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COLLEGE OF EARTH & ENERGY
THE UNIVERSITY OF OKLAHOMA

Multidisciplinary Approach to Identify and Mitigate the Hazard from Induced Seismicity in Oklahoma

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Acknowledgements

RPSEA

Research Partnership to Secure Energy for America

Industry contributors to RPSEA and fault database

Oklahoma Independent Petroleum Association (OIPA)

USGS – providing many different temporary seismic stations

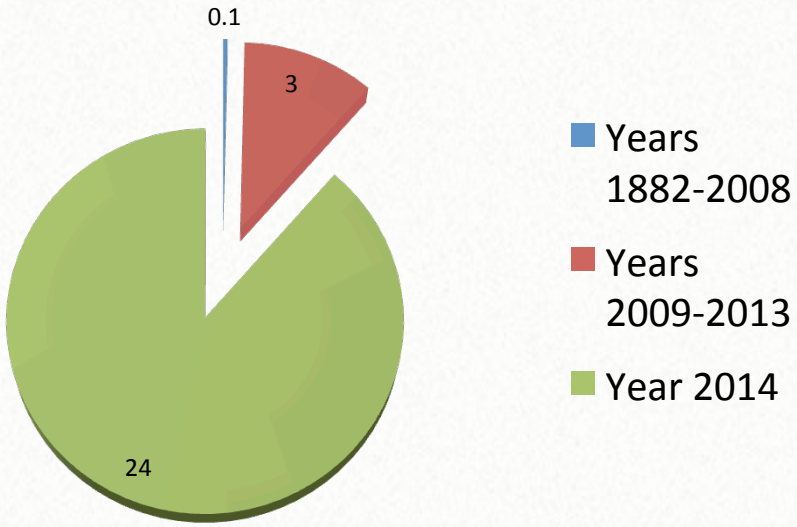
Oklahoma Secretary of Energy and Environment

Oklahoma Corporation Commission

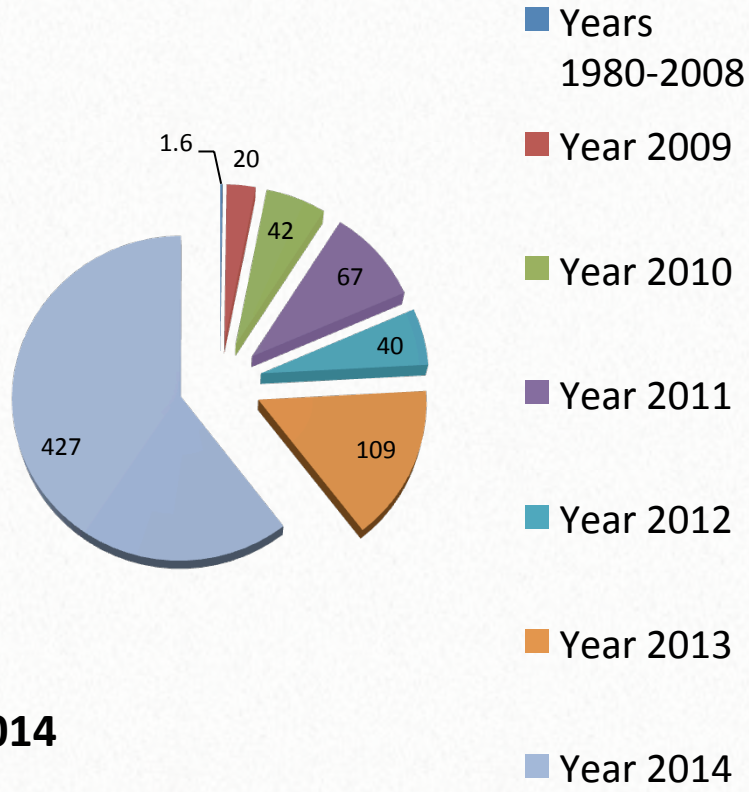
OU Mewbourne College of Earth and Energy

