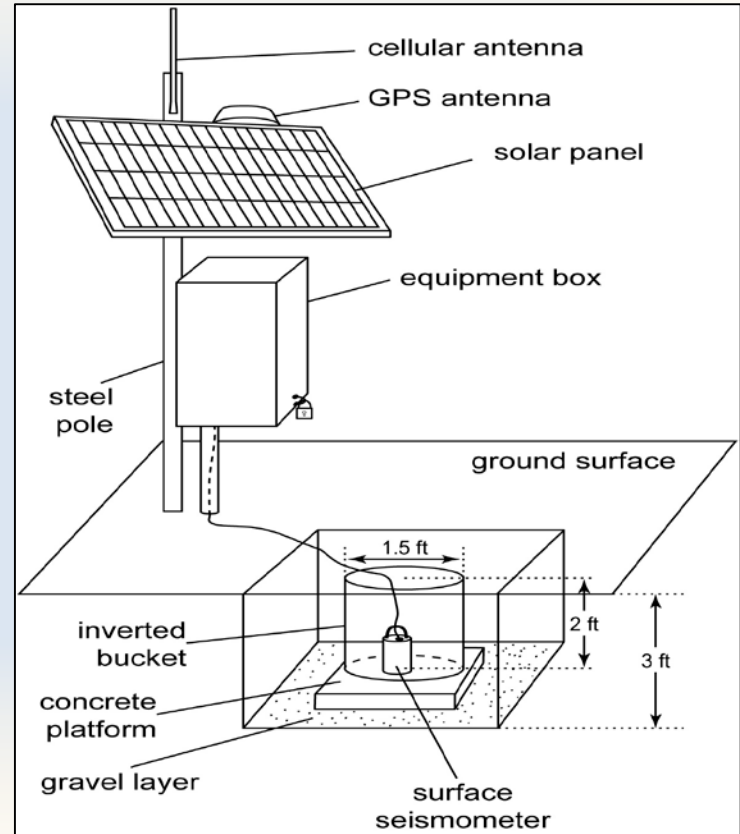
charge controller

two deep-cycle marine batteries

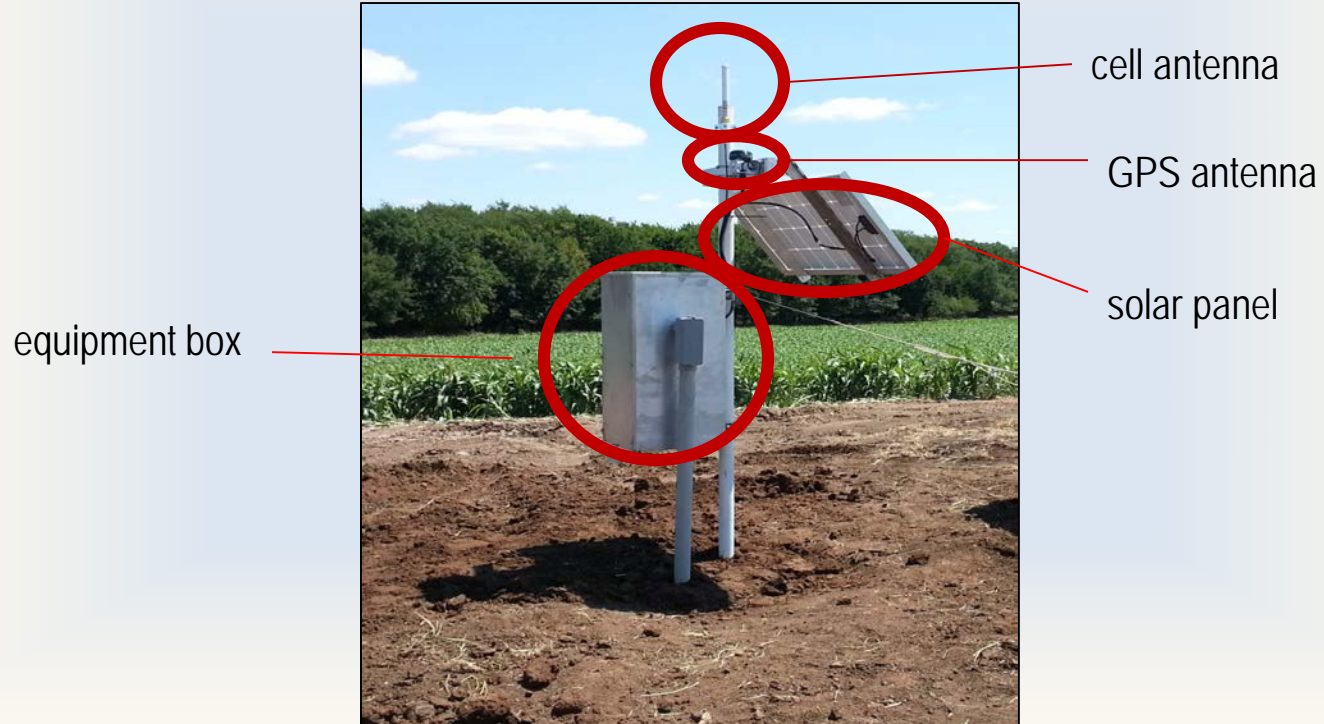
Operation (\$2,000/year)

