Regional Trends and Local Seismicity Near CSTS Member Wells

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Kansas Geological Survey

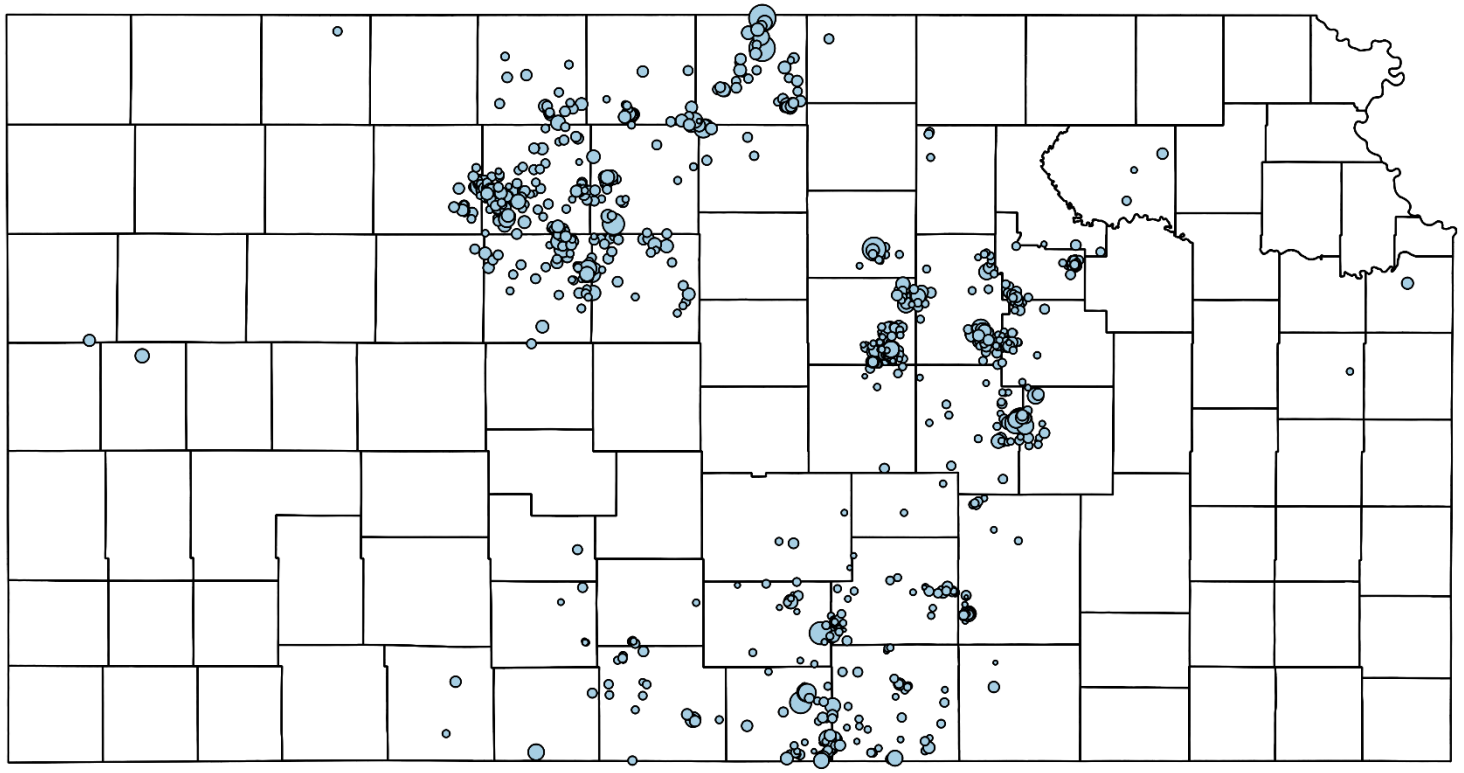
Fifth Annual CSTS Meeting

August 9, 2023

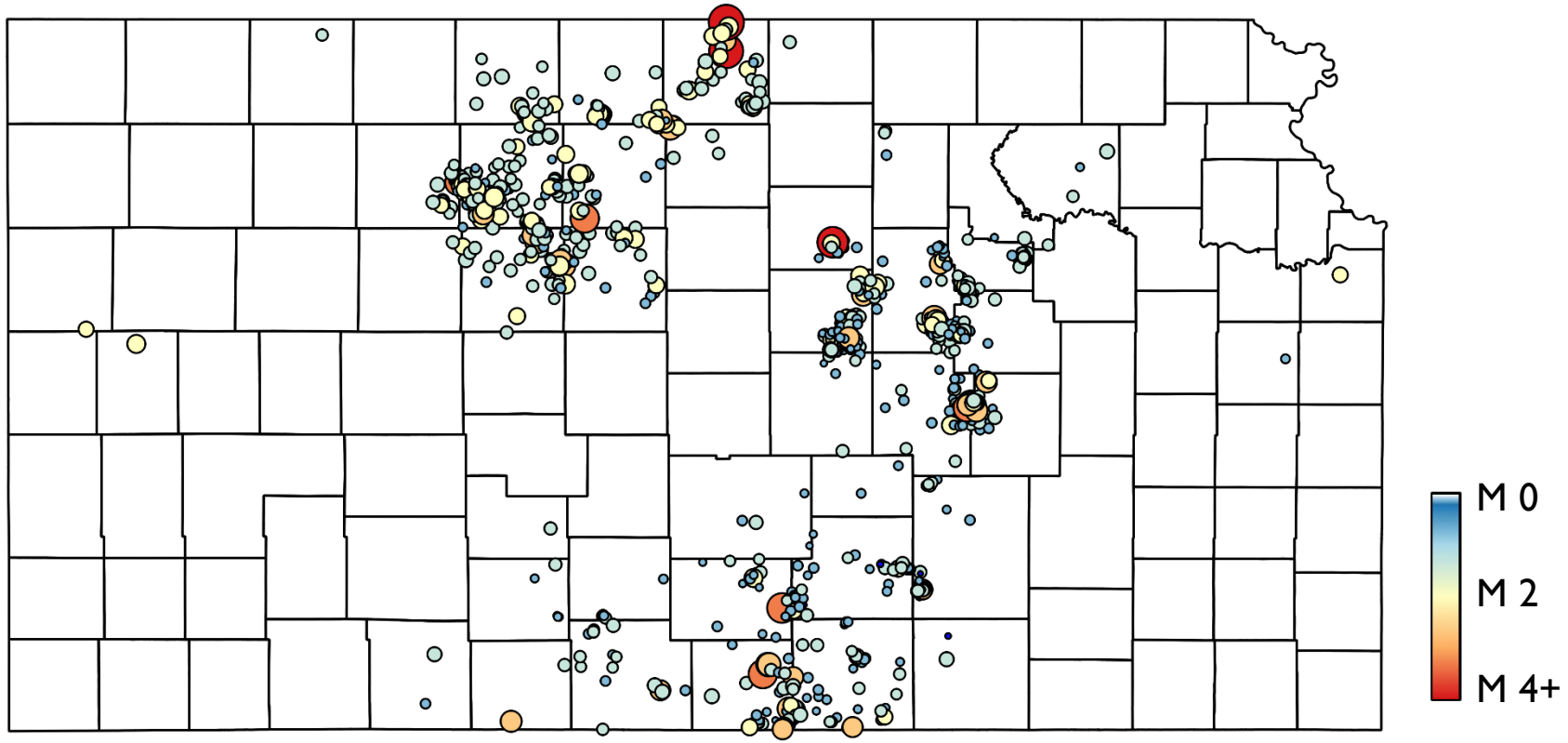
McPherson, KS

Statewide Overview: 2022-2023

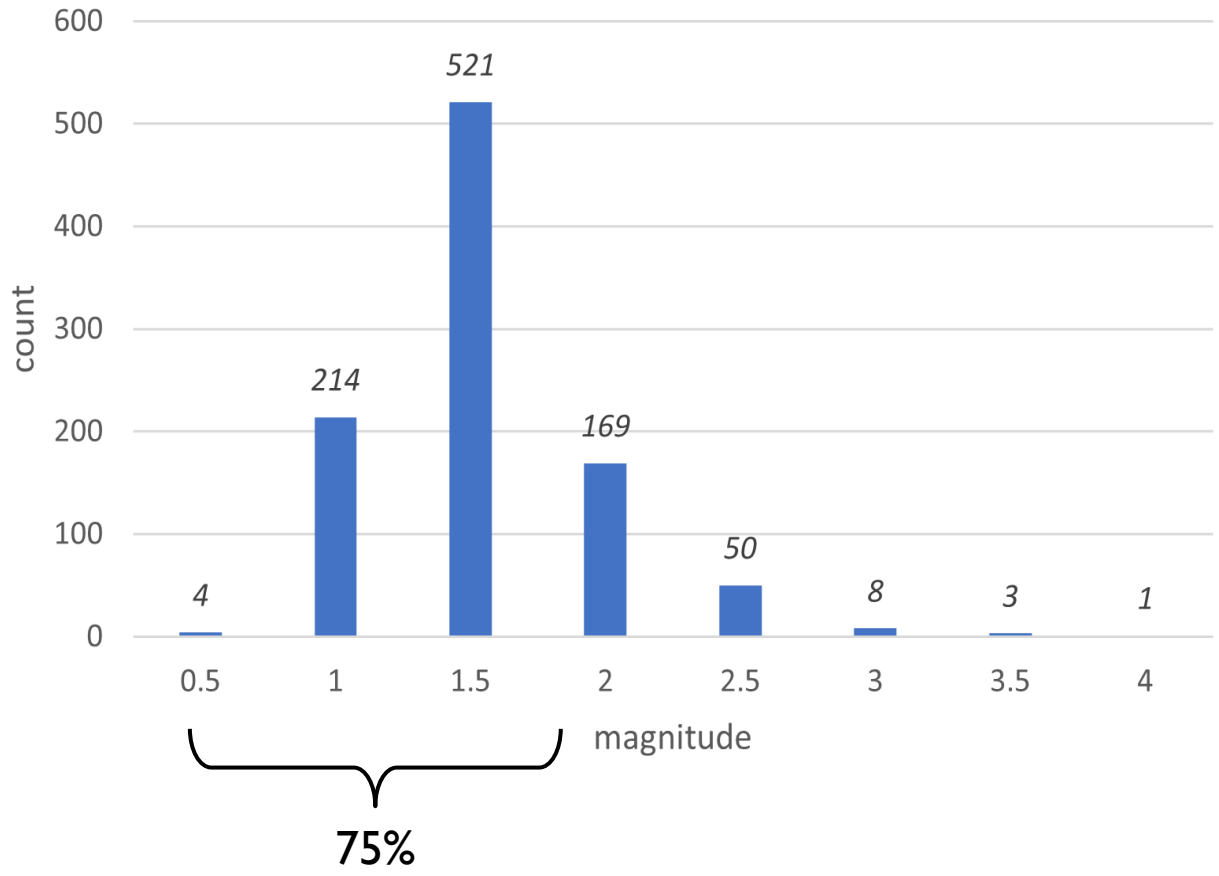
total earthquakes = 971 (1689 previous year)



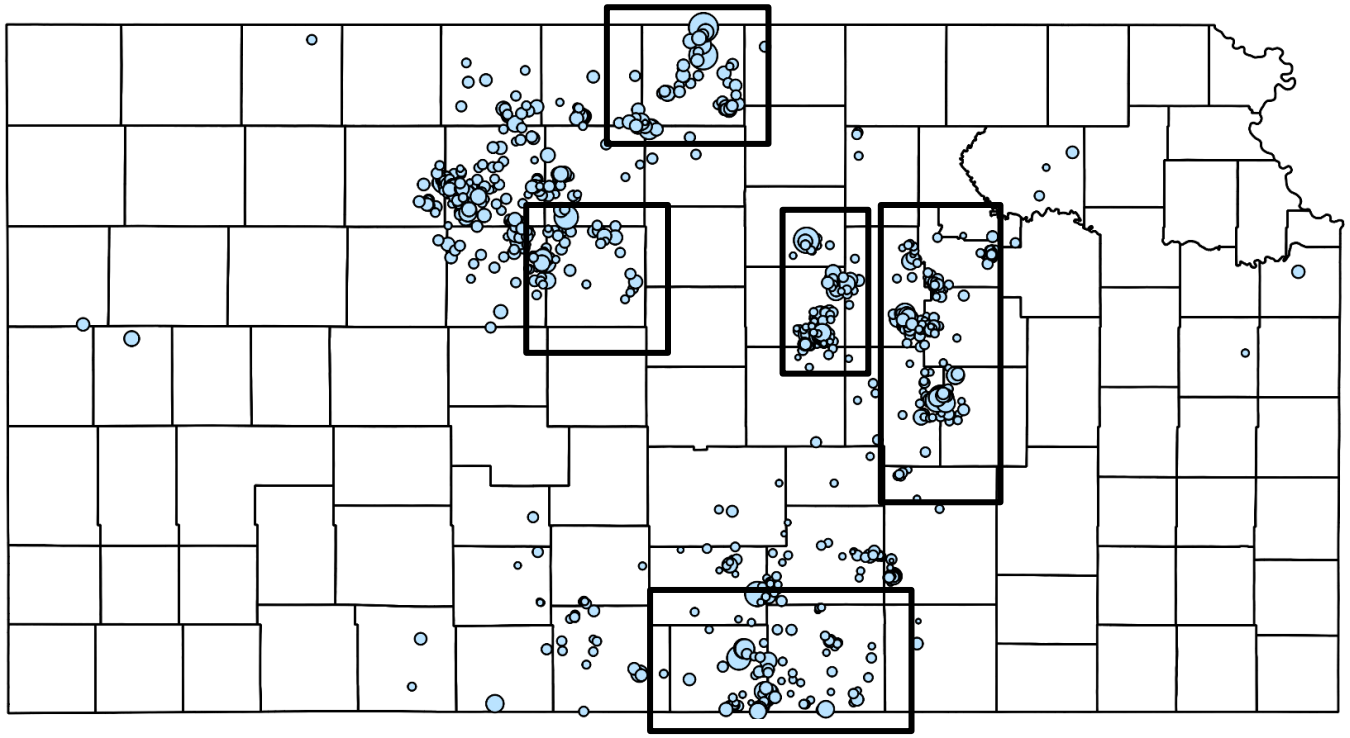
Earthquakes by Magnitude



Magnitude Distribution



Notable Observations



Earthquake rates:

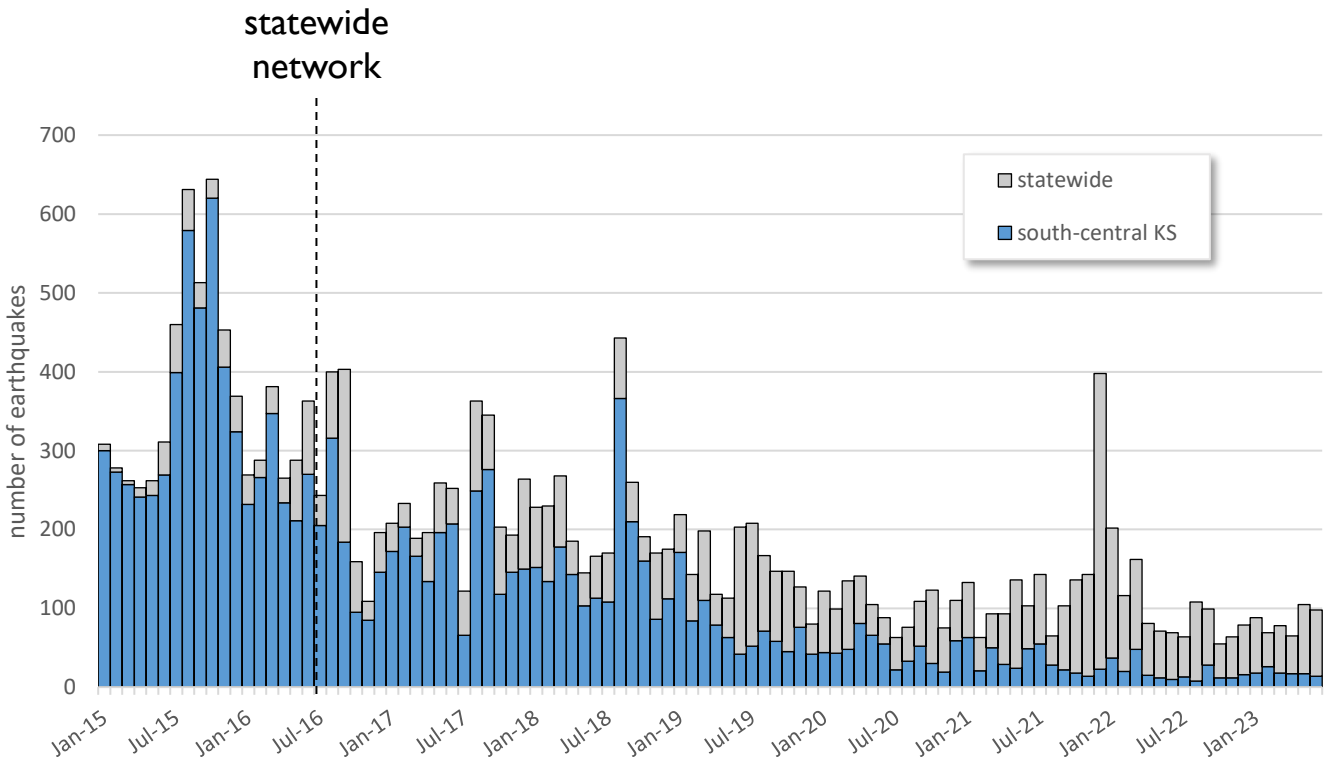
M 3+ = one/month

M 4+ = one/yr

M 5+ = one/decade

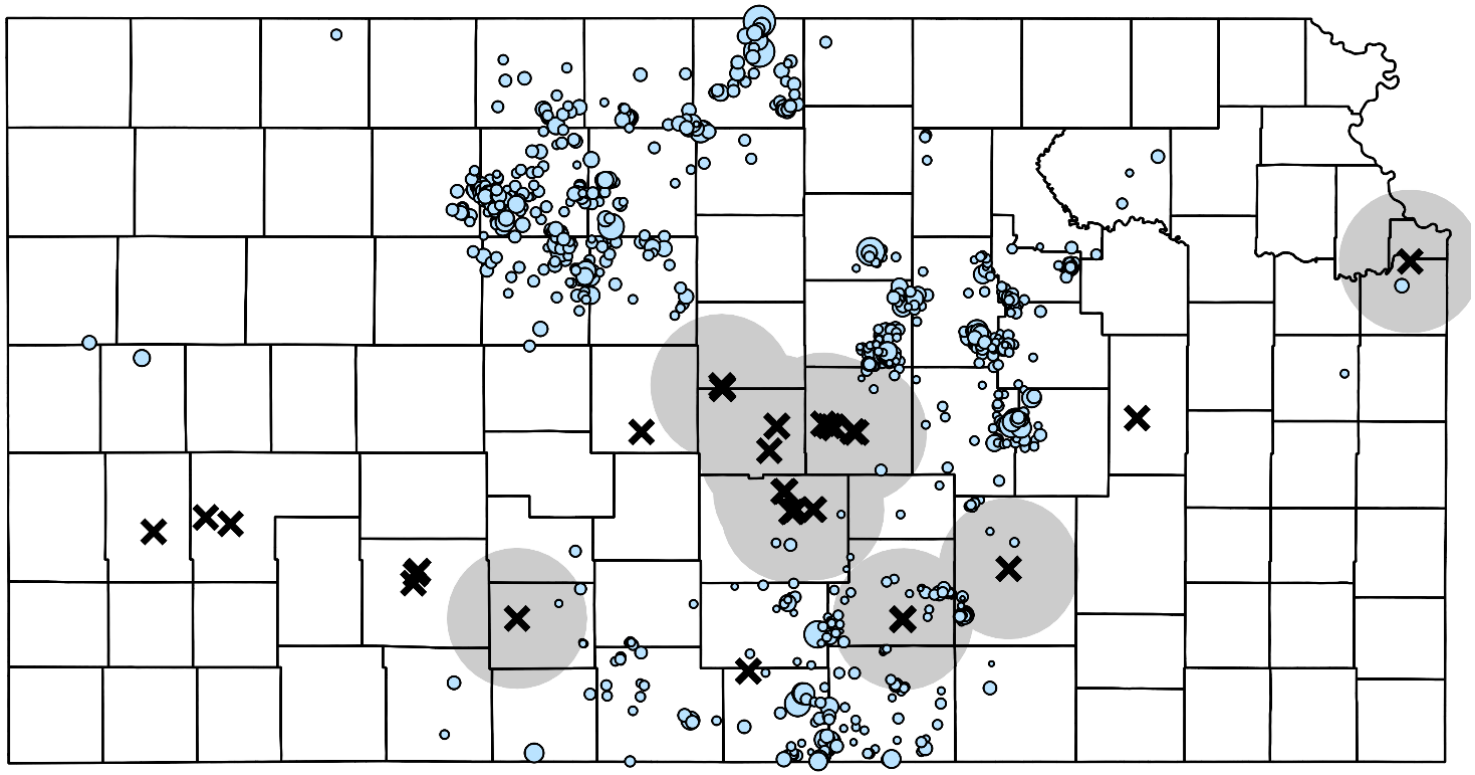
- MGA
  - Saline County
    - 129 events (>800 last year)
    - 19 M 2 (170 last year)
    - 0 M 3+ (19 last year, 3 M 4+))
  - Ottawa County
    - M 3.6 in April 2023
- Nemaha Ridge: similar to last year
- Russell County: continued low-magnitude seismicity
- Jewell County
  - M 3.9 and M 4.0
- Harper/Sumner
  - Only one M > 3