Oklahoma's Increase in Earthquakes
Earthquake rates per year

Magnitude 4 or Greater Earthquakes



Magnitude 3 or Greater Earthquakes



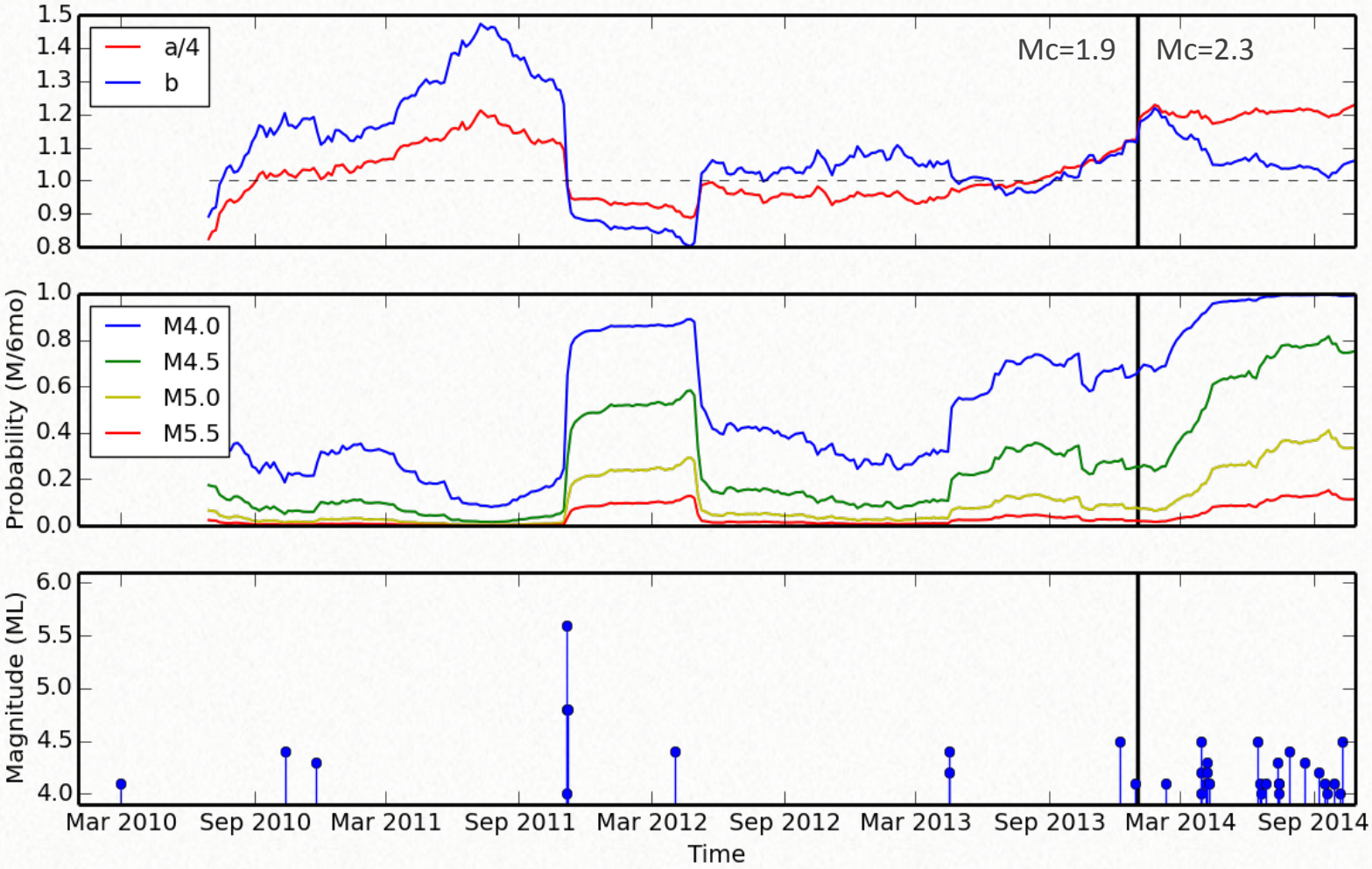
Updated Oct. 20, 2014

Earthquake Forecasting

- Probability of one or more earthquakes of magnitude (m) over the specified time
- Not a prediction, but a forecast

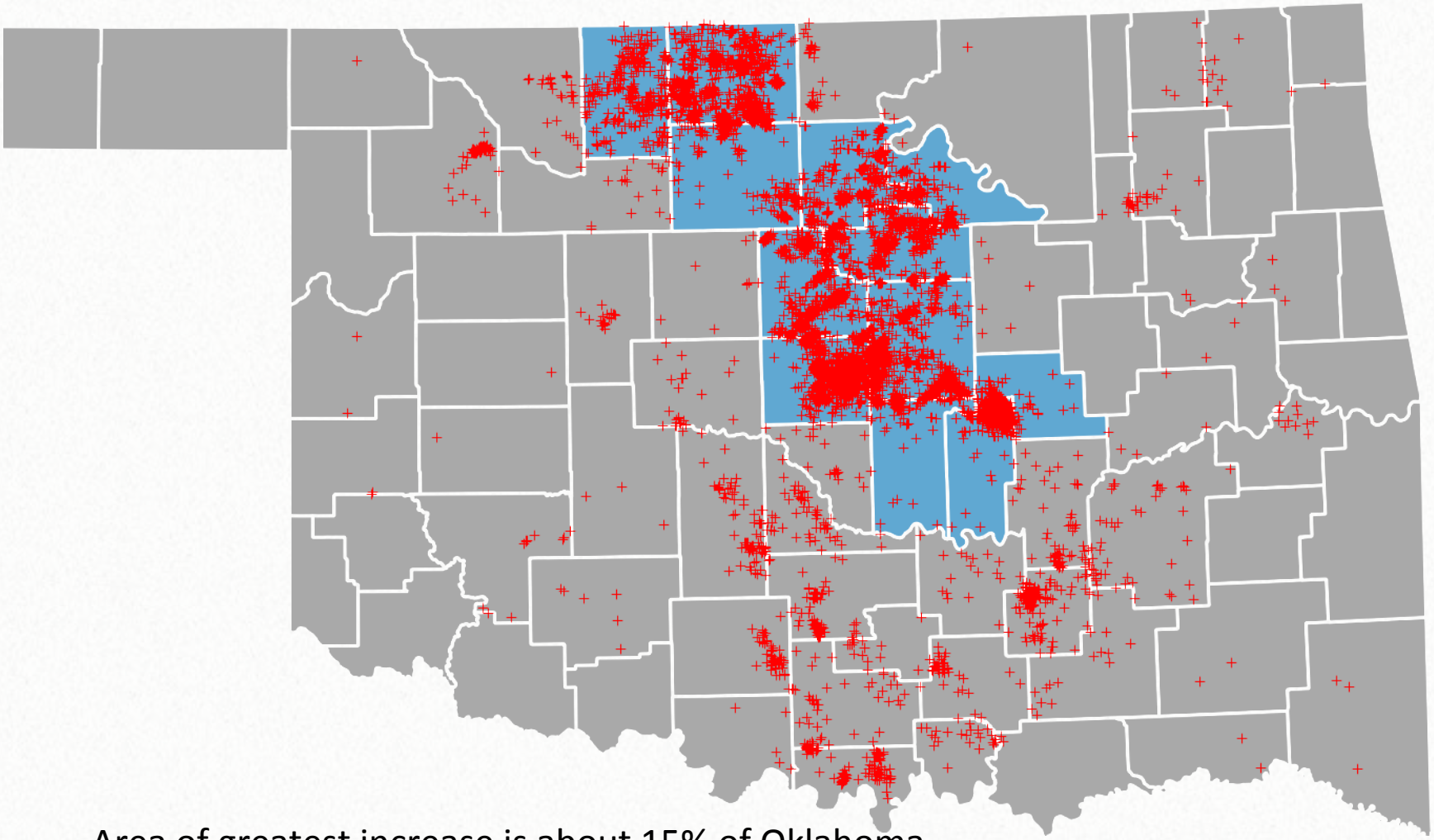
	Magnitude (m)					
Duration	**3.0**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**
4 Year	1.0000	1.0000	0.9212	0.4621	0.1404	0.0362
1 Year	1.0000	0.9983	0.7908	0.3179	0.0893	0.0226
6 months	1.0000	0.9755	0.5849	0.1882	0.0482	0.0117
30 days	1.0000	0.6067	0.2036	0.0540	0.0135	0.0033
10 days	0.9984	0.2470	0.0579	0.0125	0.0026	0.0006

