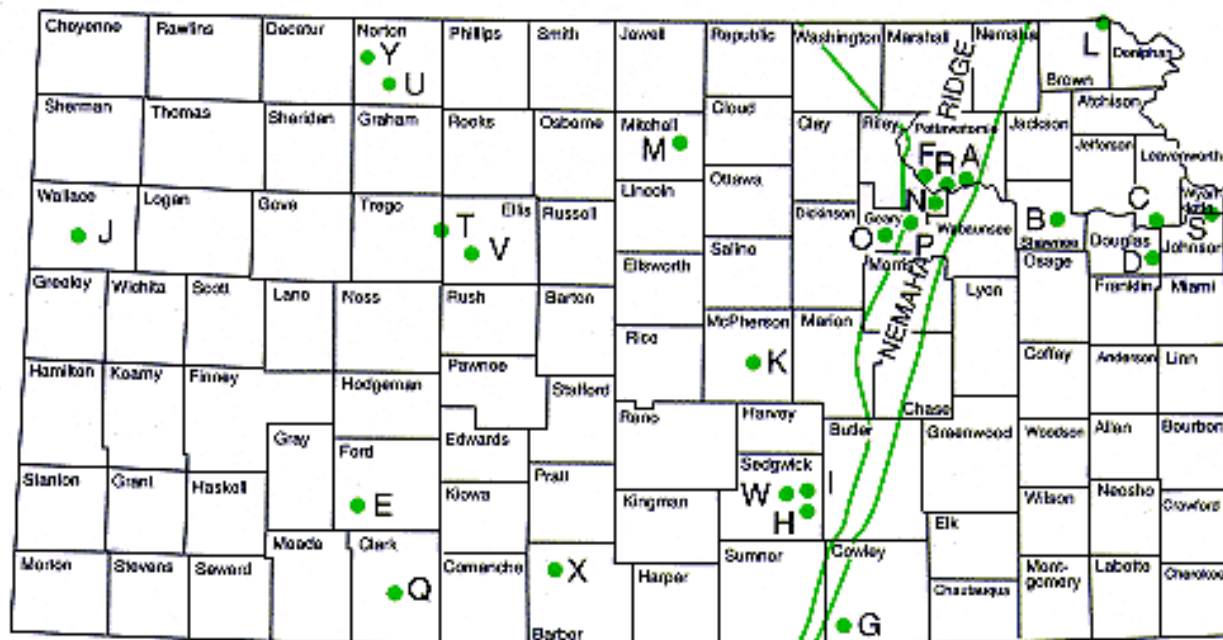


Recent Seismicity in Kansas: Events and Responses

Rex Buchanan
Director Emeritus

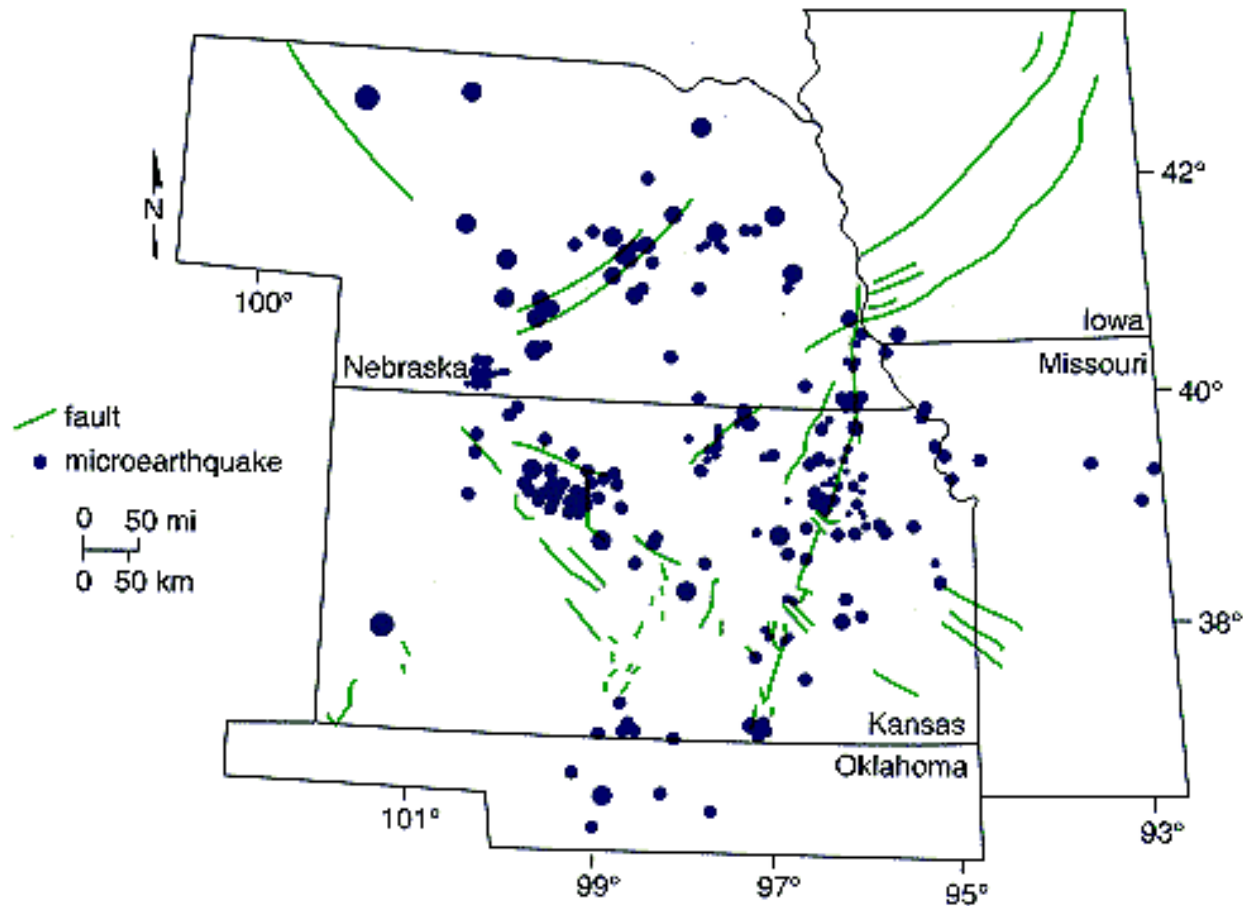
Kansas Geological Survey
University of Kansas

Historic Kansas Earthquakes



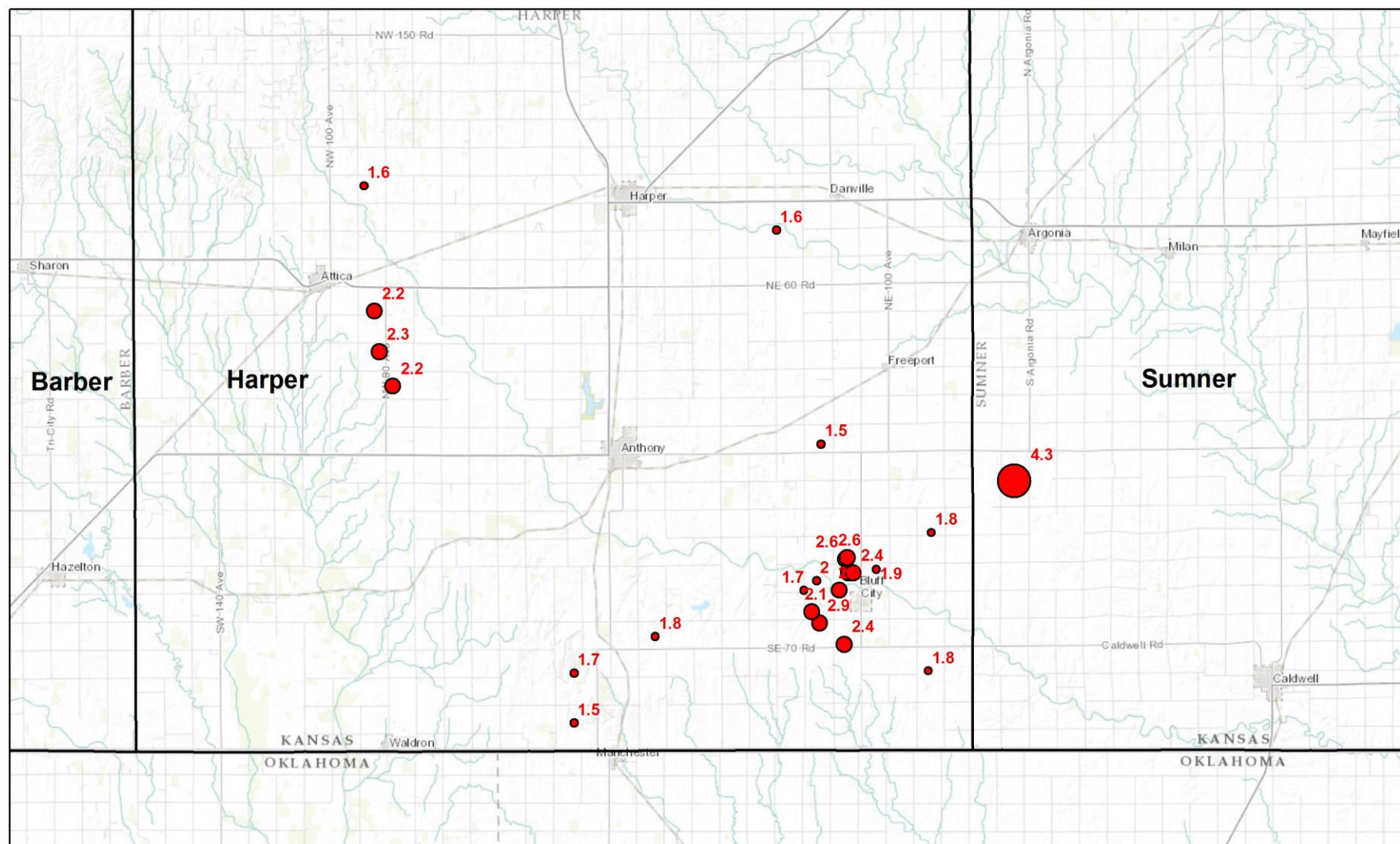
A. 1867	VII	F. 1906	VII	K. 1927	V	P. 1929	V	U. 1933	V
B. 1875	V	G. 1907	IV	L. 1927	VI	Q. 1929	V	V. 1942	IV
C. 1881	III	H. 1919	IV	M. 1928	IV	R. 1929	V	W. 1948	IV
D. 1902	II	I. 1919	IV	N. 1929	V	S. 1931	VI	X. 1956	VI
E. 1904	IV	J. 1926	?	O. 1929	V	T. 1932	V	Y. 1961	V

