

Seismicity Research Activities by State Geological Surveys: Southern Mid-Content of the US

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Rick Miller³
Michael Timmons⁴, Mairi Litherland⁴
Scott Ausbrooks⁵

1- Bureau of Economic Geology, University of Texas at Austin

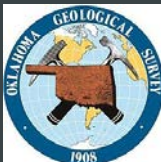
2- Oklahoma Geological Survey, University of Oklahoma

3- Kansas Geological Survey, University of Kansas

4- New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech

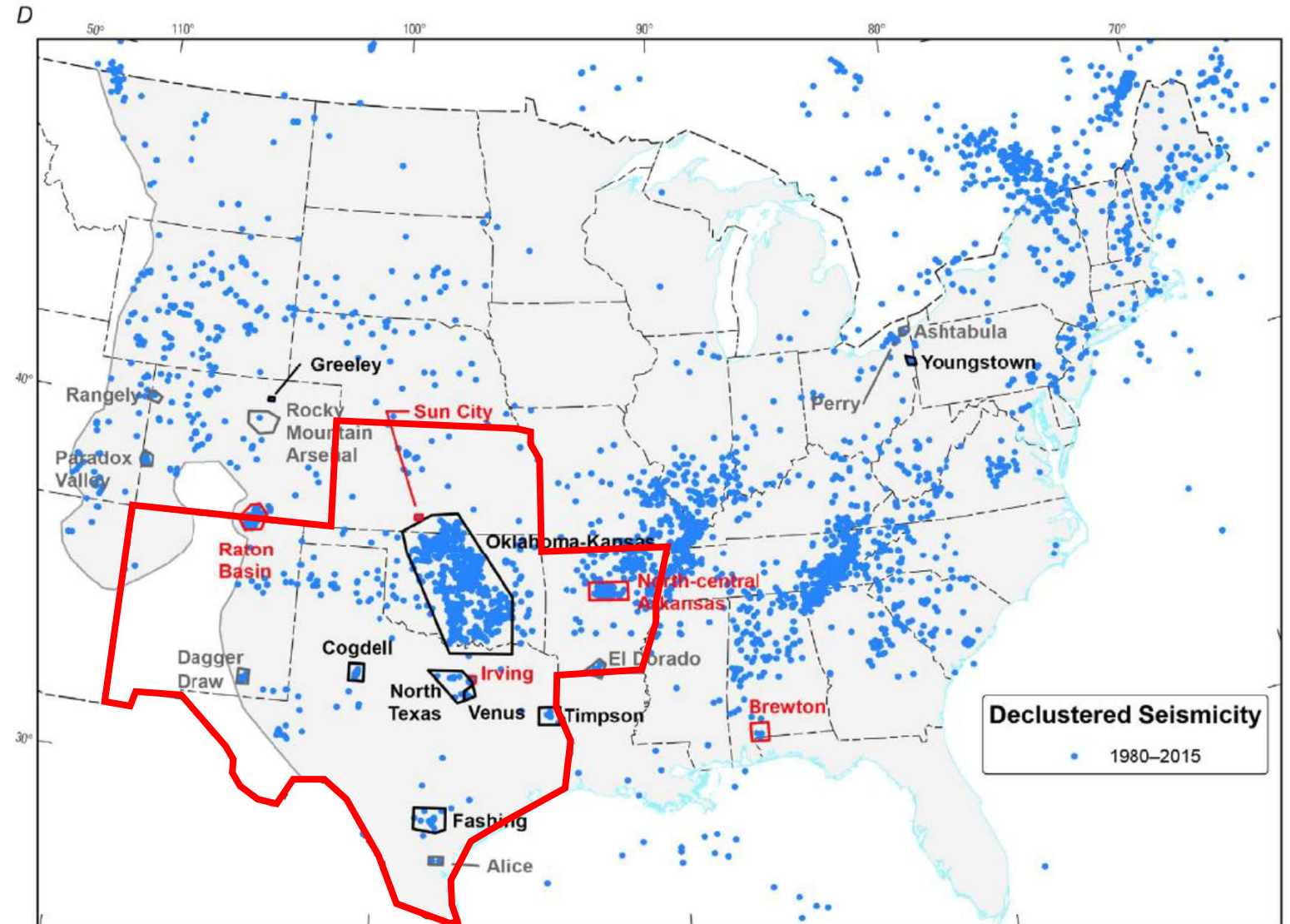
5- Arkansas Geological Survey, State of Arkansas

July 9, 2018



Seismic Activity in the Central and Eastern US

- State geological surveys provide information and data on geological issues to stakeholders in their respective states.
- The Regional Induced Seismicity Collaborative (RISC) connects seismicity research groups at different state geological surveys.
- RISC goals are to avoid data gaps and overlaps of ideas and technical approaches, and facilitate and add value to ongoing research.



Agenda

Introduction to RISC - Young

Introduction to Research Conducted at Member State Surveys

- OK State Survey - Murray
- KS State Survey - Miller
- NM State Survey - Litherland
- AR State Survey - Ausbrooks
- TX State Survey - Hennings

Wrap-up - Young

Q&A

Adjourn

OVERVIEW AND STATUS OF SEISMICITY RESEARCH AT THE OKLAHOMA GEOLOGICAL SURVEY



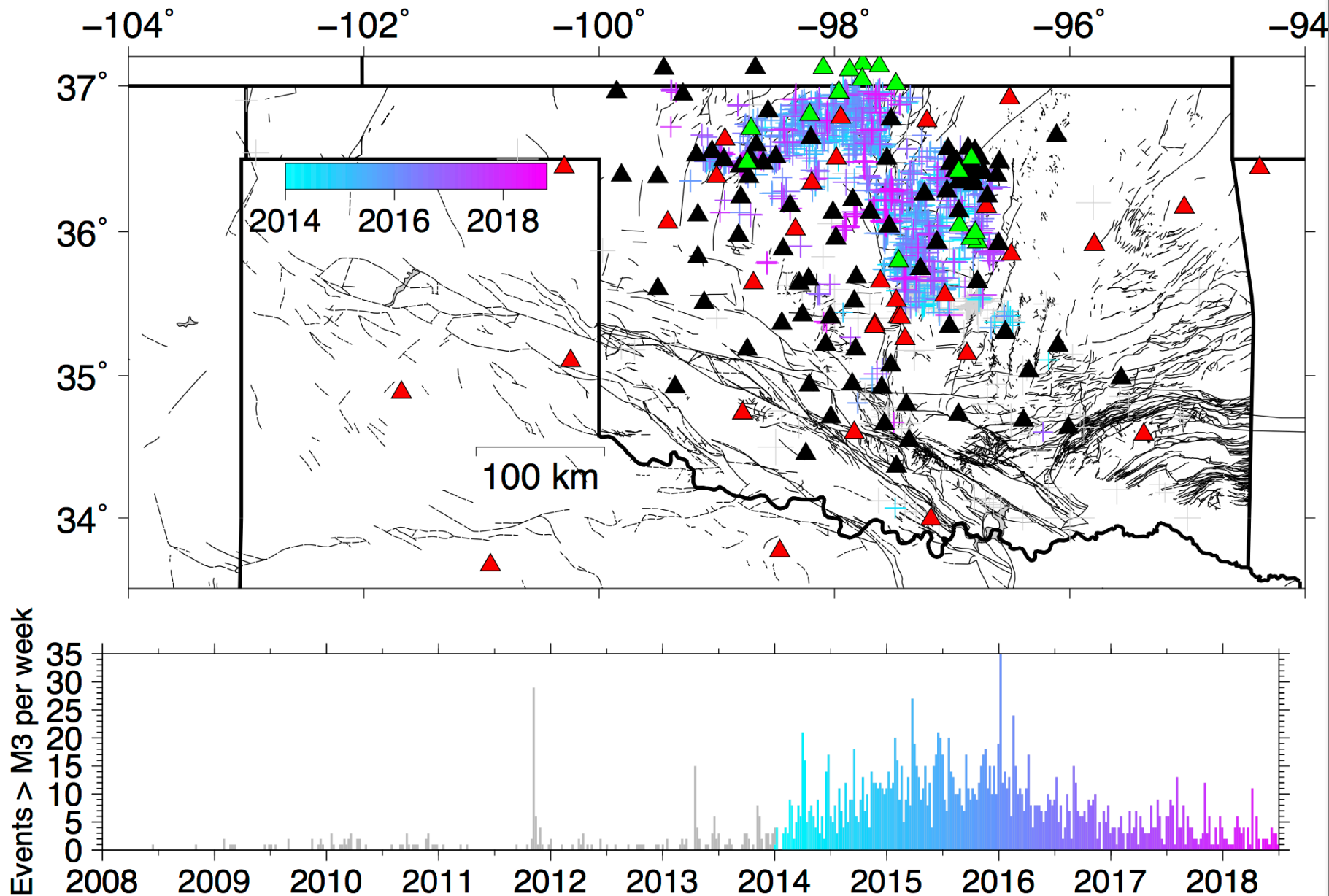
The
UNIVERSITY
of
OKLAHOMA

*Mewbourne College
of Earth and Energy*

Jeremy M. Boak, Director
Jacob I. Walter, Seismologist
Kyle E. Murray, Hydrogeologist



Seismic Monitoring Network and Earthquakes in Oklahoma



OGS operates ~72 seismic stations between our permanent (black) and temporary (red) locations. In addition, we pull in data from USGS (green) and surrounding states (red).

- Raw data are publicly accessible, in real-time, at IRIS

<http://ds.iris.edu/mda/OK>

<http://ds.iris.edu/mda/O2>

<http://ds.iris.edu/mda/ZP>

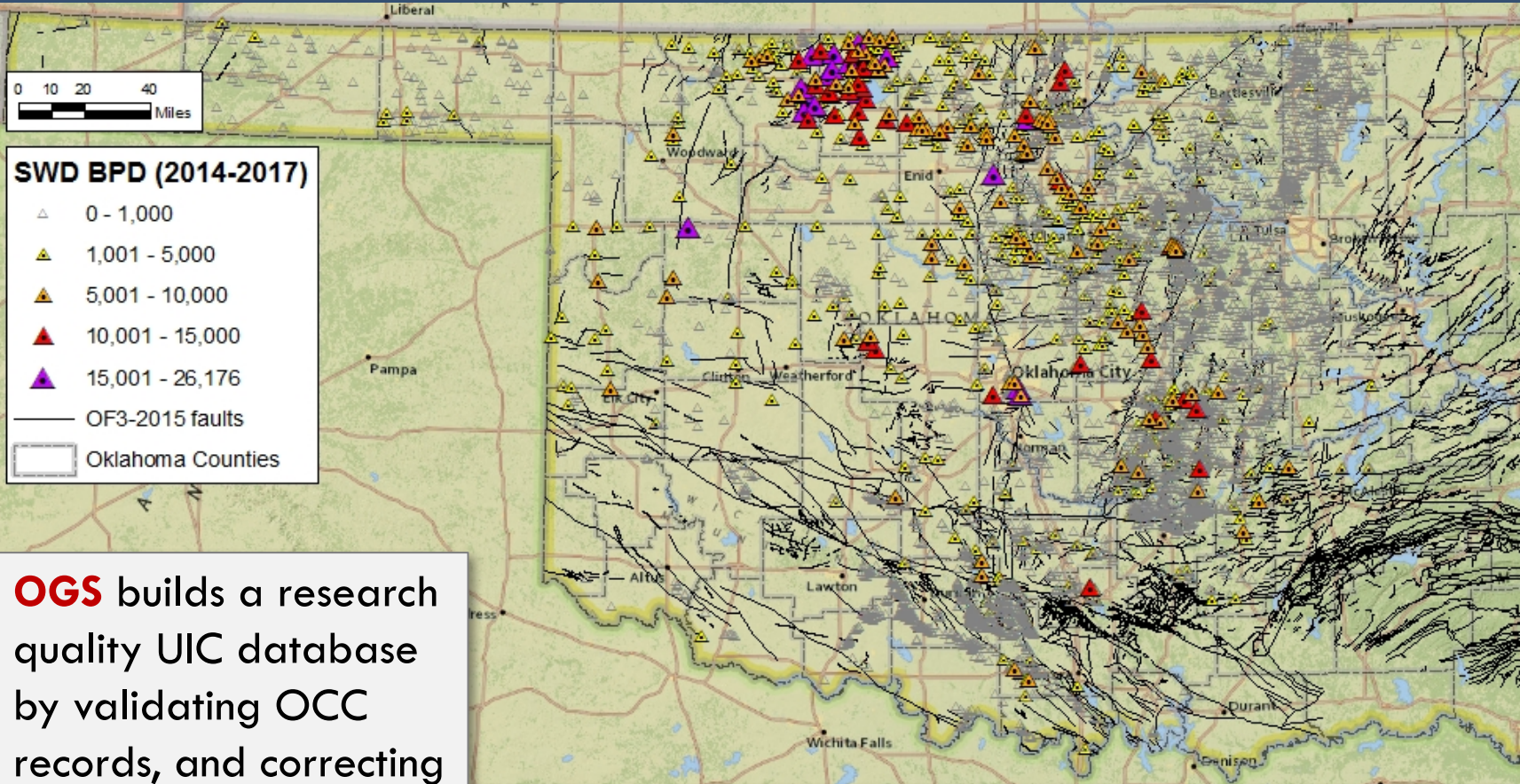
<http://ds.iris.edu/mda/Y7>

<http://ds.iris.edu/mda/Y9>

- Earthquake catalogs are available from OGS

<http://www.ou.edu/ogs/research/earthquakes/catalogs>

UIC Saltwater Disposal (SWD) or 2D volumes in Oklahoma



OGS builds a research quality UIC database by validating OCC records, and correcting errors and gaps. Database to be published and publicly available after 2017 monthly data are completely reviewed.