Monthly Earthquakes



Relation to CSTS Member Facilities

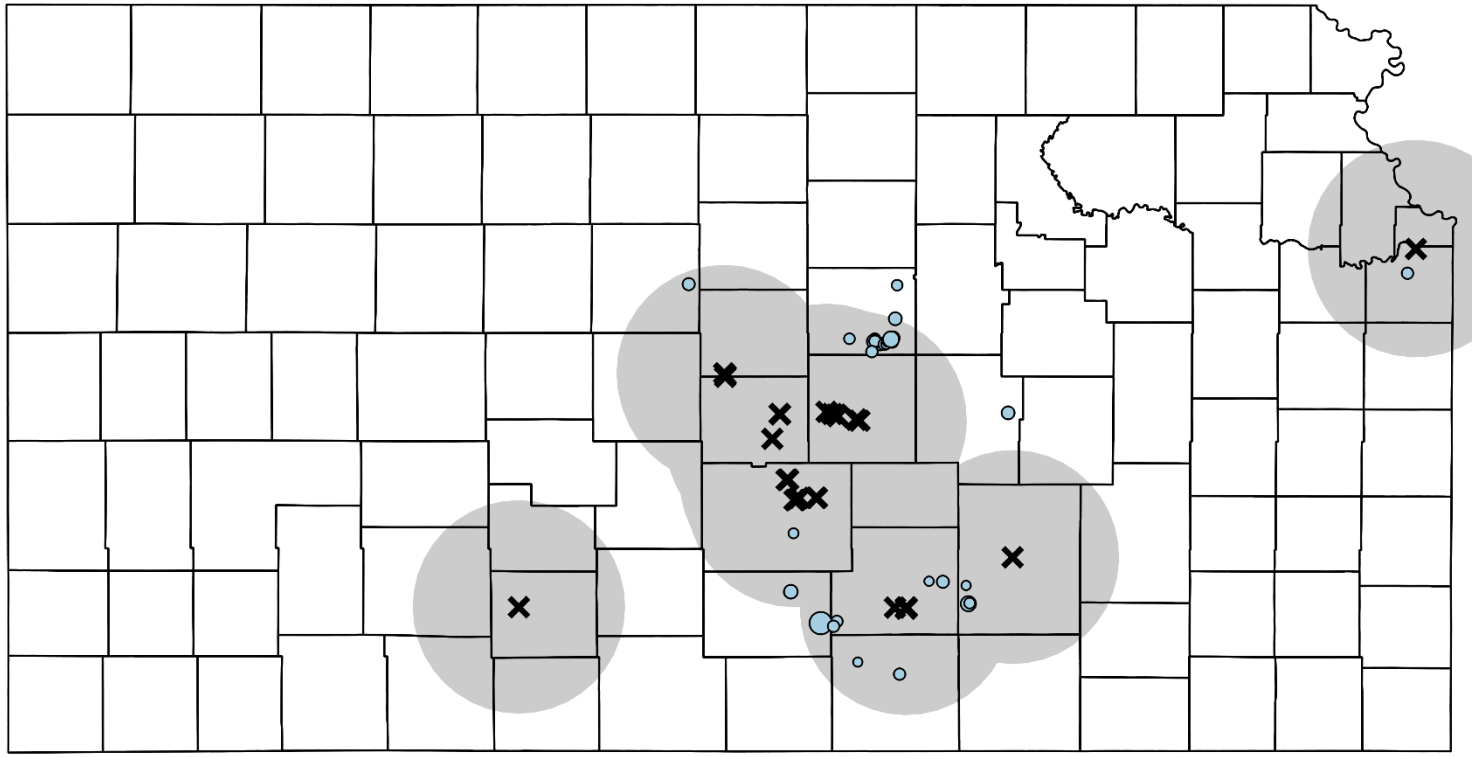
84 within 20 mi (157 last year)



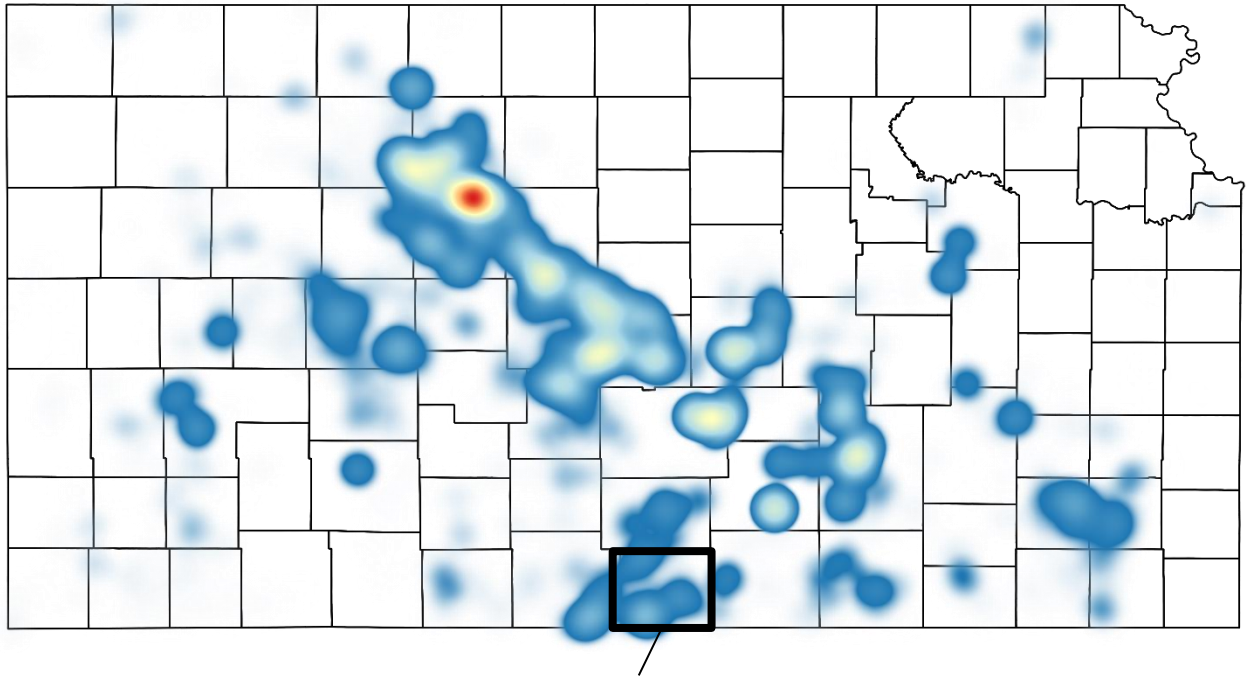
× Class I wells 20 mi radius from CSTS wells

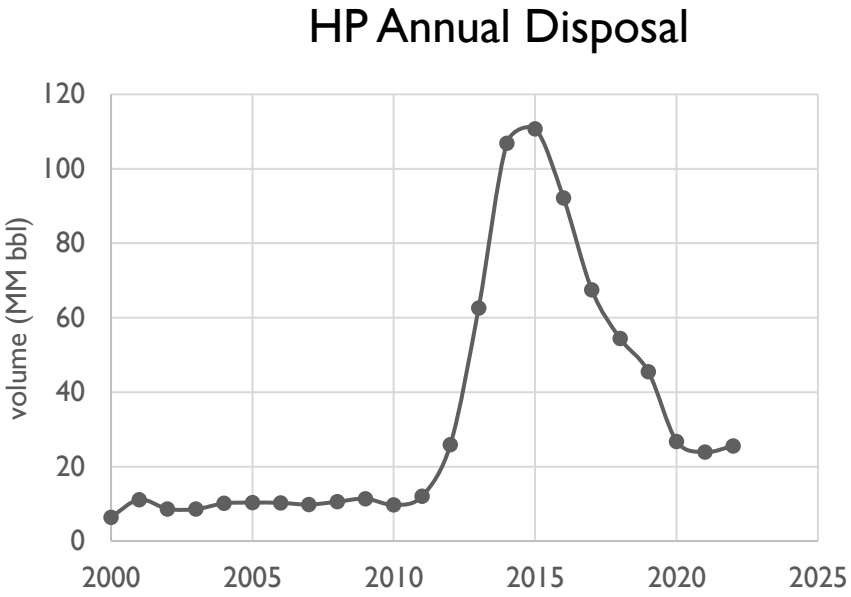
CSTS Alerts

M 2+ within 30 mi = 33 (249 previous year)