cell data line

annual maintenance



Seismic Station Installation



Seismic Station Installation

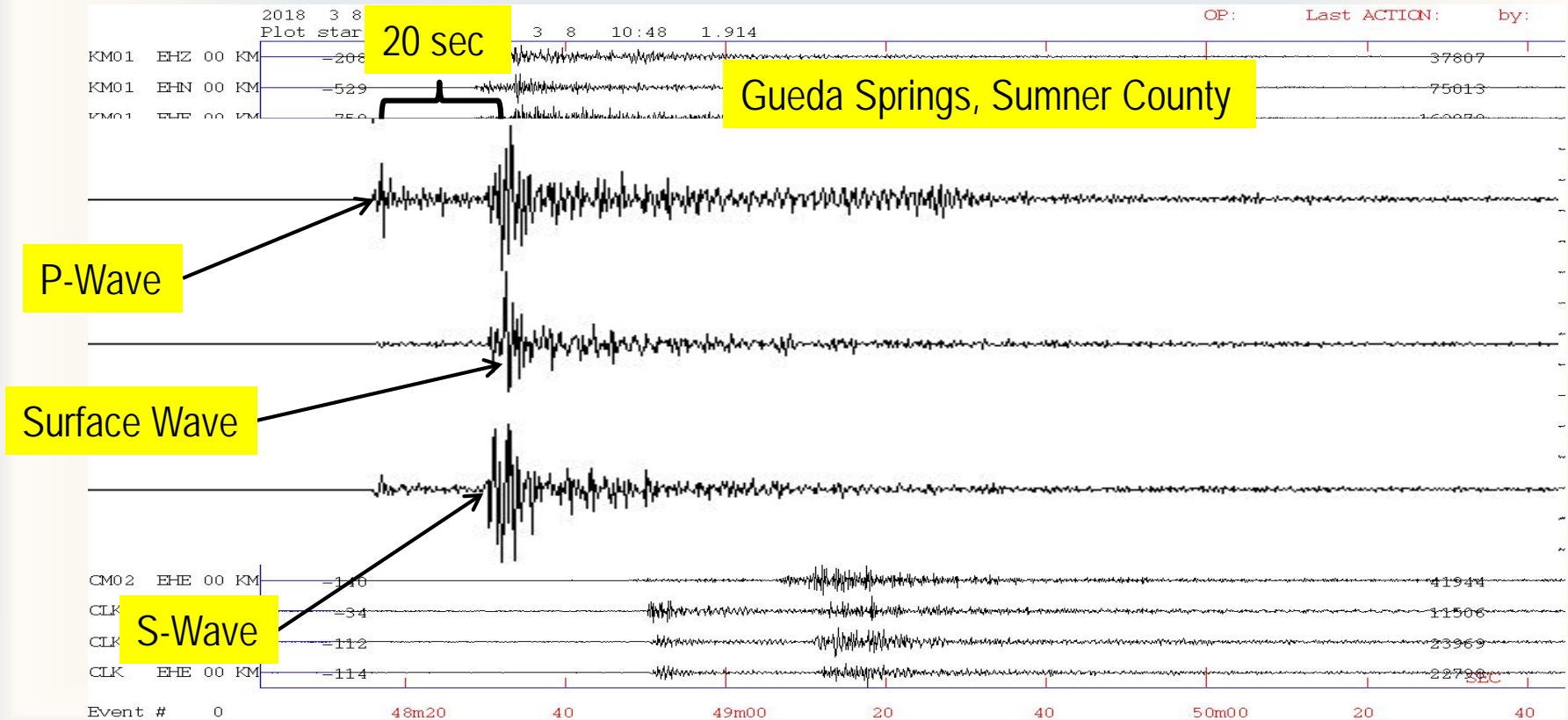


Seismic Station Installation



Hutchinson Cluster M3.6 Earthquake

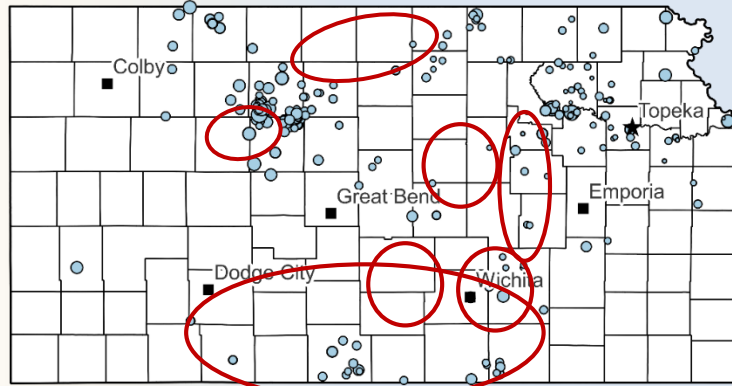
March 8, 2018 4:48 AM



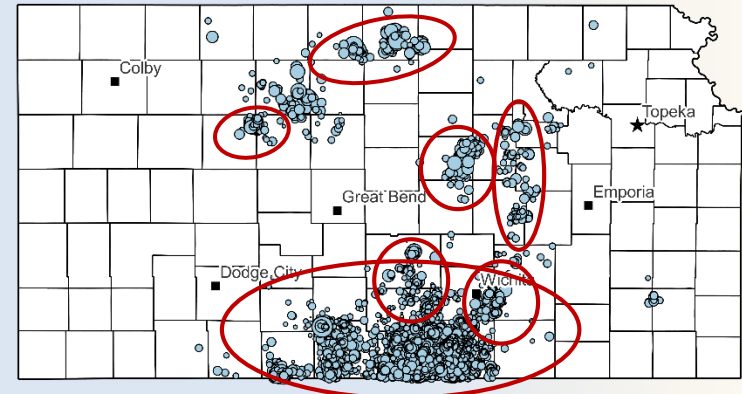
Historical Compared to New Normal

Nearly 150 years of consistent seismicity began abruptly transitioning in 2013