Midcontinent Micro-earthquakes, 1977–1989



Earthquake Activity - 2013

PRELIMINARY

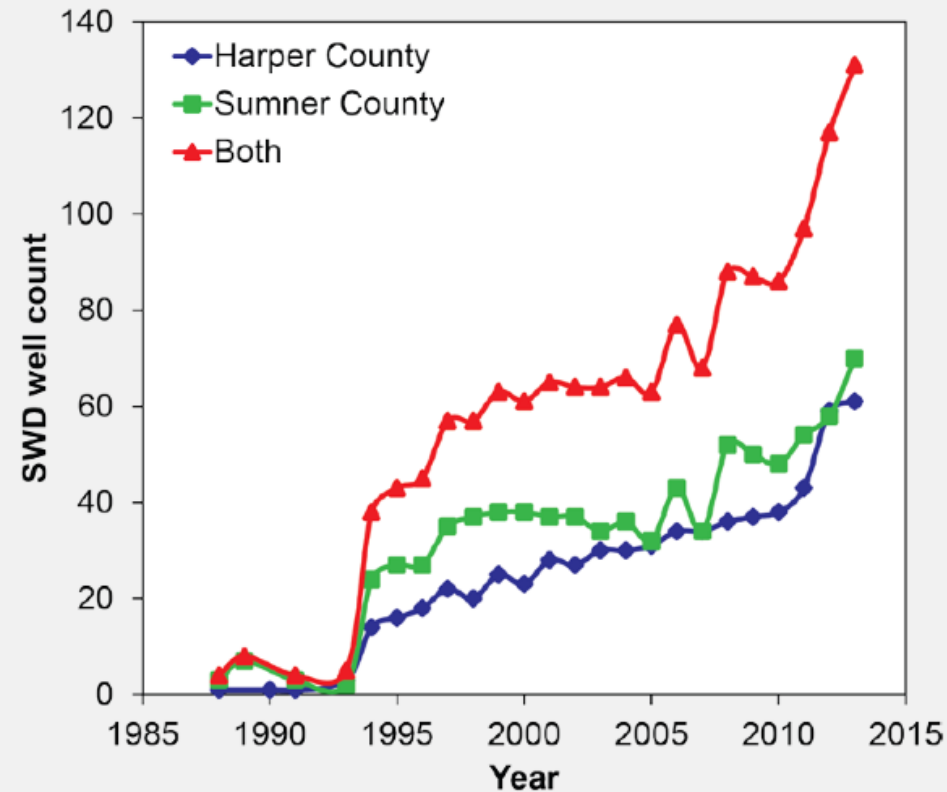


Kansas Geological Survey
Data from Oklahoma Geological Survey, USGS
18 March 2014

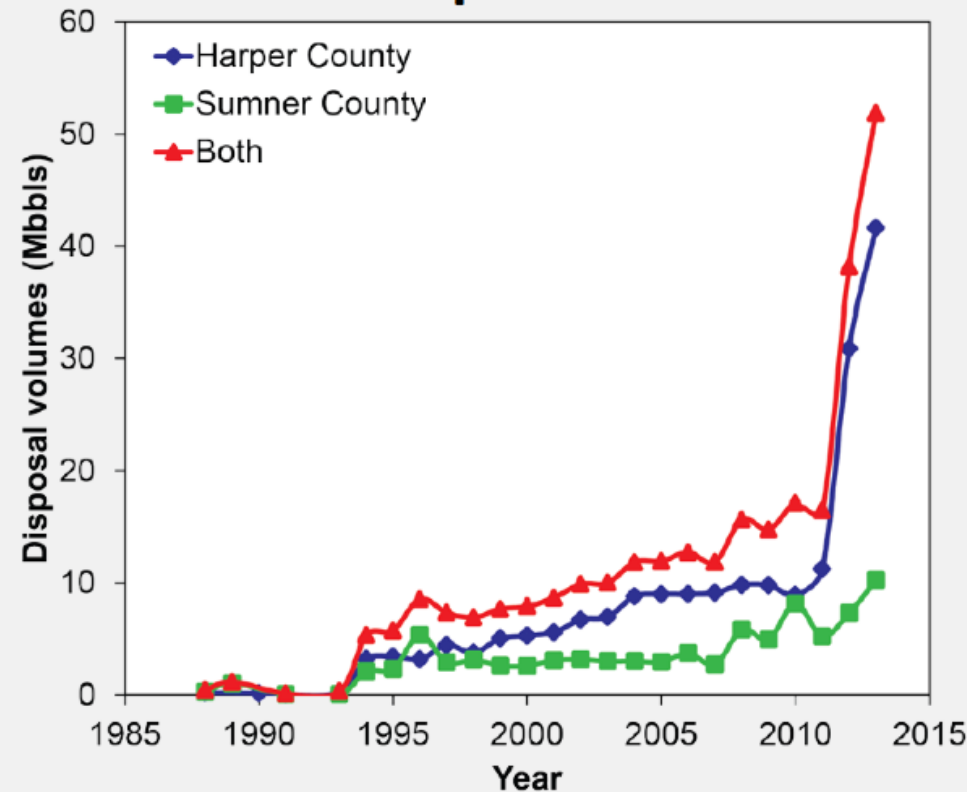
0 2.5 5 10 Miles

Brine disposal trends

Well count

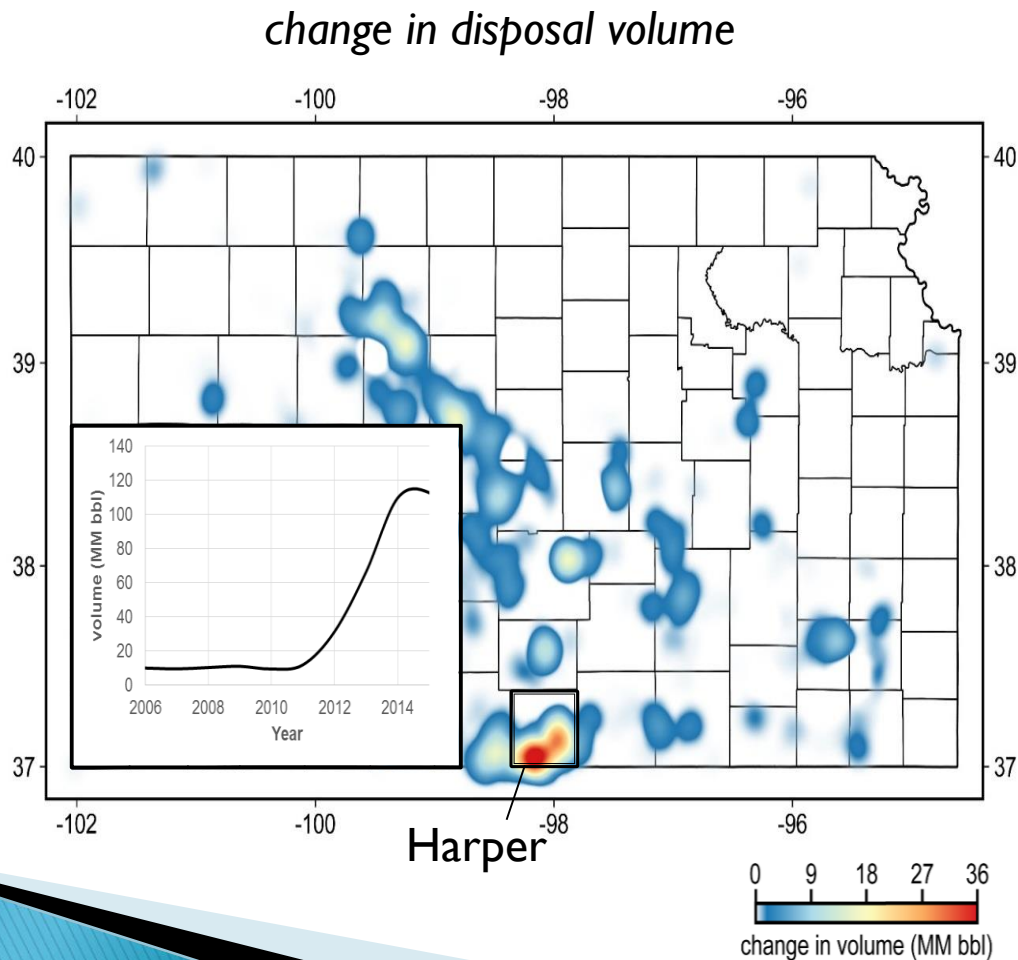


Brine disposal volumes



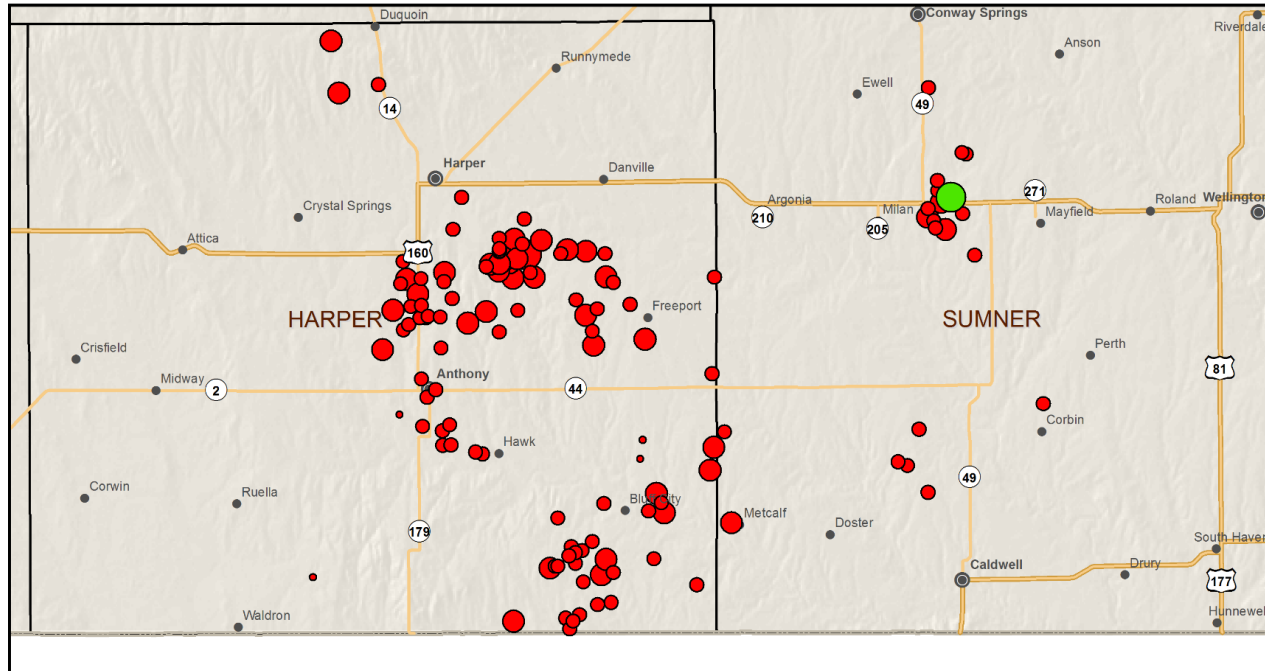
- Well count has doubled since 2005
- 6-fold increase in yearly disposal volumes since mid-1990s
- Yearly volumes have tripled since 2011