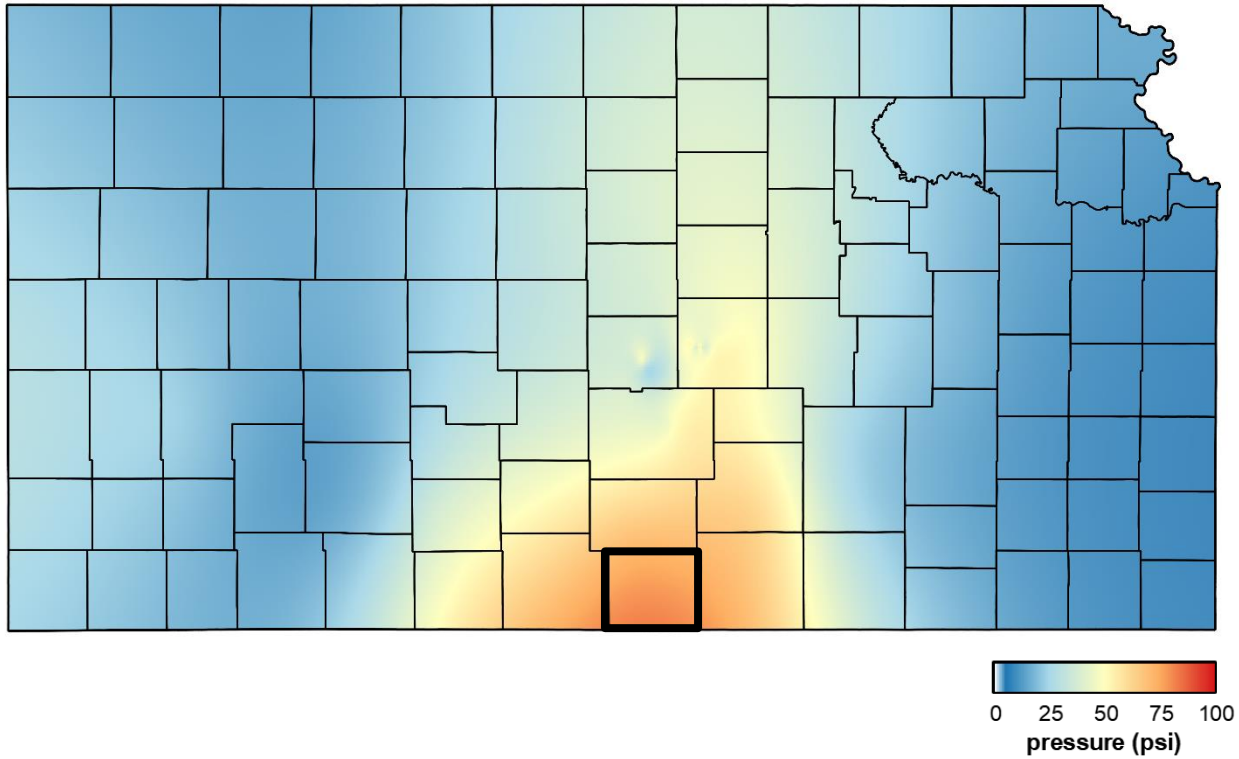


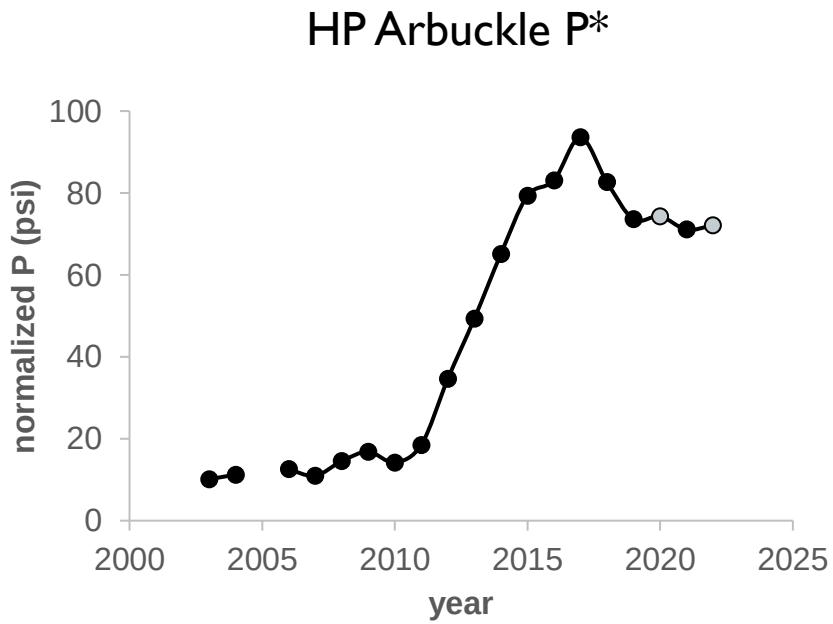
2022 Disposal Volumes



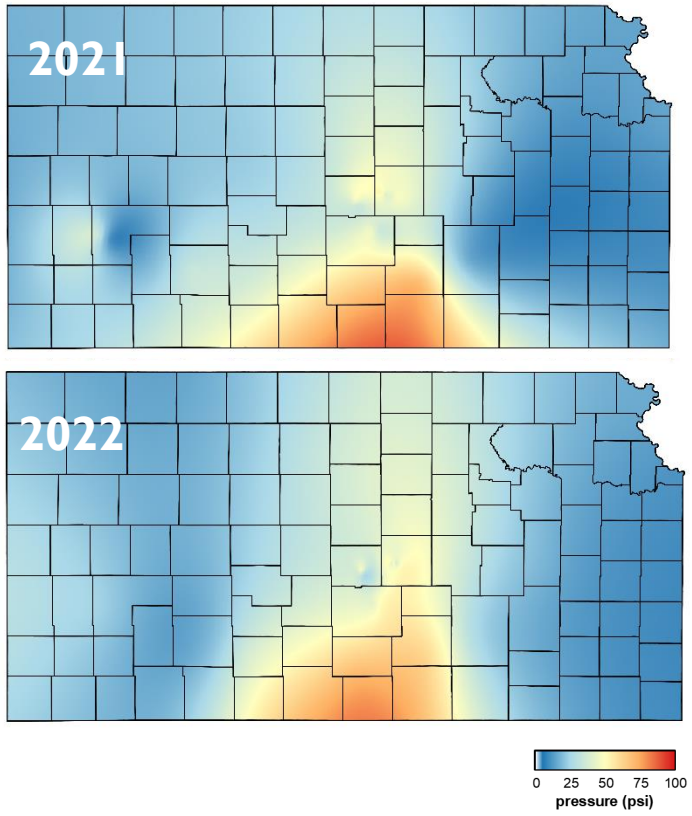


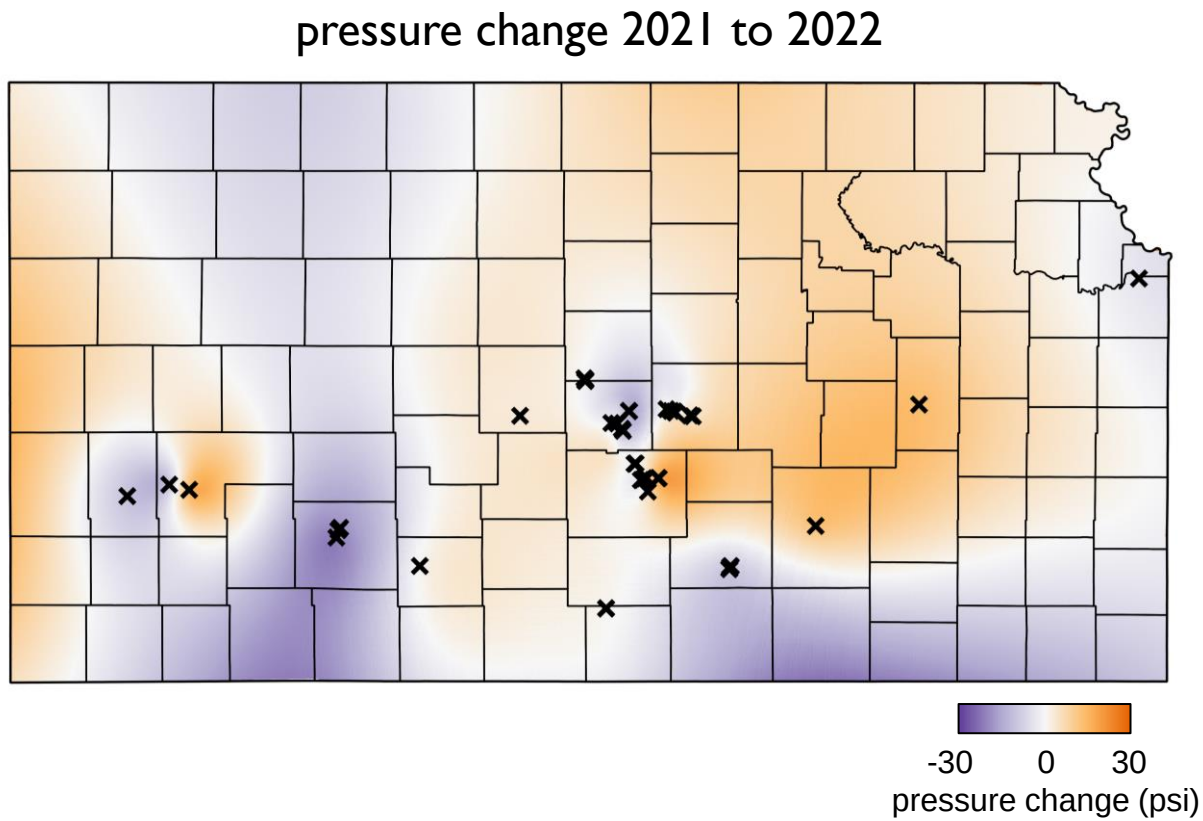
2022 Formation Pressure



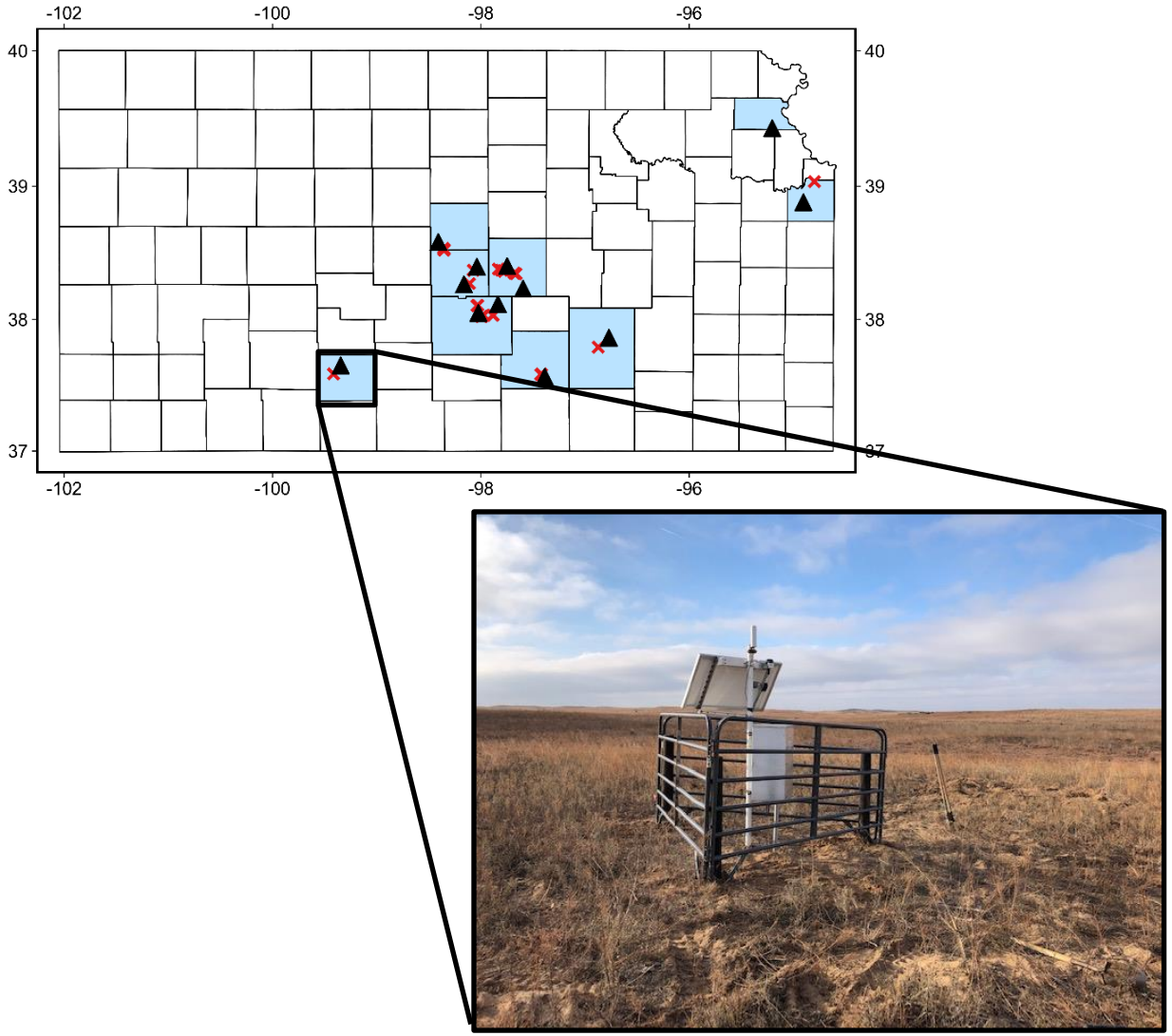


Formation Pressure Change





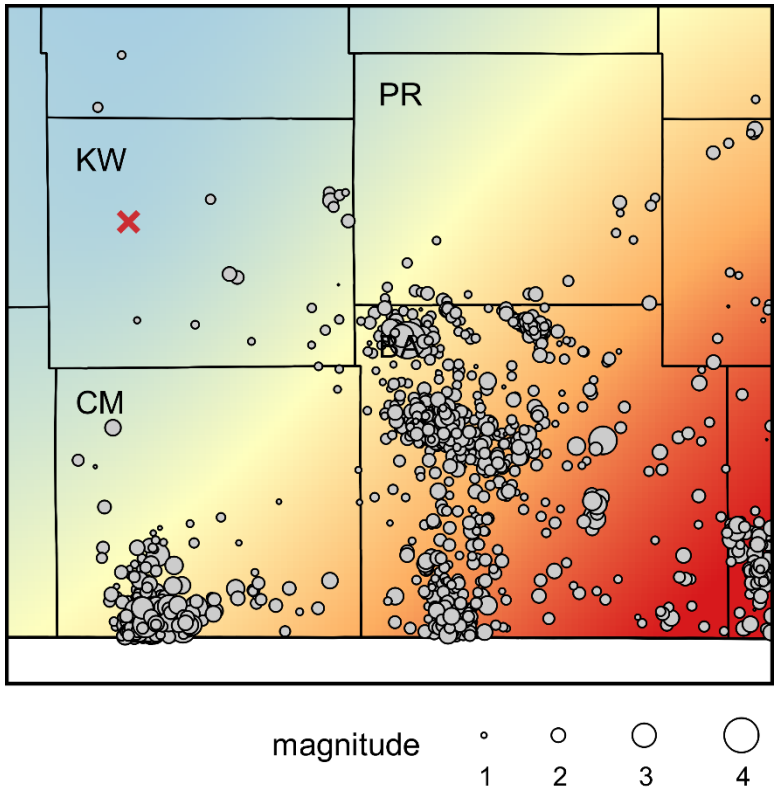
Kiowa County



- KW02
  - north central KW
  - pasture
  - Greensburg

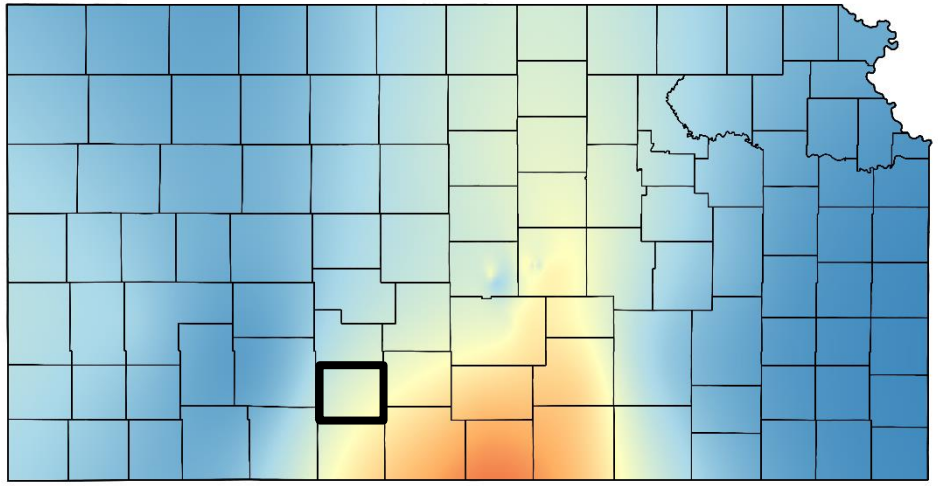
Kiowa County

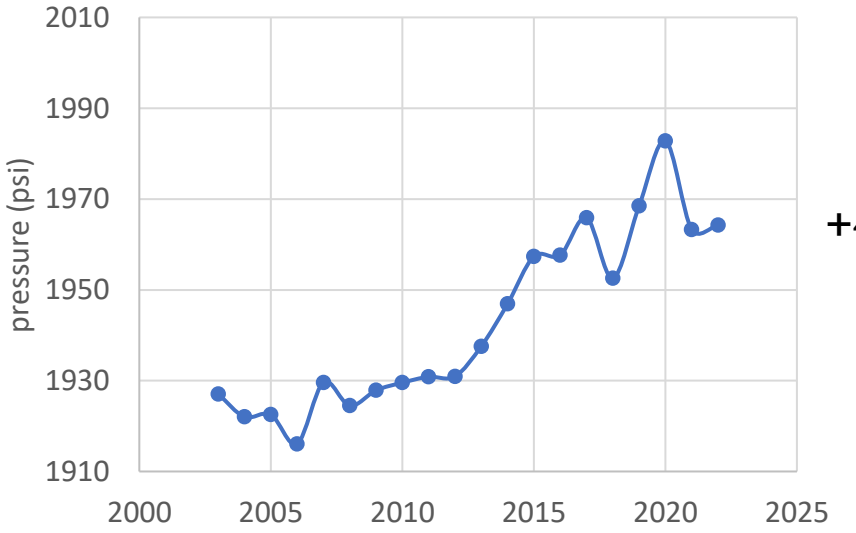
Arbuckle Group pressure



- Central Kansas Uplift
  - southwest margin
  - west of Pratt Anticline
- Mapped faults
  - None
- Historic earthquakes
  - None
  - Influenced by pore pressure
  - Sparse recent seismicity

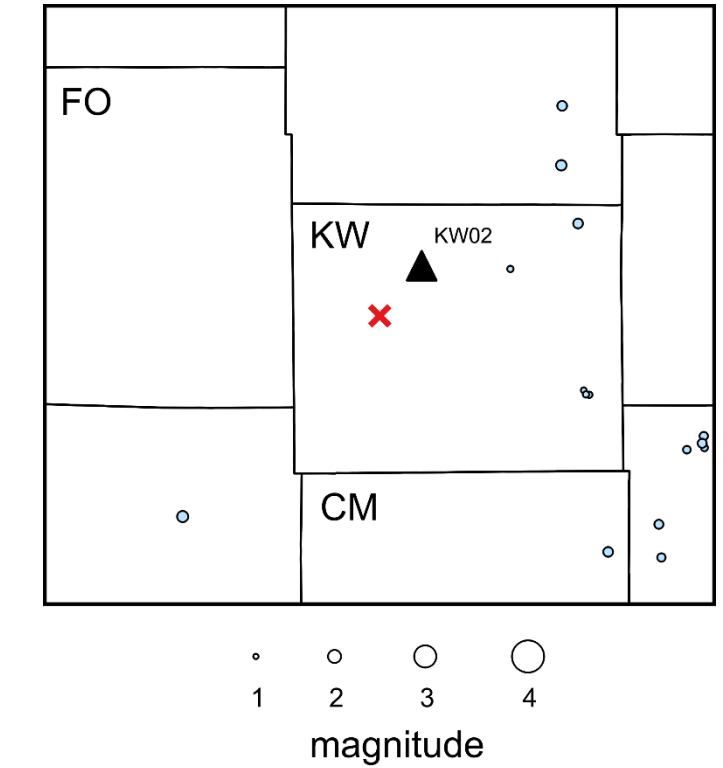
Kiowa County





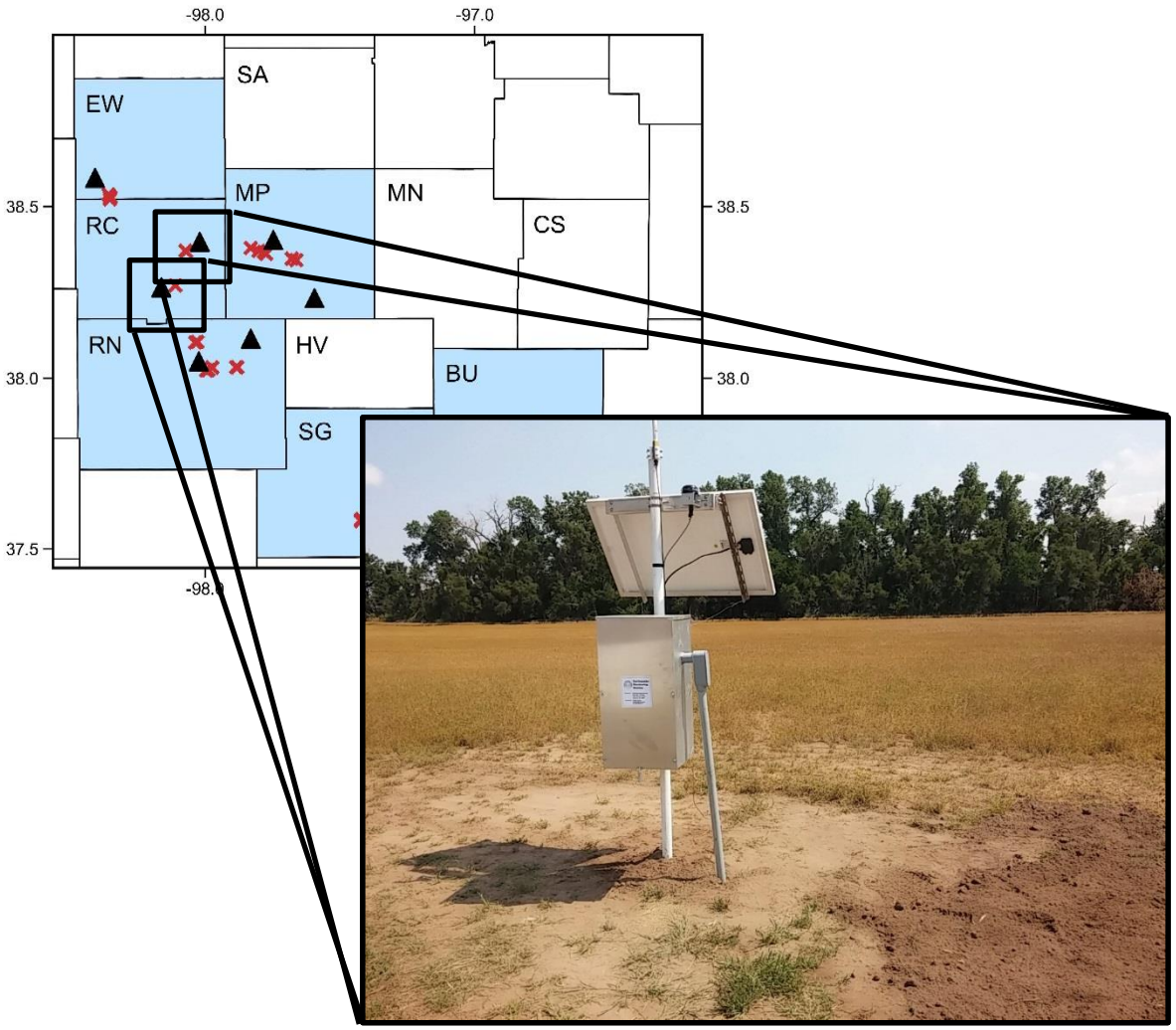
+40 psi

Kiowa County



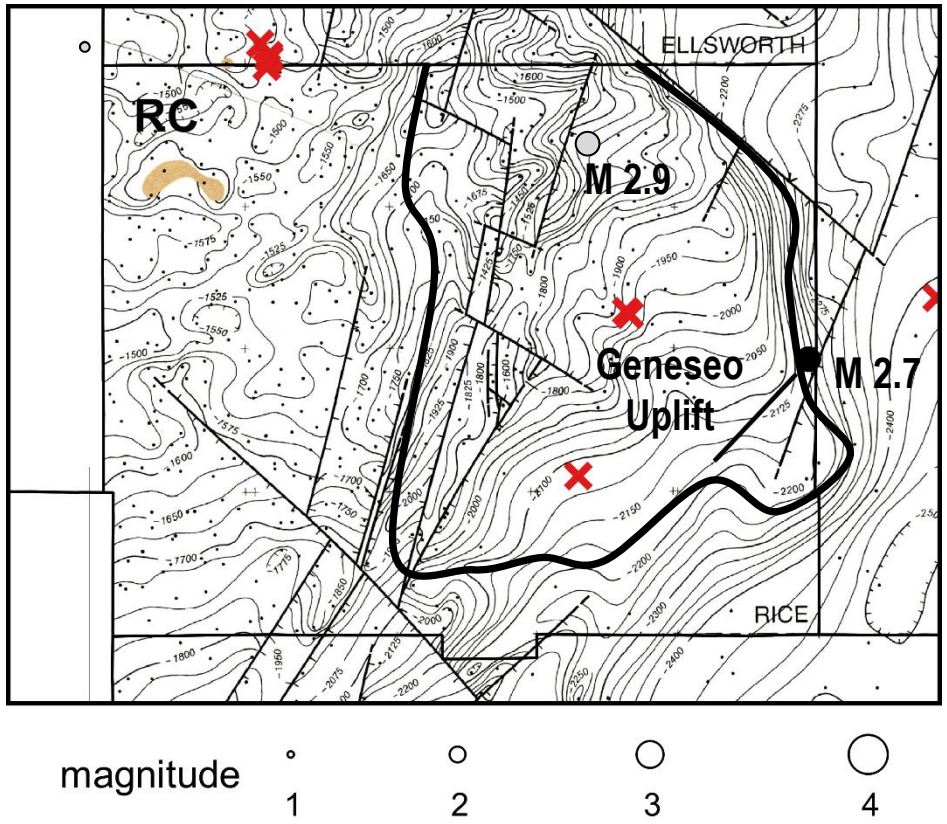
- Local Earthquakes (<20 mi)
  - 3, largest = M 1.8
  - 2 just > 20 mi
- Subnetwork events
  - Recorded on < 3 stations
  - 1 event (5/yr average)
  - M 0.4
  - 10.5 mi from KW02
- Sparse, low-magnitude

Rice County



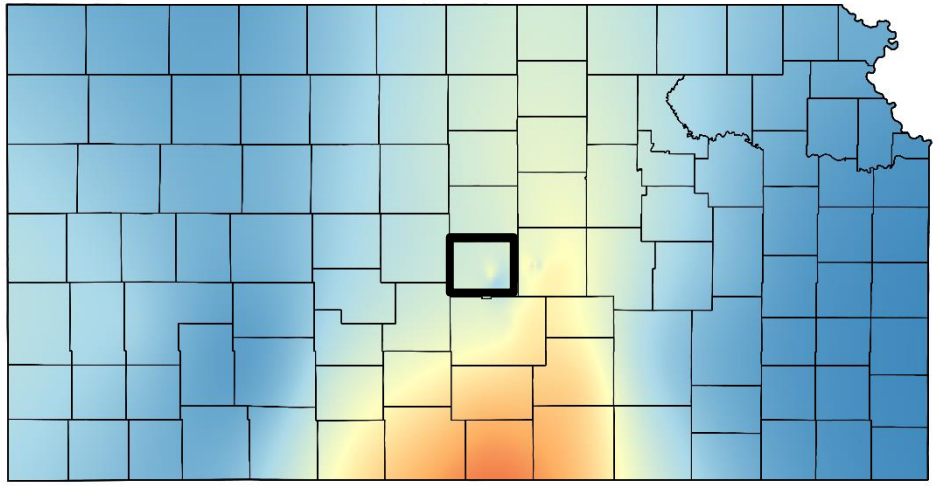
- RC02
  - northeast RC
  - pasture
  - Little River
- RC03
  - Pasture
  - between Lyons and Sterling