Only locating more earthquakes because more stations



1867 - 2012



2013 - Today

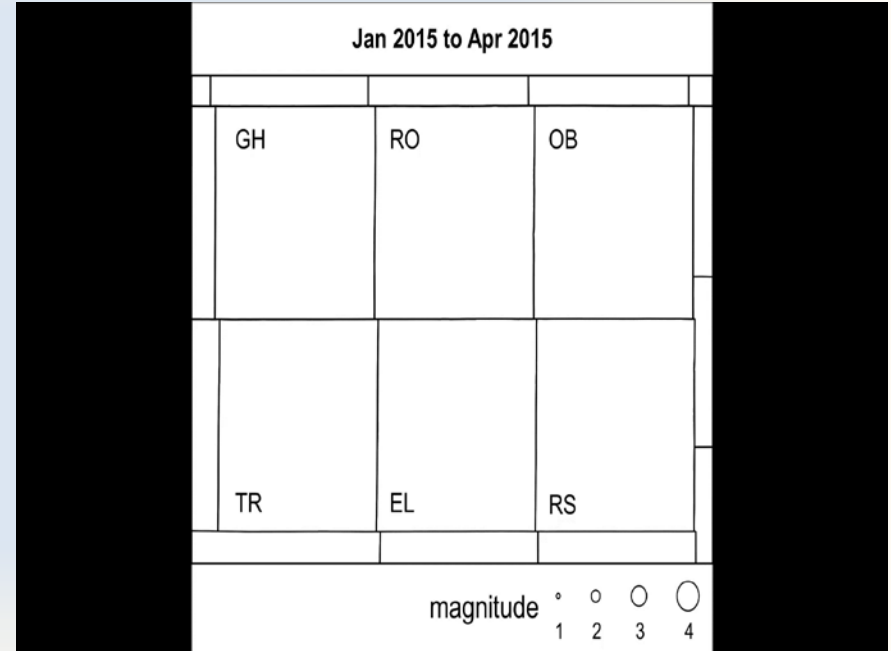
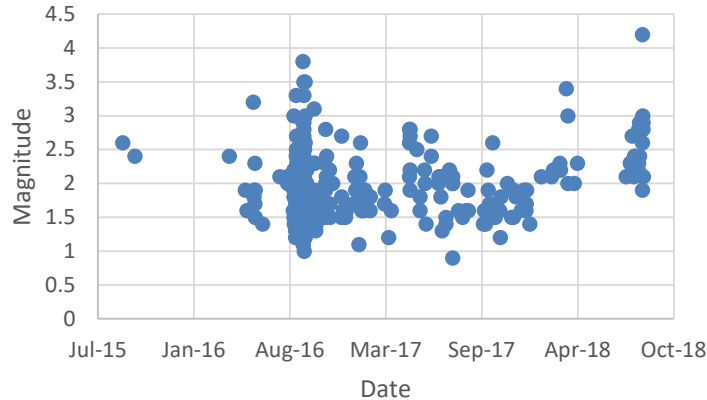
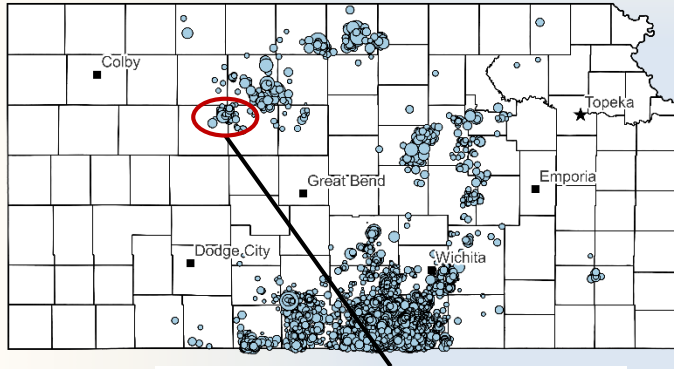
1977-2009 (33 years) there were 35 earthquakes reported $> M2.5$ and 15 $> M3.0$

2010-2013 (4 years) there were 4 earthquakes reported $> M2.5$ and 2 $> M3.0$

2014-2017 (4 years) there were 618 earthquakes reported $> M2.5$ and 178 $> M3.0$