Increased Disposal Volume

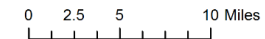
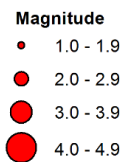


2014 Earthquakes: Harper and Sumner Counties

Preliminary



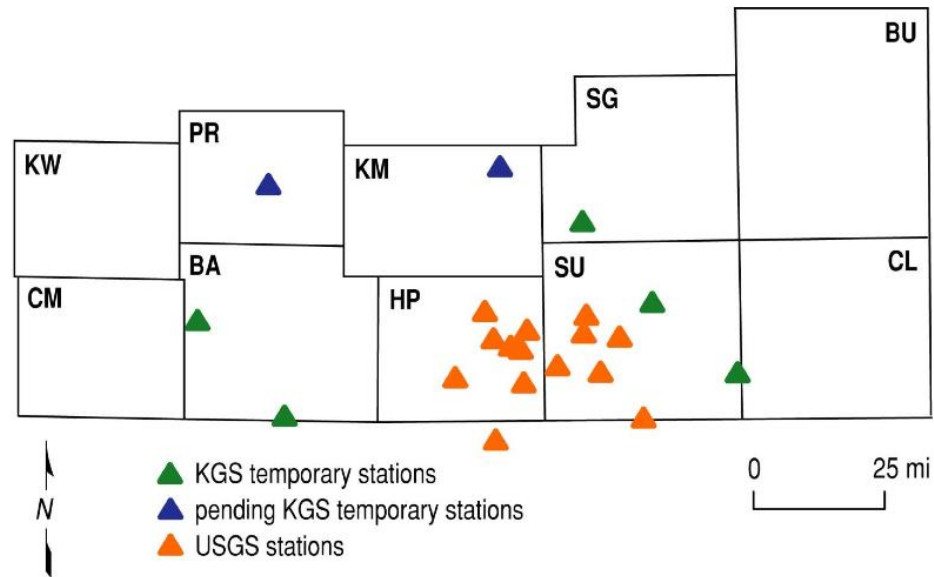
Kansas Geological Survey
Data from Oklahoma Geological Survey, USGS
3 August 2015

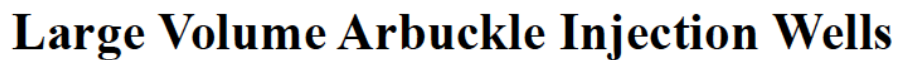


Kansas Responses

- ▶ Governor's Task Force on Induced Seismicity
 - KGS, KCC, KDHE
 - 1) enhanced monitoring
 - 2) Seismic Action Score
- ▶ USGS, OGS, University of Missouri
- ▶ Permanent network
- ▶ Public information, legislative interaction
- ▶ Interstate Oil and Gas Compact Commission/Groundwater Protection Council

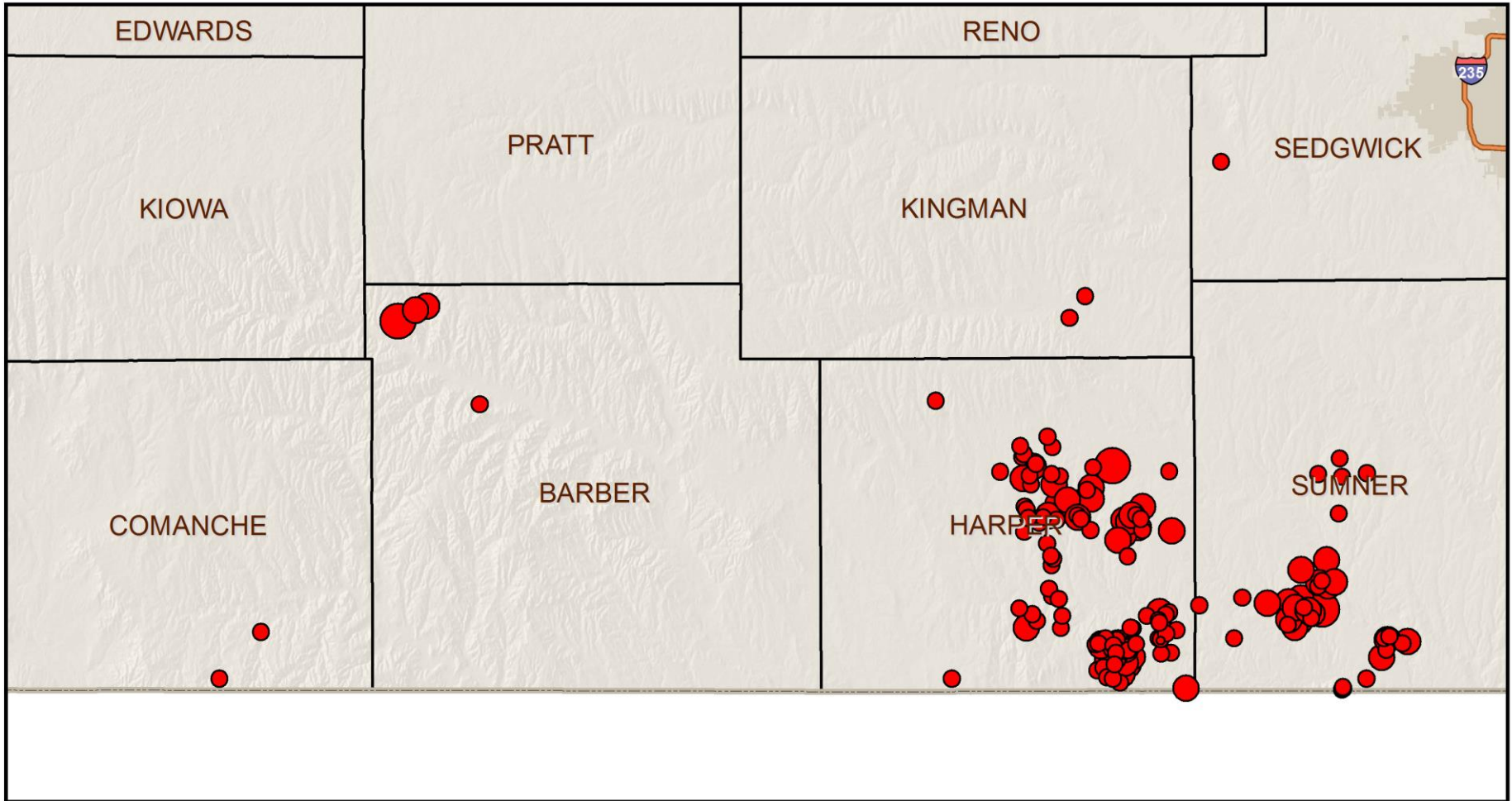
KGS and USGS Temporary Networks





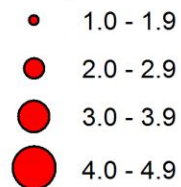
2015 Earthquakes: South Central Kansas

Preliminary



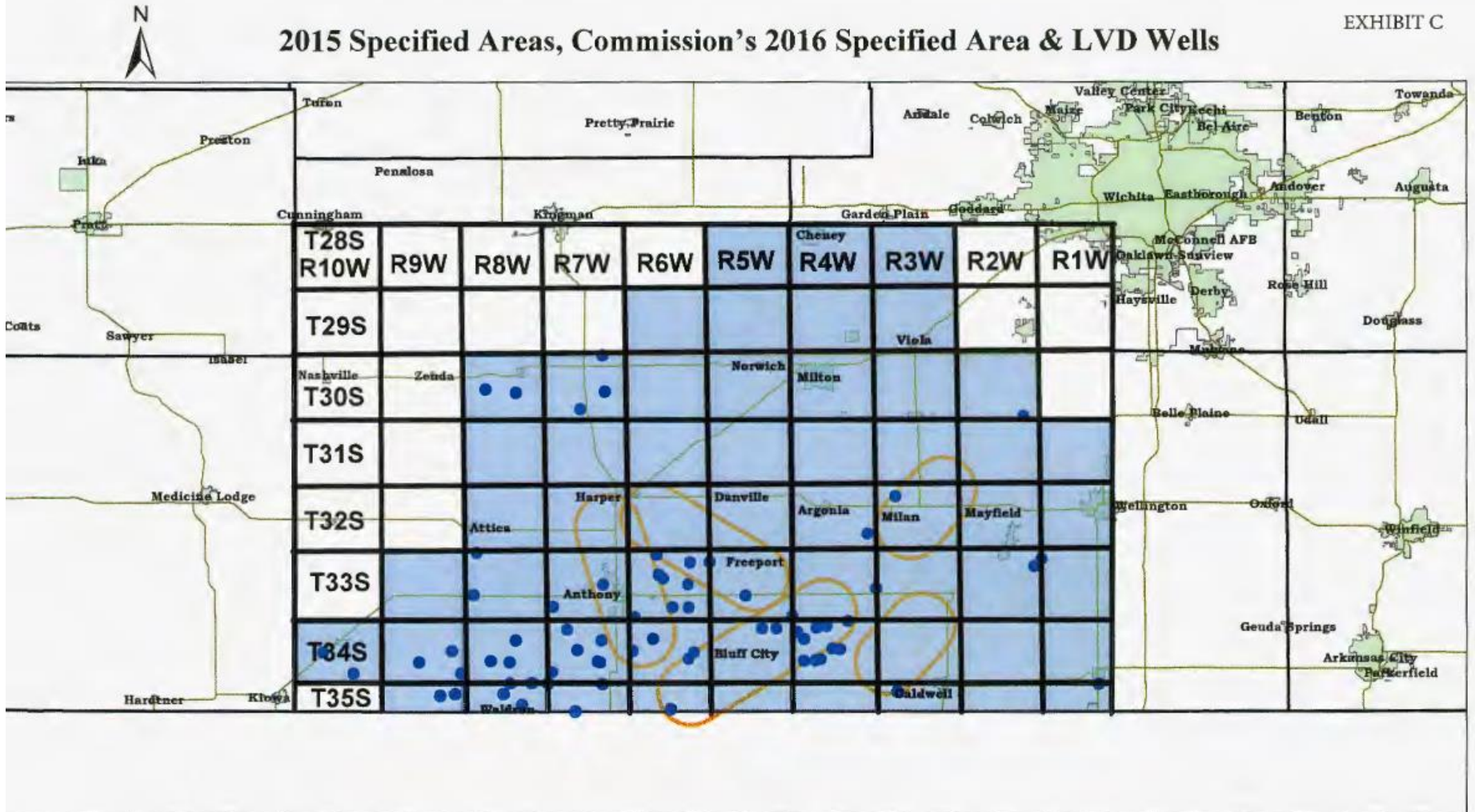
Kansas Geological Survey
Data from USGS
29 December 2015