Oklahoma Recurrence Rates & Probabilities



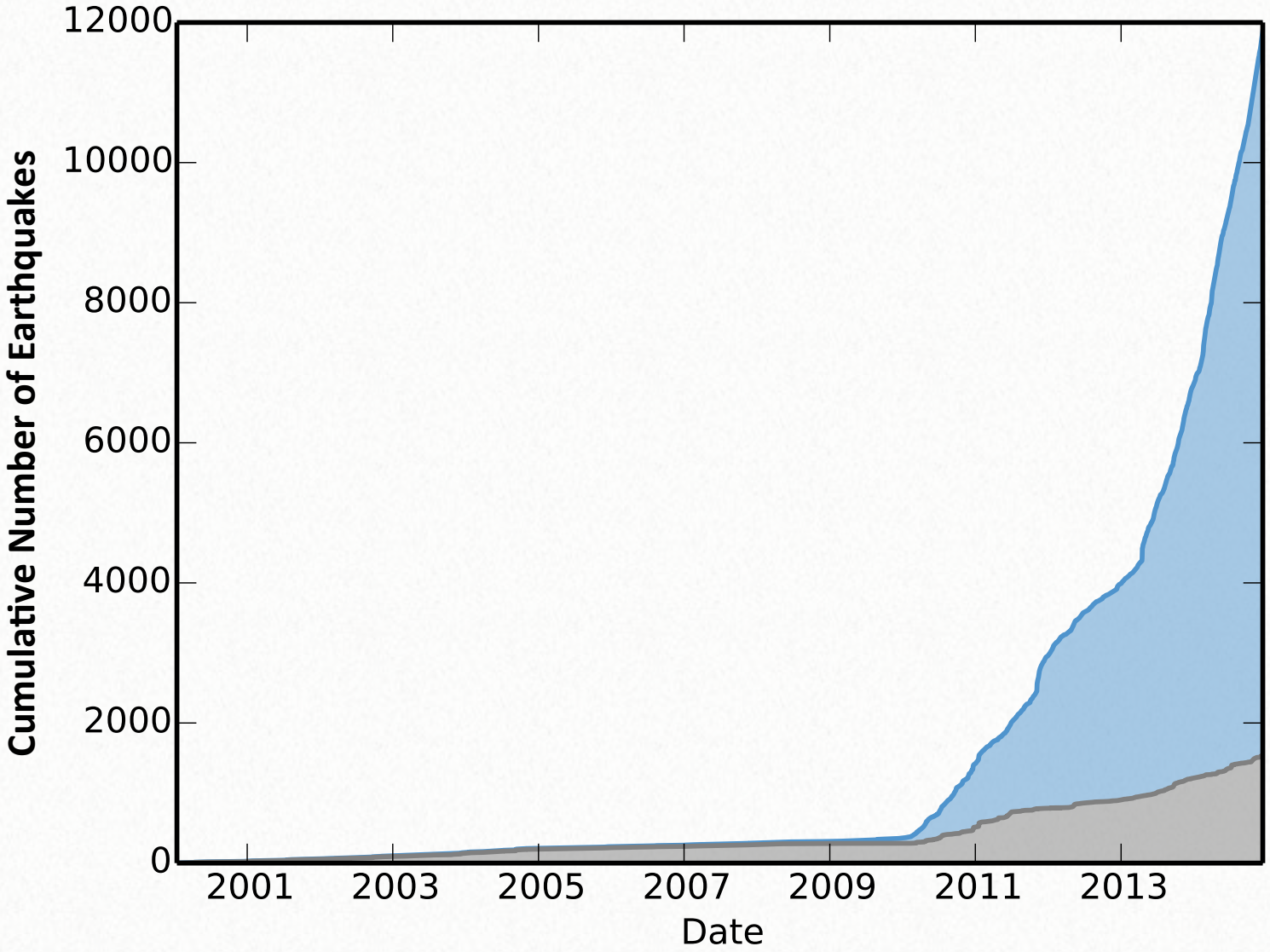
Calculated with a 6 month moving window

Oklahoma Earthquakes 2009-2014

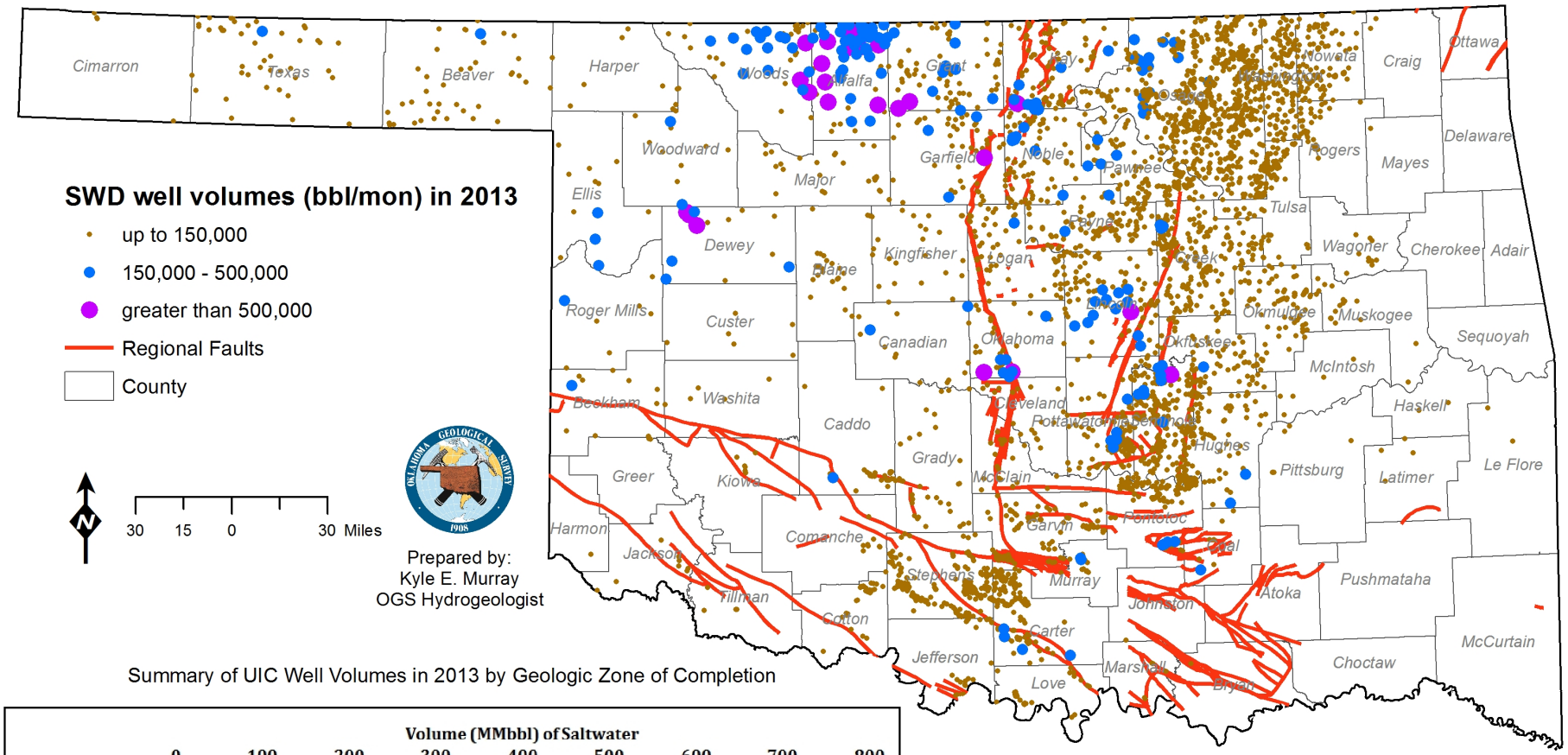


Area of greatest increase is about 15% of Oklahoma.
Captures areas of significant waste-water disposal wells