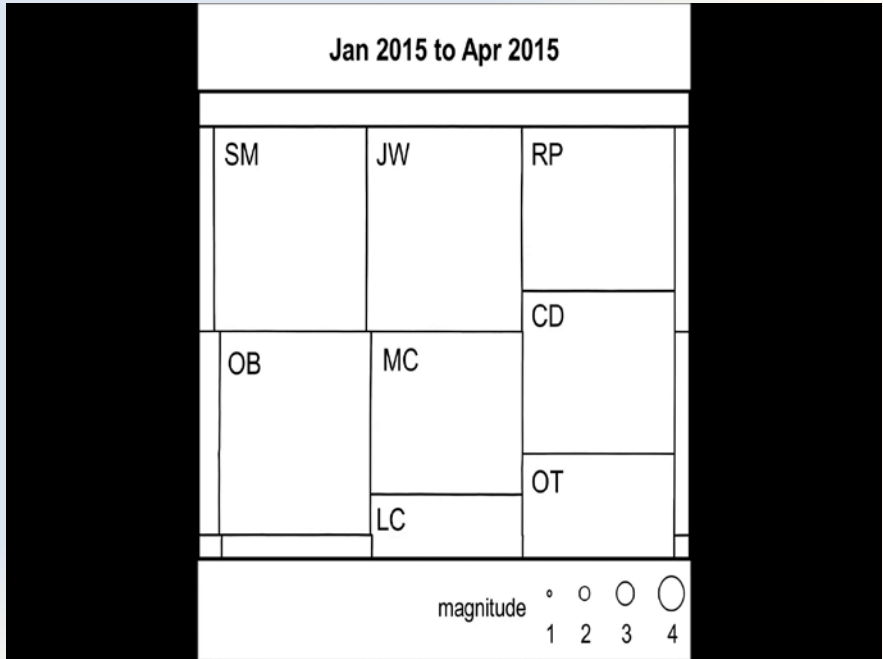
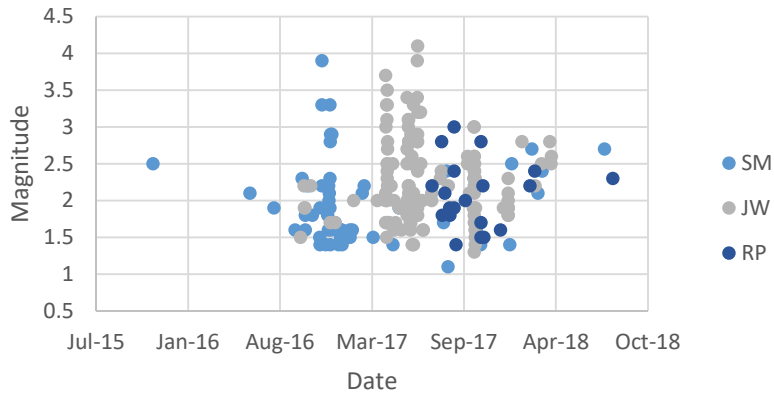
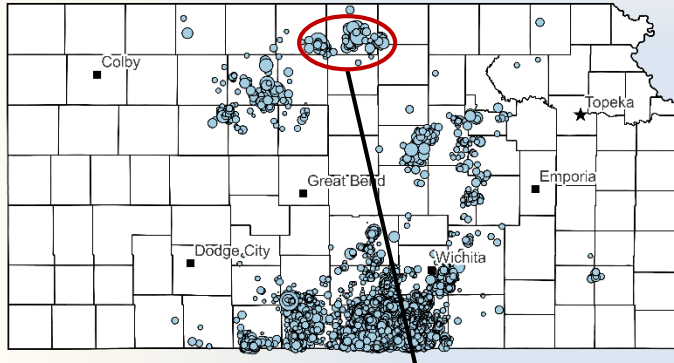
Trends Along Structures: Some Known, Some Not