Magnitude



0 5 10 20 Miles

2015 Specified Areas, Commission's 2016 Specified Area & LVD Wells



0 3 6 12 18 24 Miles

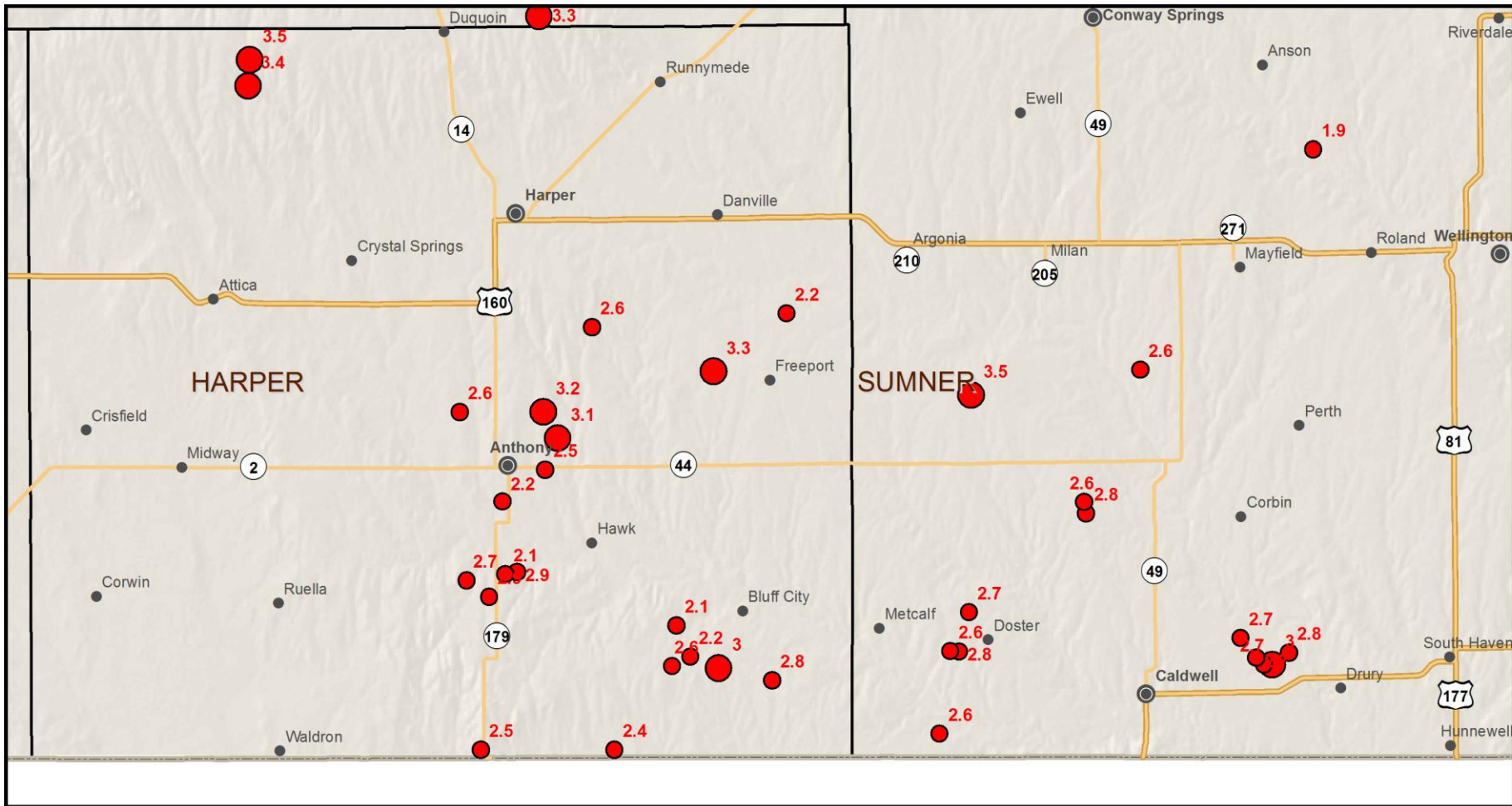
● Large Volume Disposal Wells (5001+ bpd)