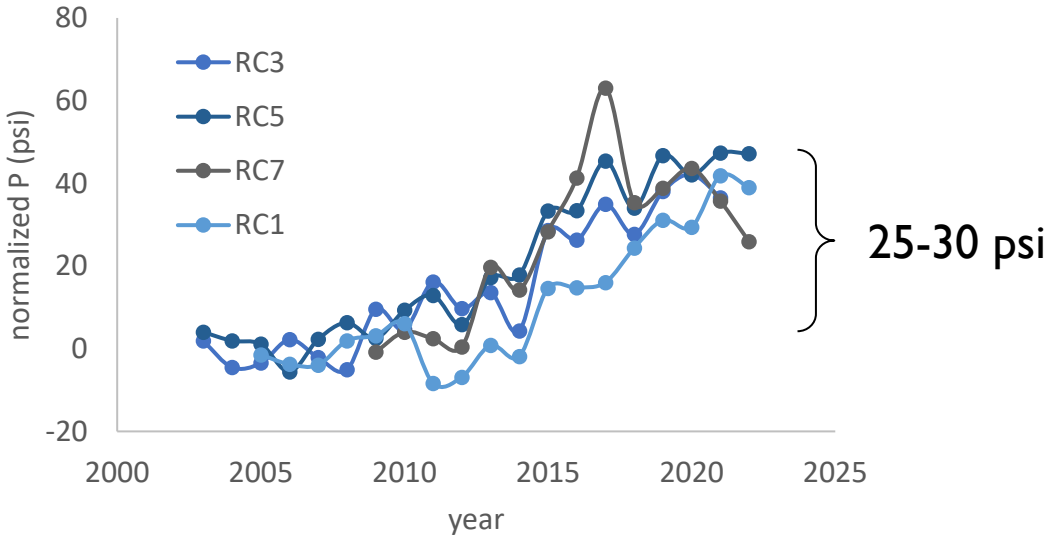
Rice County



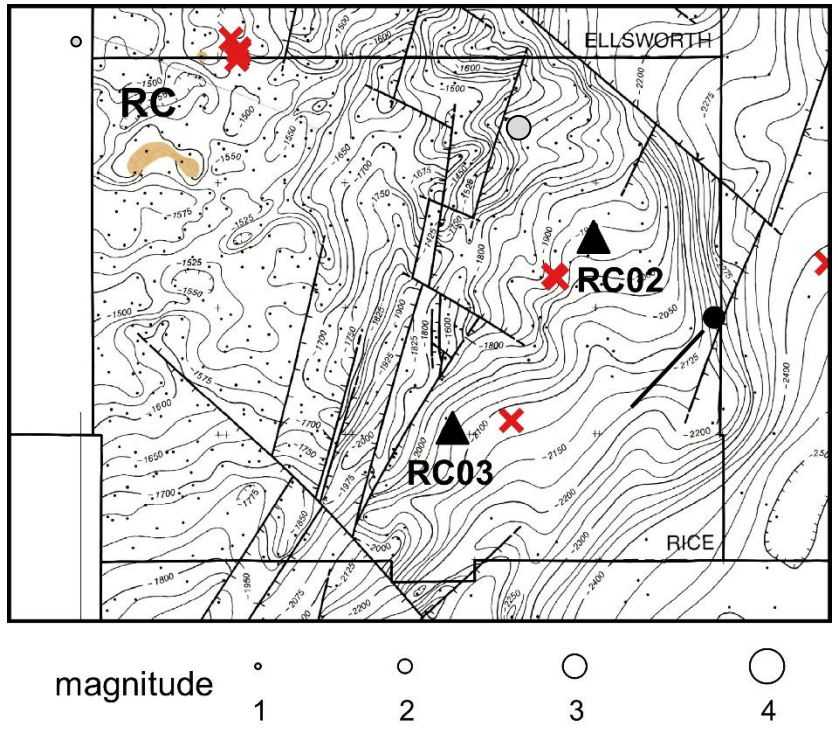
- Eastern margin of the CKU
- Mapped structures
  - Peace Creek TZ
  - Geneseo Uplift
  - bounded by faults
- Historic earthquakes
  - M 2.7 in 1981
  - M 2.9 in 2022

Rice County




80
60
40
20
0
-20
normalized P (psi)
RC3
RC5
RC7
RC1
2000
2005
2010
2015
2020
2025
year
25-30 psi

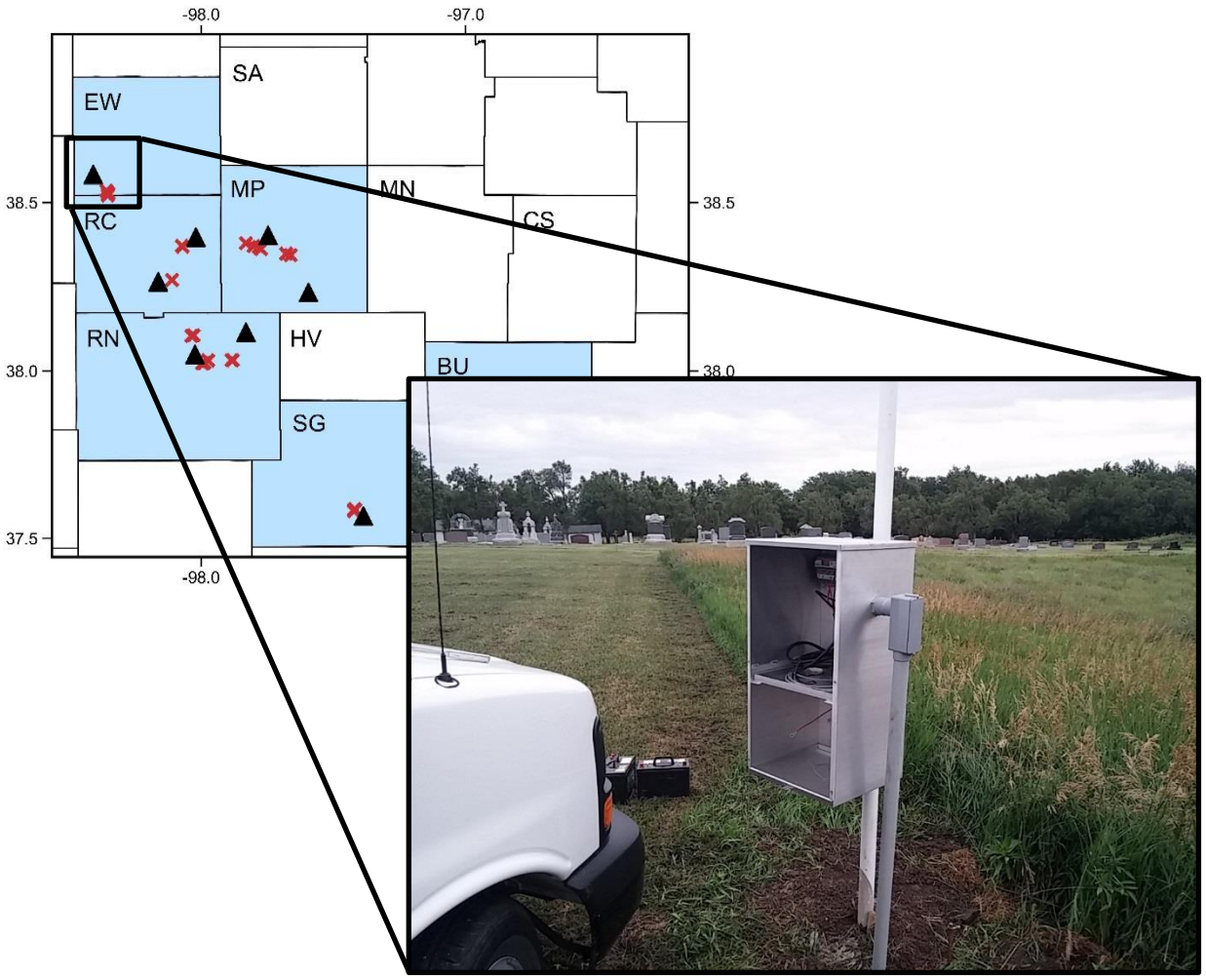
Rice County



- Historic (1977-2014)
- KGS network (2015-2022)
- KGS/CSTS network (2022-2023)

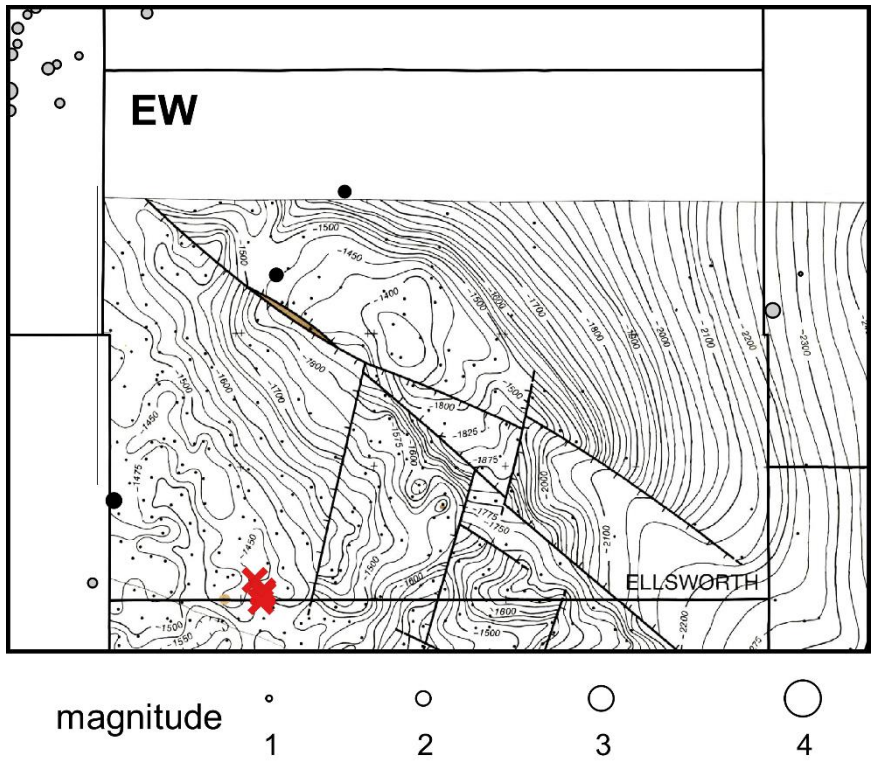
- Local earthquakes (< 20mi)
  - None
- Subnetwork events
  - RC02: 7 (22/yr avg.)
    - M -0.4 to 0.4
    - distance: 4-9 mi
    - Geneseo Uplift
  - RC03: 4 (15/yr avg.)
    - M 0.1 to 0.8
    - distance: 3-8 mi

Ellsworth County



- EW01
  - southwest EW
  - Holyrood
  - pasture, cemetery

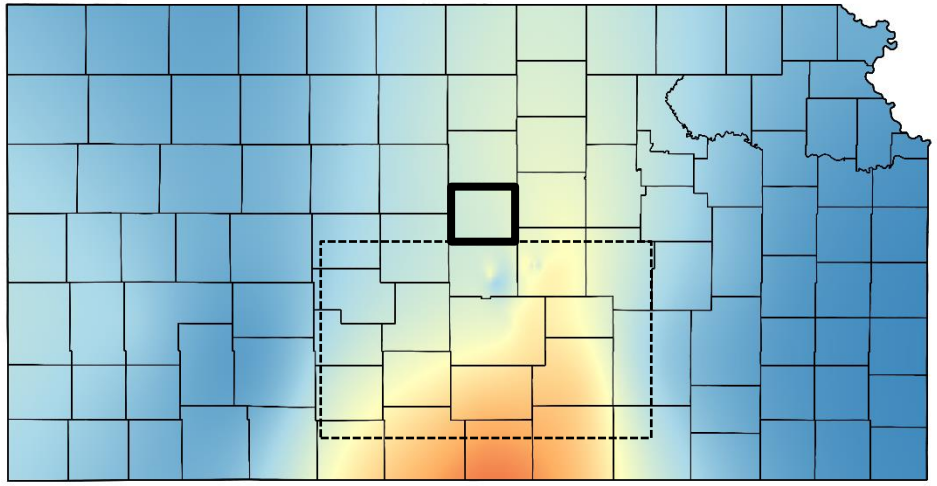
Ellsworth County

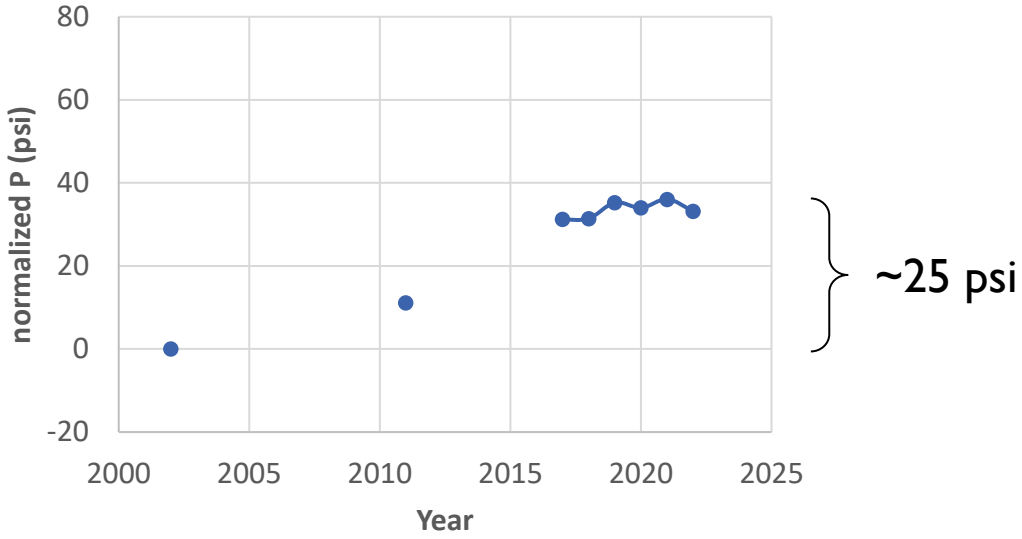


- Historic (1977-2014)
- KGS network (2015-2022)

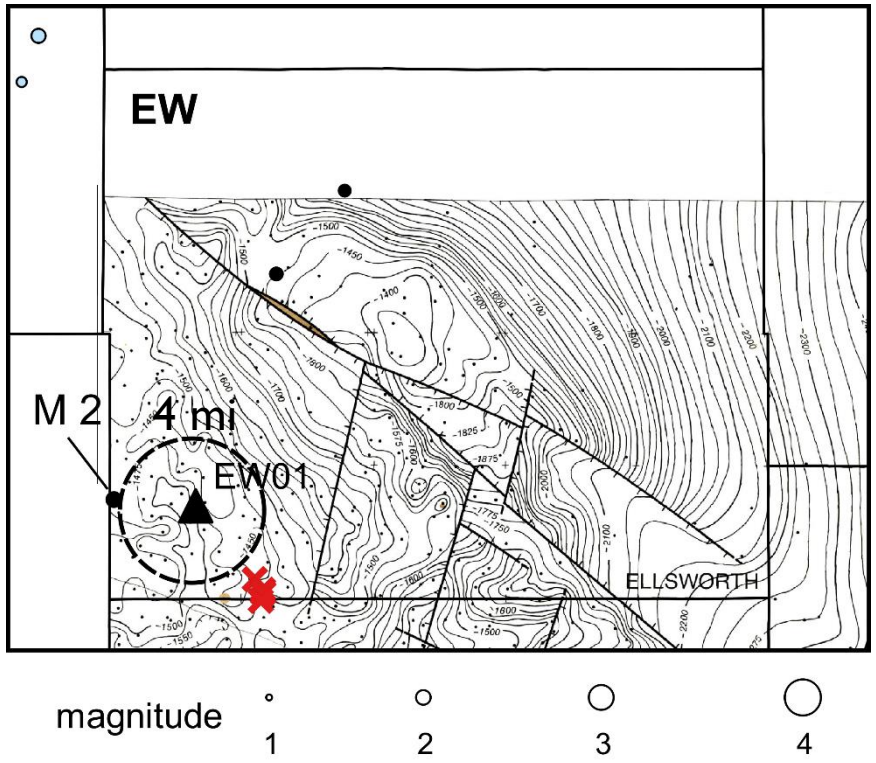
- Eastern margin of the CKU
- Mapped structures
  - faults
- Historic earthquakes
  - M 1.7 to 2.0 in 1980s
  - M 1.4 in 2018 (Barton)
  - Recent seismicity in RS

Ellsworth County





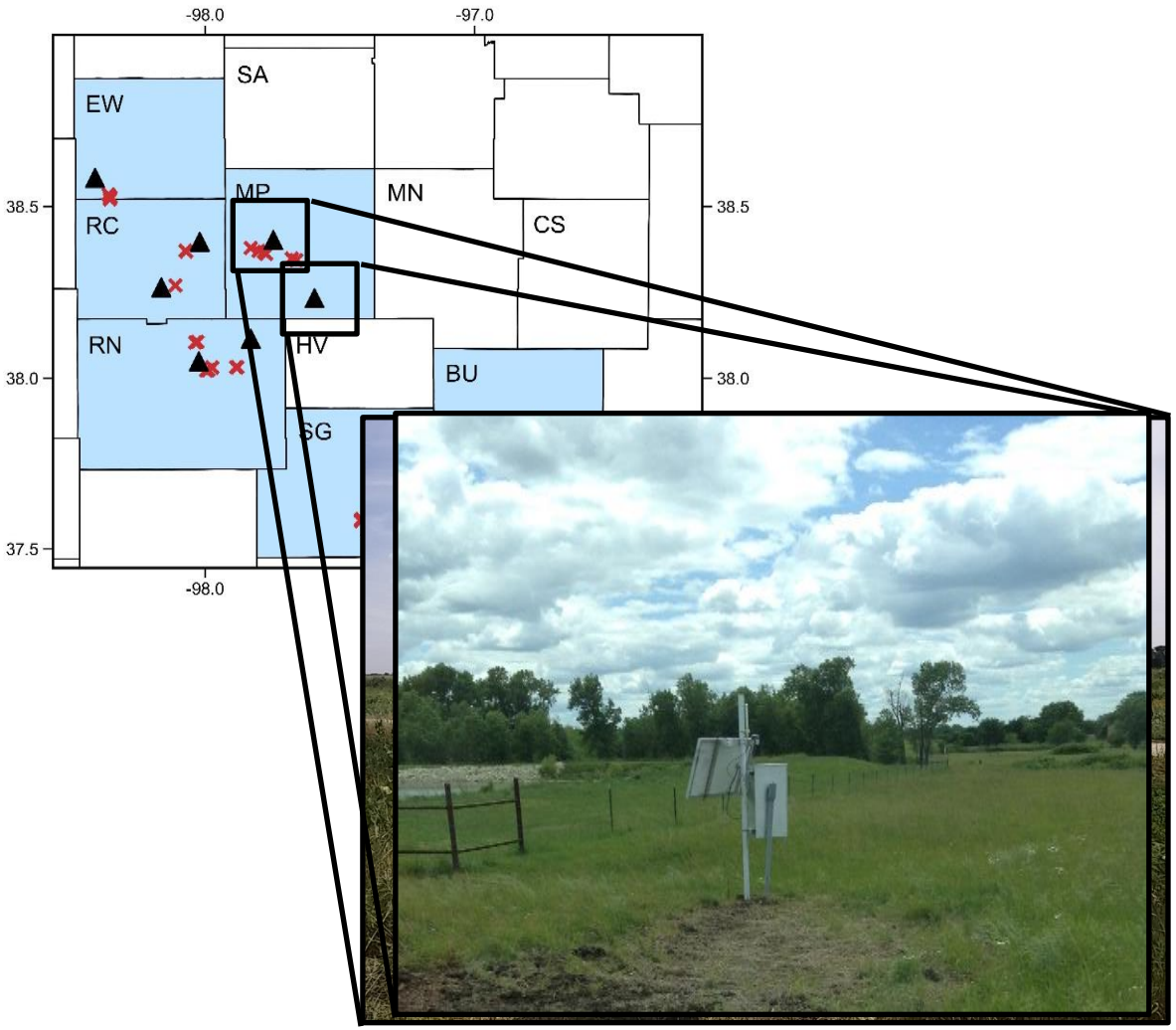
Ellsworth County



- Historic (1977-2014)
- KGS/CSTS network (2022-2023)