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



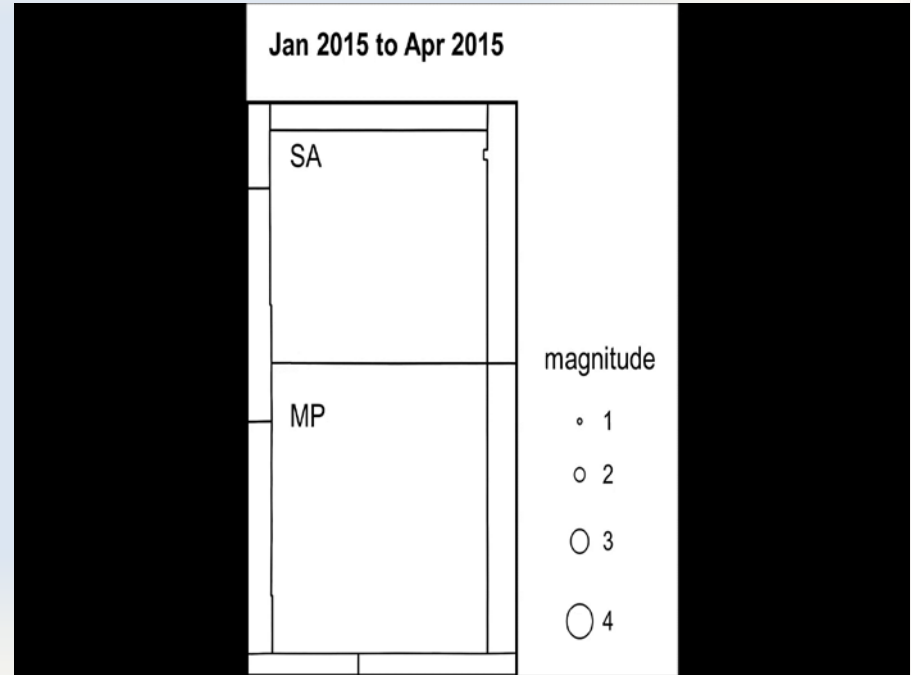
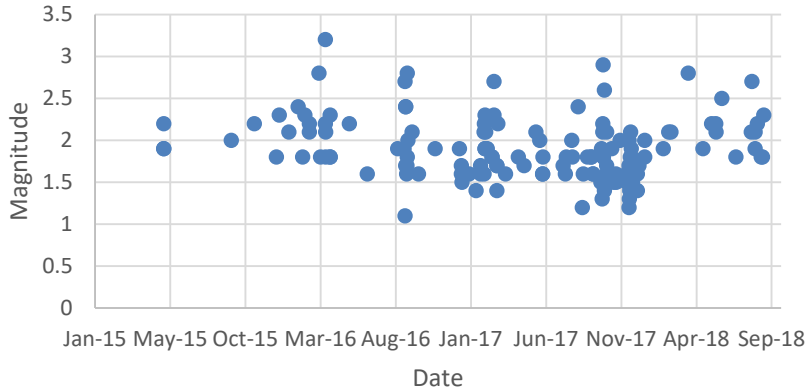
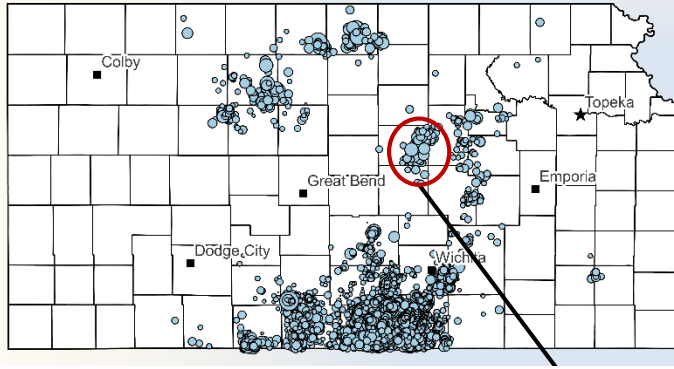
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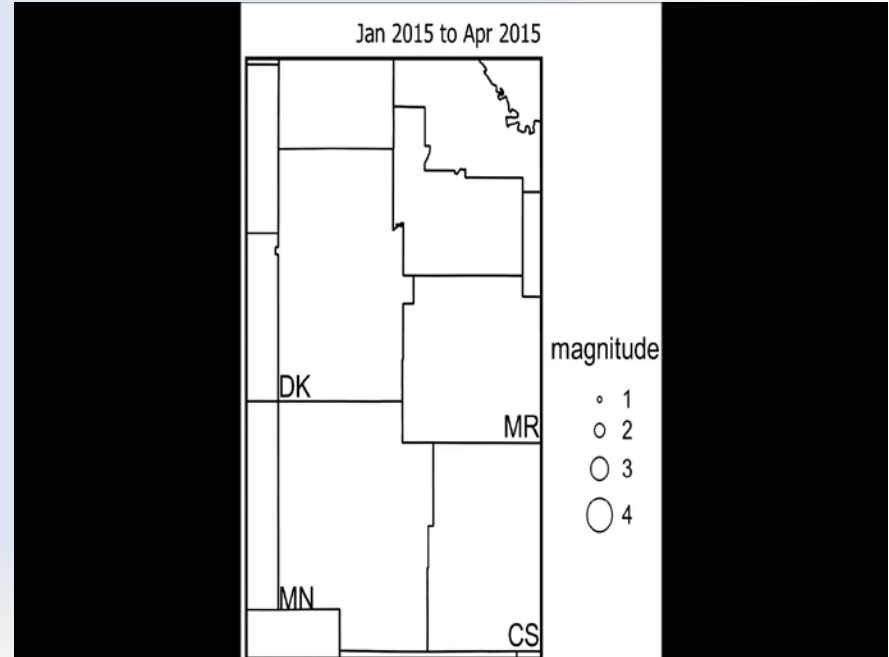
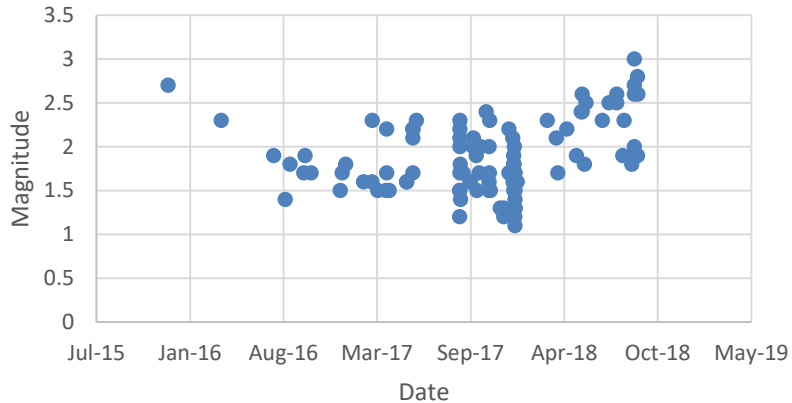
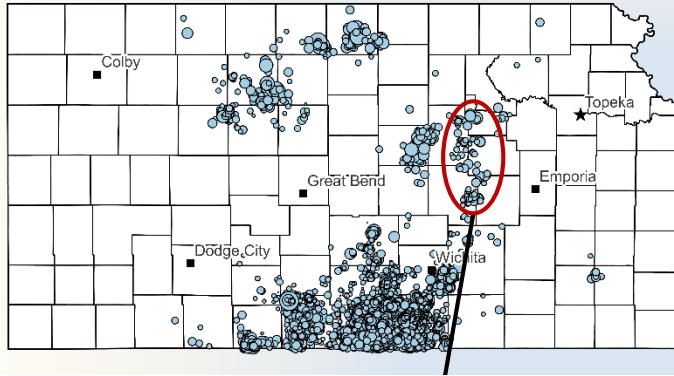
Trends Along Structures: Some Known, Some Not