OCC makes UIC data publicly available in a few formats:

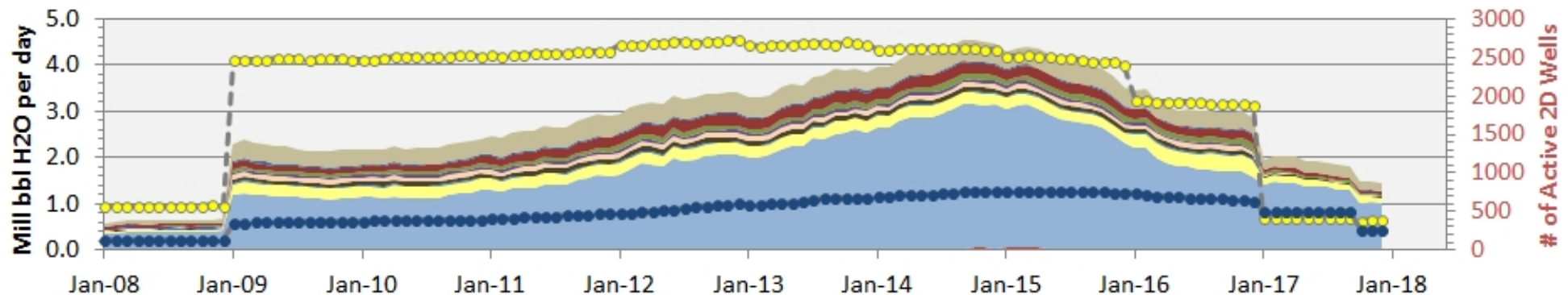
- Monthly resolution, Annual Fluid Injection Reports (Form 1012A)

http://imaging.occeweb.com/imaging/UIC1012_1075.aspx

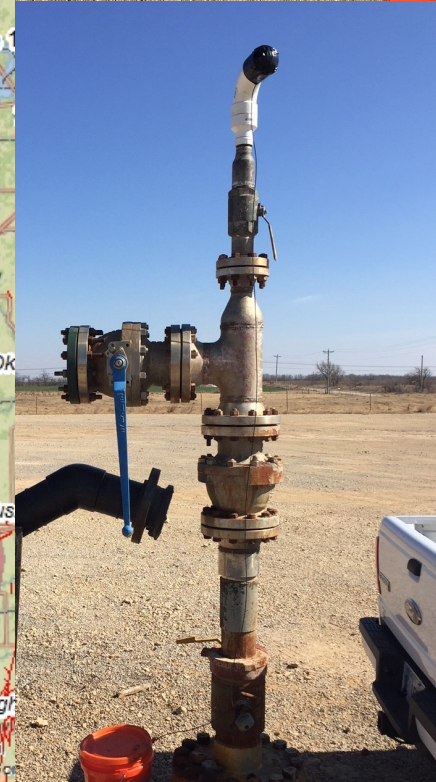
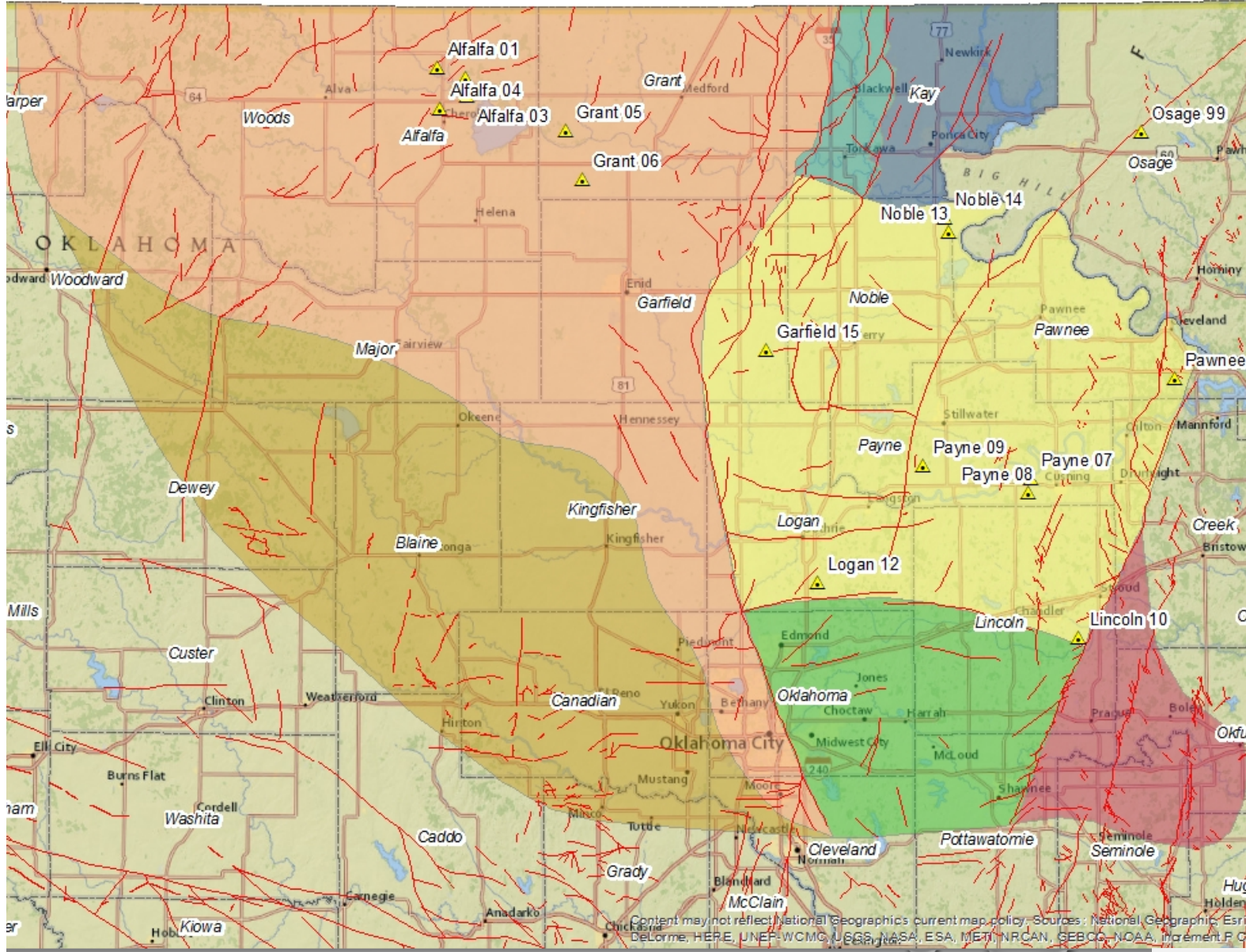
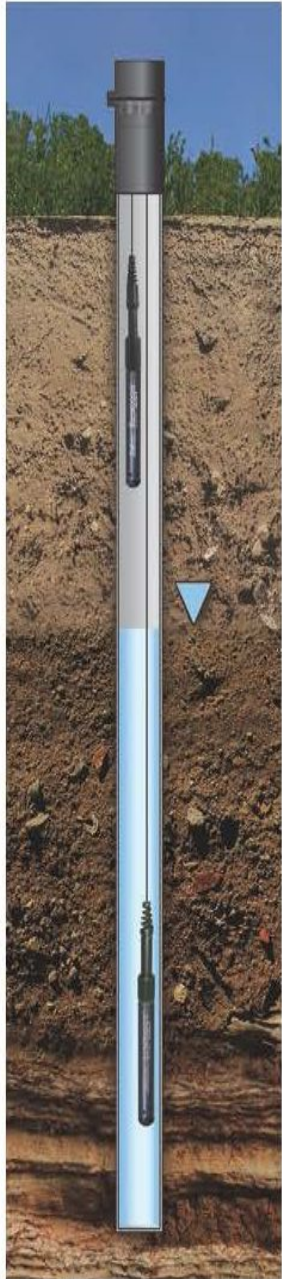
- Daily resolution, Daily Fluid Injection Reports (Form 1012D)

<http://www.occeweb.com/og/ogdatafiles2.htm>

EPA (Osage County) data must be obtained by a FOIA request

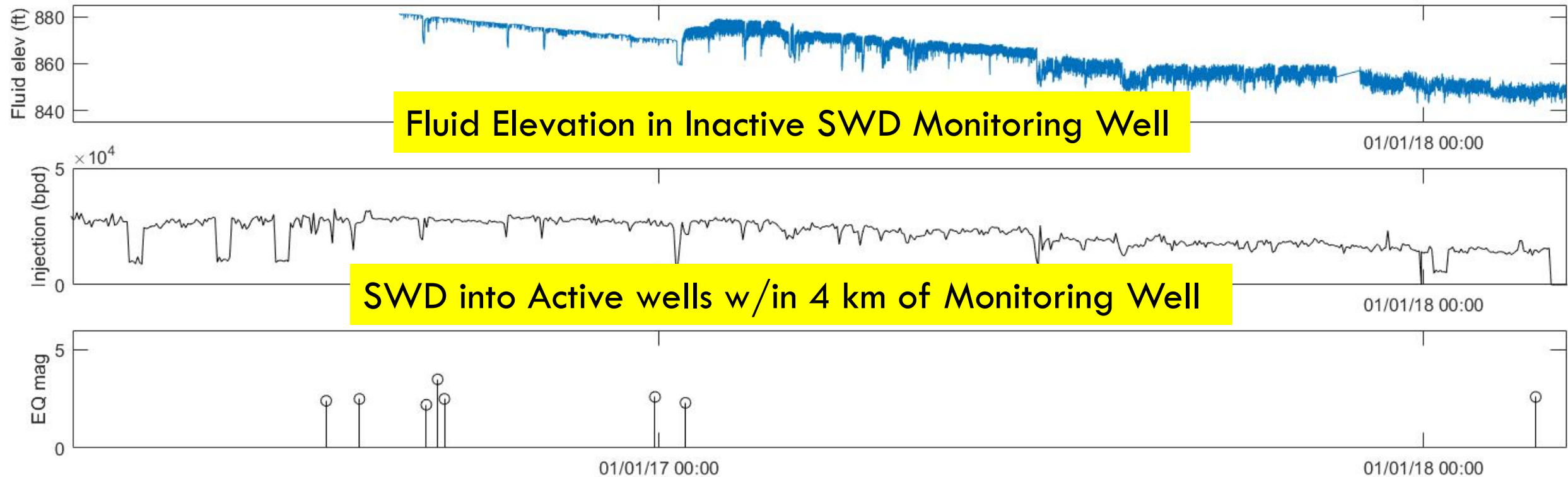


Configuration & Deployment of Arbuckle Pressure Monitoring Network



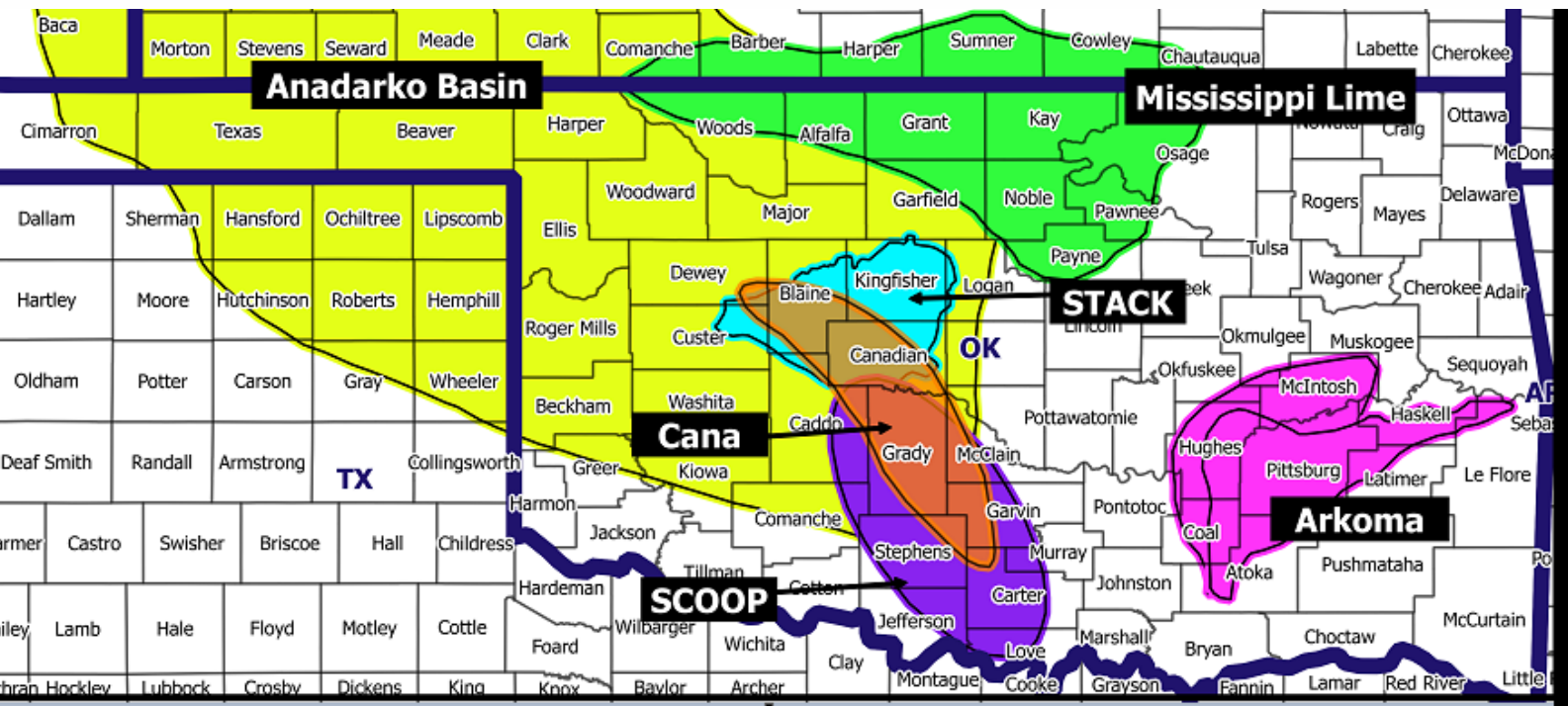
(Murray, et al., 2018 in preparation)

Examining Relationships between Observed Strain (Pressure in Arbuckle) from System Stresses (Injection or Seismicity)



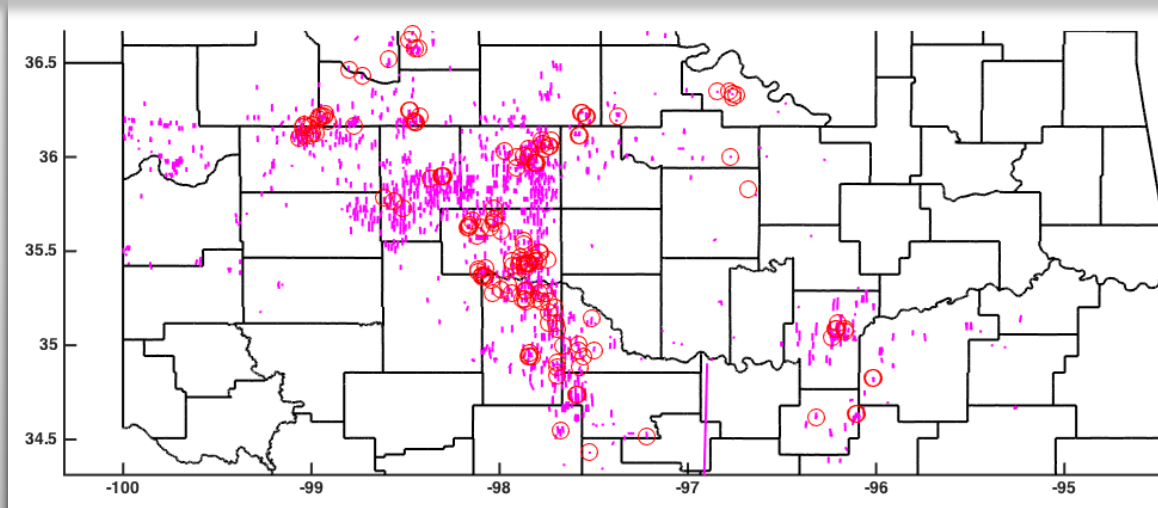
Frac Notices w/in 4 km of Monitoring Well – not updated since Jan 2018

Earthquakes in areas of exploration and production (E&P)



Fracking makes smaller earthquakes – so far largest M3.6

Spatio-temporal comparison of FracNotice and OGS Catalog – earthquakes within Distance and Time of start of frac job (Oct 2016–May 2018)



	5 km	10 km
5 days	4%	8%
10 days	7%	13%

FracNotice is an Oklahoma Corporation Commission notification system, available since Oct 2016



Kansas Geological Survey Research and Service Division of the University of Kansas



KGS Mission: “..conduct geological studies and research and ... collect, correlate, preserve, and disseminate information leading to a better understanding of the geology of Kansas, with special emphasis on natural resources of economic value, water quality and quantity, and geologic hazards.”

The **KGS** has no regulatory authority and does not take positions on natural resource issues.