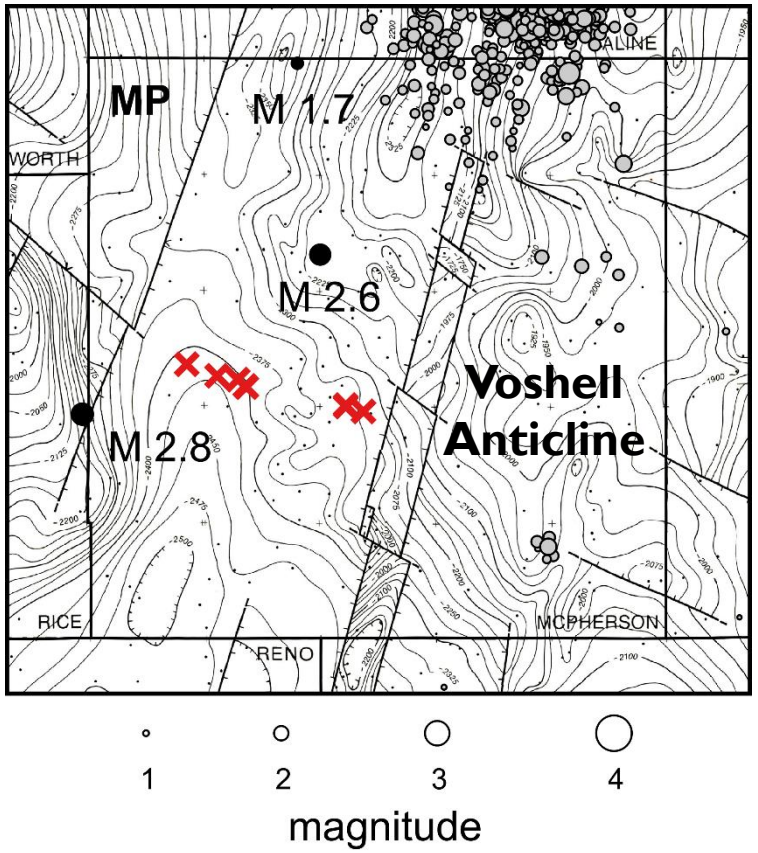
- Local earthquakes (< 20 mi)
  - None
  - events in Russell Co > 20 mi
- Subnetwork events
  - 4 events (10/yr avg.)
  - M 0.1 to 0.6
  - 4-11 mi from station
- Consistent with past years

McPherson County



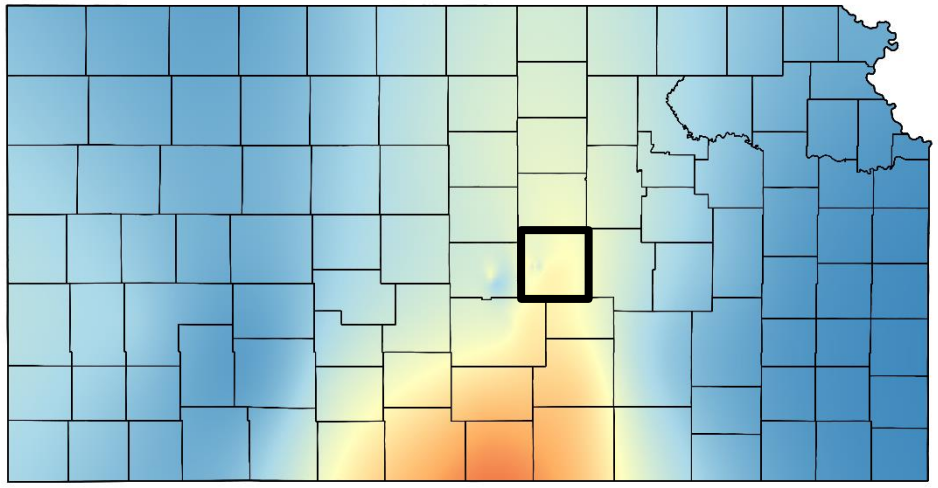
- MP01
  - northeast of Conway
  - pasture
  - McPherson Valley Wetlands
- MP02
  - south of McPherson
  - pasture
  - local church

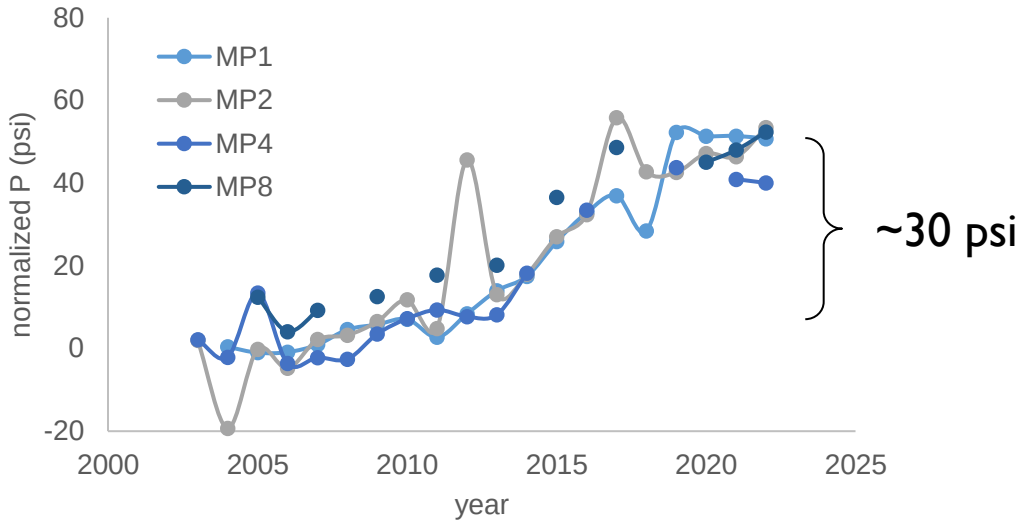
McPherson County



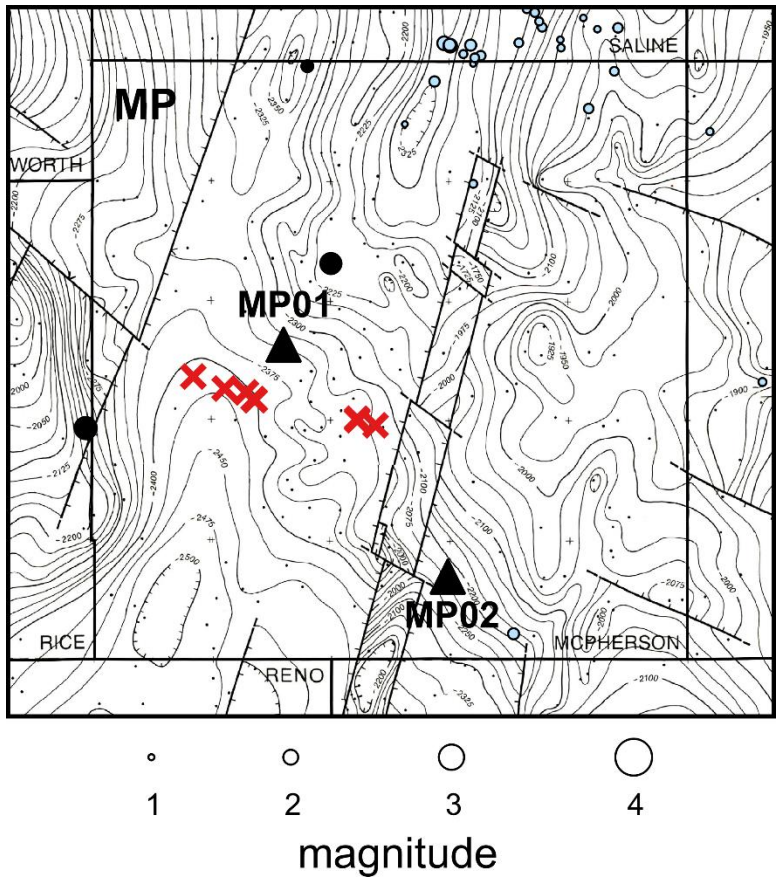
- Midcontinent Rift System
- Mapped structures
  - Voshell Anticline
  - bounded by faults
- Previous earthquakes
  - M 2.8 in 1981
  - M 1.7 in 1983
  - M 2.6 in 2014
  - Recent seismicity near MP–SA county line
  - Southeast corner near Peabody Fault

McPherson County





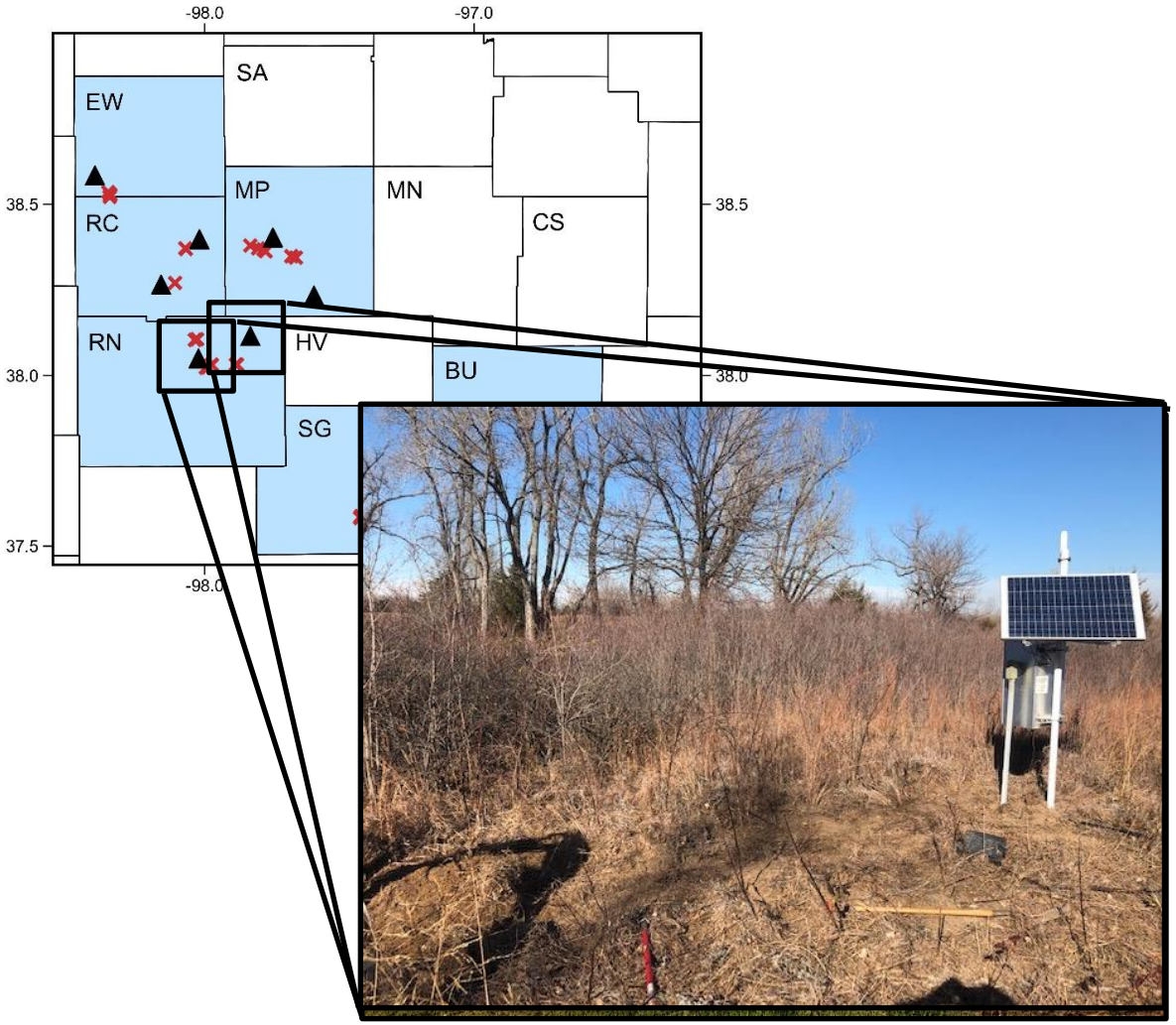
McPherson County



- Historic (1977-2014)
- KGS/CSTS network (2022-2023)

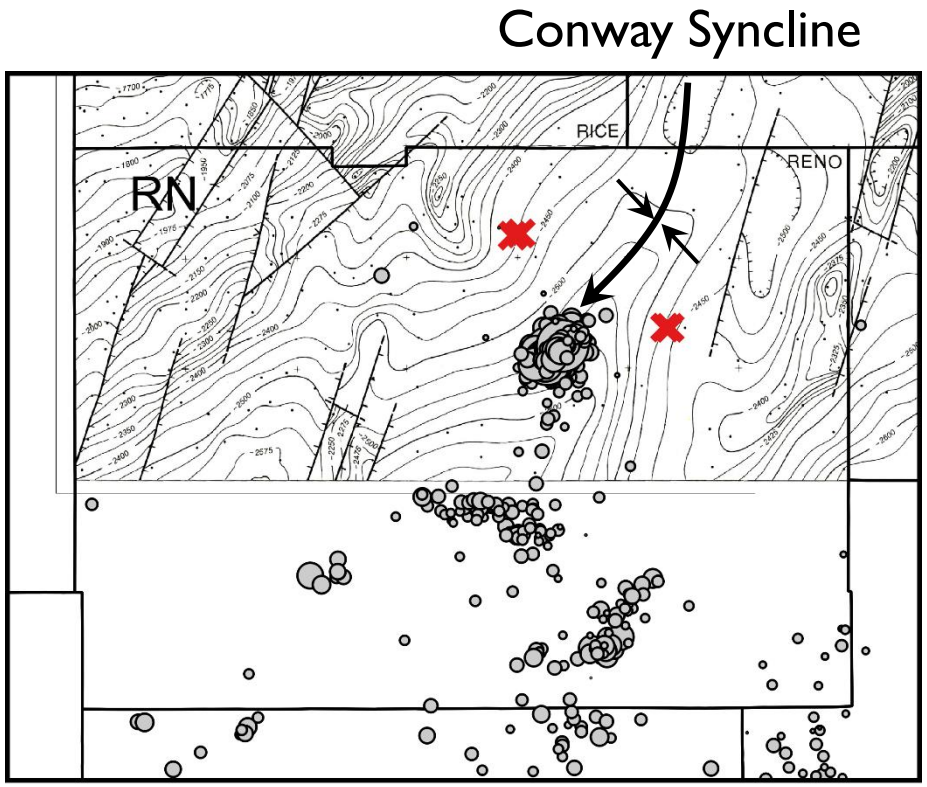
- Local earthquakes (< 20 mi)
  - 15 earthquakes, M 1.1 to M 2.1
  - mostly near Saline cluster
  - M 1.8 near Halstead fault
- Subnetwork events
  - MP01: 3 events (23/yr avg.)
    - M -0.2 to 0.9
    - avg. 5 mi away, corresponds to historic earthquakes
  - MP02: 4 events (34/yr avg)
    - M 0.1 to 0.8
    - 5-10 mi away
    - corresponds to Peabody cluster

Reno County



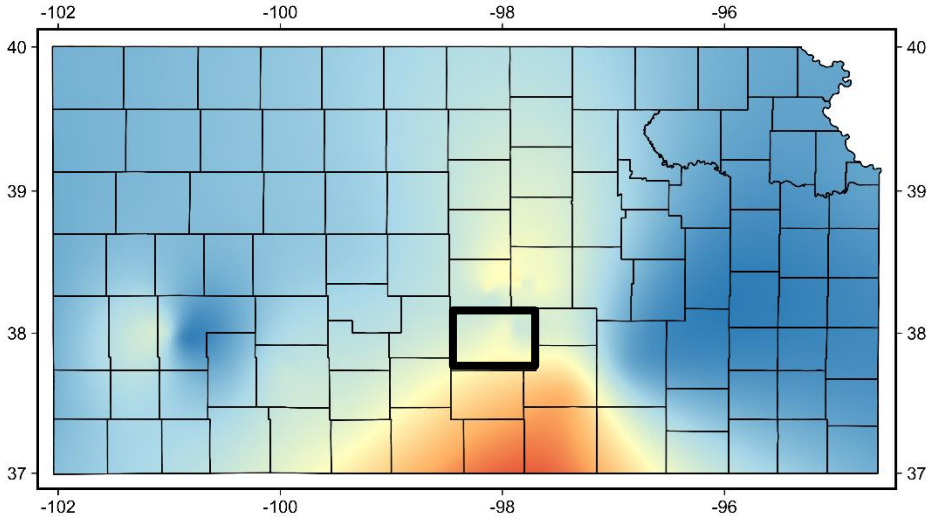
- RN01
  - west of Hutchinson
  - cemetery
- RN03
  - pasture
  - Sand Hills State Park