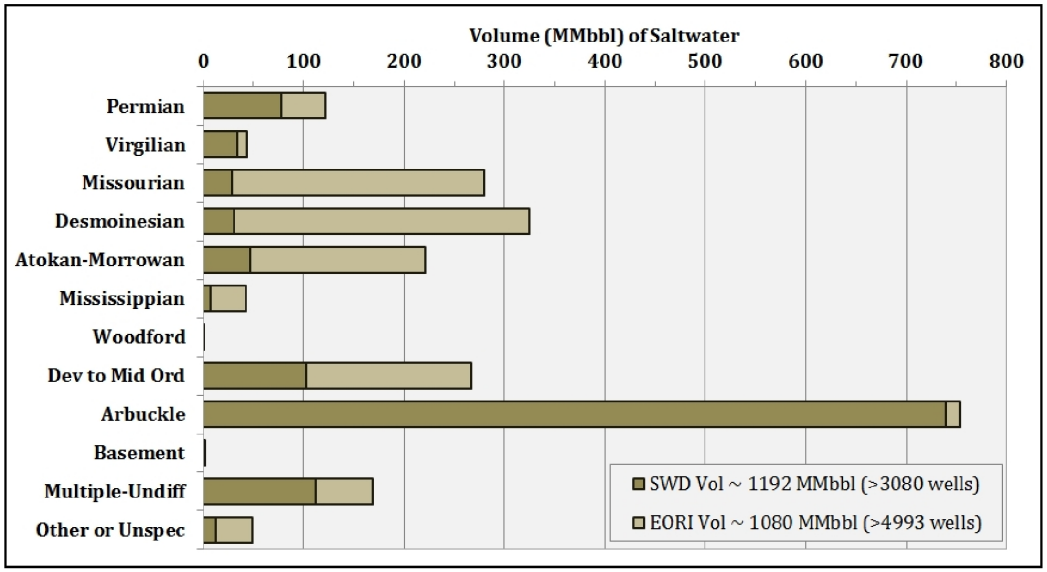
Cumulative Seismicity in Oklahoma



Oklahoma Geol. Survey www.okgeosurvey1.gov/pages/earthquakes/catalogs.php

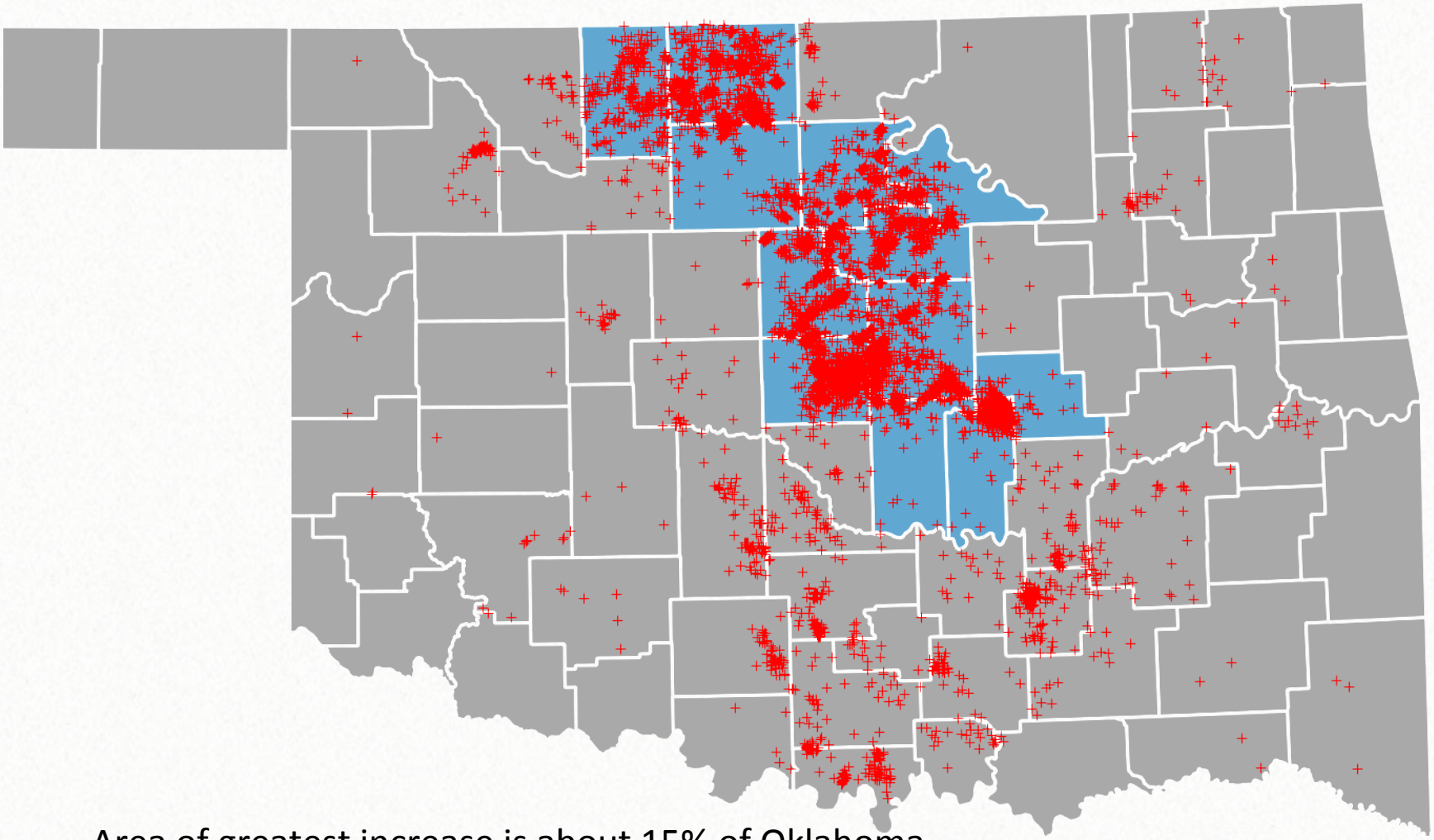


Summary of UIC Well Volumes in 2013 by Geologic Zone of Completion