■ 2016 Specified Area

□ 2015 Specified Area





2016 Earthquakes: Harper and Sumner Counties

Preliminary



**Kansas Geological Survey
Data: USGS
9 September 2016**

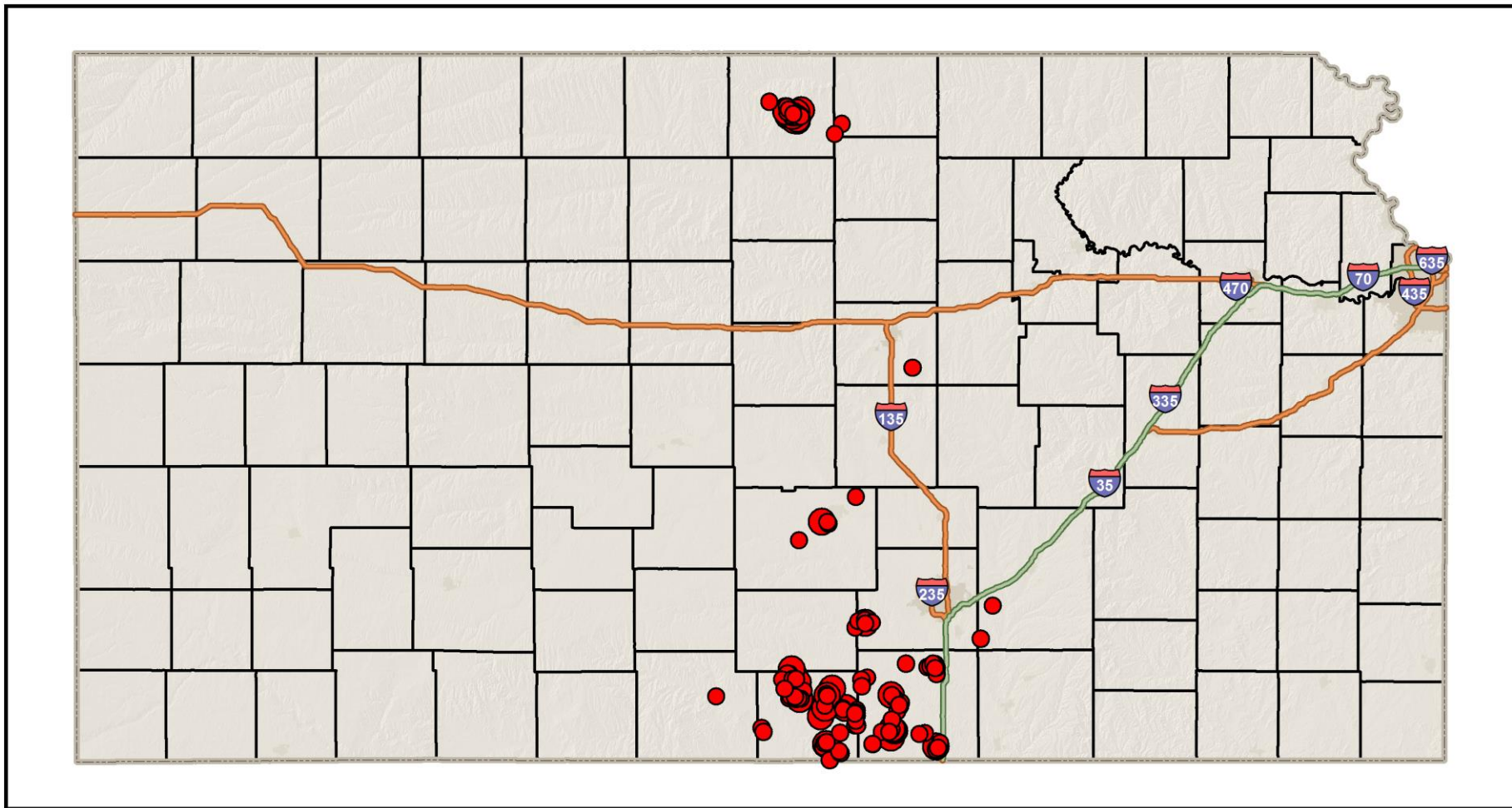
Magnitude

-  1.0 - 1.9
 2.0 - 2.9
 3.0 - 3.9
 4.0 - 4.9

0 2.5 5 10 Miles

2017 Earthquakes

Preliminary



Kansas Geological Survey
Data: USGS
12 January 2018

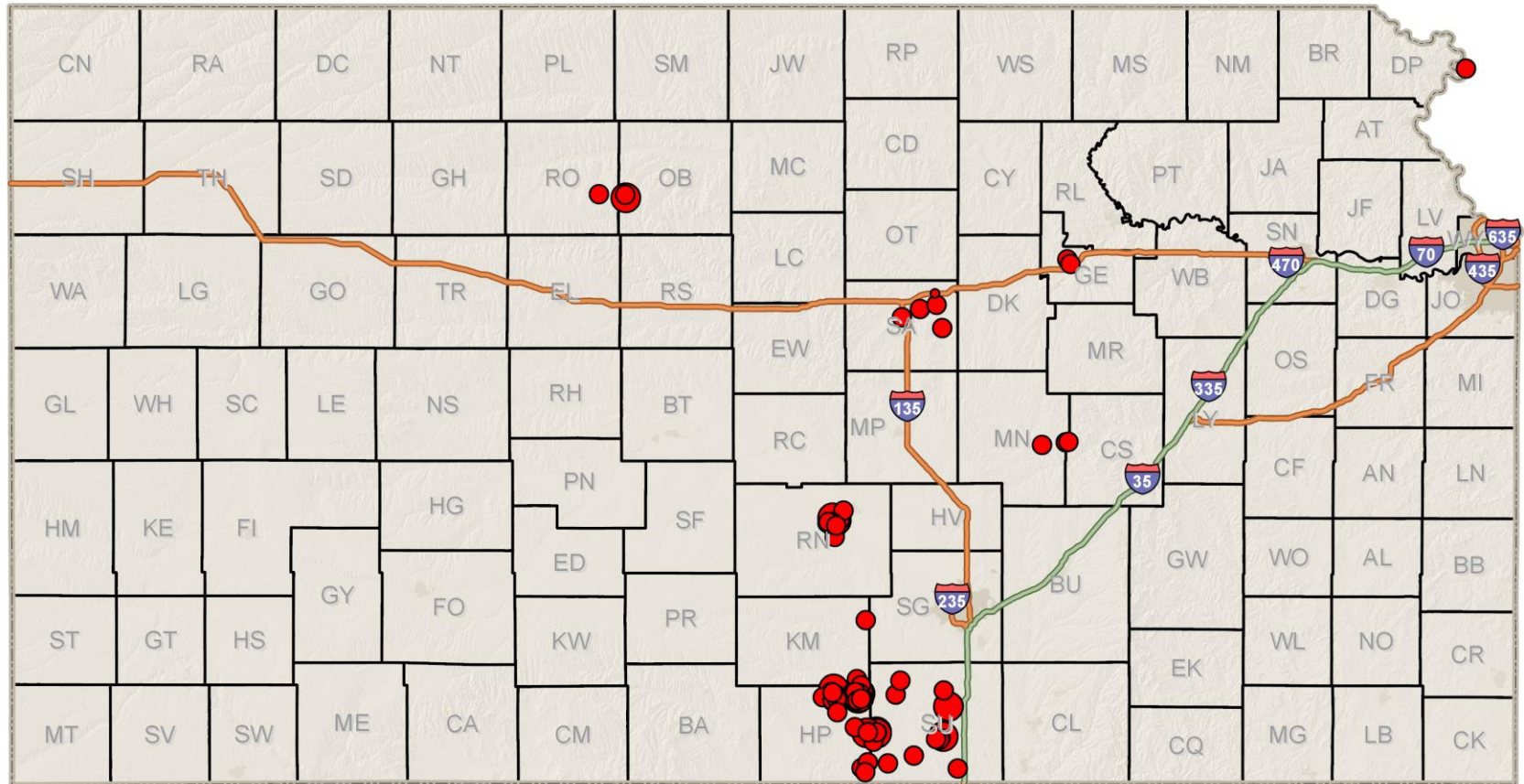
Magnitude

- 1.0 - 1.9
- 2.0 - 2.9
- 3.0 - 3.9
- 4.0 - 4.9

0 20 40 80 Miles

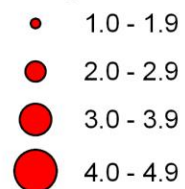
2018 Earthquakes

Preliminary



Kansas Geological Survey
Data: USGS NEIC
12 October 2018

Magnitude

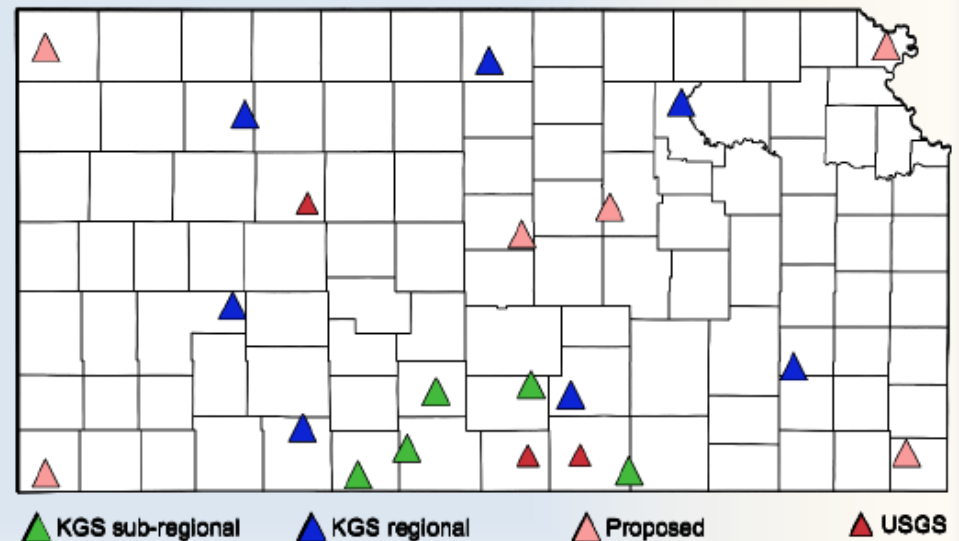


0 20 40 80 Miles

Combined Kansas Networks

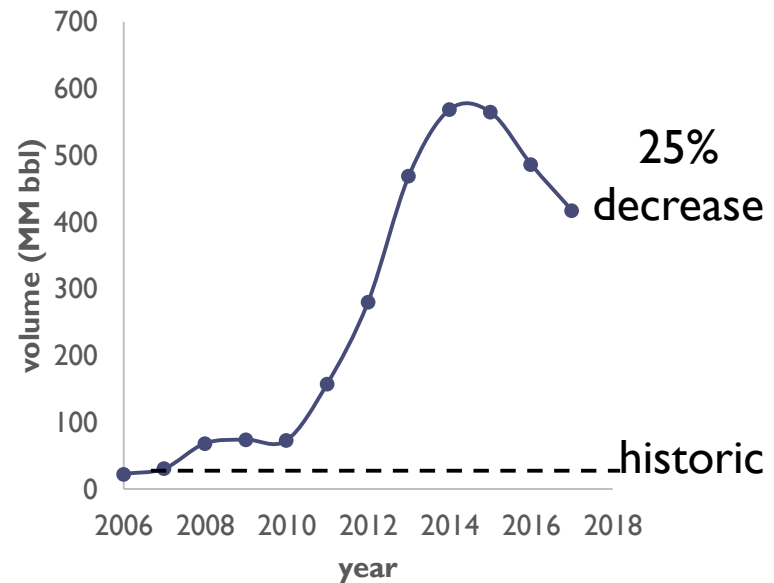
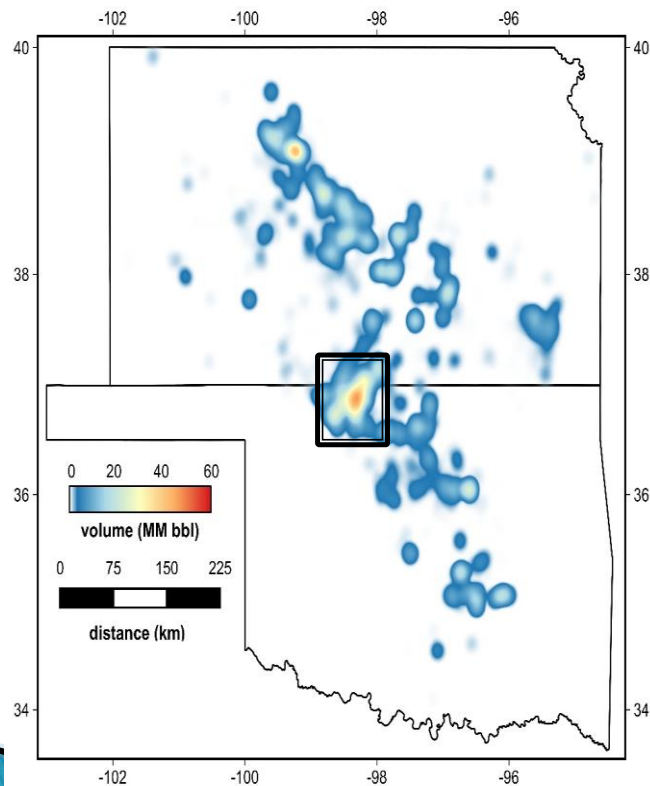
Dense networks provide for enhance location accuracy and improves depth determinations