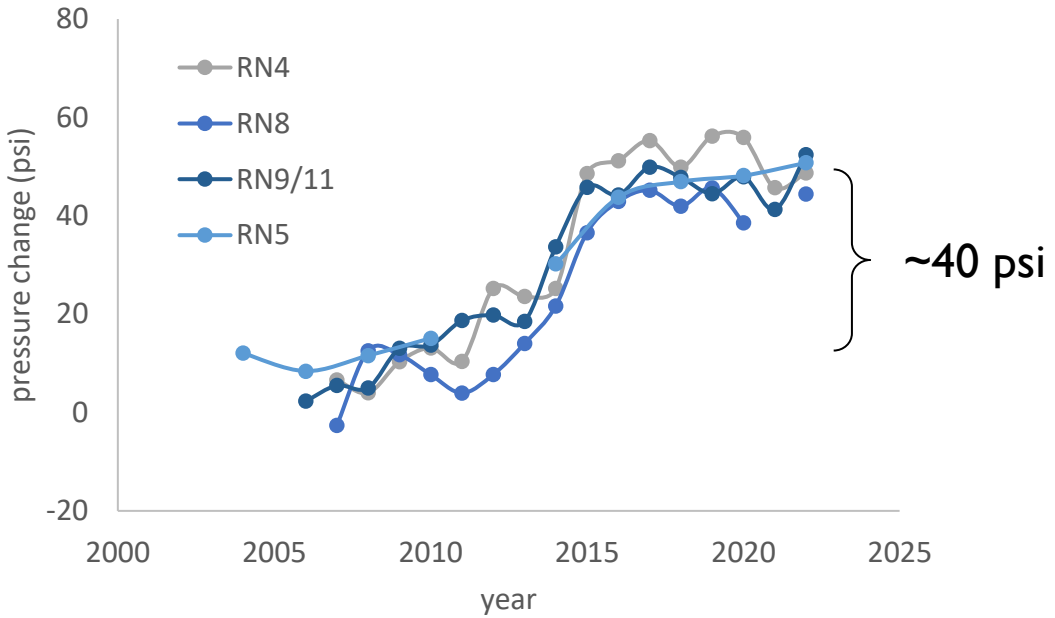
Reno County



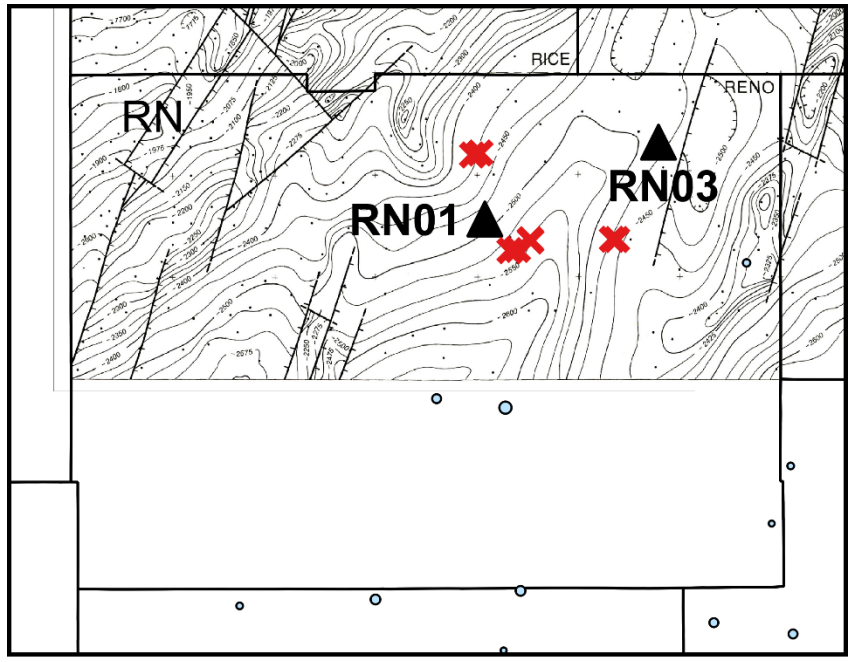
- Geologic Setting
  - CKU and MRS
  - structural low
  - Conway Syncline
  - faults bounding uplifted areas
- Historic earthquakes
  - None (M 3+)
  - Recent seismicity (2015-present)
    - progressed north
    - structural low
    - three M 4+ in 2019-2020

Reno County


-102
-100
-98
-96
40
39
38
37


80
60
40
20
0
-20
pressure change (psi)
RN4
RN8
RN9/11
RN5
2000
2005
2010
2015
2020
2025
year
~40 psi

Reno County

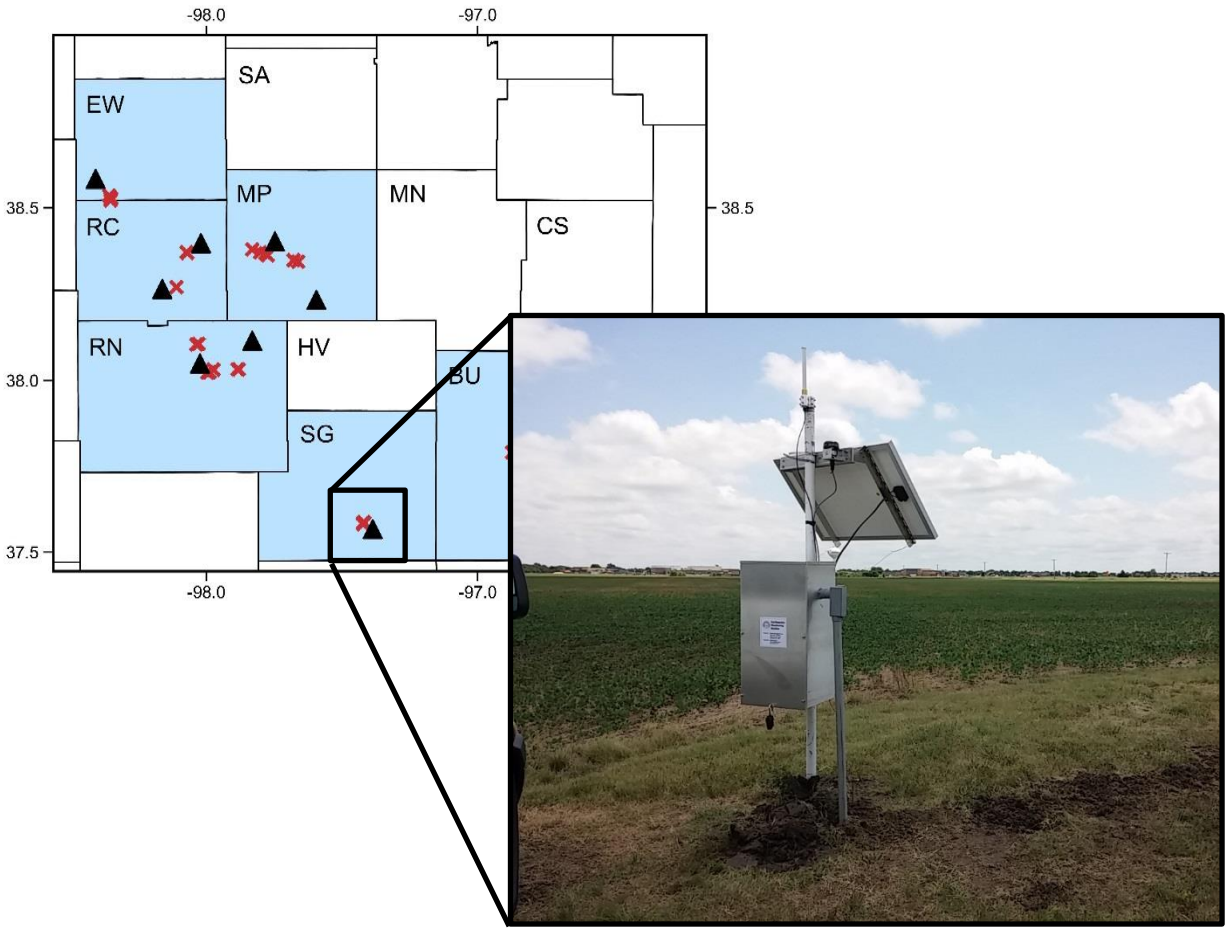


magnitude ○ ○ ○ ○
1 2 3 4

KGS/CSTS network (2022-2023)

- Local earthquakes (w/in 20 mi)
  - 5 events, M < 2
  - Largest M 1.9 on May 6th, 2023
- Subnetwork events
  - RN01
    - 1 (309/yr avg.)
    - M 0.4
    - corresponds to Hutchinson cluster
  - RN03
    - None (22/yr avg)
    - Hutchinson fault

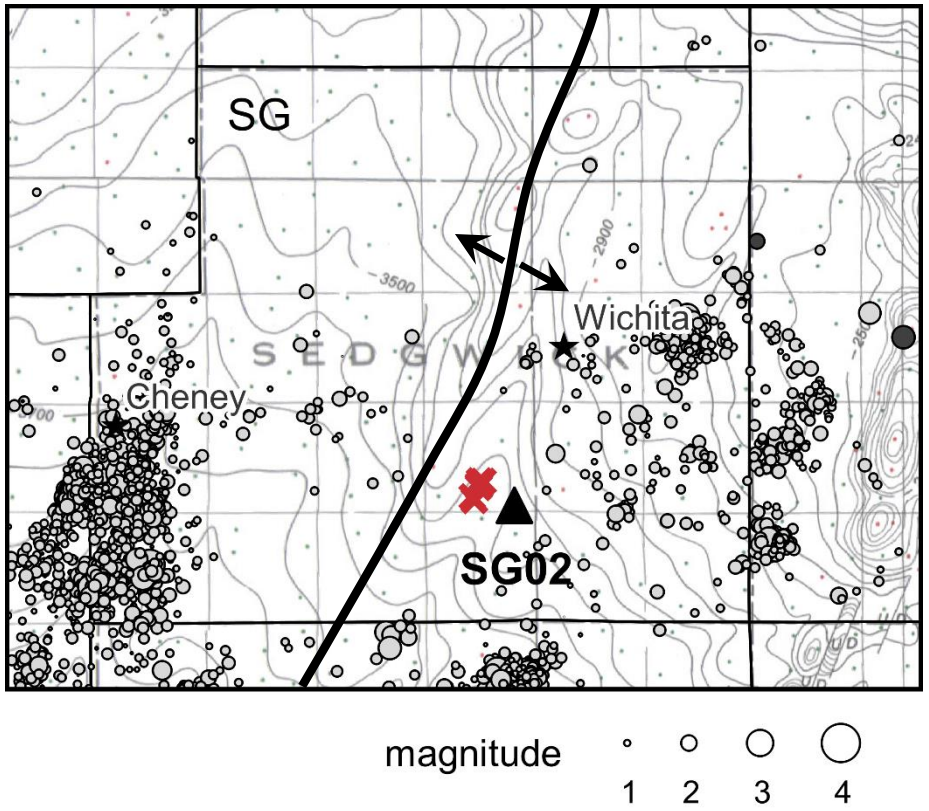
Sedgwick County



- SG02
  - south of Wichita
  - pasture
  - local church

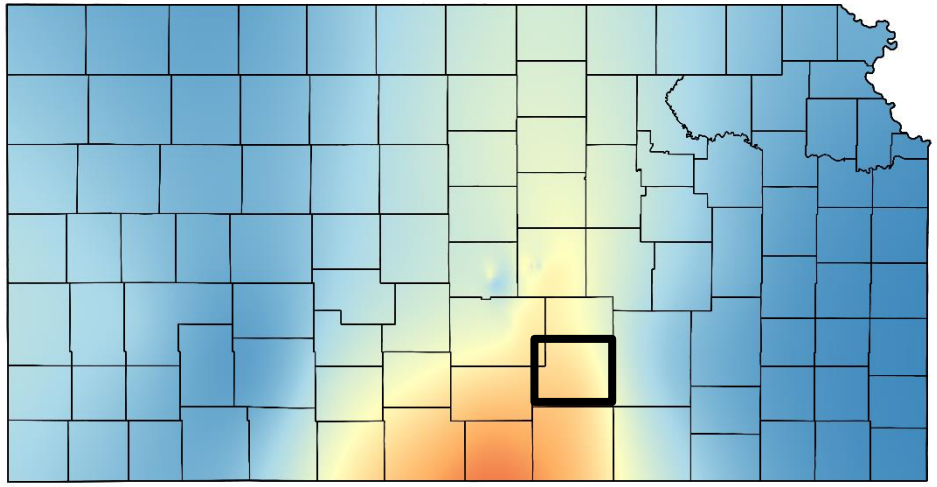
Sedgwick County

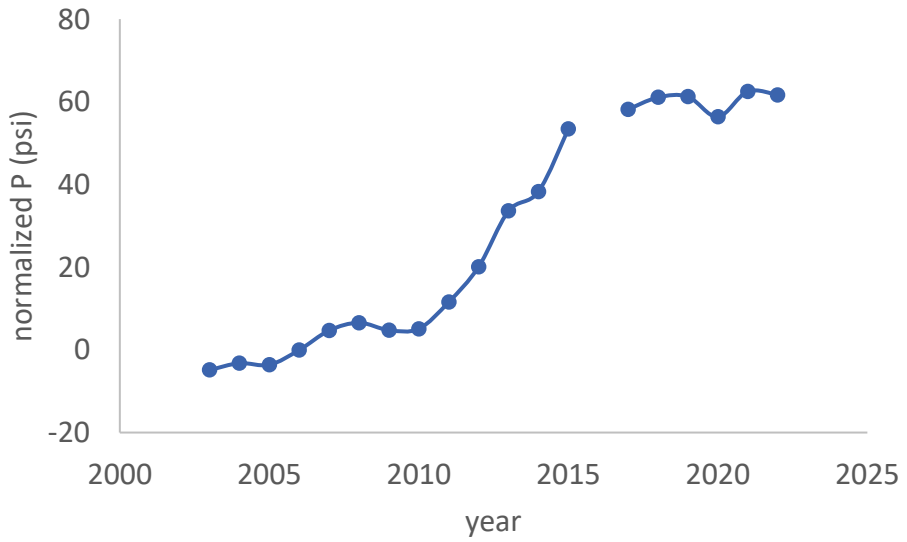
Valley Center Anticline



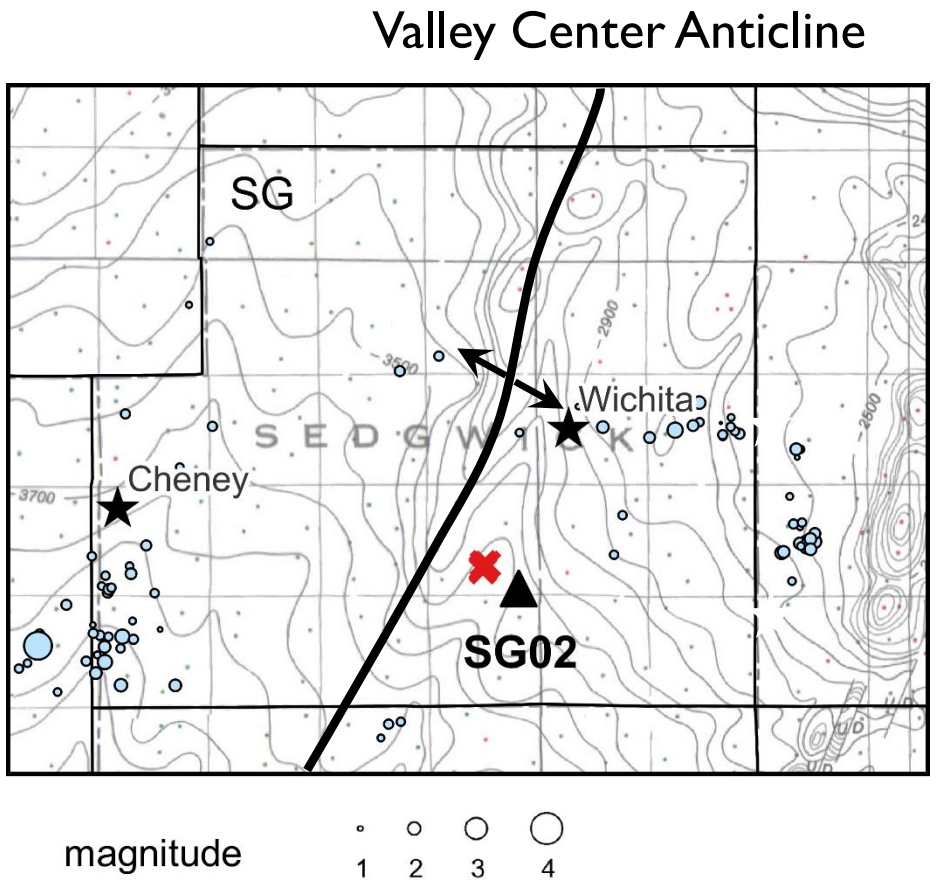
- Nemaha Ridge
- Mapped structures
  - Valley Center Anticline
  - likely associated faults
- Previous earthquakes
  - Historic
    - none recorded
    - felt events in early 1900s
  - Recent seismicity recorded by KGS network
    - predominantly NE trends
    - migrated from KS-OK
    - likely induced
    - dozen M 3 2021-2021