Index Location Map for Oklahoma

Oklahoma Earthquakes 2009-2014



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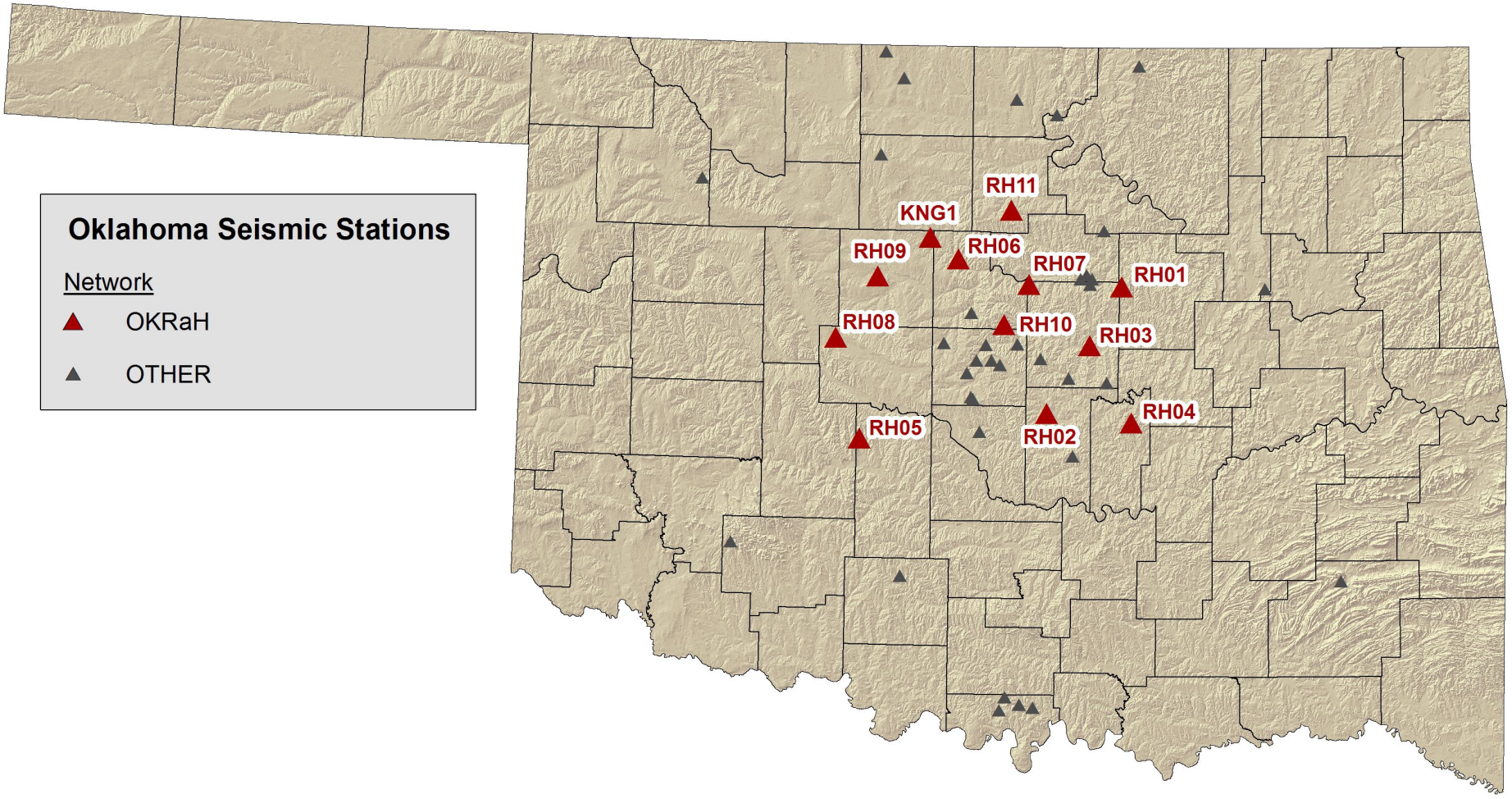
RPSEA - 4D Integrated Multi-scale Reservoir and Geological Modeling