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



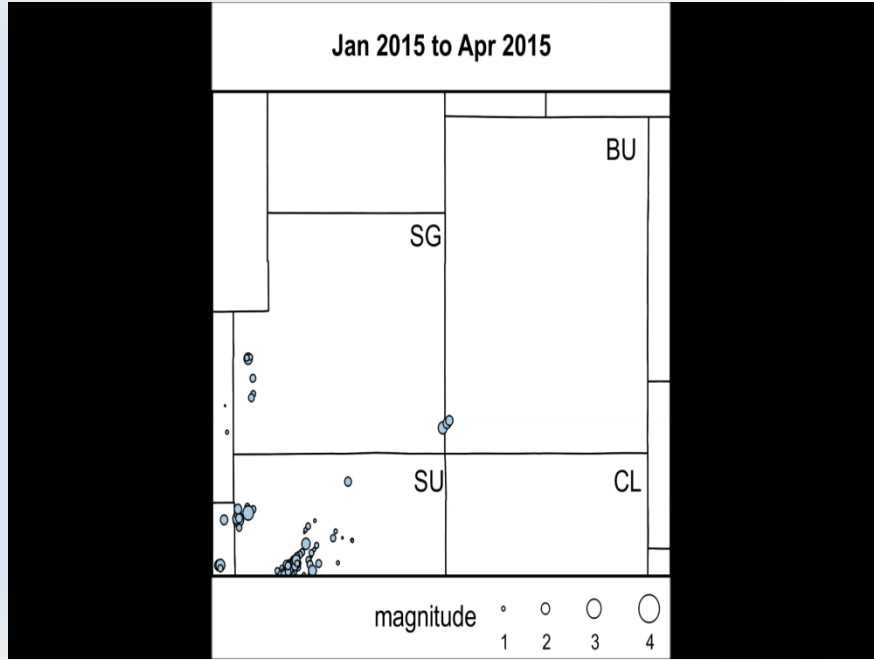
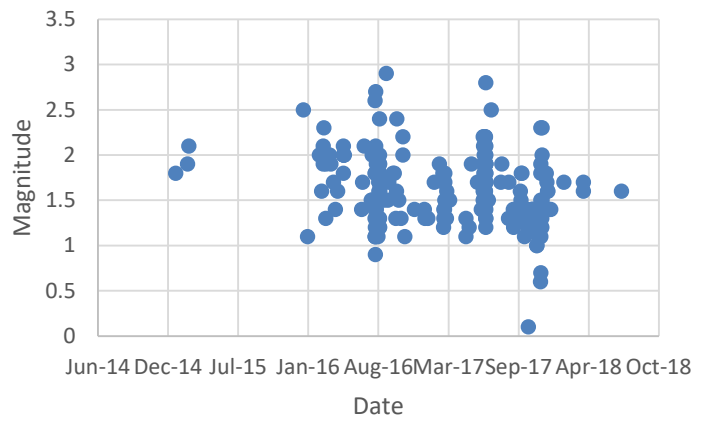
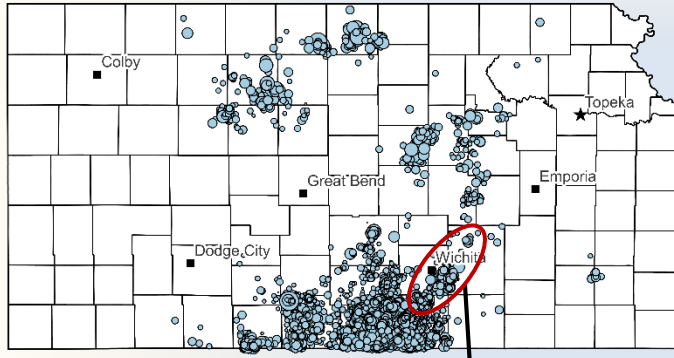
Trends Along Structures: Some Known, Some Not

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



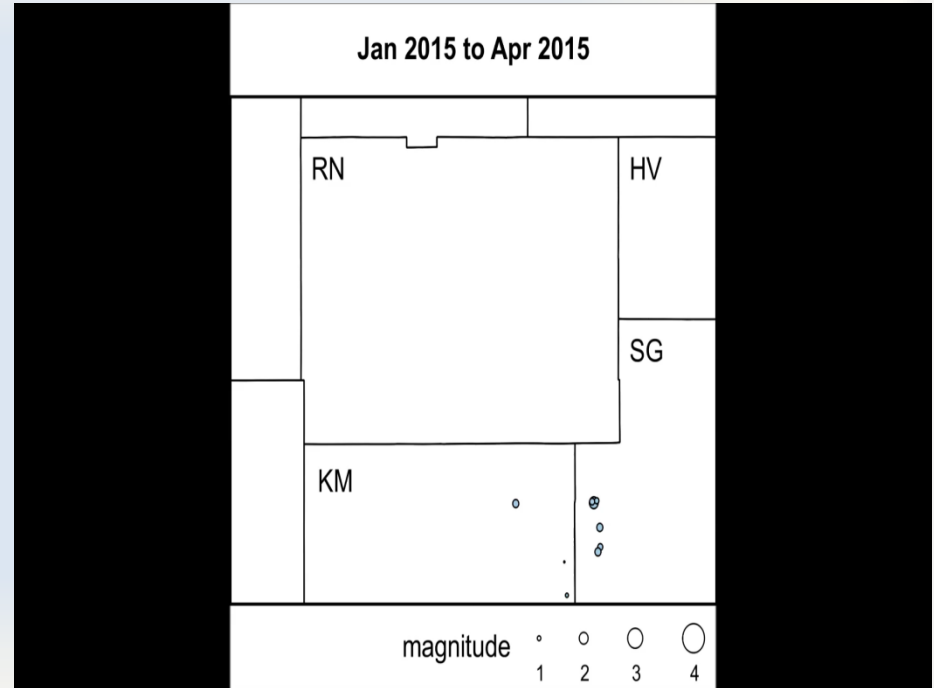
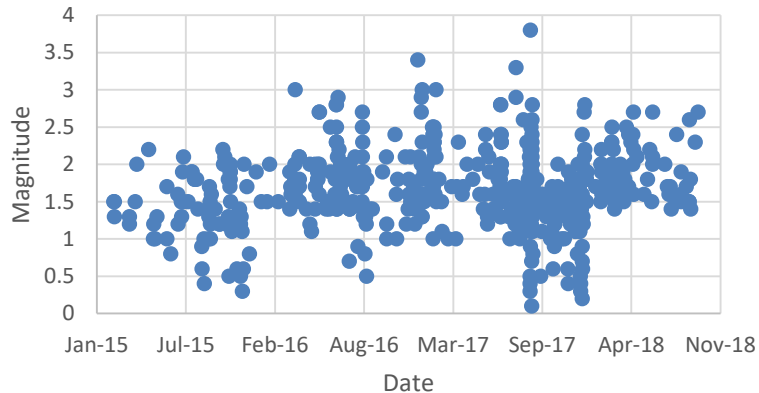
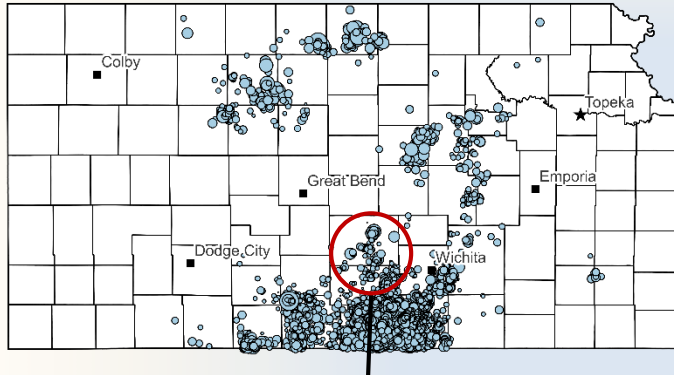
Trends Along Structures: Some Known, Some Not