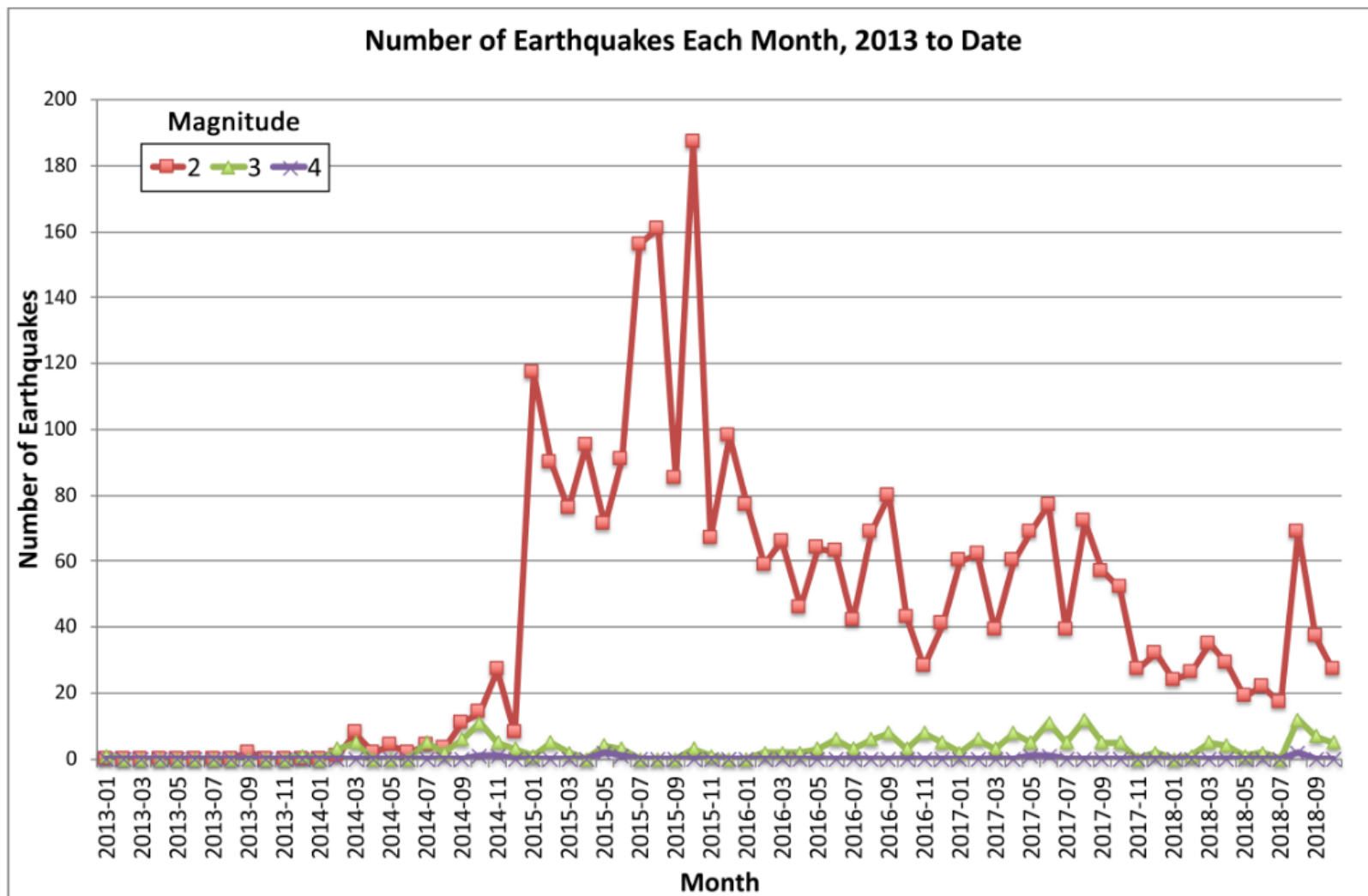
- ▲ USGS has more than 20 stations in Kansas, with all but two in southcentral Kansas focused on Harper and Sumner Counties
- ▲ Sub-regional (5) initially sponsored by the KCC, but is currently operated and funded by KGS and designed to monitor for any expansion in the two county area where earthquakes 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



2017 Disposal

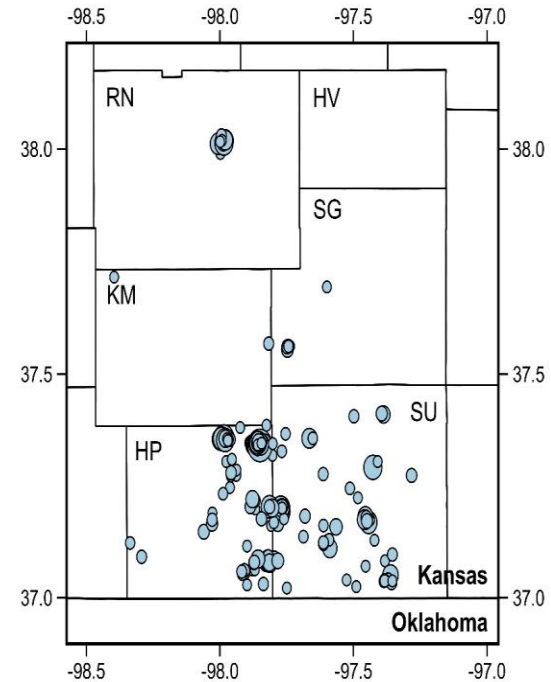
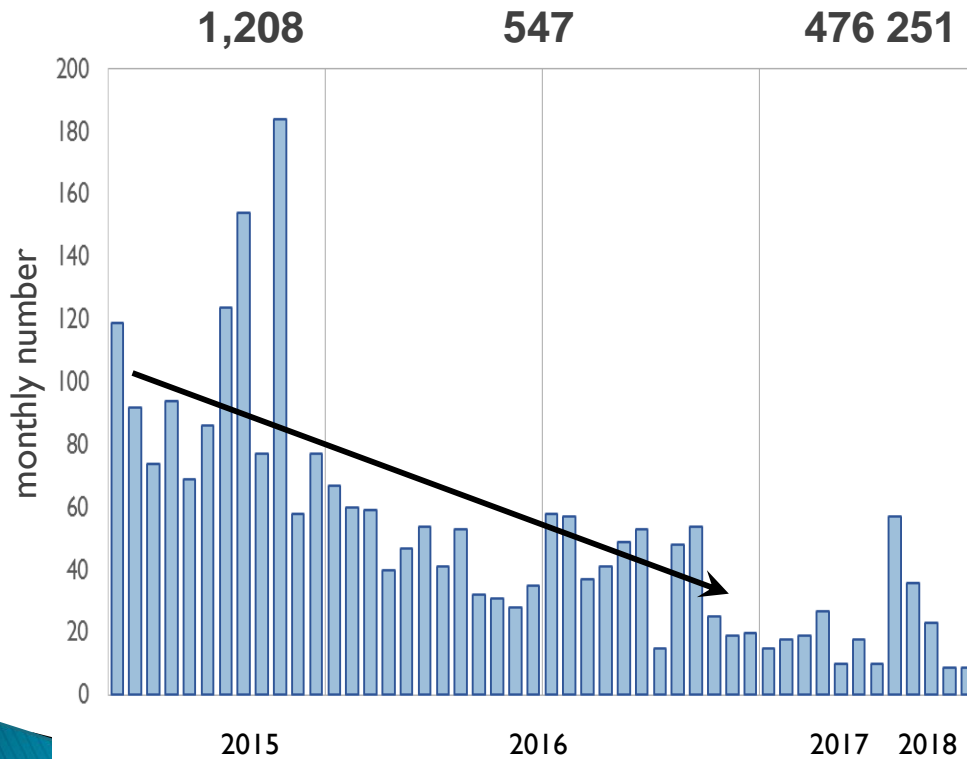
Arbuckle disposal volume (2017)



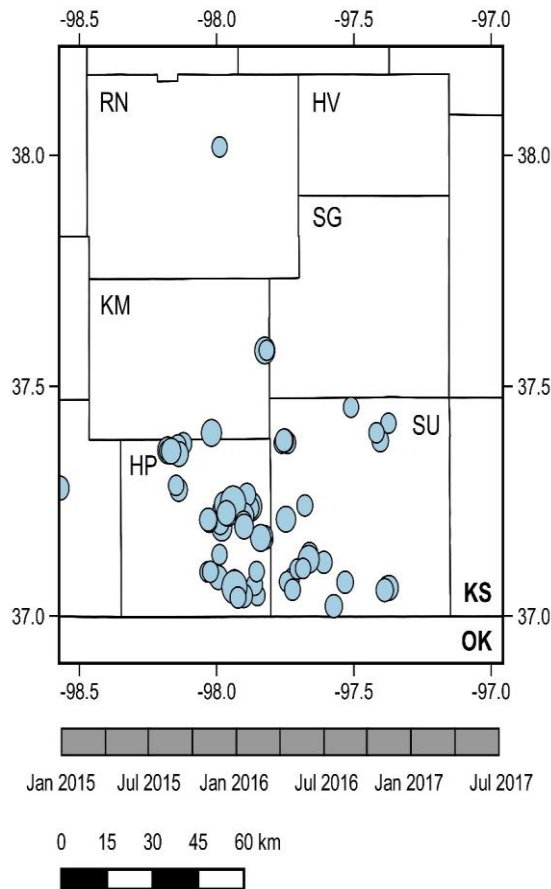


2018 Seismicity

$M \geq 2$ earthquakes



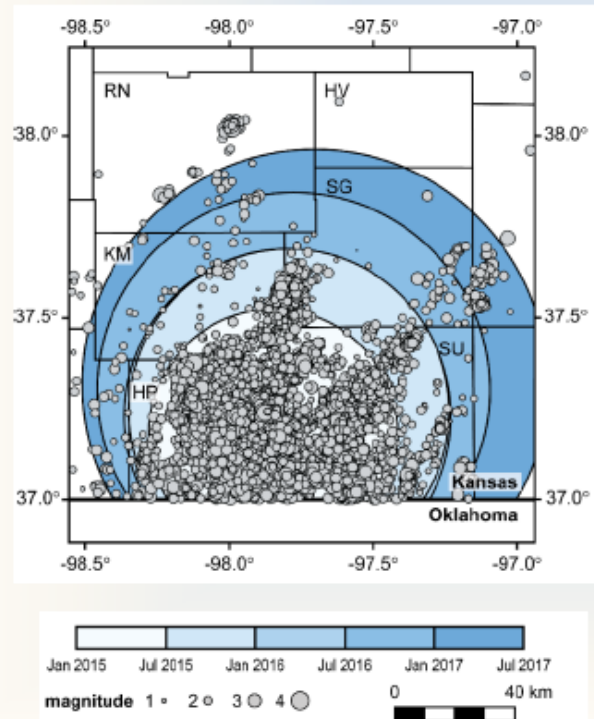
Magnitude Distribution



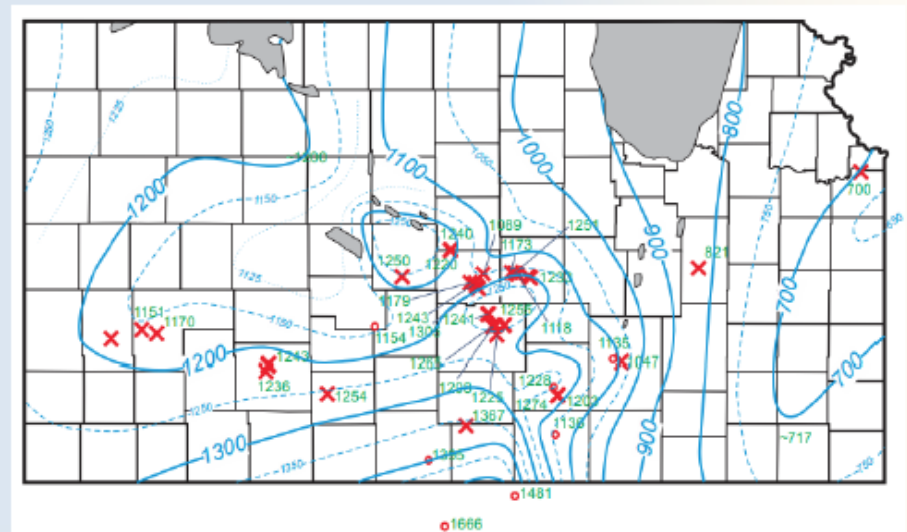
- ▶ Total earthquakes: 6,944
- ▶ Vast majority are microearthquakes
 - $M < 2 = 4,958$ (70%)
 - $M 2-3 = 1,912$
 - $M \geq 3 = 74$
- ▶ Regional network (USGS) $M \sim 3$
 - no obvious trend
 - isolated, unrelated
- ▶ Value of local network
 - microearthquake data
 - improved understanding
 - insight into causal factors