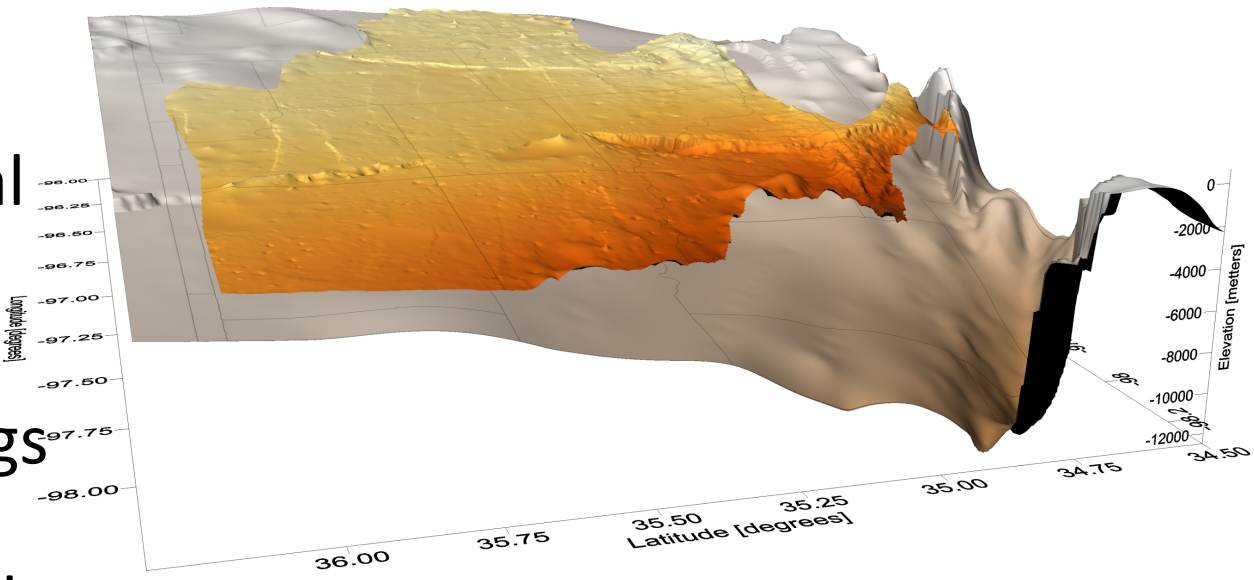
- 4D geophysical monitoring
- Localized well-based pressure tests
- Goals
  - Improve model predictive capabilities
  - Maintain a suite of progressively updated models
  - Improved representation of the preferential flowpaths
  - Geomechanical properties and fault characteristics in the subsurface

OKRaH Seismic Network



3D geologic and geophysical model

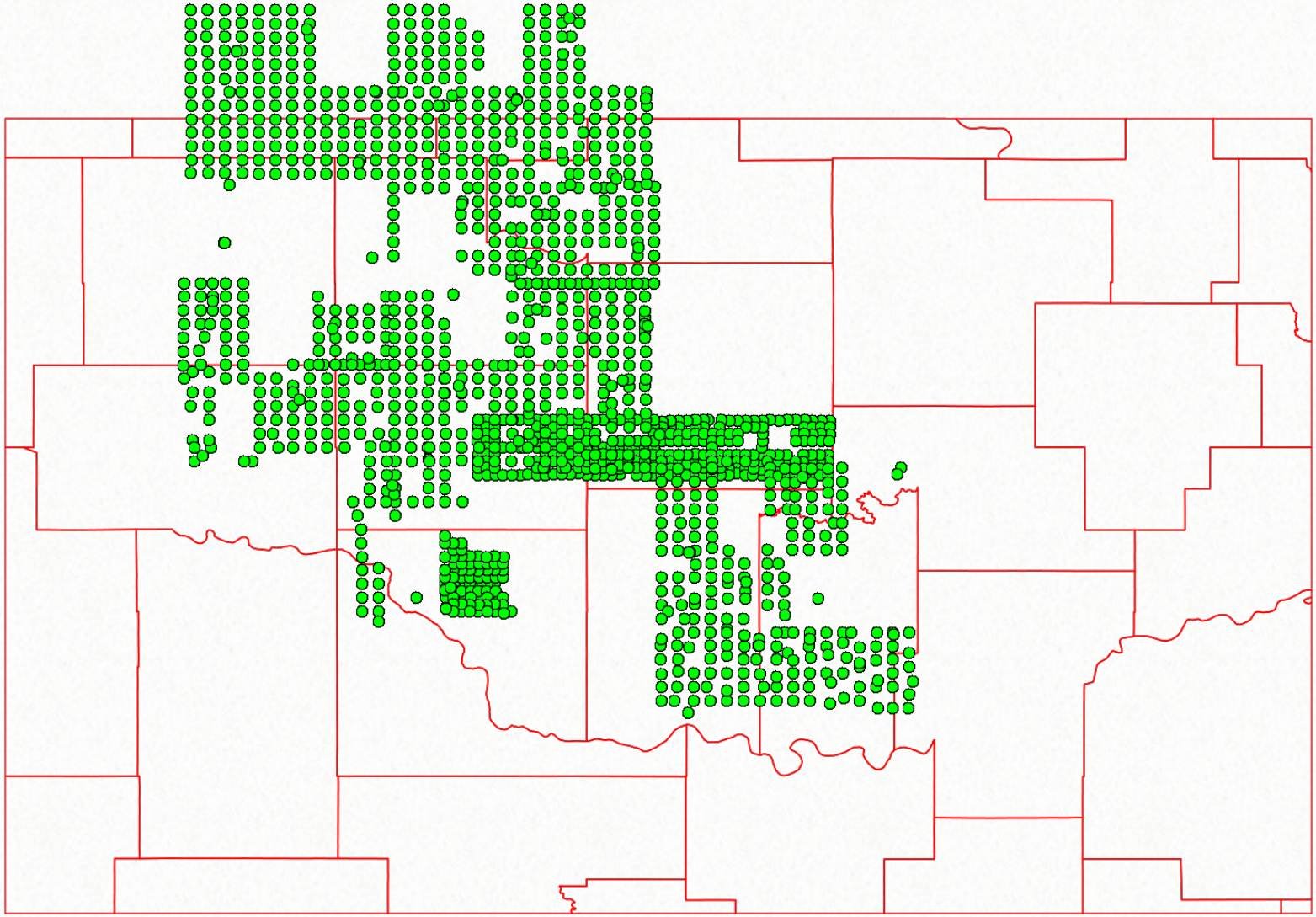
- 100,000's of Wells in central Oklahoma
- Geological and geophysical logs combined to build 3D models
- Incorporated into 3D seismic velocity models