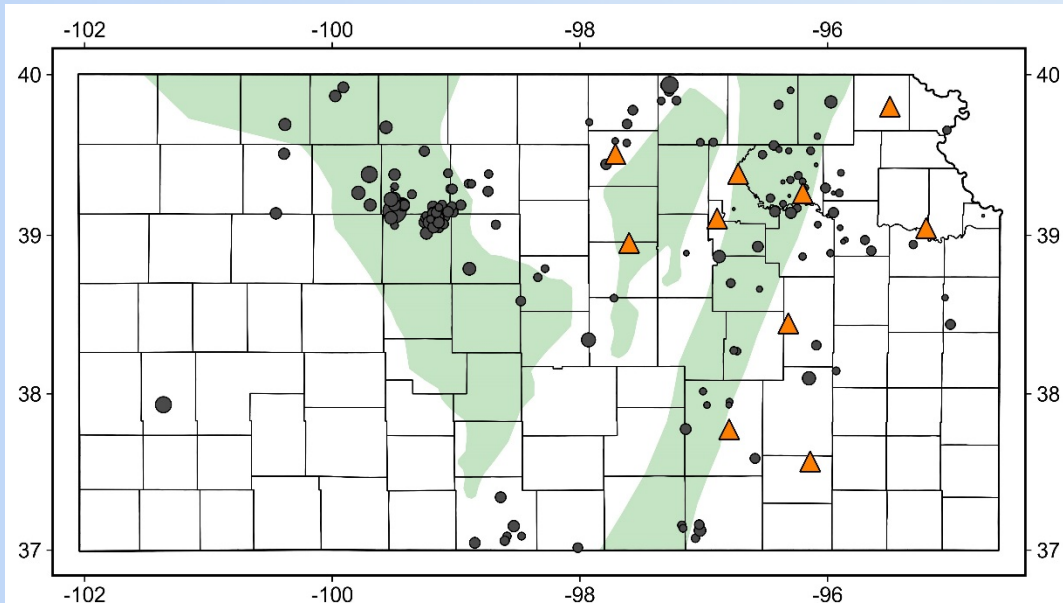
KGS's 104 staff members include: 15 scientist, 20 professional, 40 support, and 29 students

KGS scientists pursue research related to surface and subsurface geology, energy resources, groundwater, and environmental hazards. Their analyses, findings, and data are shared with the scientific community and general public through publications, online resources, and presentations.

History Studying Earthquakes in Kansas

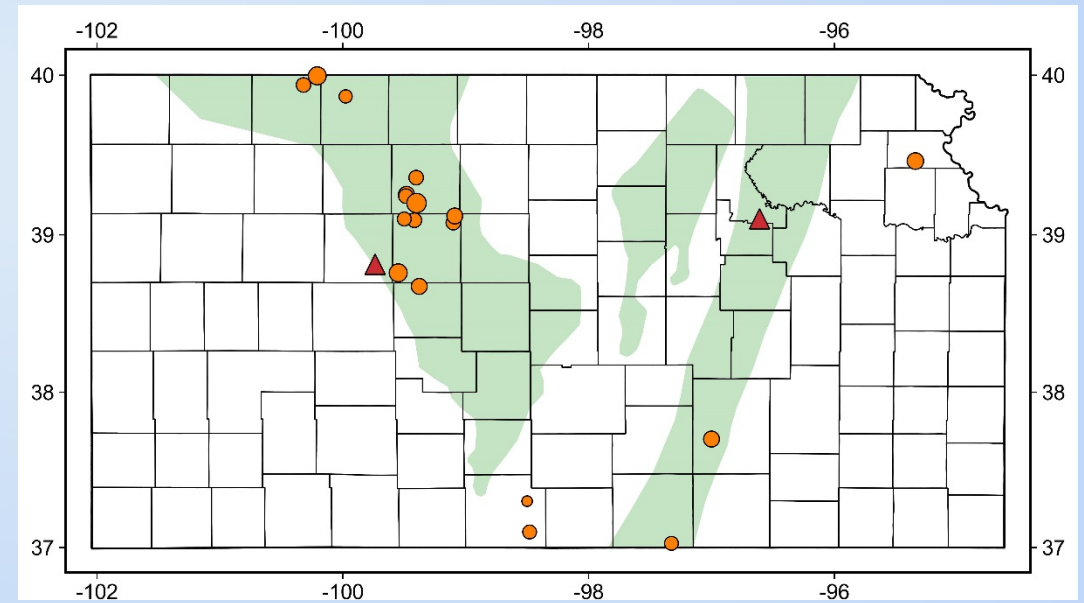
1867-1976 Historical Intensity Based on Documentation
110 years, 30 felt earthquakes, ~M2.5 to M5

KGS Operated Network
1977-1989



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

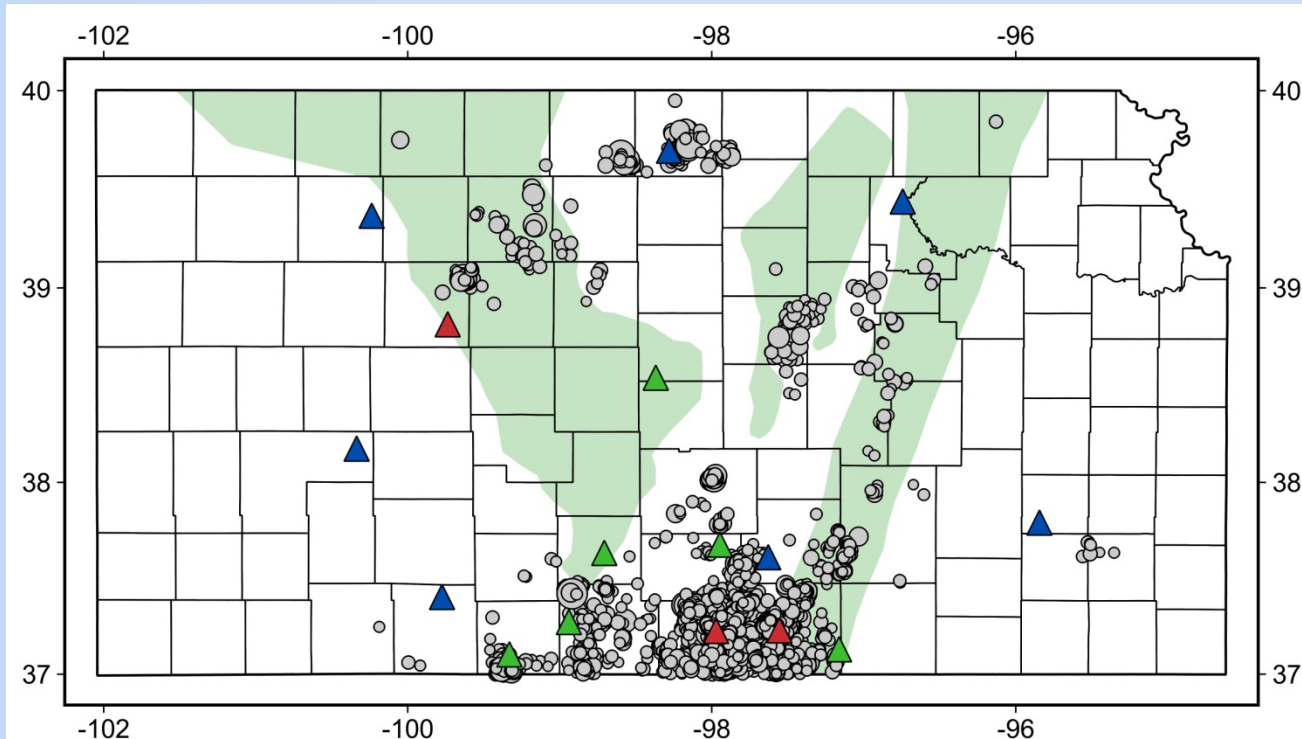
USGS Operated Network
1990-2014



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

Earthquake Monitoring Restart at the KGS in 2015

Basic Make-up and Operations

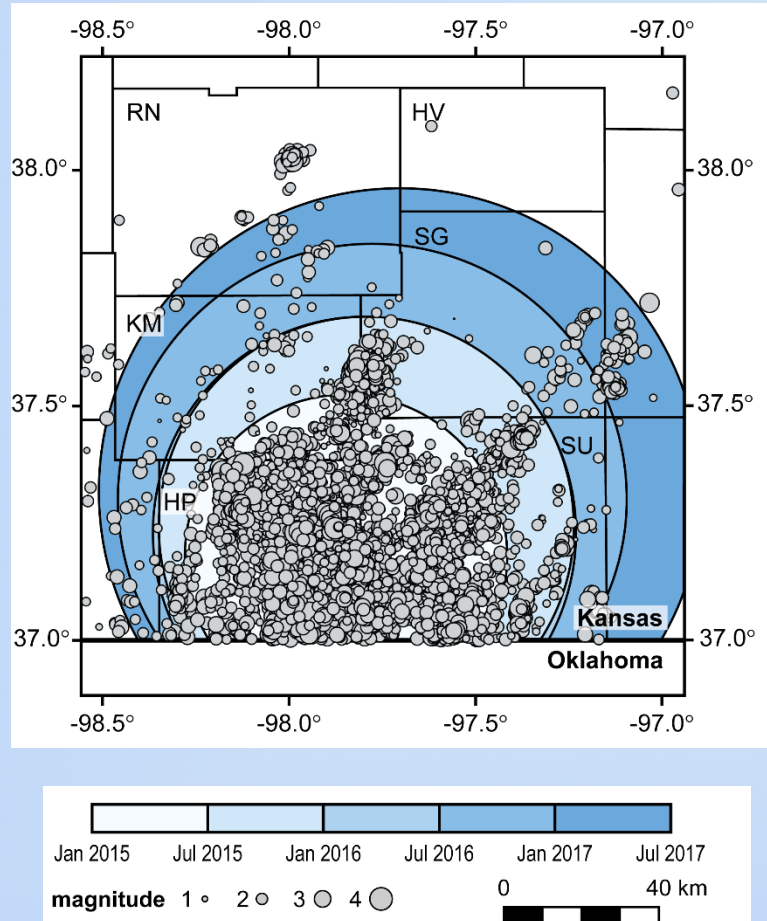


- ▲ 7 KGS permanent stations—2 vertical & 2 horizontal
- ▲ 6 KGS temporary station—1 vertical & 2 horizontal
- ▲ 3 USGS stations occasionally used by KGS

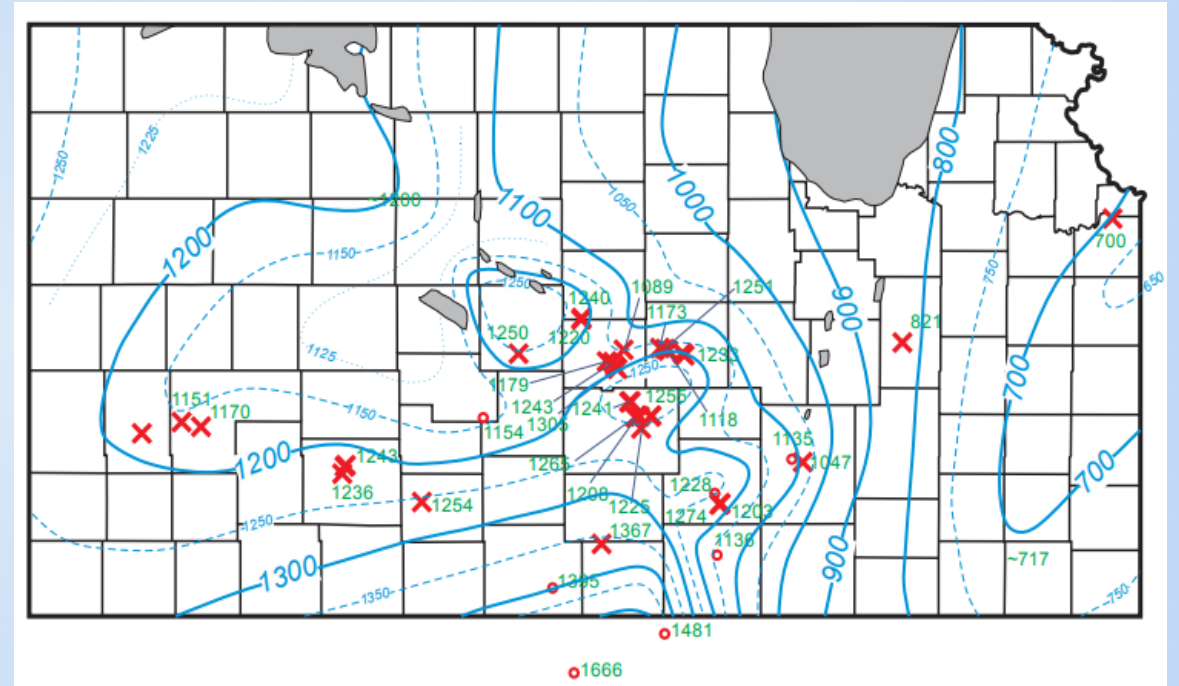
- 2013-2016 Gov Task Force, KGS working with KS Dept of Health and Environment (KDHE) and KS Corp Commission (KCC)
- Real-time
 - Earthworm system
 - email alerts
 - $M \geq 2$
- Near-real time
 - Waveforms and preliminary catalog open access
- Full catalog (1 week lag, currently 10,213 events)
 - manual analysis of continuous data
 - $M \geq 1.8$ 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

Areas of research with focus on seismicity

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



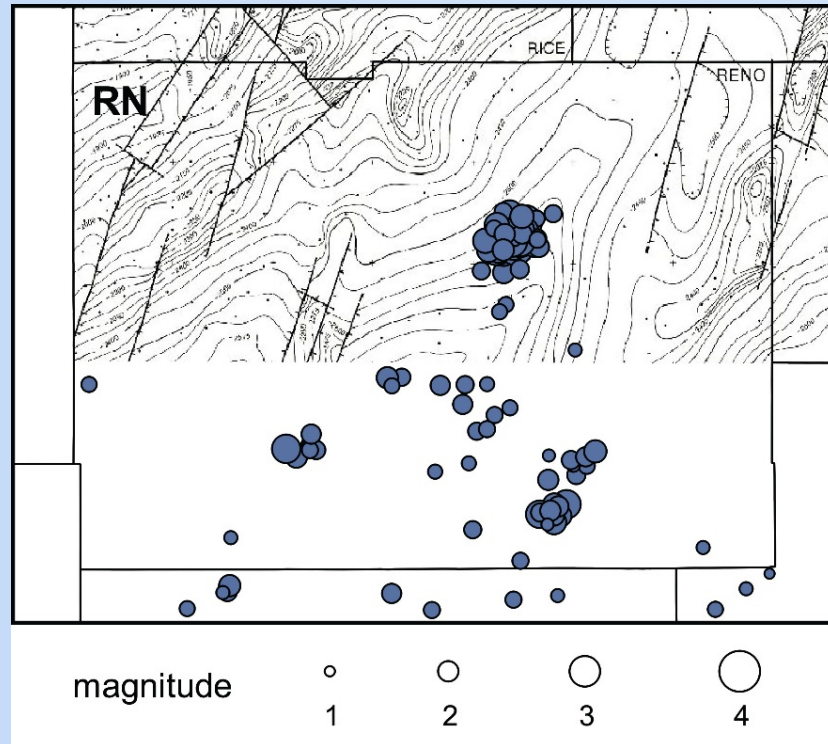
Mapping Arbuckle Group hydrostatic surface and pressure