Sedgwick County



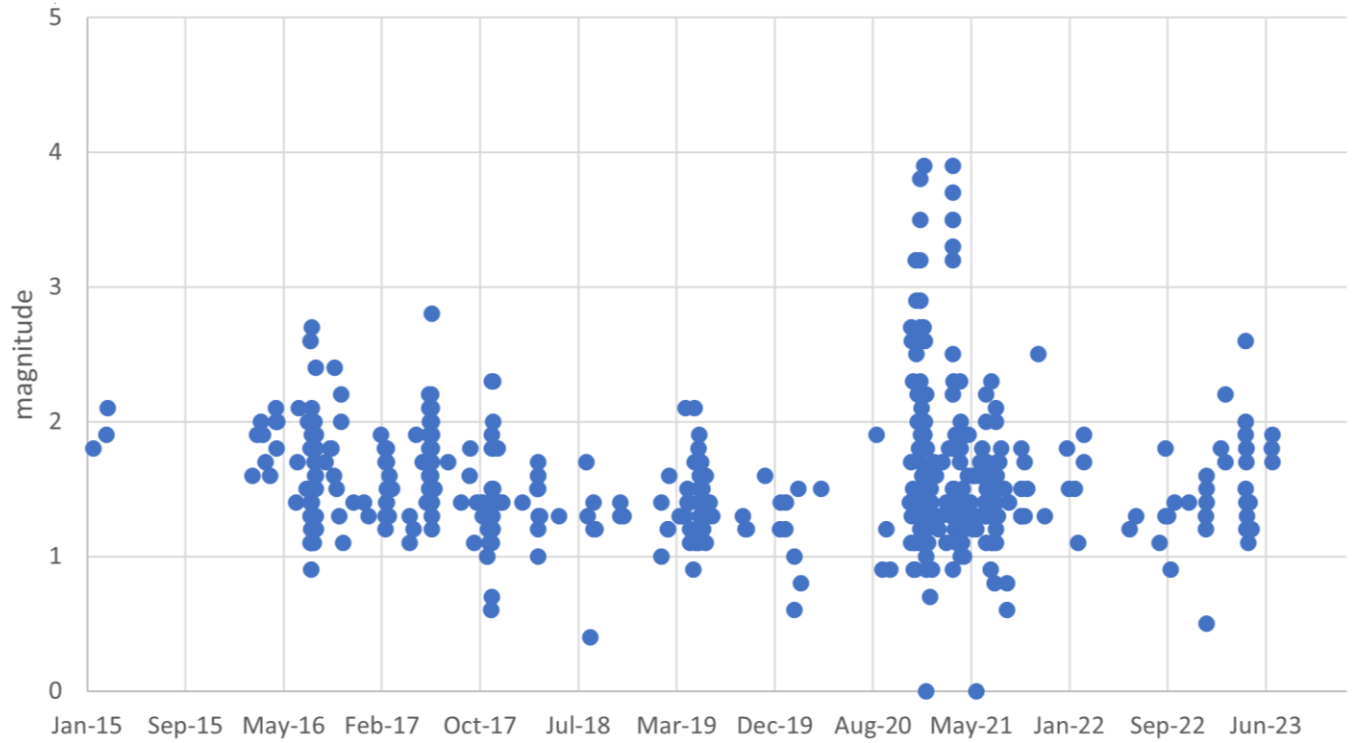


Sedgwick County

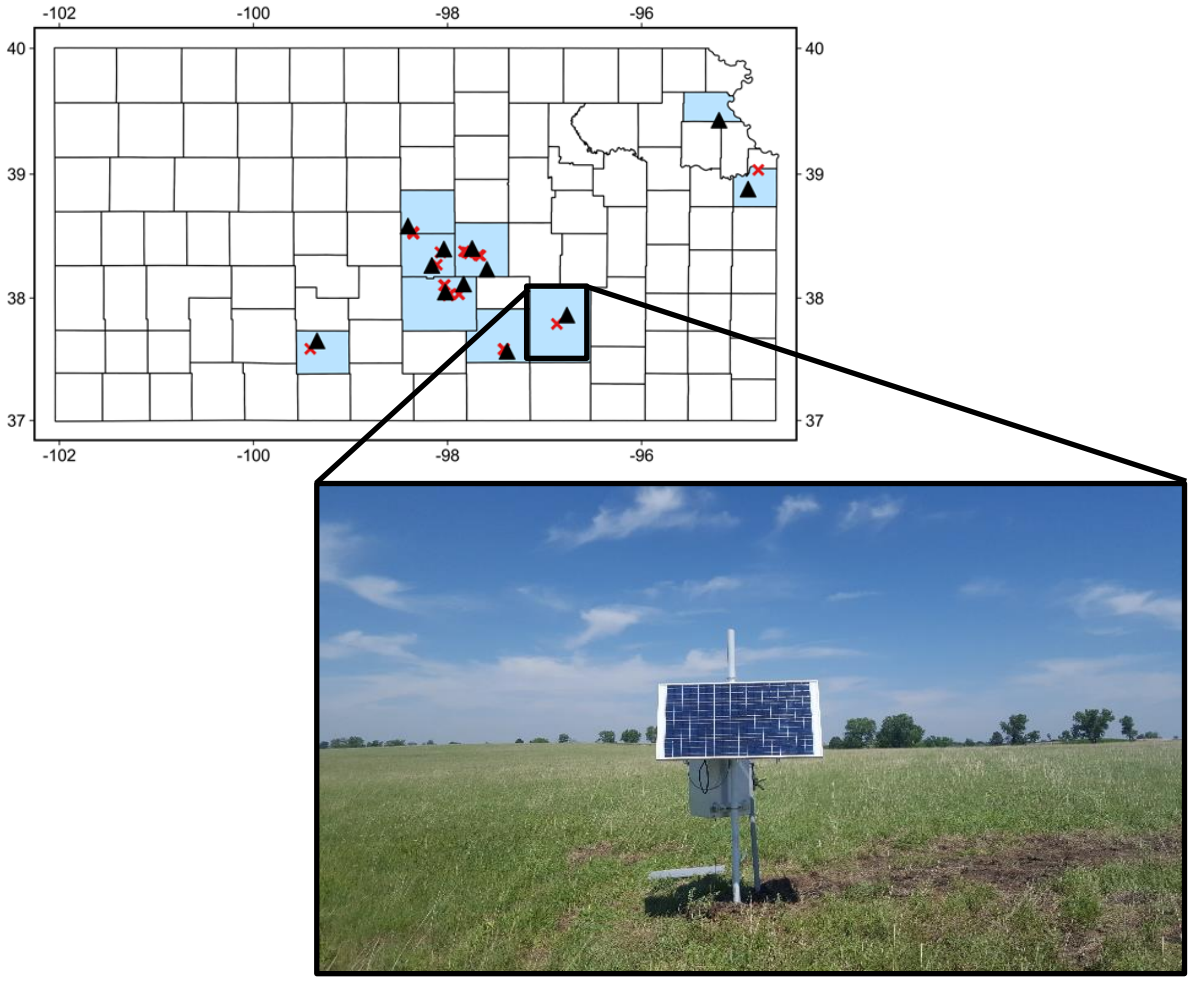


- Local earthquakes (< 20 mi)
  - 63, M 0.5 to 2.6
  - clusters identified previously
- Cheney
  - ~68, largest was M 3.5
- Wichita
  - 40, largest M 2.6
- Subnetwork Events
  - 2 events (27/yr avg)
  - M -0.6 and -0.2
  - 1 and 5 miles

Wichita

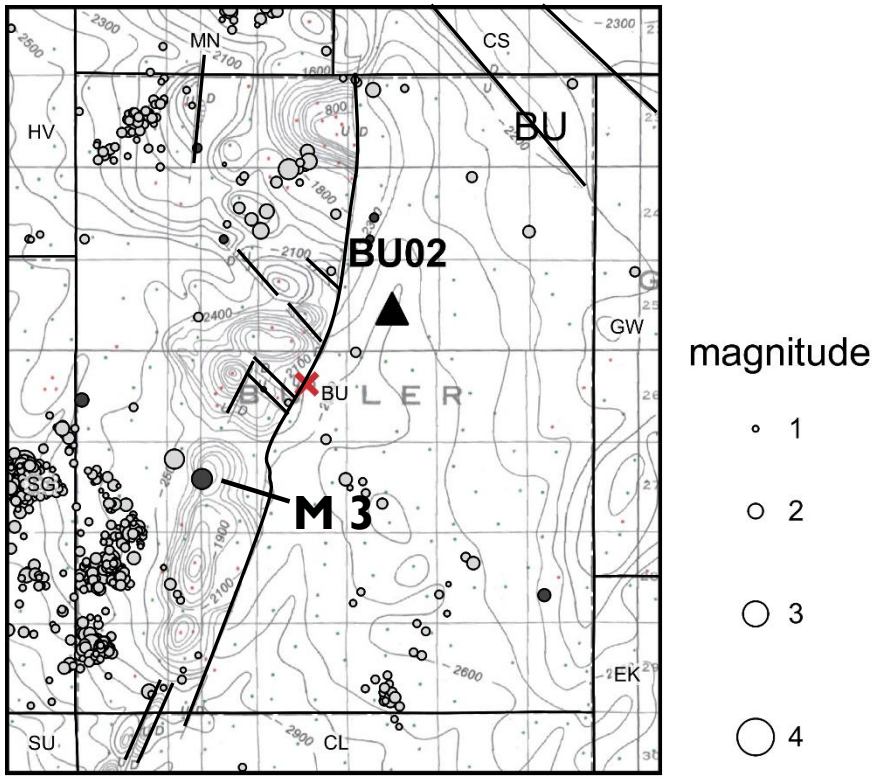

magnitude
5
4
3
2
1
0
Jan-15
Sep-15
May-16
Feb-17
Oct-17
Jul-18
Mar-19
Dec-19
Aug-20
May-21
Jan-22
Sep-22
Jun-23

Butler County



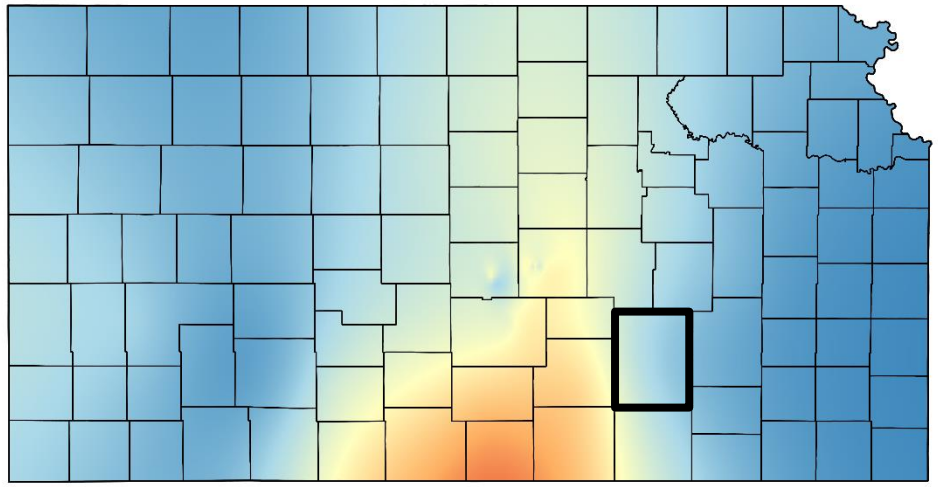
- BU02
  - northeast of El Dorado
  - pasture
  - El Dorado State Park

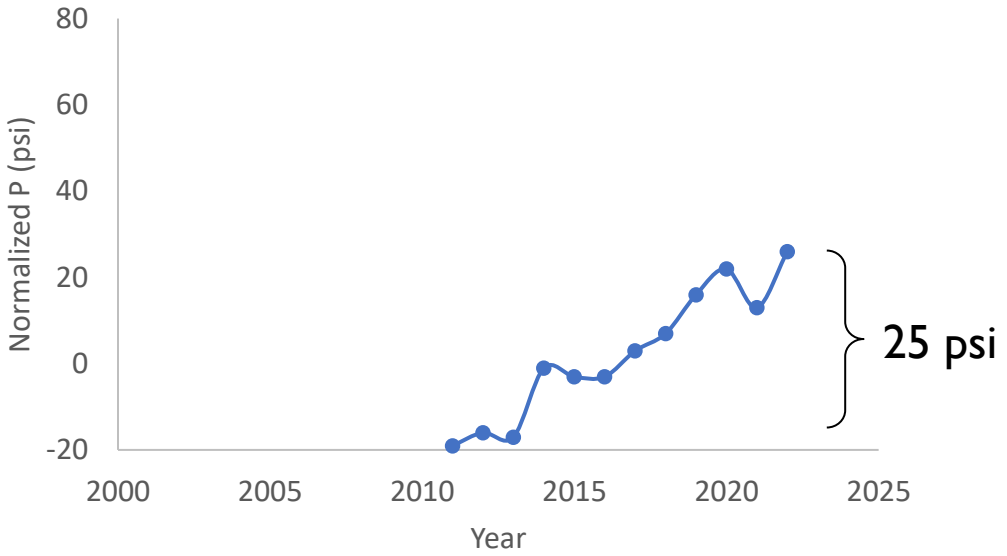
Butler County



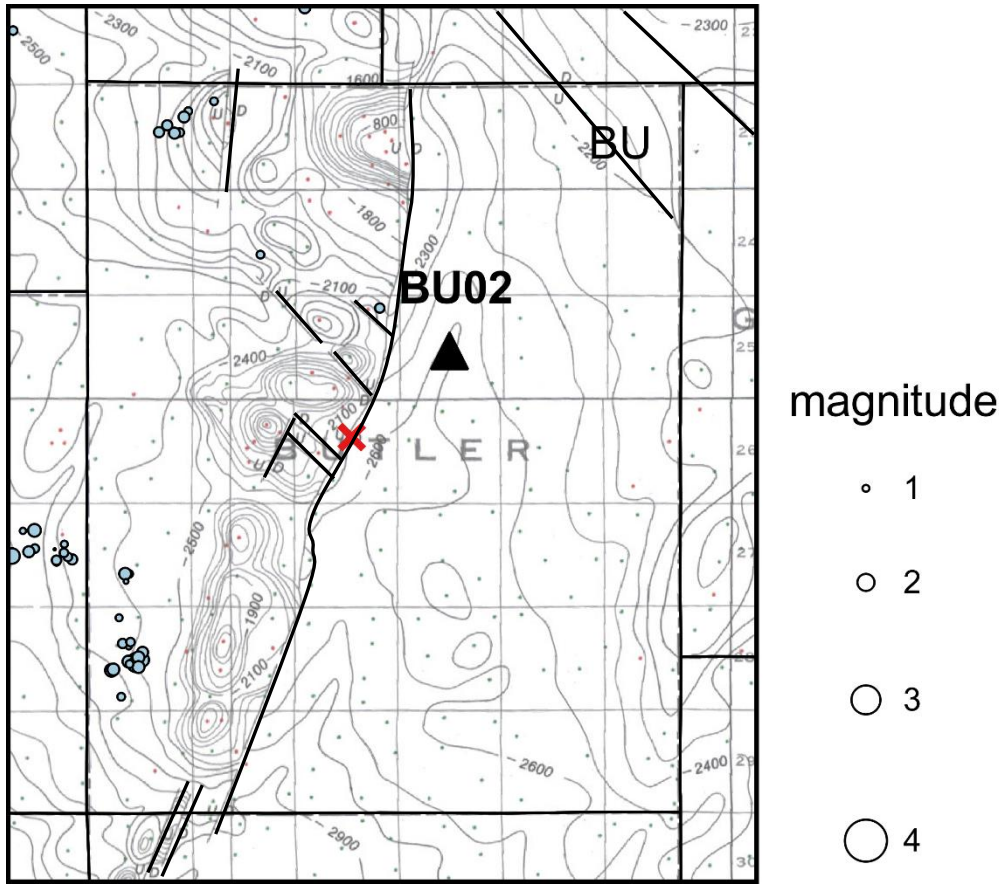
- Nemaha Ridge
- Mapped structures
  - Nemaha Ridge/Humboldt FZ
  - anticlines/synclines
  - mapped faults
- Previous earthquakes
  - 7 historic events (M 3 in 2001)
  - Recent seismicity recorded by KGS network
    - Activity near the SG-BU line
    - Clusters in northern and southern BU

Butler County



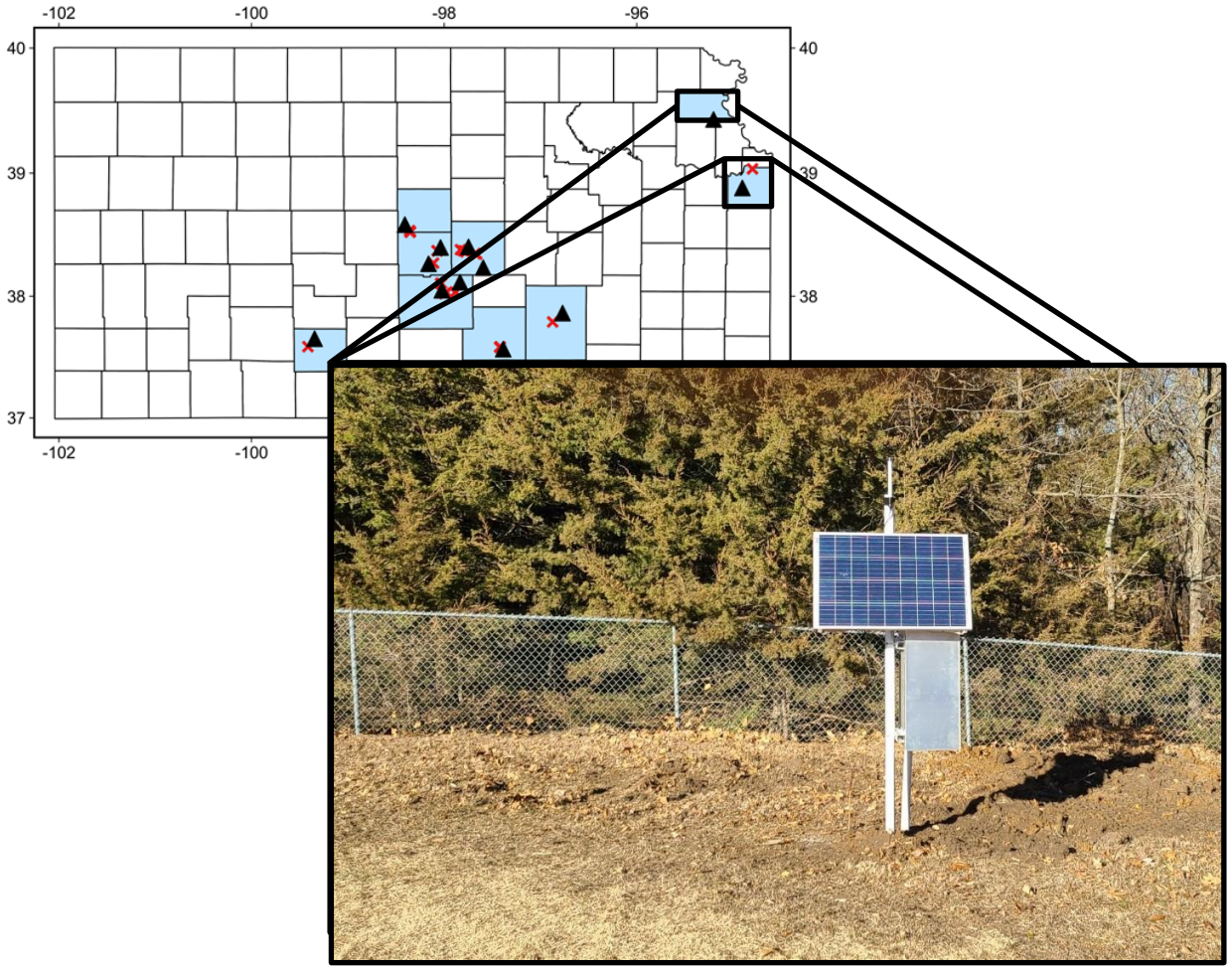


Butler County



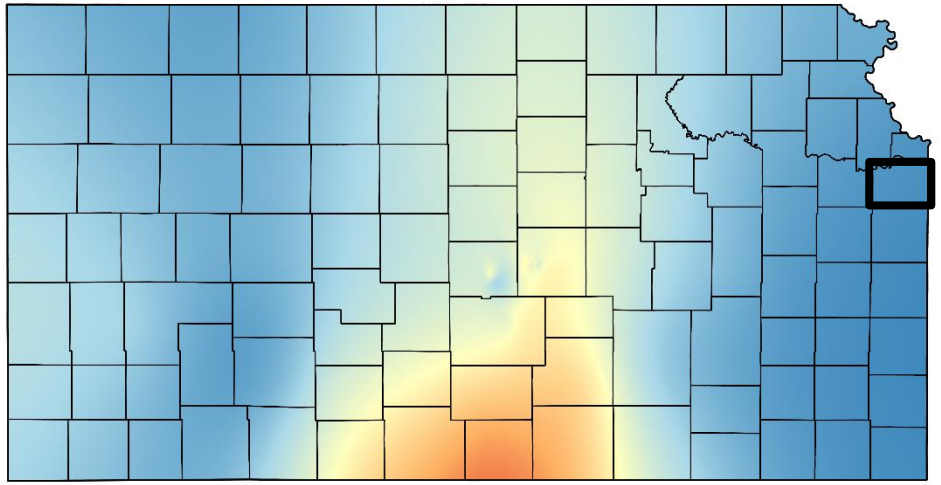
- Local earthquakes (< 20 mi)
  - 31 earthquakes
  - M 0.5 to 2.6
  - previously identified areas
- Subnetwork events
  - None (16/yr avg.)
- Overall reduced earthquake magnitudes and rate