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



Trends Along Structures: Some Known, Some Not

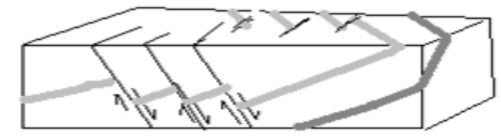
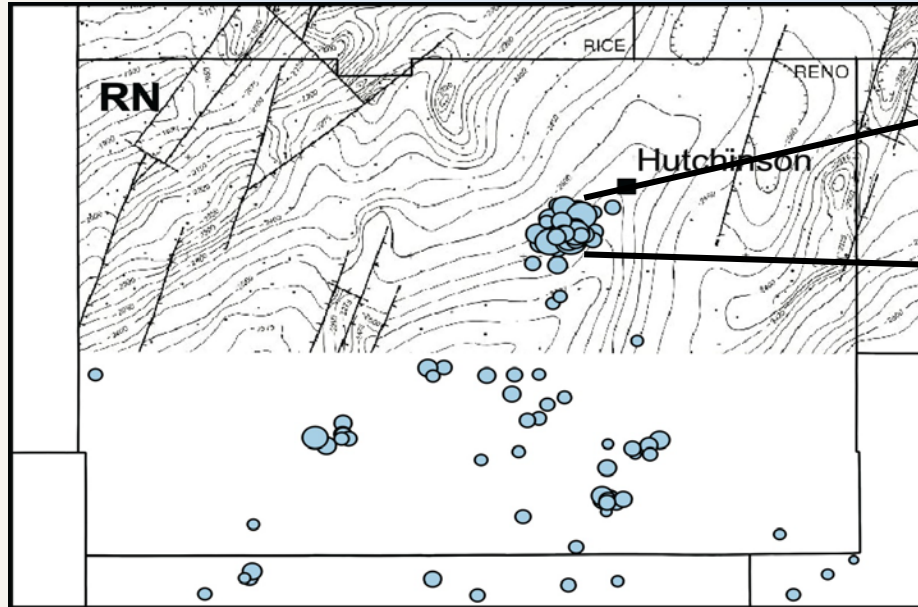
Earthquakes can only occur on faults w/displacement and aligned w/regional stress field



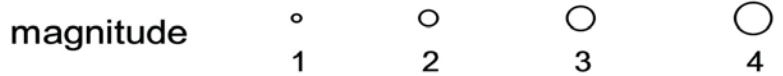
Trends Along Structures: Some Known, Some Not

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

structural contours (Arbuckle Group)