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

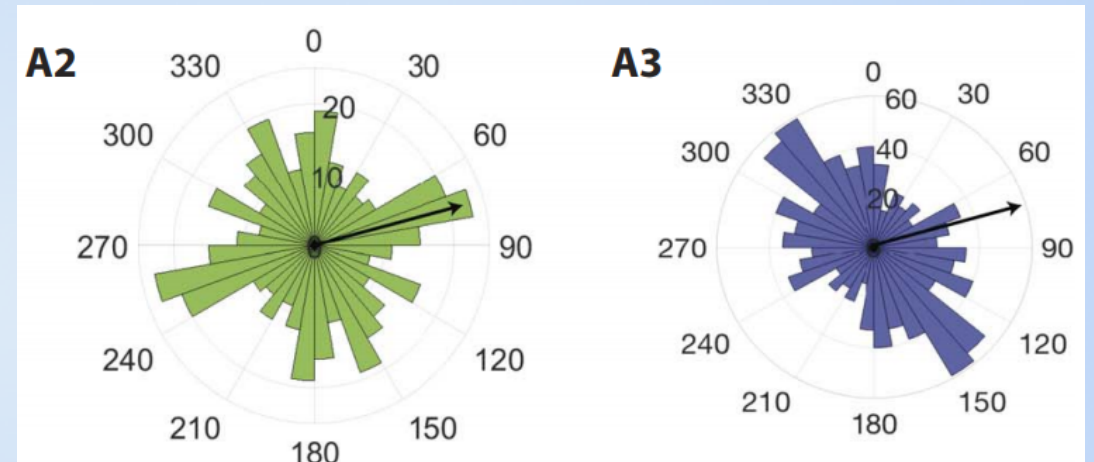
Areas of research with focus on seismicity

Trends in Seismicity, Structure, and Disposal in Reno County



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

Shear-wave anisotropy (Nolte et al., 2017)

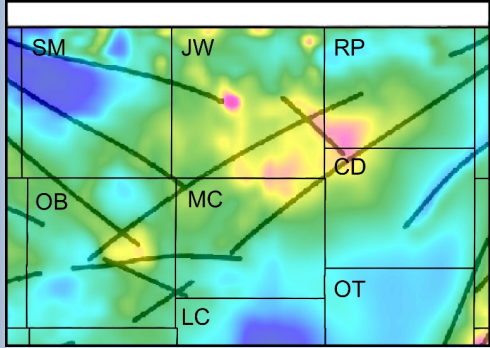


Fast direction changed from direction of SH-max to SH-min

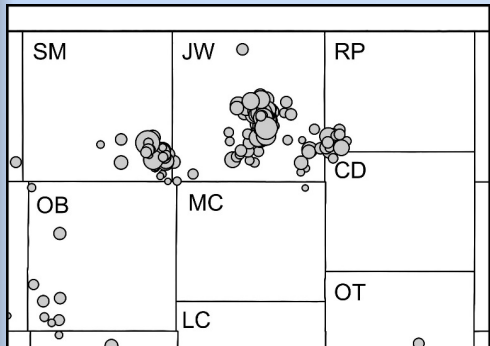
Consistent with expectations for critical pore pressure (associated with opening of closed cracks)

Areas of research with focus on seismicity

aeromag w/lineaments
interpreted in 1983

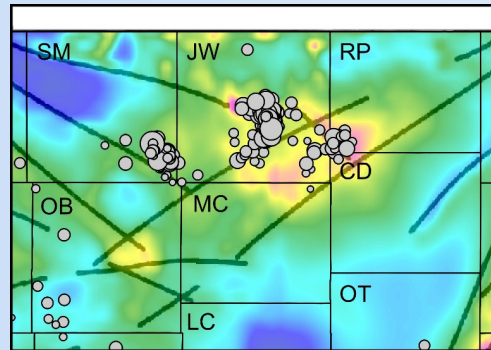


Data Integration



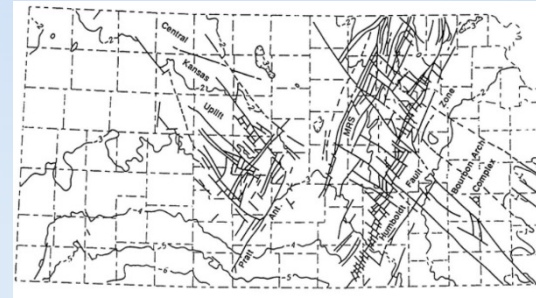
earthquakes (2015-present)

Seismicity in the Salina Basin

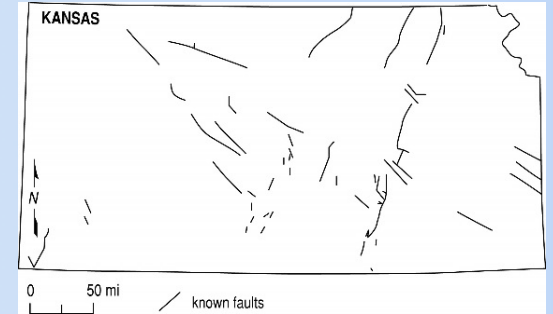


2015-present earthquakes
1983 aeromag w/lineaments

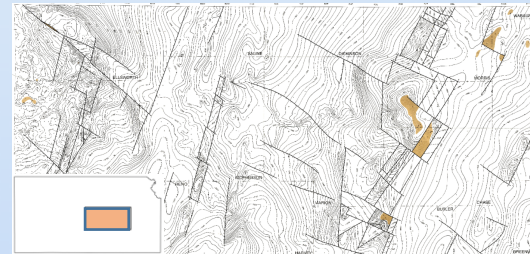
Comprehensive Fault Mapping from Published Data



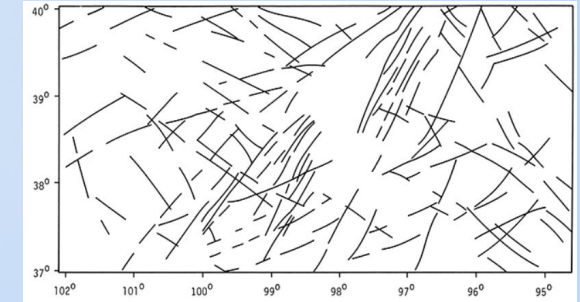
Baars and Watney, 1991



Cole 1976



Berendsen and Blair, 1986



Yarger 1983

Seismicity Research/Service at KGS w/ an Eye Toward RISC

Summary

Differentiating induced from natural

Identifying active trends

Characterizing the hydrology of the Arbuckle and influences

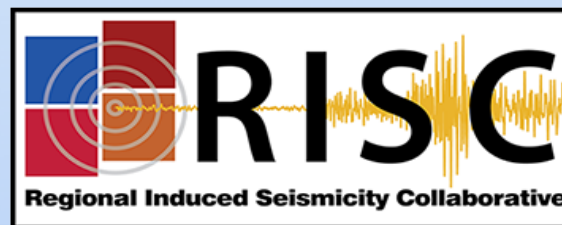
Studying injection practices and seismicity characteristics

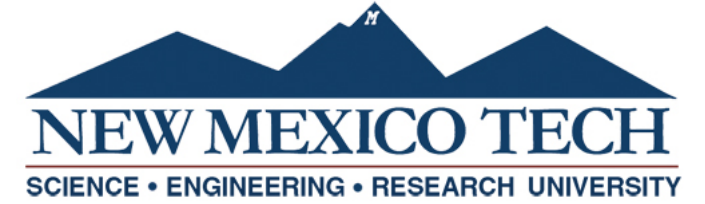
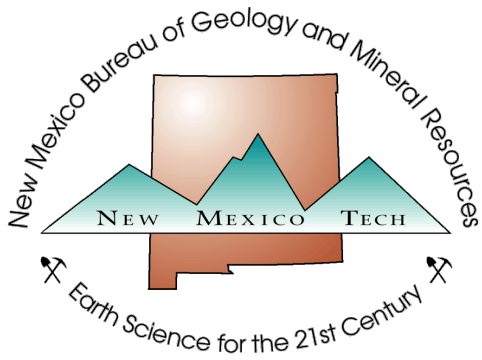
Assimilating reliable fault maps

Correlating seismic trends w/faults: seismically sensitive zones

Integration of available subsurface data/images with seismicity

Evaluating sensitivity of analysis with velocity functions: regional vs local





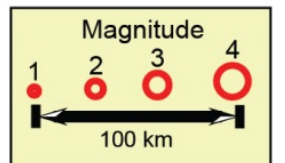
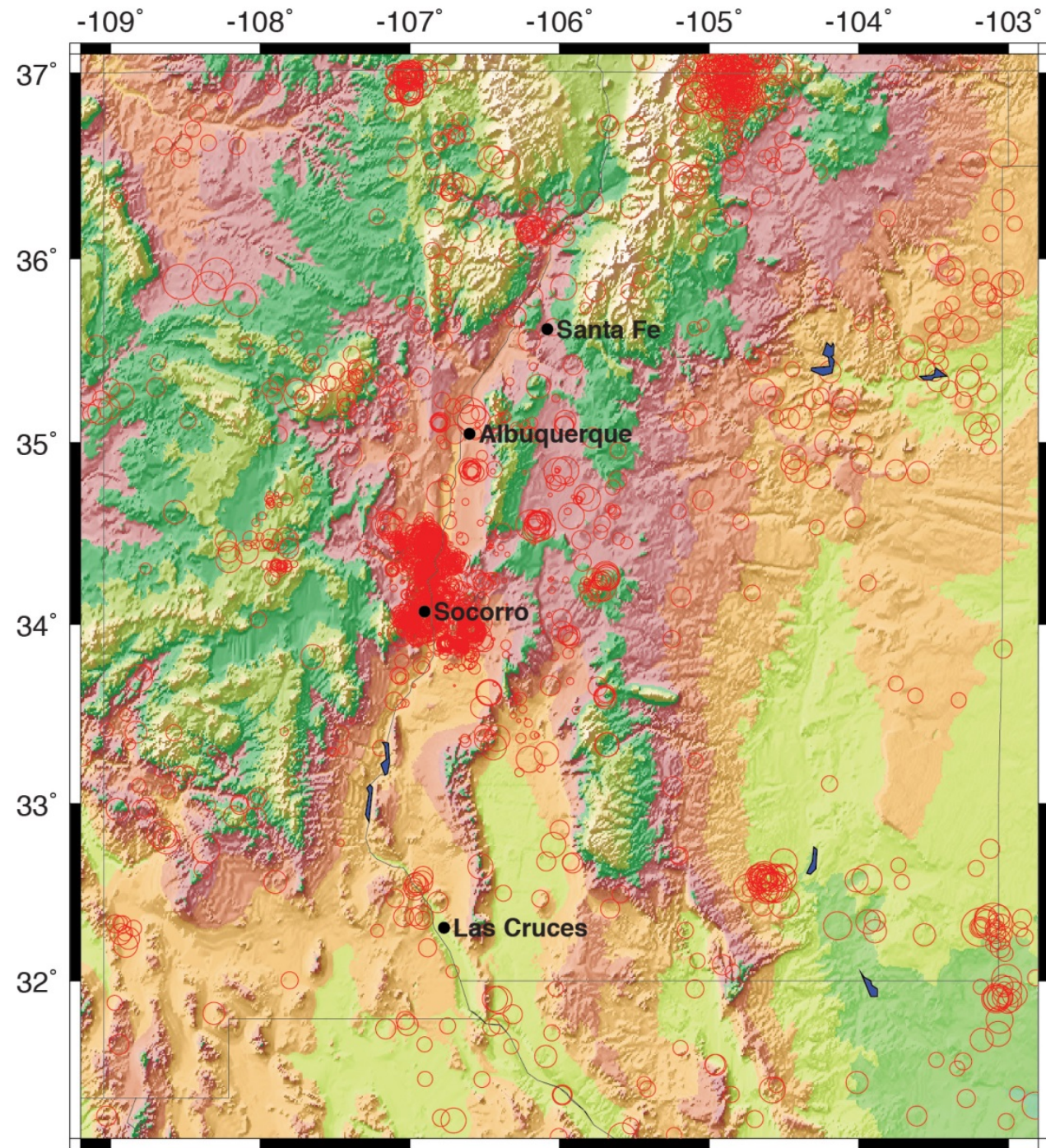
New Mexico Seismicity and Monitoring Efforts

