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

Michael Young¹, Peter Hennings¹
Jeremy Boak², Jake Walter², Kyle Murray²
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
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.
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

Jeremy M. Boak, Director
Jacob I. Walter, Seismologist
Kyle E. Murray, Hydrogeologist
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
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/datafiles2.htm

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

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.
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)

- Fluid Elevation in Inactive SWD Monitoring Well
- SWD into Active wells w/in 4 km of Monitoring Well
- Earthquakes w/in 4 km of Monitoring Well
- Frac Notices w/in 4 km of Monitoring Well – not updated since Jan 2018

(Murray, et al., 2018 in preparation)
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)

<table>
<thead>
<tr>
<th></th>
<th>5 km</th>
<th>10 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 days</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>10 days</td>
<td>7%</td>
<td>13%</td>
</tr>
</tbody>
</table>

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 an 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

- Comprehensive Fault Mapping from Published Data
  - Berendsen and Blair, 1986
  - Cole 1976
  - Yarger 1983

- Seismicity in the Salina Basin
  - 2015-present earthquakes
  - 1983 aeromag w/lineaments interpreted in 1983

- Data Integration
  - aeromag w/lineaments
  - earthquakes (2015-present)
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

Zhang et al., 2016
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 Thu 2018
Total: 2229 events

Areas in Blue considered all natural earthquakes

Areas in Red suspected some induced earthquakes
Recent and Guy-Greenbrier Swarm Earthquakes in North-Central Arkansas
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.
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

- 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

![Diagram showing TexNet-CISR Program]

**TexNet-CISR Program**

- **Academia**
- **Industry**
- **Public and Educators**
- **Government and Regulators**

- **TexNet deployment and operation**
  - 35%
- **TexNet research**
  - 33%
- **CISR research**
  - 32%

![Sponsors logos including Anadarko, Apache, BHP, Chevron, ConocoPhillips, etc.]

![State of Texas Seal]
TexNet-CISR Organization

TexNet-CISR Program Leadership
Peter Hennings, PI Subsurface Integration and Industry Liaison
Ellen Rathje, PI Earthquake Hazard and Risk
Alexandros Savaidis, 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

http://www.beg.utexas.edu/texnet/catalog

Statewide Mc ~1.3

N = 3844
n = 126
Footprint of Study Areas by Technical Theme

- Earthquake characterization
- Injection data and analytics
- Static geologic characterization and earthquake analysis
- Dynamic modeling and earthquake analysis
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