Areas of research with focus on seismicity

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

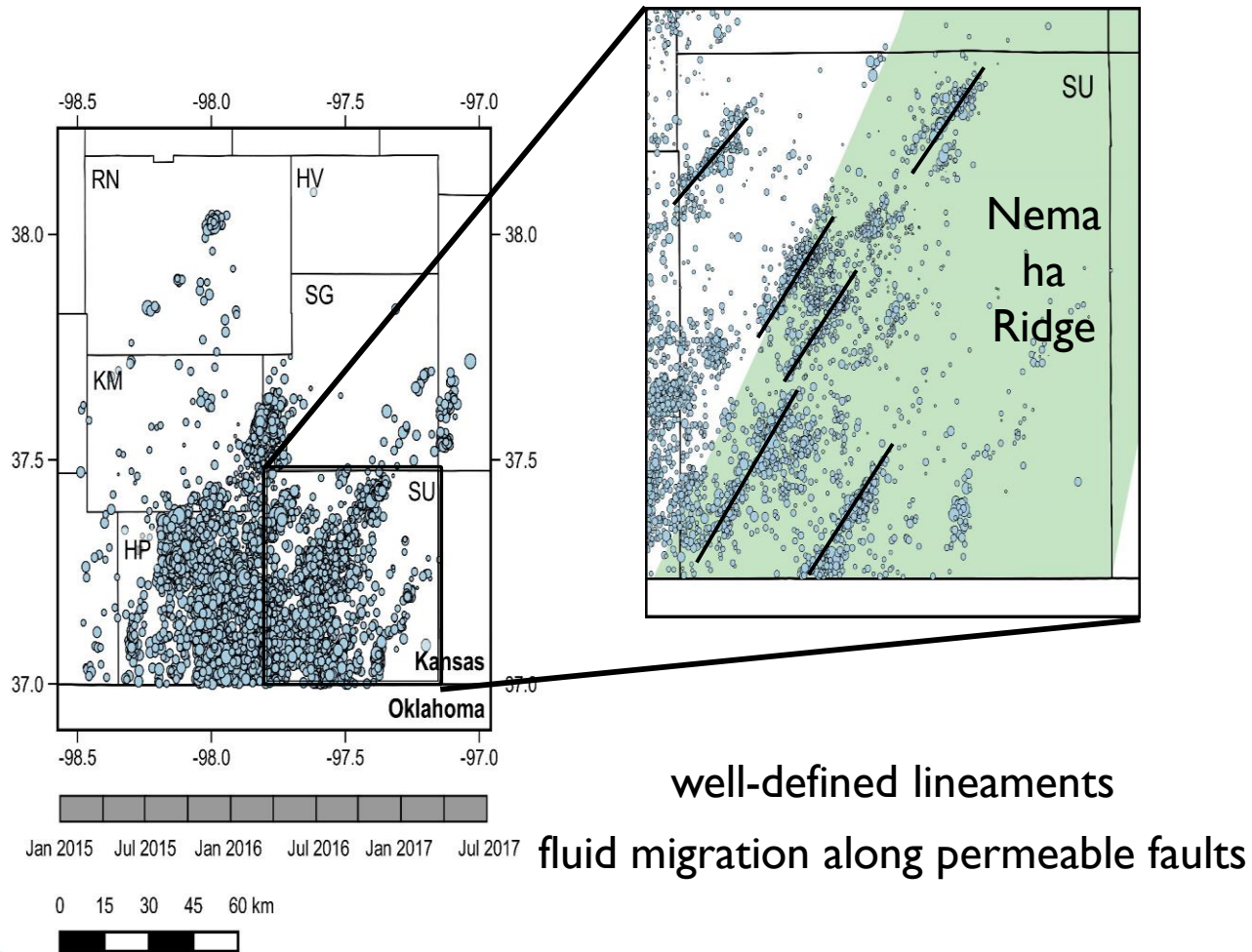


Mapping Arbuckle Group hydrostatic surface and pressure

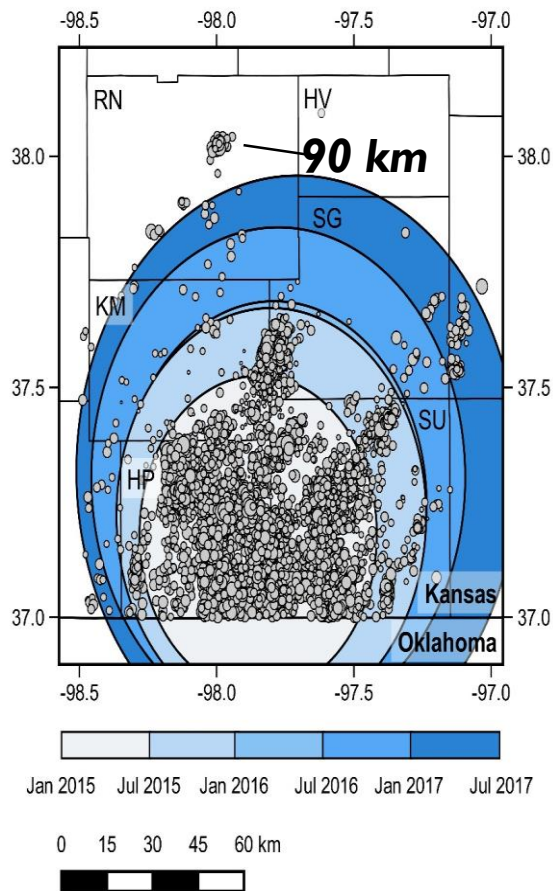


Arbuckle Working Group is a multiagency effort to more completely characterize the Arbuckle by working across all UIC classes. KGS is lead working with KDHE and KCC

Migration Patterns

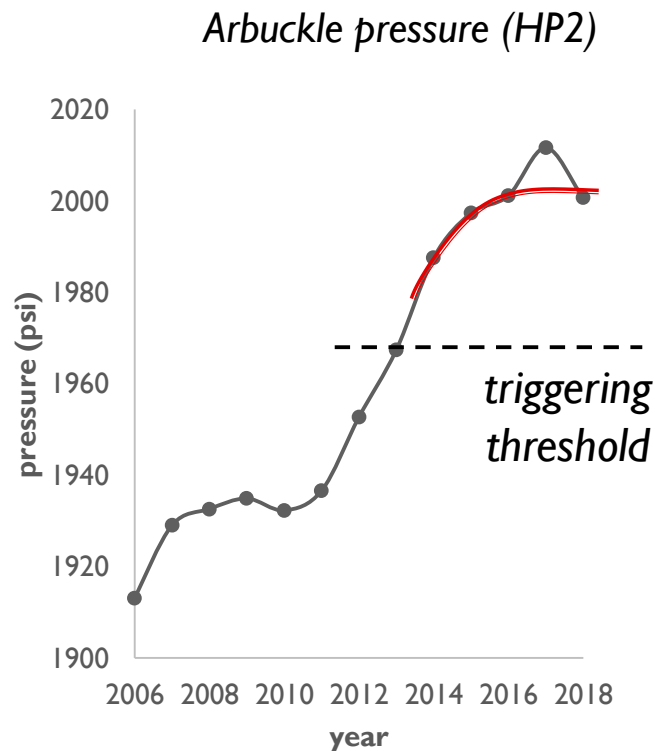


Migration of Earthquakes



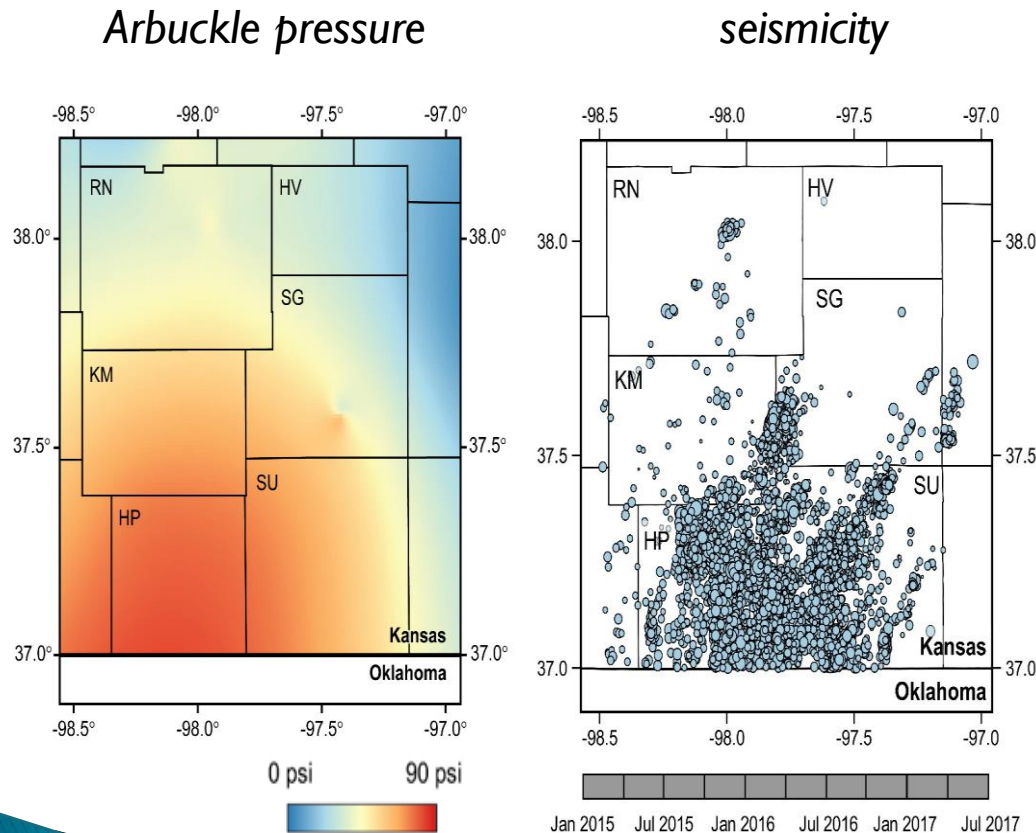
- ▶ Initially dense swarms
 - 2015–2016
 - Harper and Sumner
- ▶ Earthquake migration
 - 2016–2017
 - Persist in HP and SU
- ▶ Migrate progressively farther
 - radially away
 - up 90 km
 - challenges previous belief (20 km)