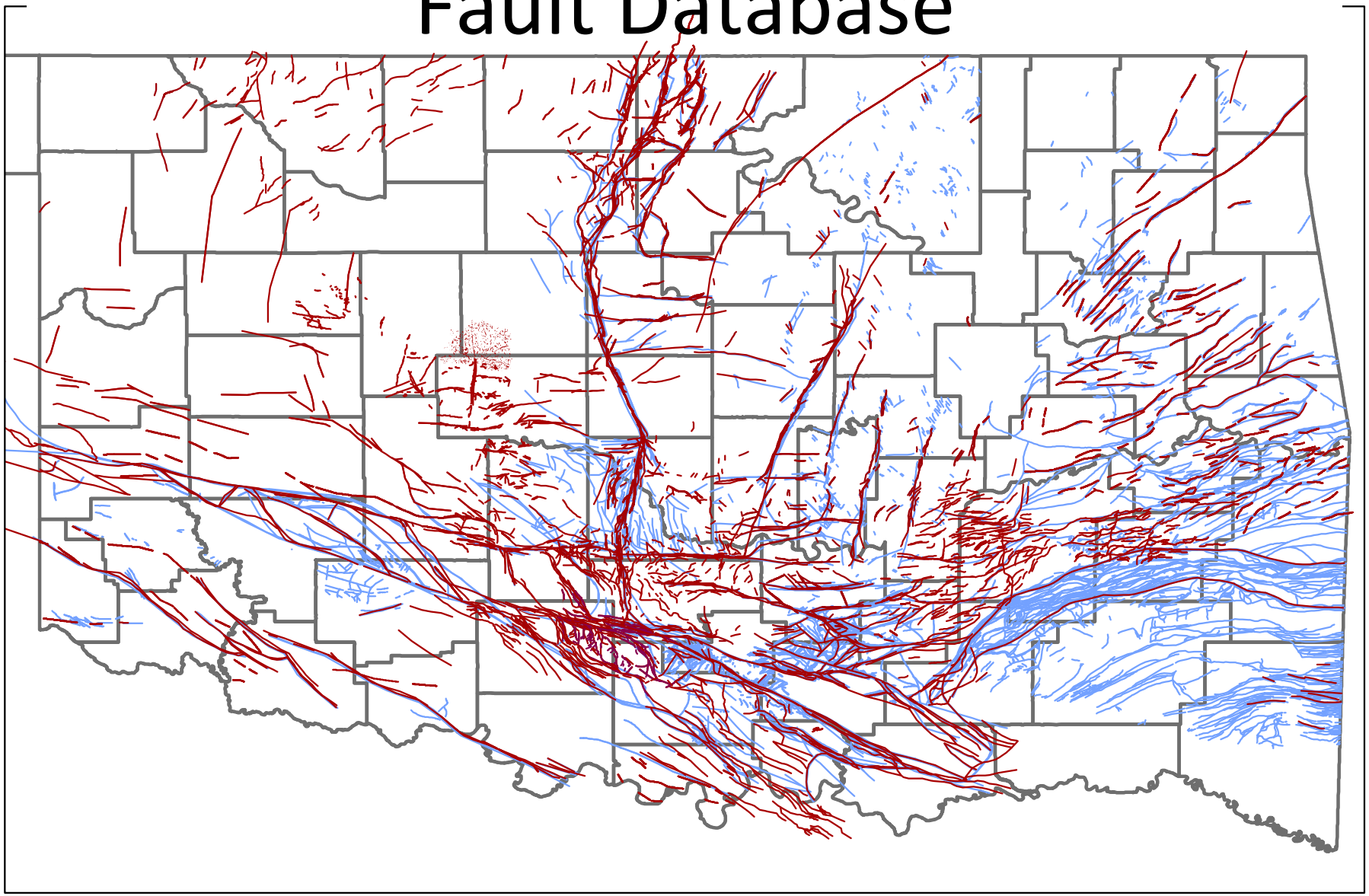
Geospatially referenced surfaces Hunton (orange) and basement (brown).

Geologic units are assigned physical properties such as from well logs with spatially varying properties such as permeability, density, porosity, and velocity.