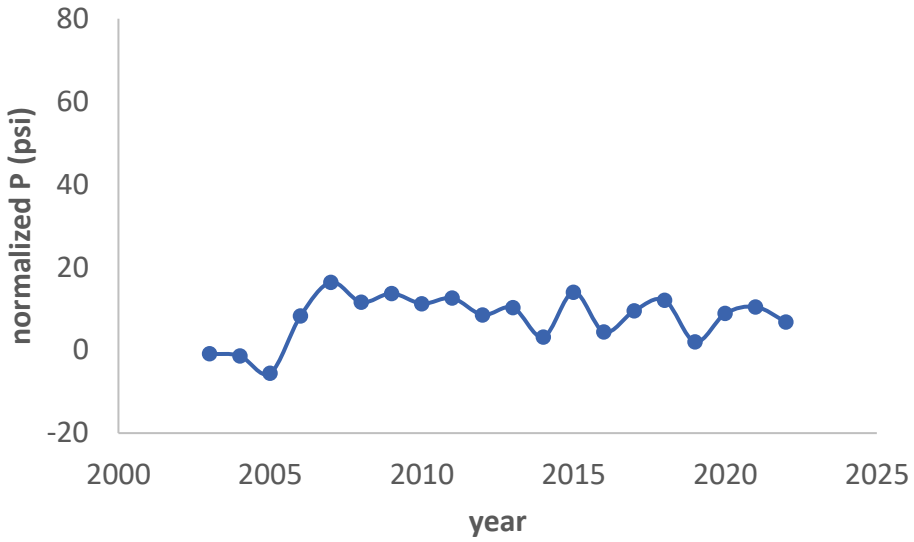
Johnson and Atchison Counties



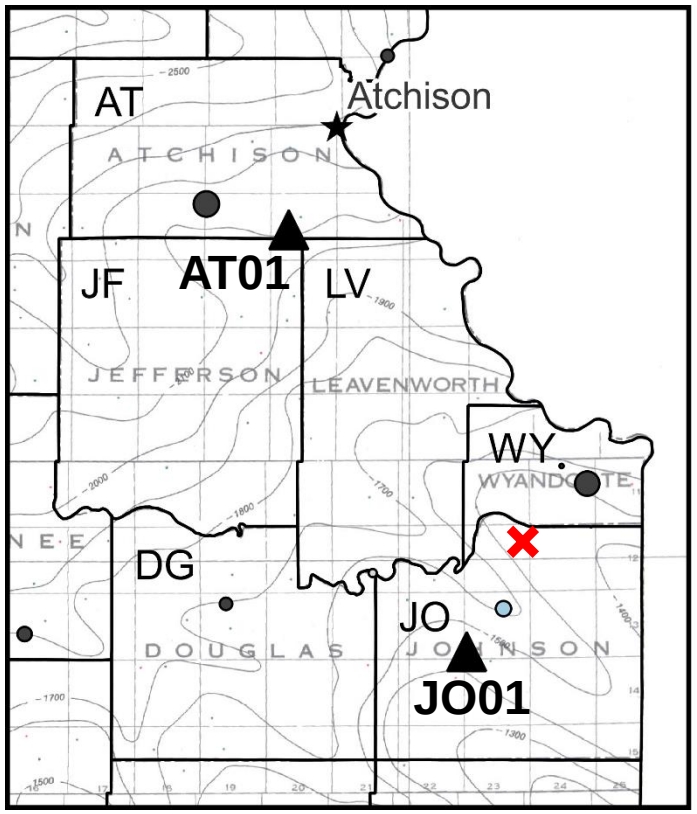
- JO01
  - western JO
  - pasture
  - Olathe Prairie Center
- 2 Quarries within 5 mi
  - characteristic waveforms
  - confidently identified
  - not cataloged
- AT01
  - cemetery

Johnson County





Johnson and Atchison Counties



magnitude

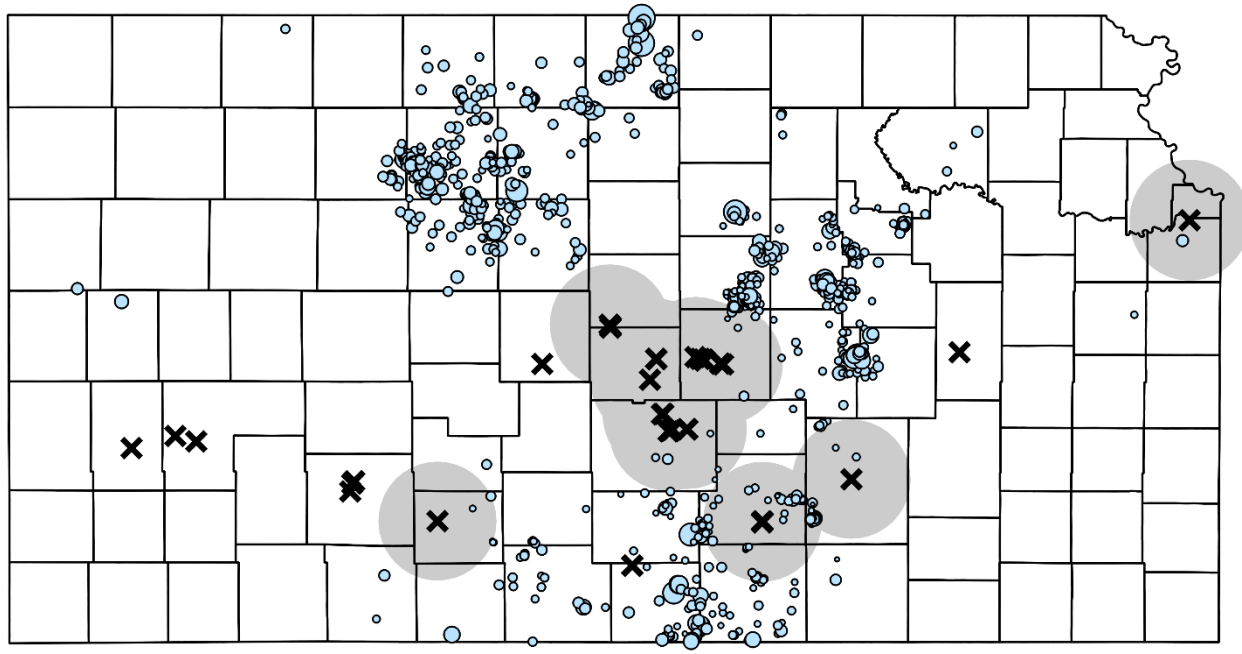
- 1
- 2
- 3
- 4

- Historic (1977-2014)
- KGS network (2015-2022)
- KGS/CSTS network (2022-2023)

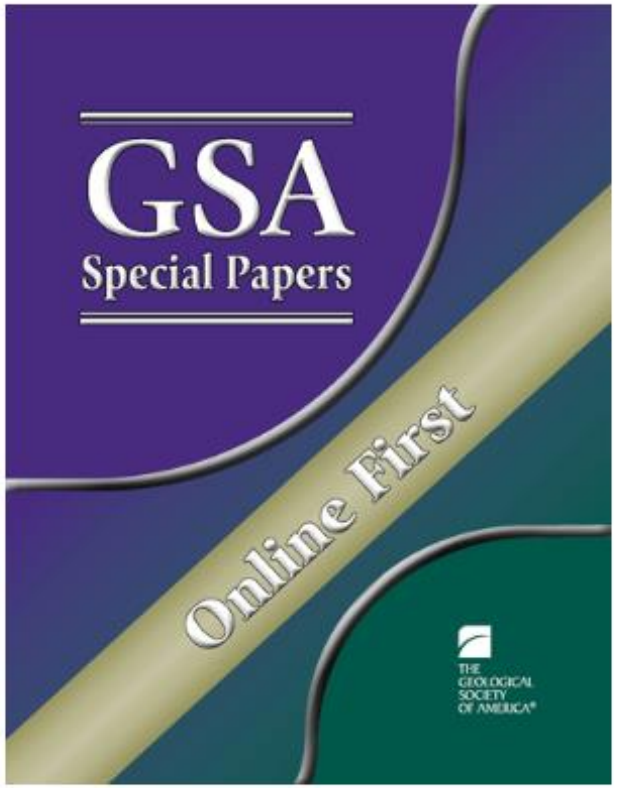
- Forest City Basin
  - Nemaha Ridge
  - Bourbon Arch
  - no mapped faults, NW structural trends
- Historic seismicity
  - WY: M 3.0 in 1999
  - AT: M 3.1 in 2007
  - M ≥ 3 every 23 years
- Local earthquakes (< 20 mi)
  - M 2.1 in Johnson County
- Subnetwork events
  - JO01
    - None (3/yr avg.)
  - AT01
    - 1 M 0.2 (3/yr avg.)
    - 5 miles away

Summary

- Statewide
  - Continued activity
  - New cluster in OT
  - Reduced seismicity in SA
- Recent trends likely new background
- Formation pressure elevated, stable
- CSTS network seismicity
  - Earthquake rates continuing to drop
  - Elevated seismicity in proximity to member areas

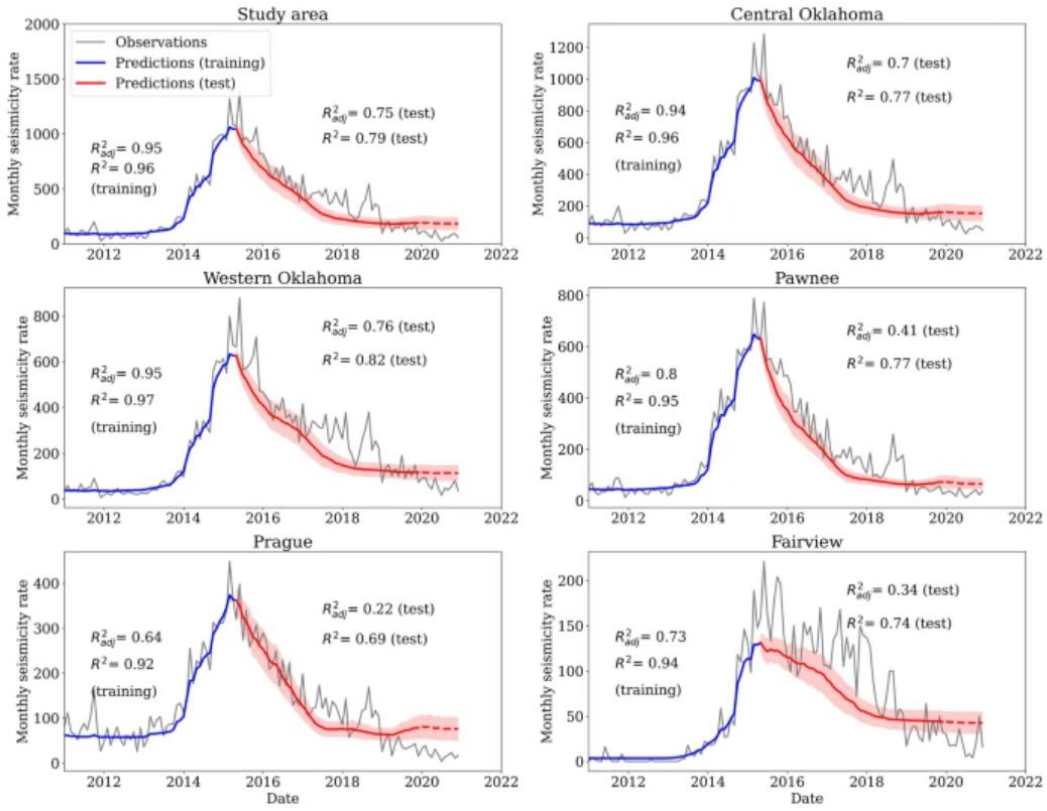


Recent Publications



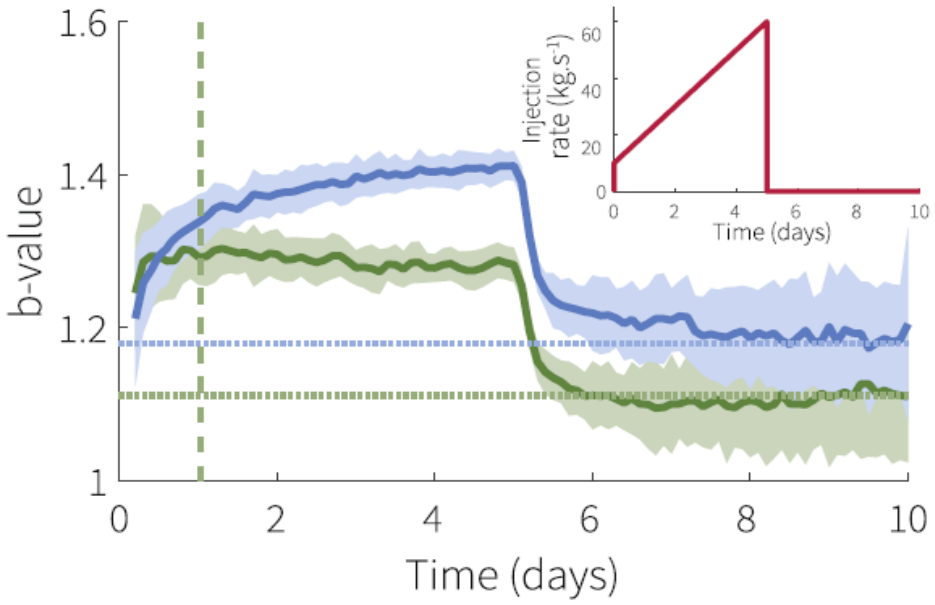
- **Buchanan et al. (2023)**: *Recent Seismicity in the Southern Midcontinent, USA: Scientific, Regulatory, and Industry Responses*
- https://doi.org/10.1130/SPE559
- Chapters on
  - Arkansas
  - Oklahoma
  - Kansas
  - Texas
  - New Mexico
  - Colorado

Recent Publications



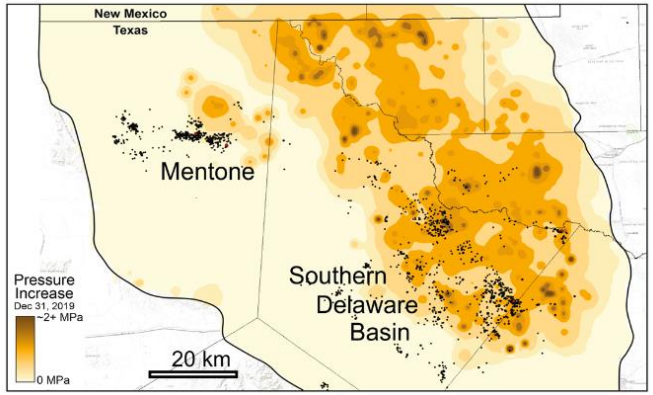
- **Qin et al. (2022)**: *Forecasting induced seismicity in Oklahoma using machine learning methods*
- https://doi.org/10.1038/s41598-022-13435-3
- Machine learning technique to forecast induced seismicity rate in Oklahoma based on injection parameters.
- The model forecasts seismicity rate during the test period based on injection parameters, geological information, and modeled pore pressure and poroelastic stress.
- Seismicity rate sensitive to pore pressure rate and poroelastic stressing rates

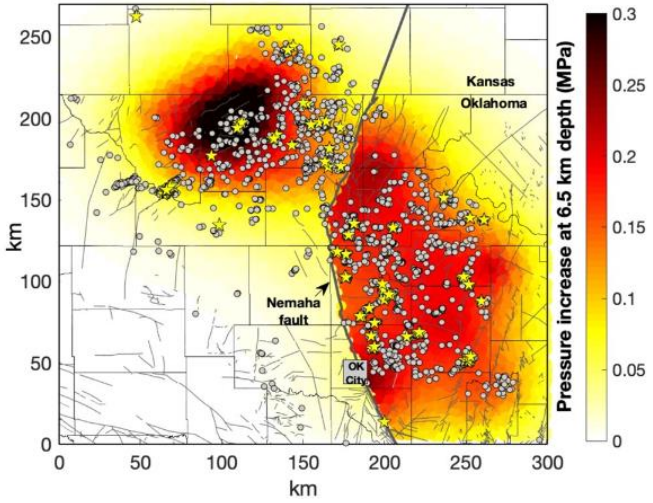
Recent Publications



- **Ritz et al. (2022)**: *Transient evolution of the relative size distribution of earthquakes as a risk indicator for induced seismicity*
- https://doi.org/10.1038/s43247-022-00581-9
- Hydromechanical modeling to assess seismic hazard with and without a fault
- Low *b*-values = greater proportion of larger magnitude earthquakes (greater probability of larger event)
- Fault can be interpreted from real-time b-value

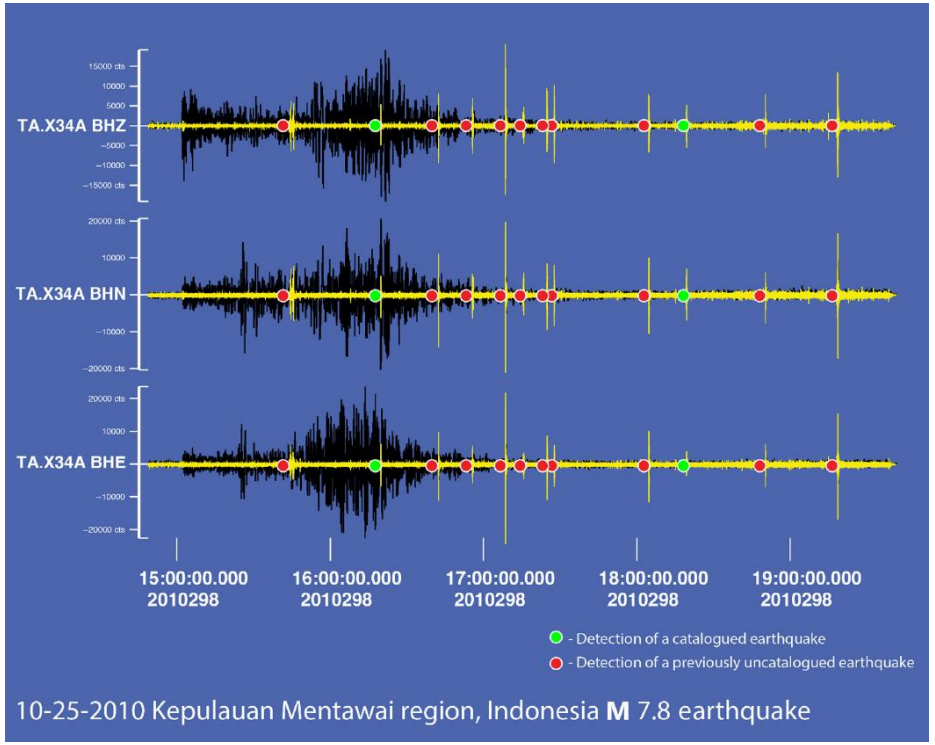
Recent Publications





- **Zoback and Smit (2023)**: *Meeting the challenges of large-scale carbon storage and hydrogen production*
- https://doi.org/10.1073/pnas.2202397120
- Safest and most practical strategy for dramatically increasing CO2 storage
- Partially depleted oil and gas reservoirs
  - Geologically and hydrodynamically well understood
  - Less prone to injection-induced seismicity than saline aquifers
- Saline aquifers (e.g., Arbuckle)
  - Small pressure changes can trigger earthquakes
  - Injection volume may be limited well below regulation limits

Recent Publications



- **Alfaro-Diaz et al. (2023)**: *Insights from Dynamically Triggered and Induced Earthquakes in Oklahoma*
- https://doi.org/10.1785/0220220211
- Global M 7+ earthquakes triggered nearly 500 earthquakes in Oklahoma
  - Increasing triggered earthquakes with increasing injection volumes
  - Half were delayed triggering, associated with high pore fluid pressure
  - Much lower stress required to trigger

Regional Trends and Local Seismicity Near CSTS Member Wells

Shelby Peterie, Rick Miller, Carl Gonzales, Marcus Tamburro, Sara Sassmann

Kansas Geological Survey

Fifth Annual CSTS Meeting

August 9, 2023

McPherson, KS