RISC Webinar

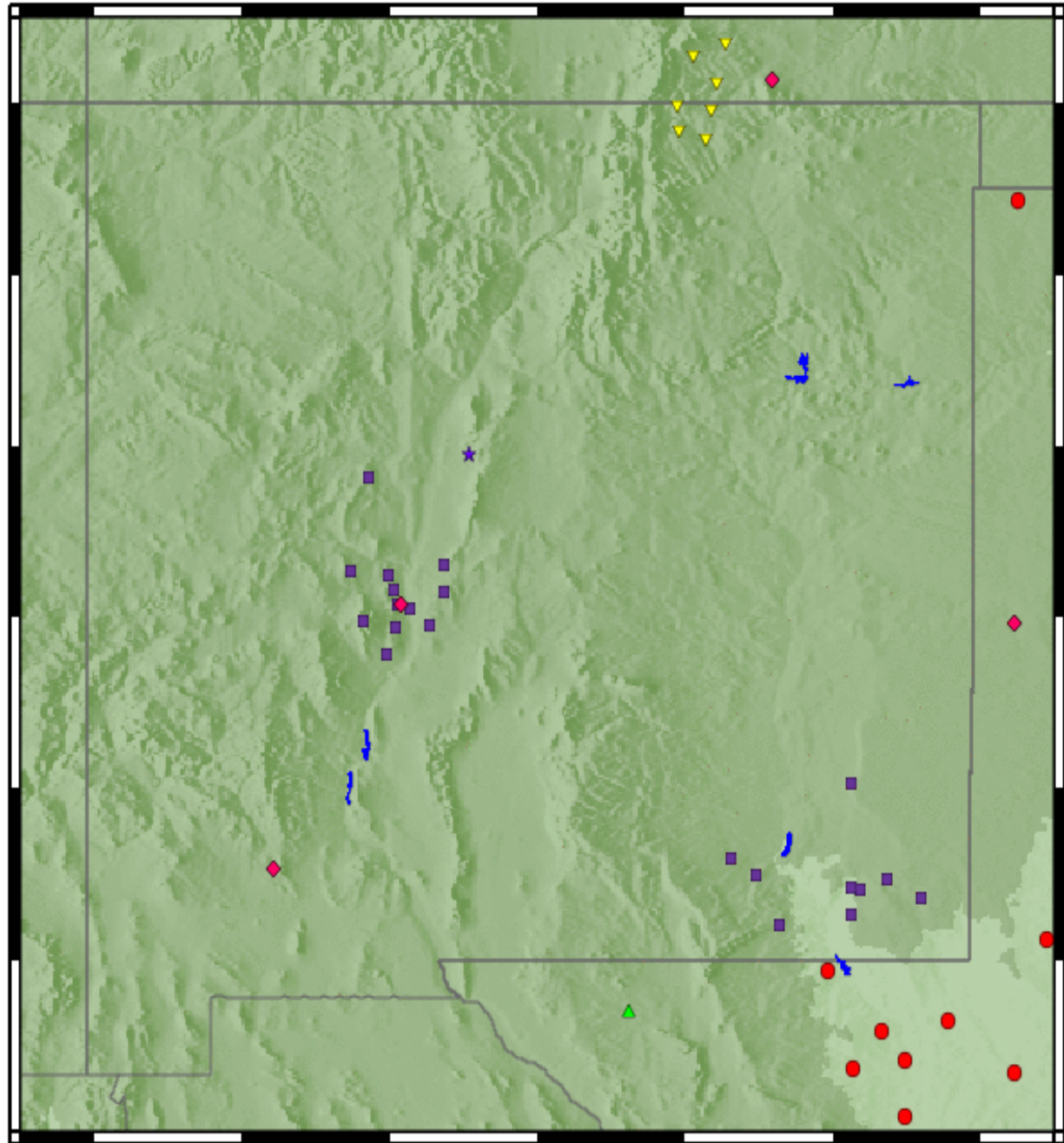
July 9, 2018

Mairi Litherland

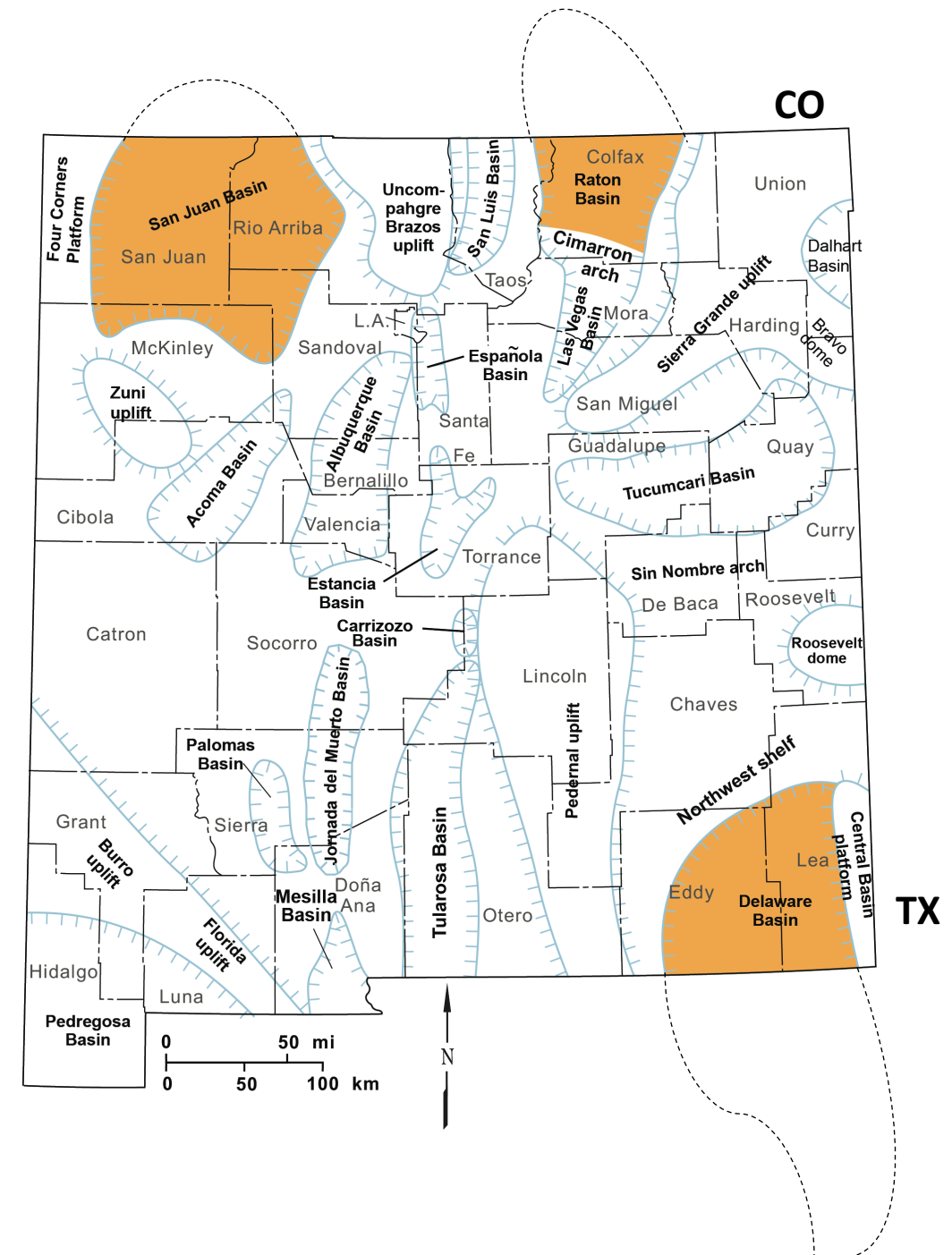
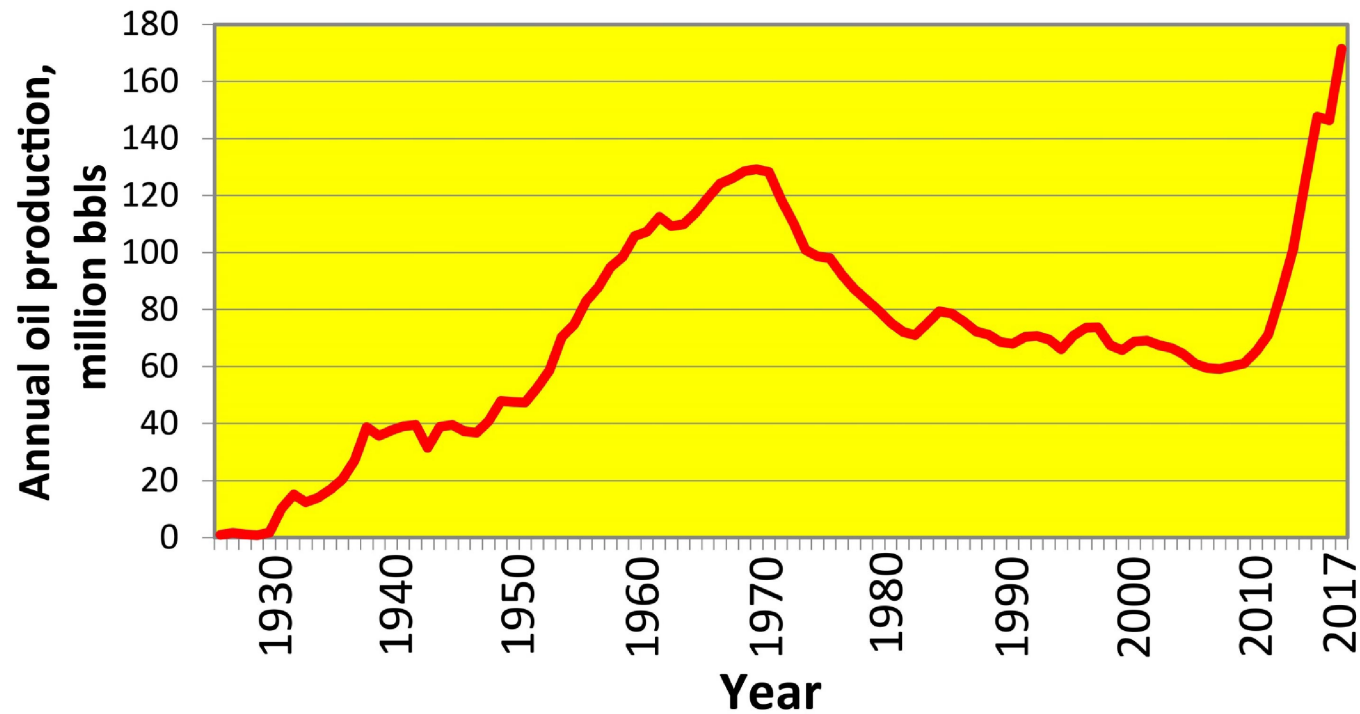
Historic seismicity in New Mexico



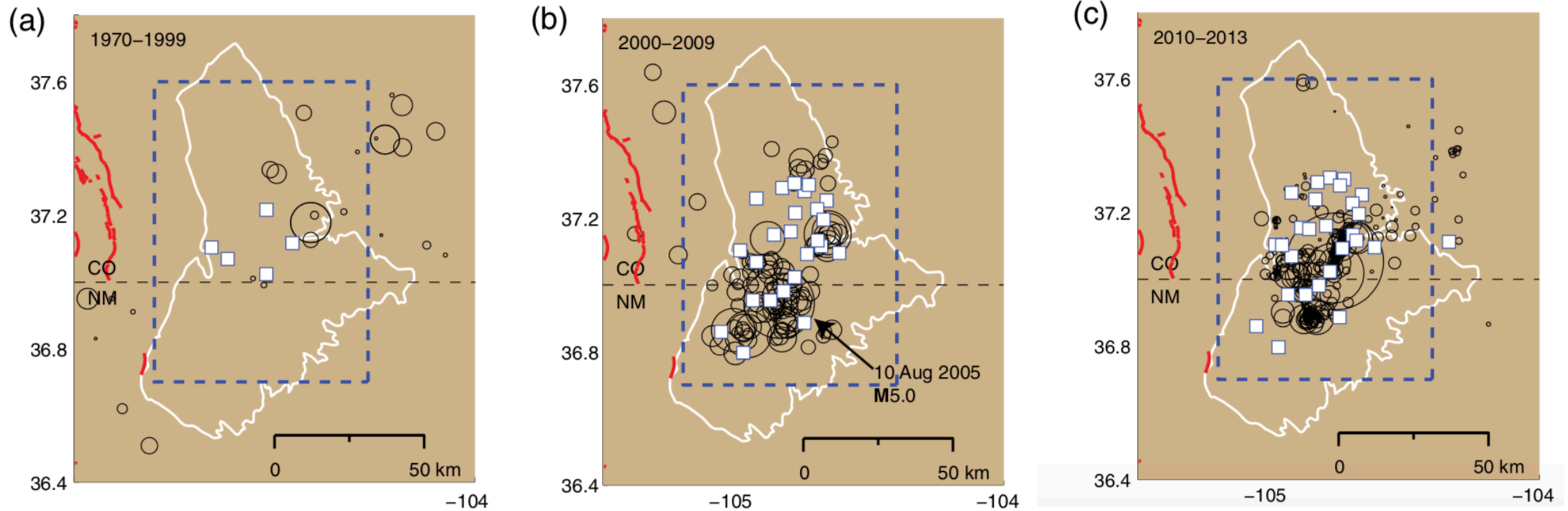
Seismic stations in New Mexico



New Mexico oil and gas production

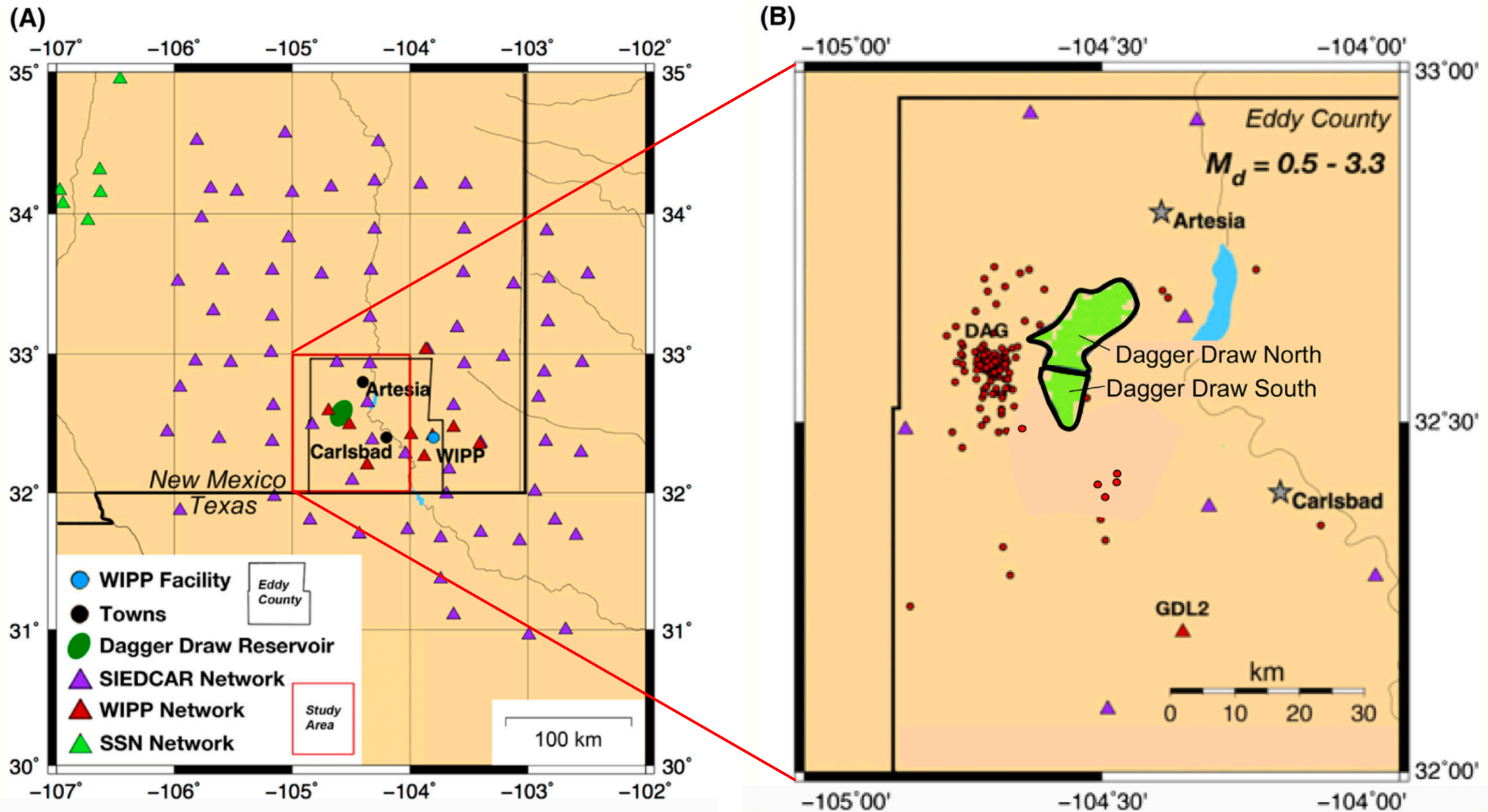


Raton Basin

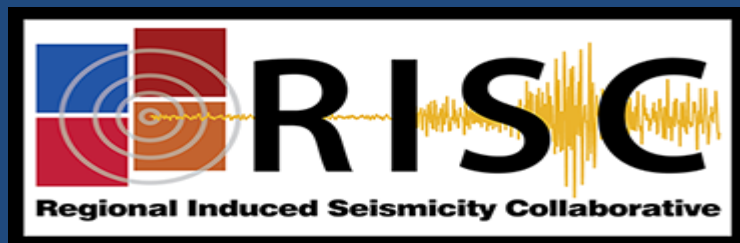


Rubinstein et al., 2014

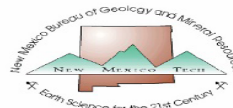
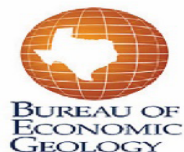
Delaware Basin: Dagger Draw