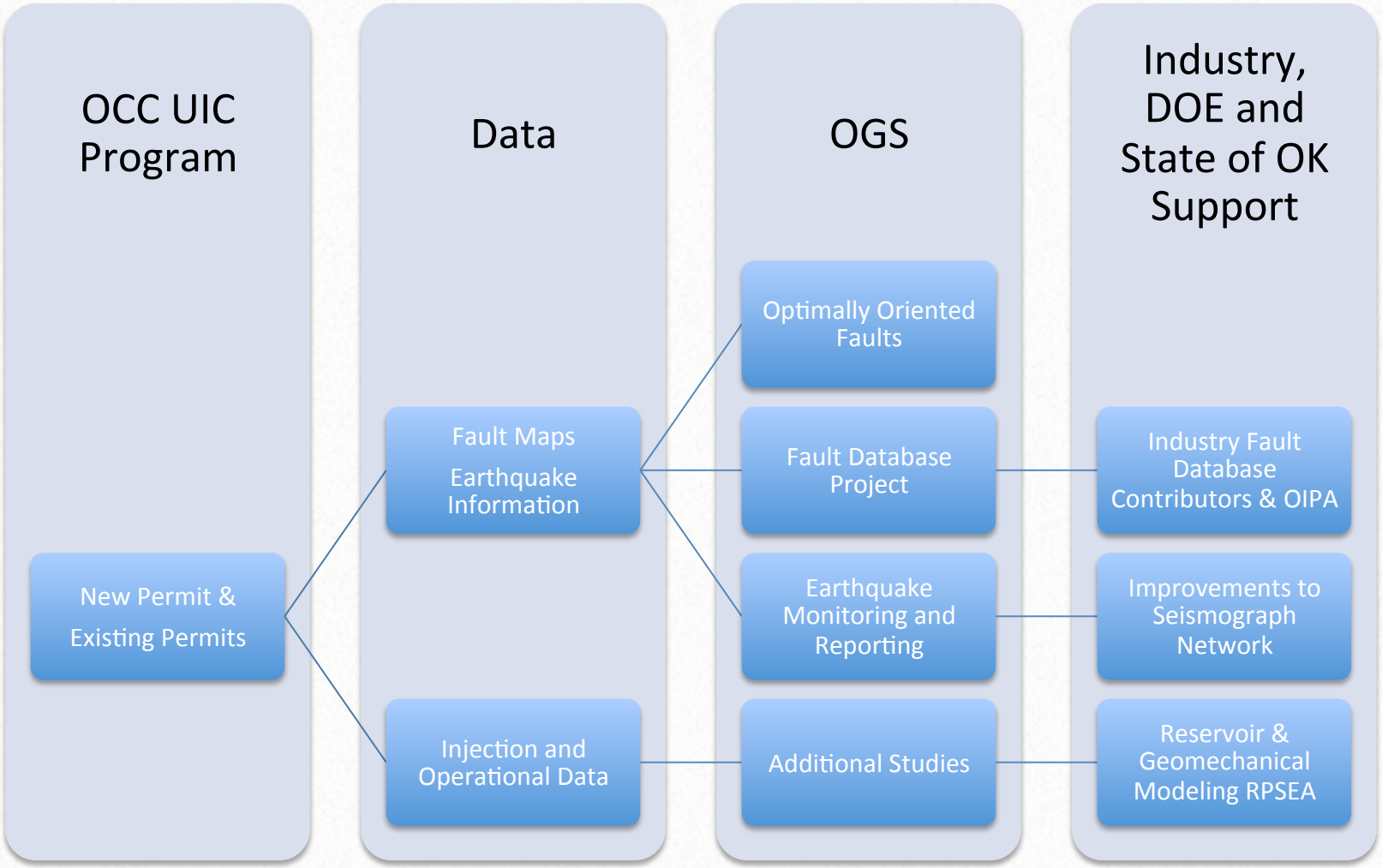
Gravity Observations Provide Constraints on Geologic Models



Industry Contributing to Enhanced Fault Database



Interagency Cooperation



Current Mitigation Steps

- Oklahoma Corporation Commission is the regulator of UIC Class II wells, and have implemented different mitigation strategies
  - New rules regarding reporting of injection volumes and pressures in the "Arbuckle"
  - Permit modifications; i.e. "Traffic Light System"
  - Enhanced reporting requirements in OCC areas of interest, currently 10 km around ML 4+ earthquakes
    - Not required by rule for non-Arbuckle wells, but operators have complied for requests of greater reporting
  - New permits are checked against fault maps and background seismicity

Summary

- The rate of seismicity has increased dramatically and so has the seismic hazard
- Building large geological and geophysical data sets at varying scales and dimensions
- Continue to provide data products to stakeholders and identifying new data sources
- A greater understanding of physical processes in Oklahoma will help to inform future mitigation strategies
- Multi-agency cooperation has now been solidified in the governor's Coordinating Council

Abstract

Oklahoma has experienced a very significant increase in seismicity rates over the last 5 years with the greatest increase occurring in 2014. The observed rate increase indicates that the seismic hazard for at least some parts of Oklahoma has increased significantly. Many seismologists consider the large number of salt-water disposal wells operating in Oklahoma as the largest contributing factor to this increase. However, unlike many cases of seismicity induced by injection, the greatest increase is occurring over a very large area, about 15% of the state. There are more than 3,000 disposal wells currently operating within Oklahoma along with injection volumes greater than 2010 rates. These factors add many significant challenges to identifying potential cases of induced seismicity and understanding the contributing factors well enough to mitigate such occurrences. In response to a clear need for a better geotechnical understanding of what is occurring in Oklahoma, a multi-year multidisciplinary study some of the most active areas has begun at the University of Oklahoma. This study includes additional seismic monitoring, better geological and geophysical characterization of the subsurface, hydrological and reservoir modeling, and geomechanical studies to better understand the rise in seismicity rates. The Oklahoma Corporation Commission has added new rules regarding reporting and monitoring of salt-water disposal wells, and continue to work with the Oklahoma Geological Survey and other researchers.