2018 Pressure



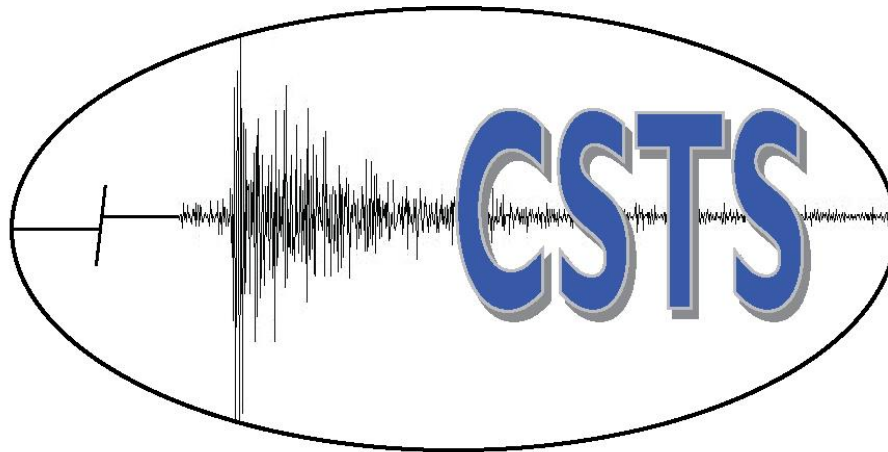
- ▶ **Regional Arbuckle pressure**
 - stabilizing in Harper county
 - unclear elsewhere
- ▶ **Above triggering threshold**
 - faults will be sensitive
 - small fluctuations
 - operations previously tolerated
- ▶ **Maintain pressure**
 - injection volumes remain high
 - pressure could remain elevated

Arbuckle Fluid Pressure



- ▶ Earthquake consistent with ΔP
 - pore pressure primary driver
 - extremely far-field diffusion
- ▶ Previous studies
 - a few high-volume wells
 - 10,000 bbl/day
- ▶ Kansas
 - spatially dense group
 - dozens of high-volume wells (4 km)
 - 500 MM bbl in 2015
 - equivalent to >100 wells
- ▶ Unprecedented

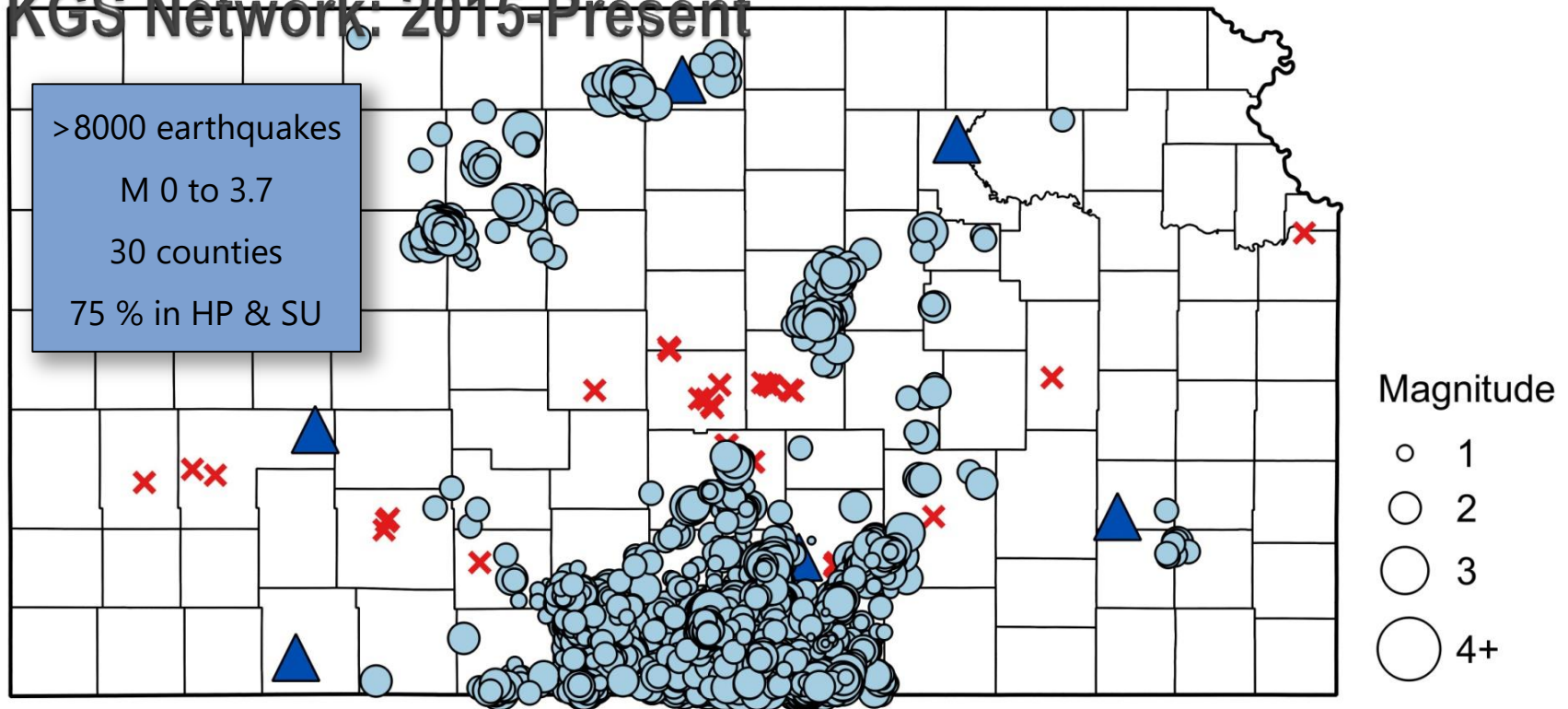
Studying Seismicity in Kansas Industry/Government Partnership

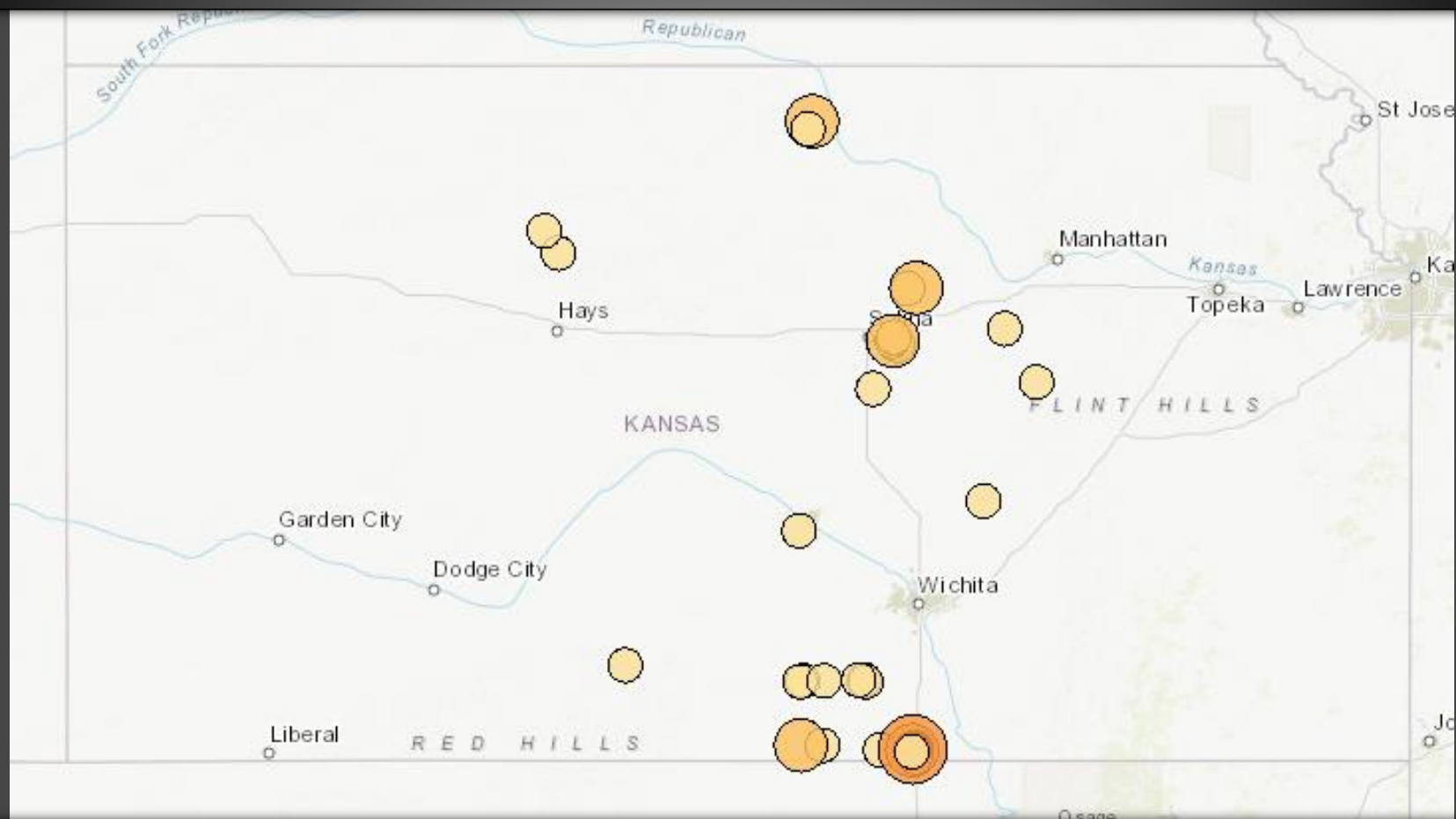


Consortium to Study Trends in Seismicity

Goals of the Seismicity Consortium: Analyze Microearthquake Trends Near Class 1

KGS Network: 2015-Present





2019 events >>

KGS interactive earthquake mapper

Recent Seismicity in Kansas: Events and Responses

Rex Buchanan
Director Emeritus

Kansas Geological Survey
University of Kansas