Overview of Induced Seismicity in Arkansas

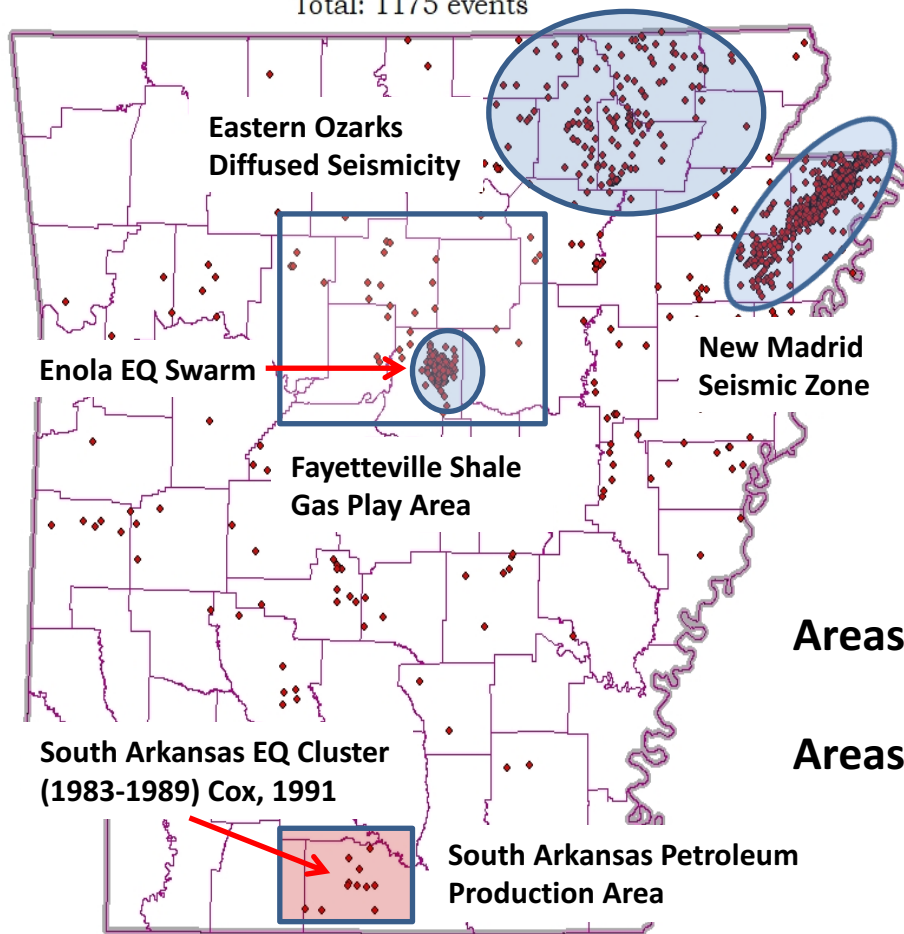


Scott M. Ausbrooks
Arkansas Geological Survey



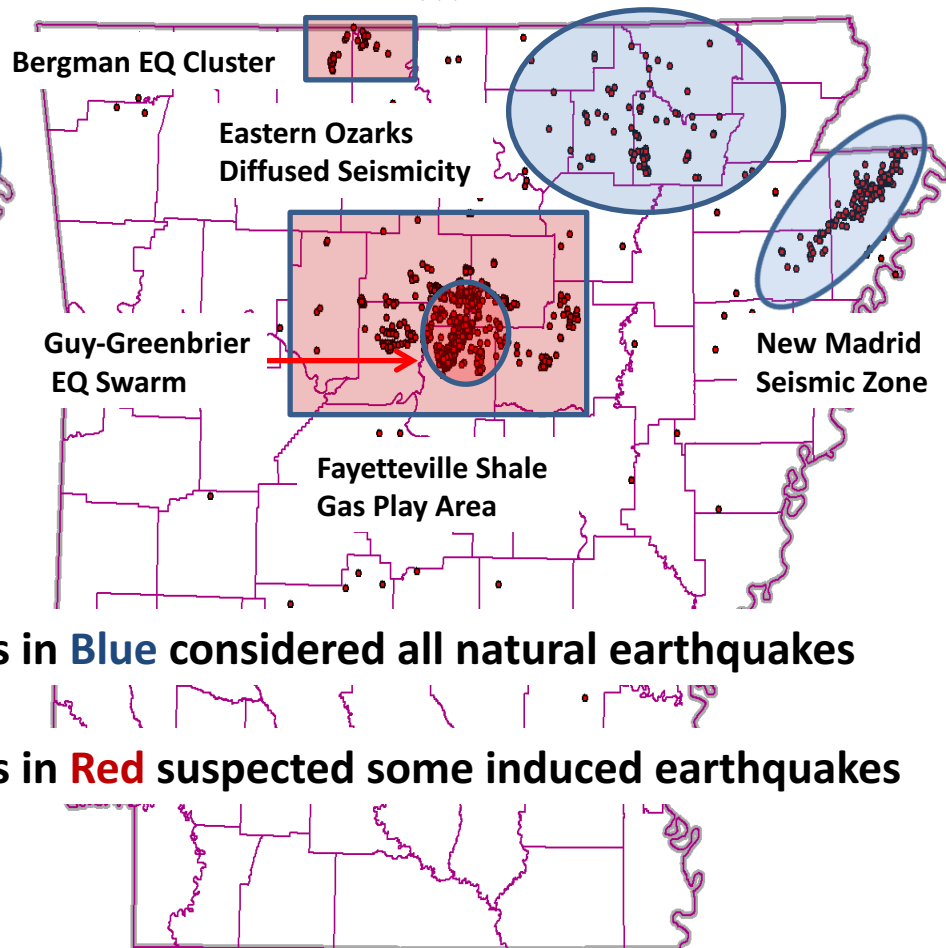
Arkansas Earthquakes from 1811 Thru 2008

Total: 1175 events



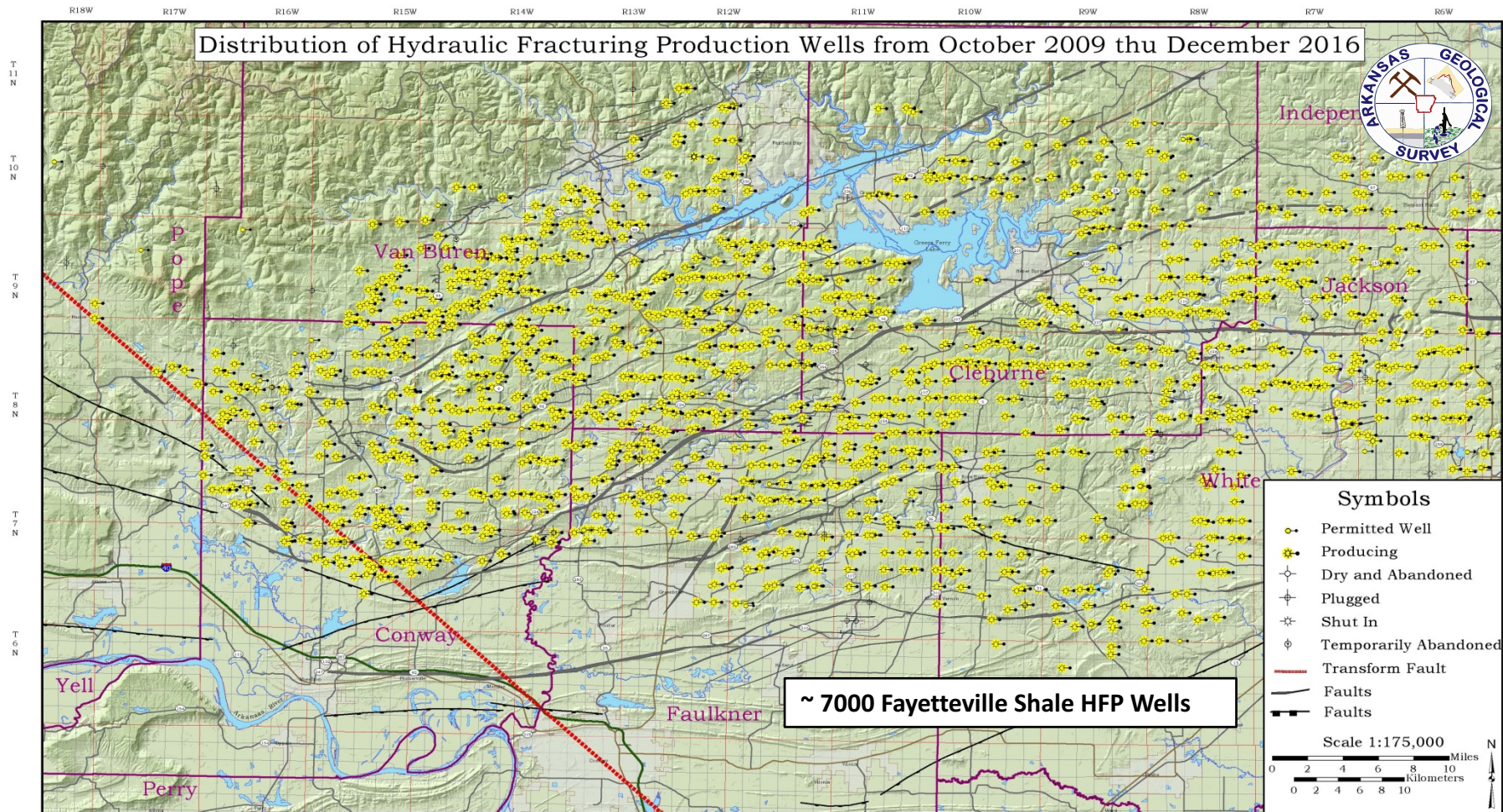
Arkansas Earthquakes from 2009 Thru 2018

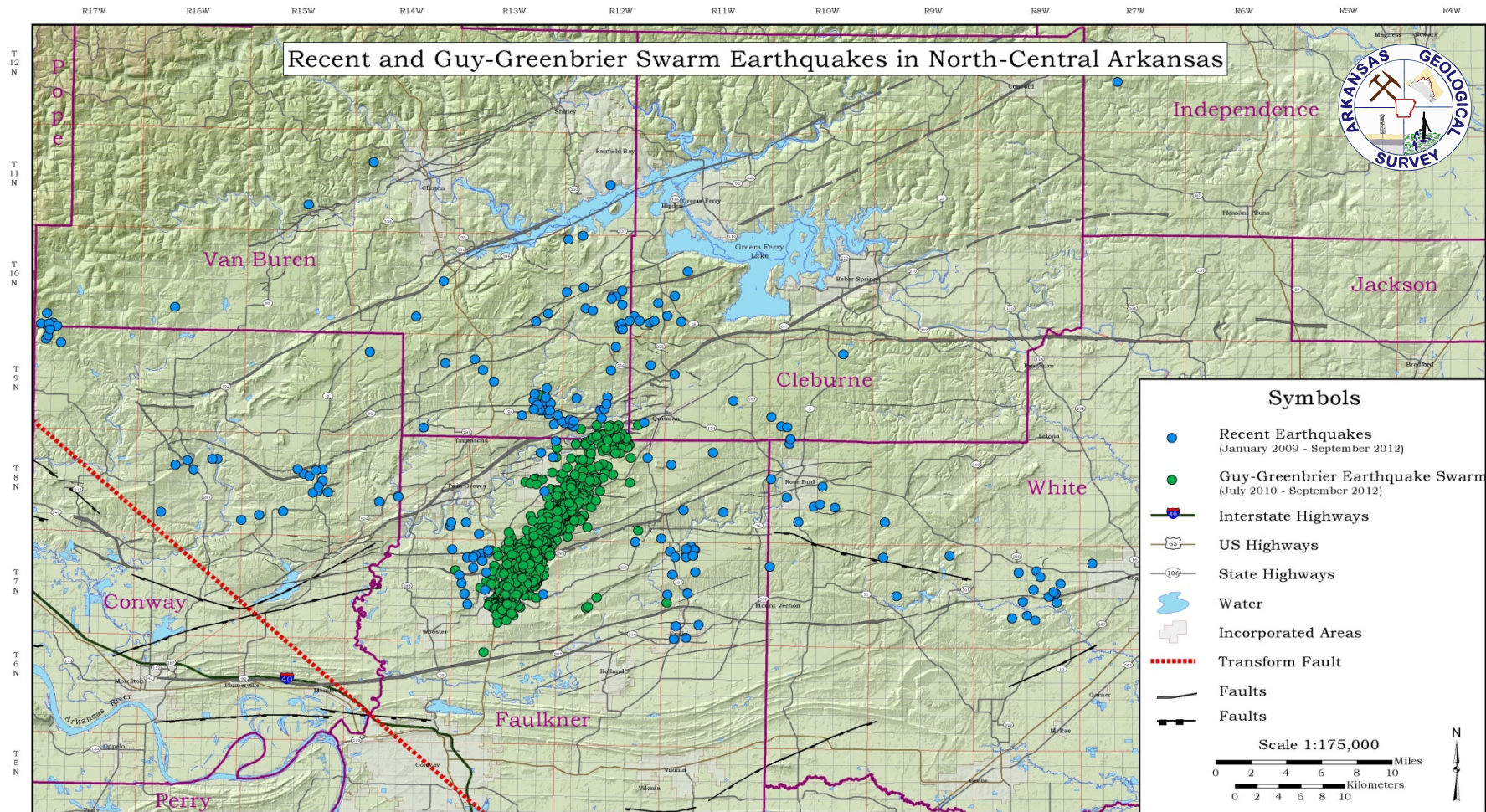
Total: 2229 events



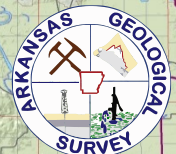
Areas in **Blue** considered all natural earthquakes