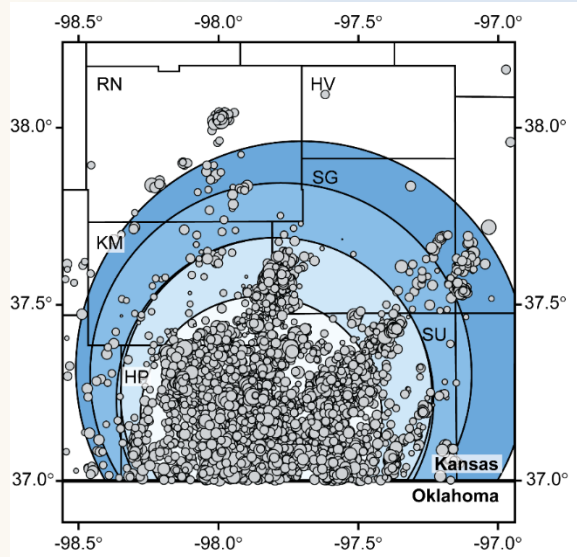
En échelon faults



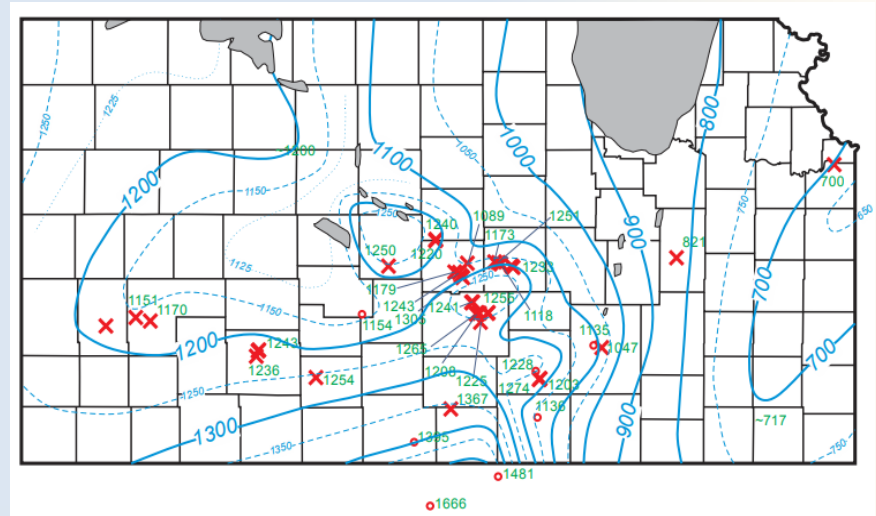
Northward migration of earthquakes across Reno County from January 2017 to July 2018

Areas of research with focus on seismicity

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



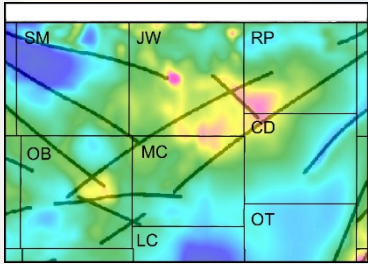
Mapping Arbuckle Group hydrostatic surface and pressure



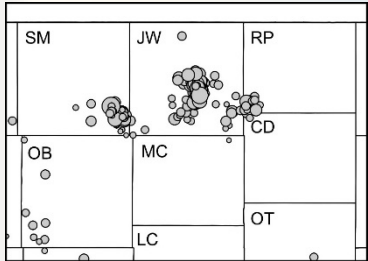
Arbuckle Working Group is a multiagency effort to more completely characterize the Arbuckle by working across all UIC classes. KGS is lead working with KDHE and KCC

Areas of research with focus on seismicity

aeromag w/lineaments
interpreted in 1983

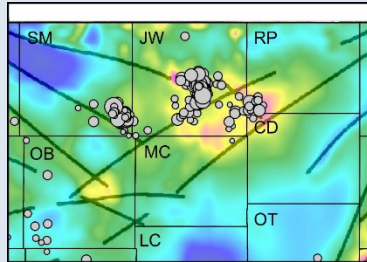


Data Integration



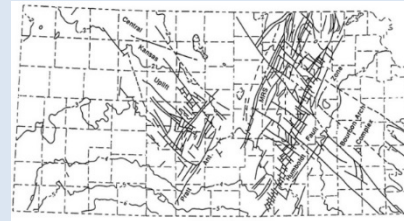
earthquakes (2015-present)

Seismicity in the Salina Basin

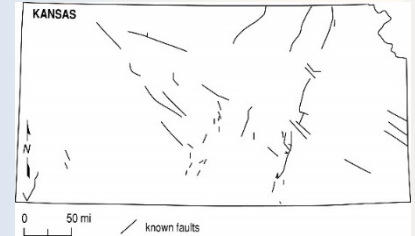


2015-present earthquakes
1983 aeromag w/lineaments

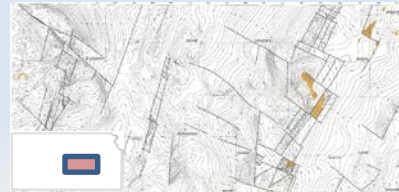
Comprehensive Fault Mapping from Published Data



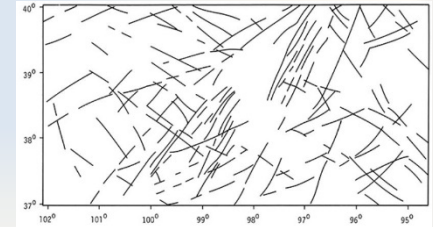
Baars and Watney, 1991



Cole 1976



Berendsen and Blair, 1986



Yarger 1983

Summing Up

- Seismicity in Kansas has dramatically changed since 2013 and continues to change
- Clusters and swarms rarely have the same characteristics
- Seismicity in Kansas (earthquakes above 2.5) spiked in 2015 and has been on the decline since that time.
- Spike in Kansas seismicity was consistent with measured, regional increase in pore pressure in the Arbuckle
 1. As injection volumes decreased, seismicity has declined and Arbuckle pressures have stabilized.
 2. Induced earthquakes occurred as Arbuckle pressures exceed triggering thresholds of critically stressed faults.
 3. Future increases in pore pressure could re-energize seismicity in previously active areas and induce felt earthquakes in areas currently only experiencing micro seismic.
- O&G prices today ~\$63/Bbl up from \$35 a year ago with rig count currently at 47 last year 33
- Several areas have been identified with potential to produce large numbers of minor earthquakes.
- Kansas networks have proven invaluable, continued operation is dependent on funding.

Trends Along Known Structures

2016-2017