Areas in **Red** suspected some induced earthquakes

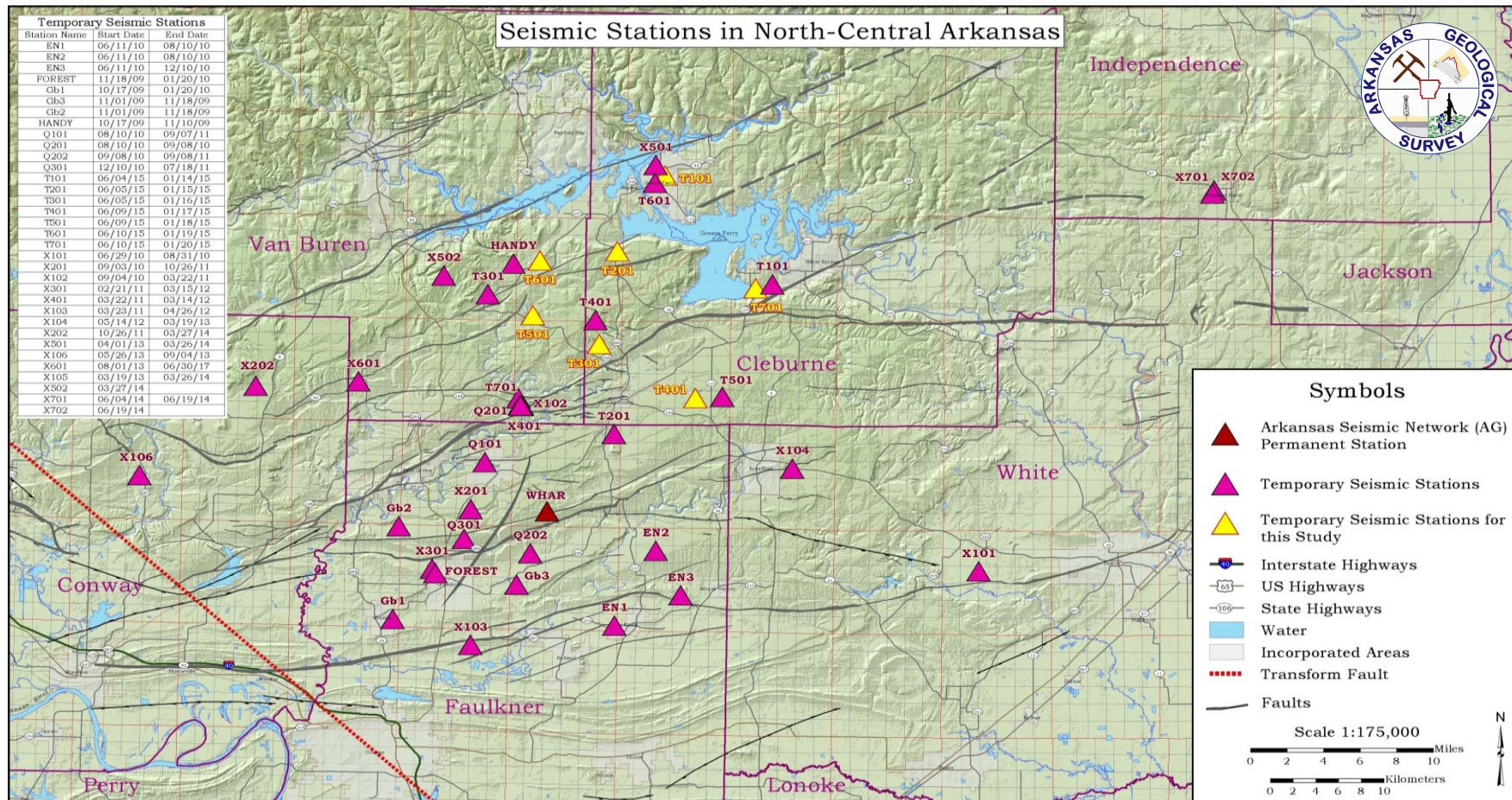




Seismic Stations in North-Central Arkansas



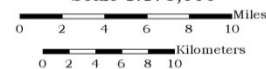
Station Name	Start Date	End Date
EN1	06/11/10	08/10/10
EN2	06/11/10	08/10/10
EN3	06/11/10	12/10/10
FOREST	11/18/09	01/20/10
Gb1	10/17/09	01/25/10
Gb3	11/01/09	11/18/09
Gb2	11/01/09	11/18/09
HANDY	10/17/09	11/10/09
Q101	08/10/10	09/07/11
Q201	08/10/10	09/08/10
Q202	09/08/10	09/08/11
Q301	12/10/10	07/18/11
T101	06/04/15	01/14/15
T201	06/05/15	01/15/15
T301	06/05/15	01/16/15
T601	06/09/15	01/17/15
T501	06/09/15	01/18/15
T601	06/10/15	01/19/15
T701	06/10/15	01/20/15
X101	06/29/10	08/31/10
X201	09/03/10	10/26/11
X102	09/04/10	03/22/11
X301	02/21/11	03/15/12
X401	03/22/11	03/14/12
X103	03/23/11	04/26/12
X104	05/14/12	03/19/13
X202	10/26/11	03/27/14
X501	04/01/13	03/26/14
X106	05/26/13	09/04/13
X601	08/01/13	06/30/17
X105	03/19/13	03/26/14
X502	03/27/14	
X701	06/04/14	06/19/14
X702	06/19/14	



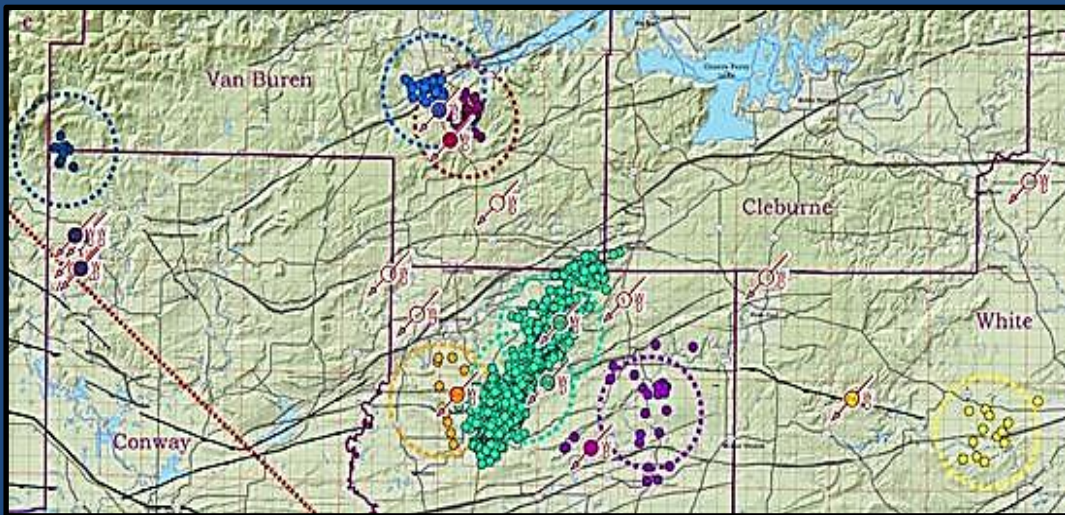
Symbols

- ▲ Arkansas Seismic Network (AG) Permanent Station
- ▲ Temporary Seismic Stations
- ▲ Temporary Seismic Stations for this Study
- Interstate Highways
- US Highways
- State Highways
- Water
- Incorporated Areas
- Transform Fault
- Faults

Scale 1:175,000

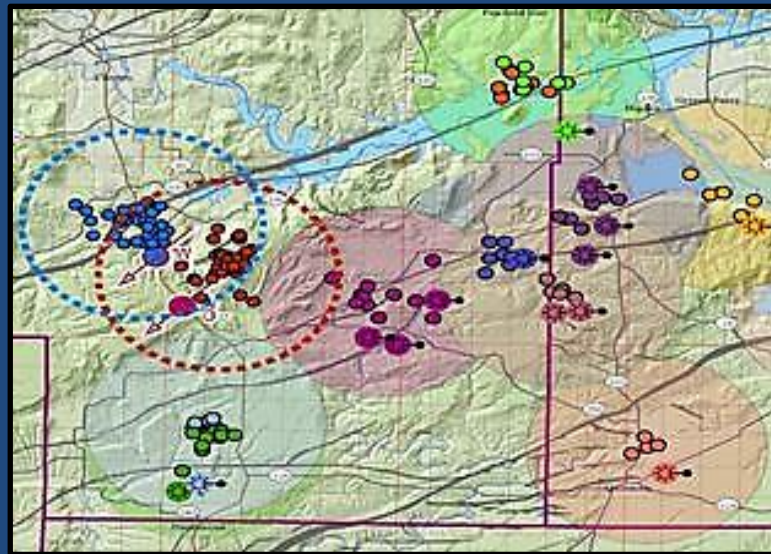


AGS Current Research Activities Related to Induced Seismicity



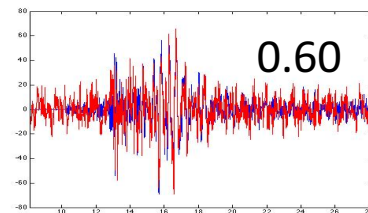
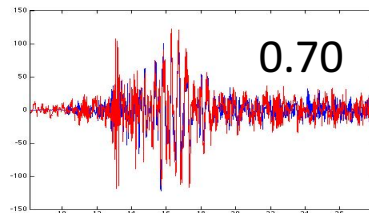
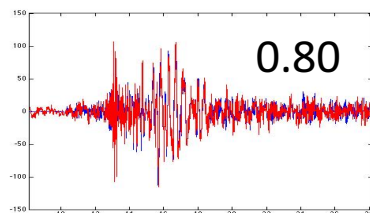
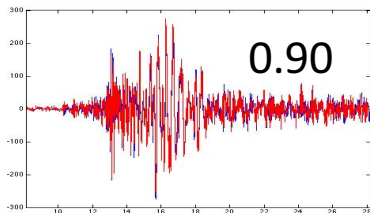
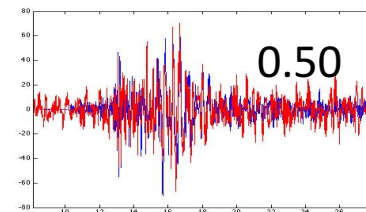
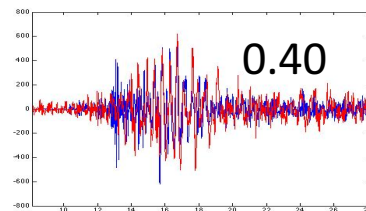
Currently characterizing and classifying 54 distinct clusters of earthquakes that are comprised of 497 regional (**> M1.0**) earthquakes between 2009 – 2016 whether they are natural or induced.

Template Matching Earthquake Clusters in NCAR





Daves Crossroads EQ Cluster: Events Per Day (WHAR)



The University of Texas Bureau of Economic Geology

- **Energy, Environment & Economic Research**
 - ~\$30 million/year budget, >90% grants & contracts
 - Established in 1909
 - 2nd largest research unit at UT
- **Geological Survey of Texas**



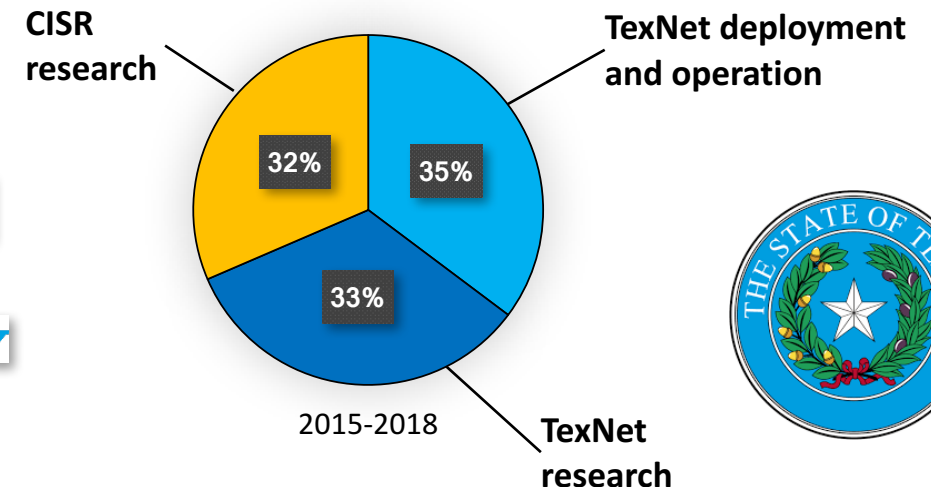
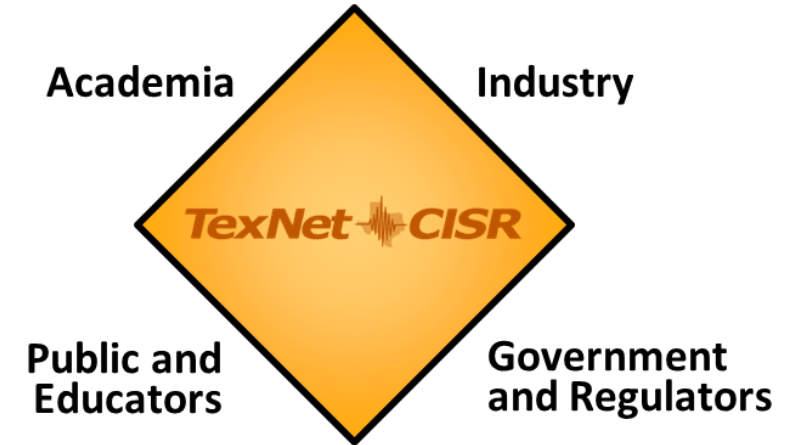
TexNet-CISR Program

TexNet

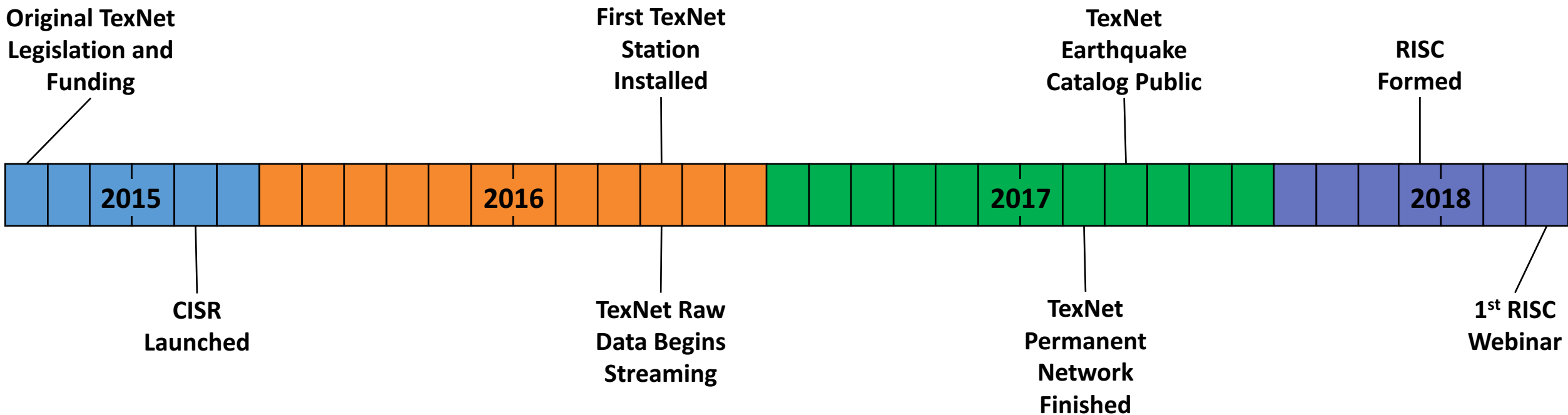
- 42-station *backbone* seismic network
- 40 temporary stations and local dense networks,
- Goals are to monitor, locate, and catalog earthquakes across Texas; disseminate earthquake data; conduct research to improve our understanding of earthquake causes.

Center for Integrated Seismicity Research

- Industry affiliate program to leverage and extend TexNet earthquake monitoring and research



TexNet-CISR Timeline June 2015–June 2018



TexNet-CISR Organization

TexNet-CISR Program Leadership

Peter Hennings, PI Subsurface Integration and Industry Liaison

Ellen Rathje, PI Earthquake Hazard and Risk

Alexandros Savvaidis, PI Seismology and TexNet Manager

Scientific Themes

**TexNet Seismic
Network**

Seismology

**Geologic
Characterization**

**Geomechanics
and Reservoir
Modeling**

**Seismic Hazard
and Risk
Assessment**

**Surface
Deformation
and Geodetics**

Organizations Directly Collaborating with BEG

UT Bureau of Economic Geology
UT Institute for Geophysics
UT Petroleum Geosystems and Engineering
UT Civil, Arch, and Environmental Engineering
UT Aerospace Engineering
Texas A&M Petroleum Engineering
SMU Geosciences
University of Houston Seismology
University of Texas at Dallas Seismology
University of Texas at El Paso Seismology
Stanford University
Southwest Research Institute
Golder Associates

Committees for Accountability/Feedback

Technical Advisory Board – designated by Governor of Texas, represented by several stakeholder groups (industry, universities, and the public)

Science Advisory Committee – one representative from each member of CISR

TexNet Network and Earthquake Catalog

42 Station Backbone for Texas

33 Portable Stations deployed

- 14+1 deployed in the DFW area
- 7 are deployed in the Snyder area
- 7+1 deployed in Permian Basin area
- 2+1 deployed in the Eagle Ford area

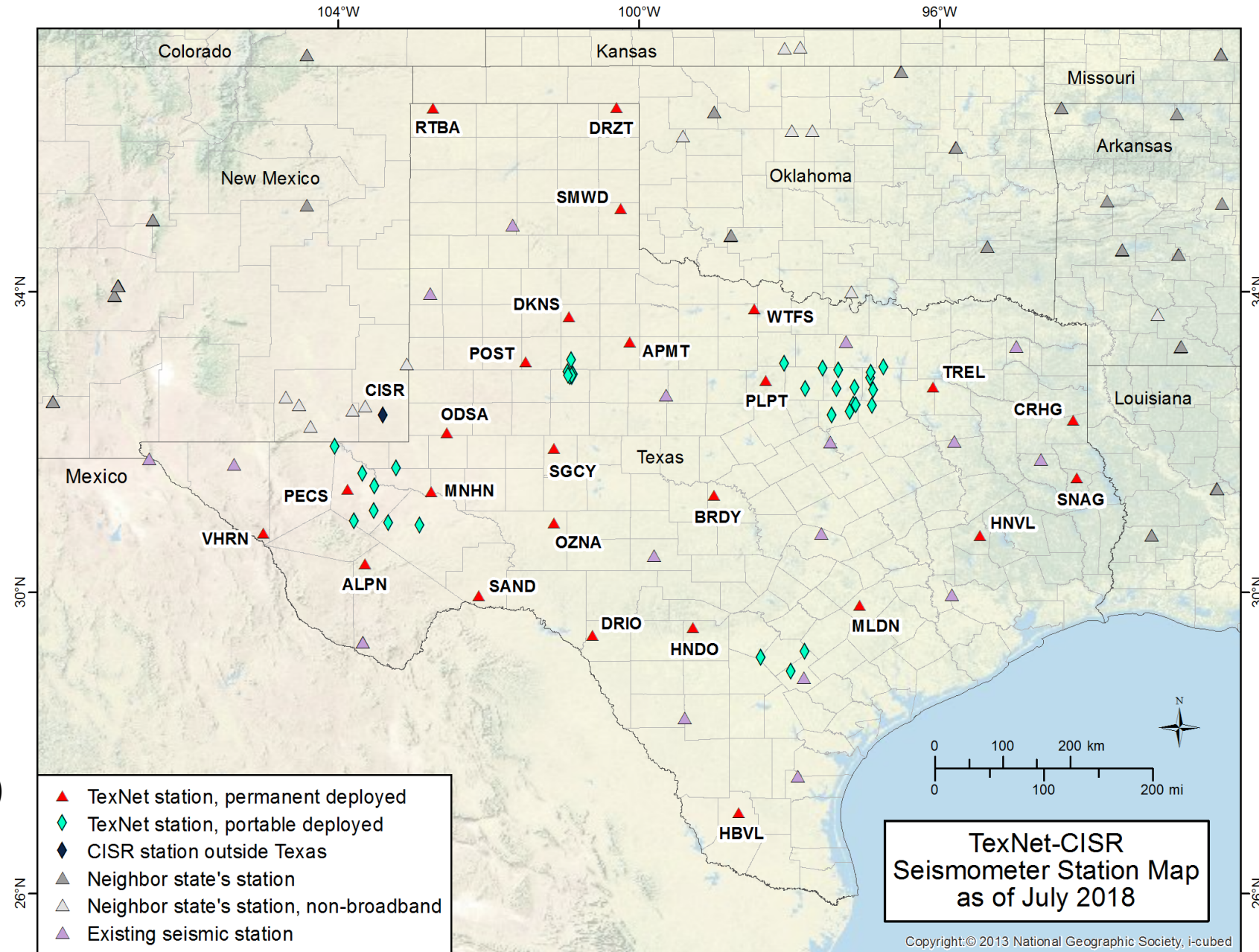
1+2 Stations deployed in NM (CISR)

6 Portable stations available

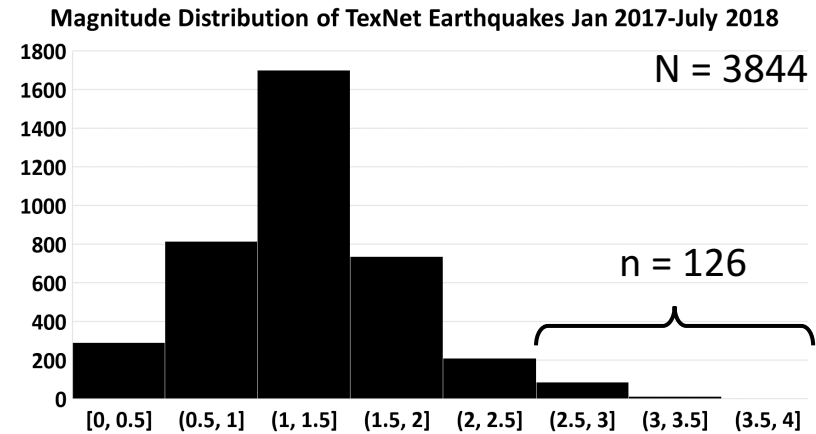
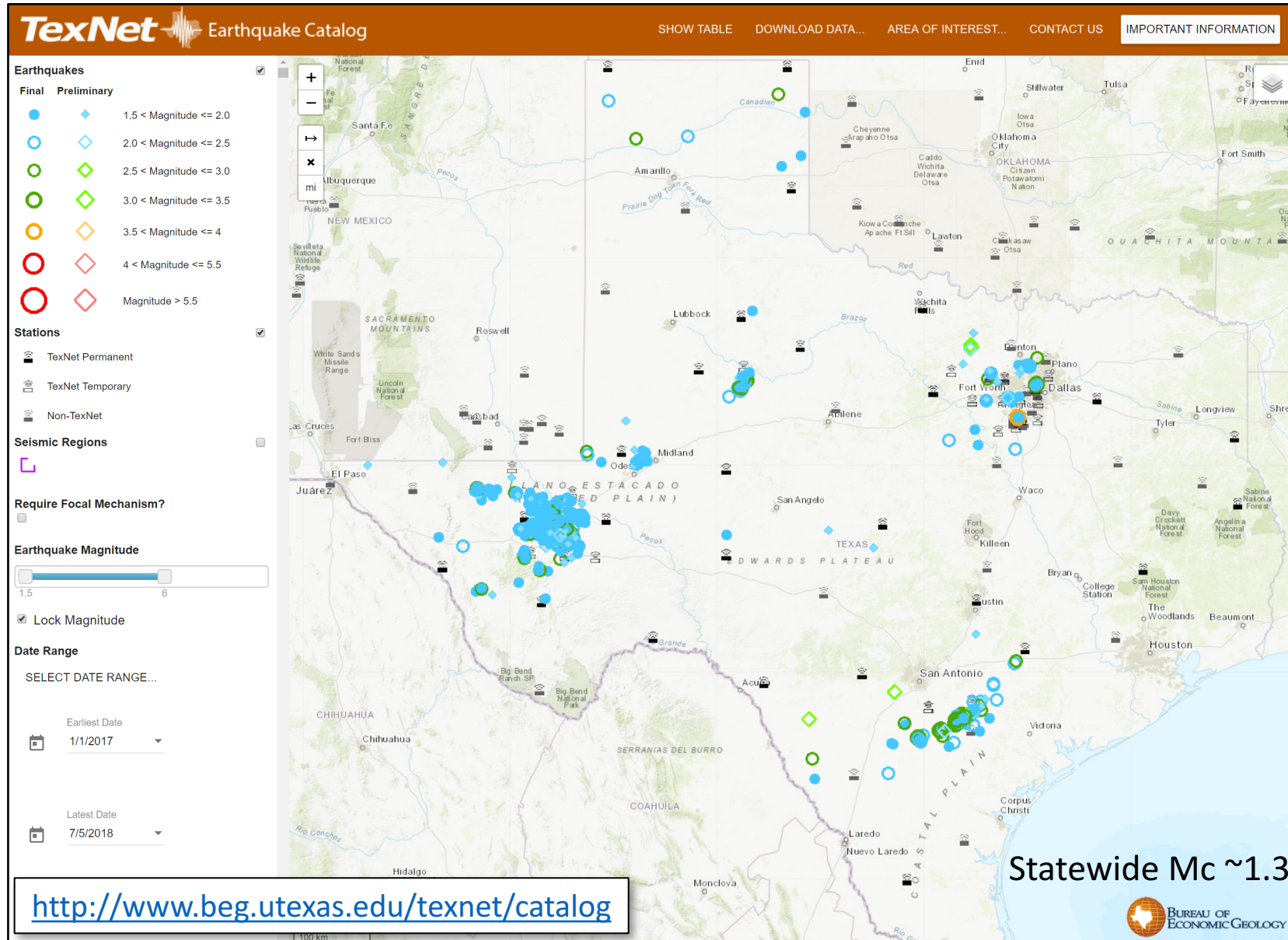
- 1 to be deployed (Permian, Eagle Ford)
- 3 available for immediate response
- 2 out for service

Dense local networks operated by:

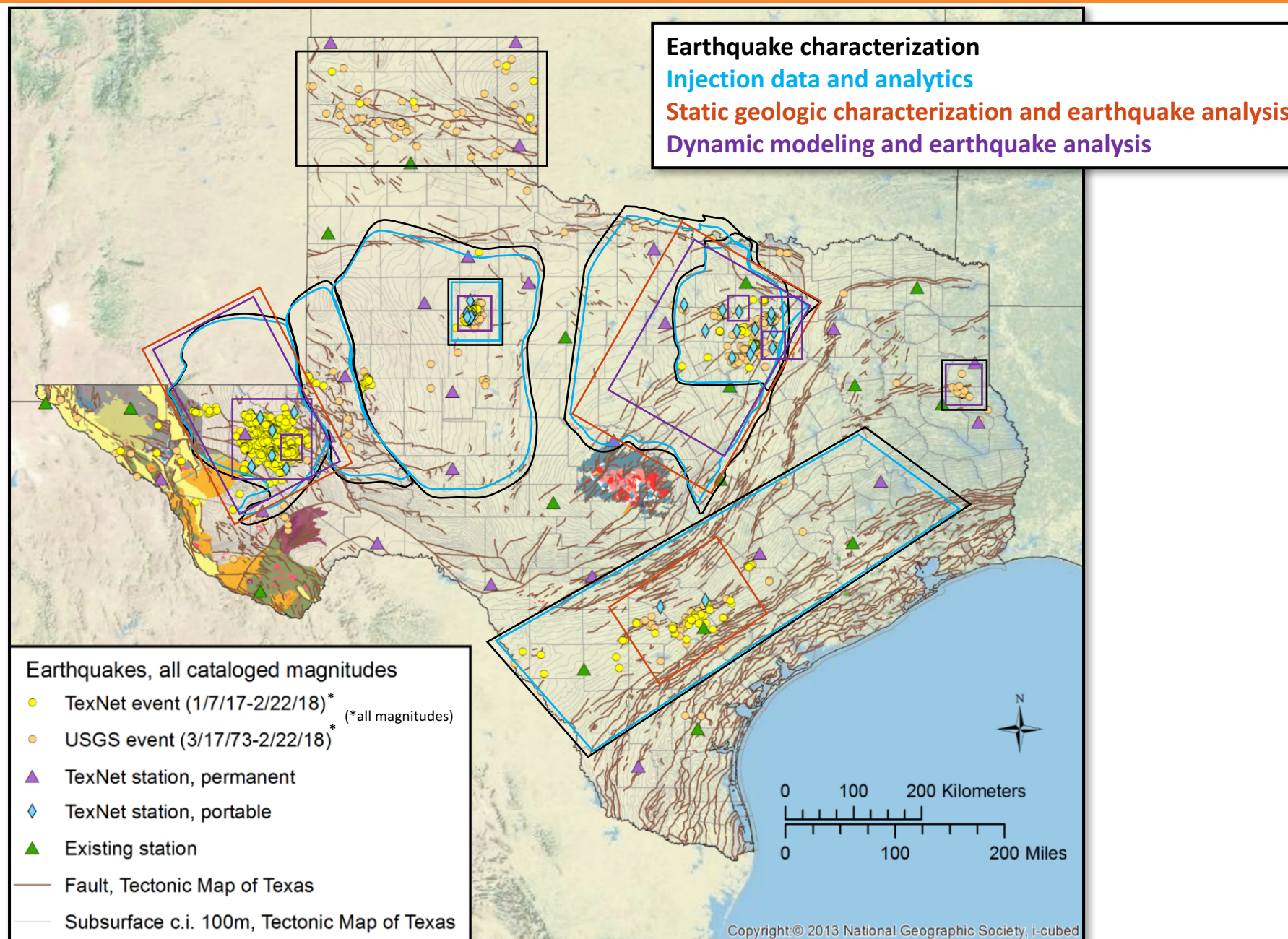
- SMU: Fort Worth Basin
- UH: Midland Basin (2018)
- UTEP: Delaware Basin (2018)
- UTIG: Eagle Ford Operating Area (2019)

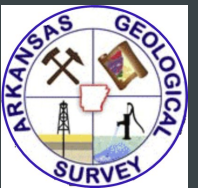
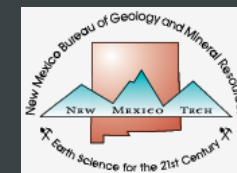
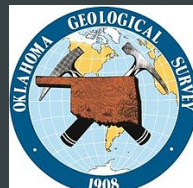
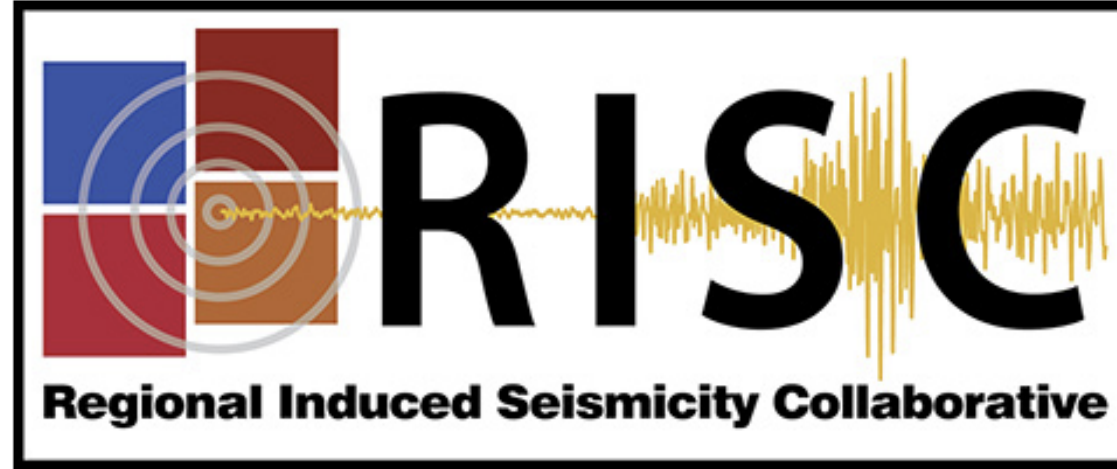


TexNet Network and Earthquake Catalog



Footprint of Study Areas by Technical Theme

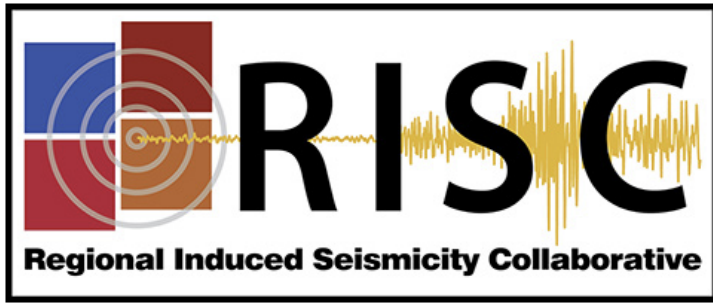




RISC: Next Webinar and other Events

Next Webinar (open to all)

- September 2018 –
 - Led by Oklahoma Geological Survey
 - Final date to be determined
- November 2018 –
 - Lead organization and specific date to be determined



We gratefully acknowledge:



Q&A Period

