



# Patterns of Induced Seismicity in Central and Northwest Oklahoma

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April 14, 2017

AGI Webinar

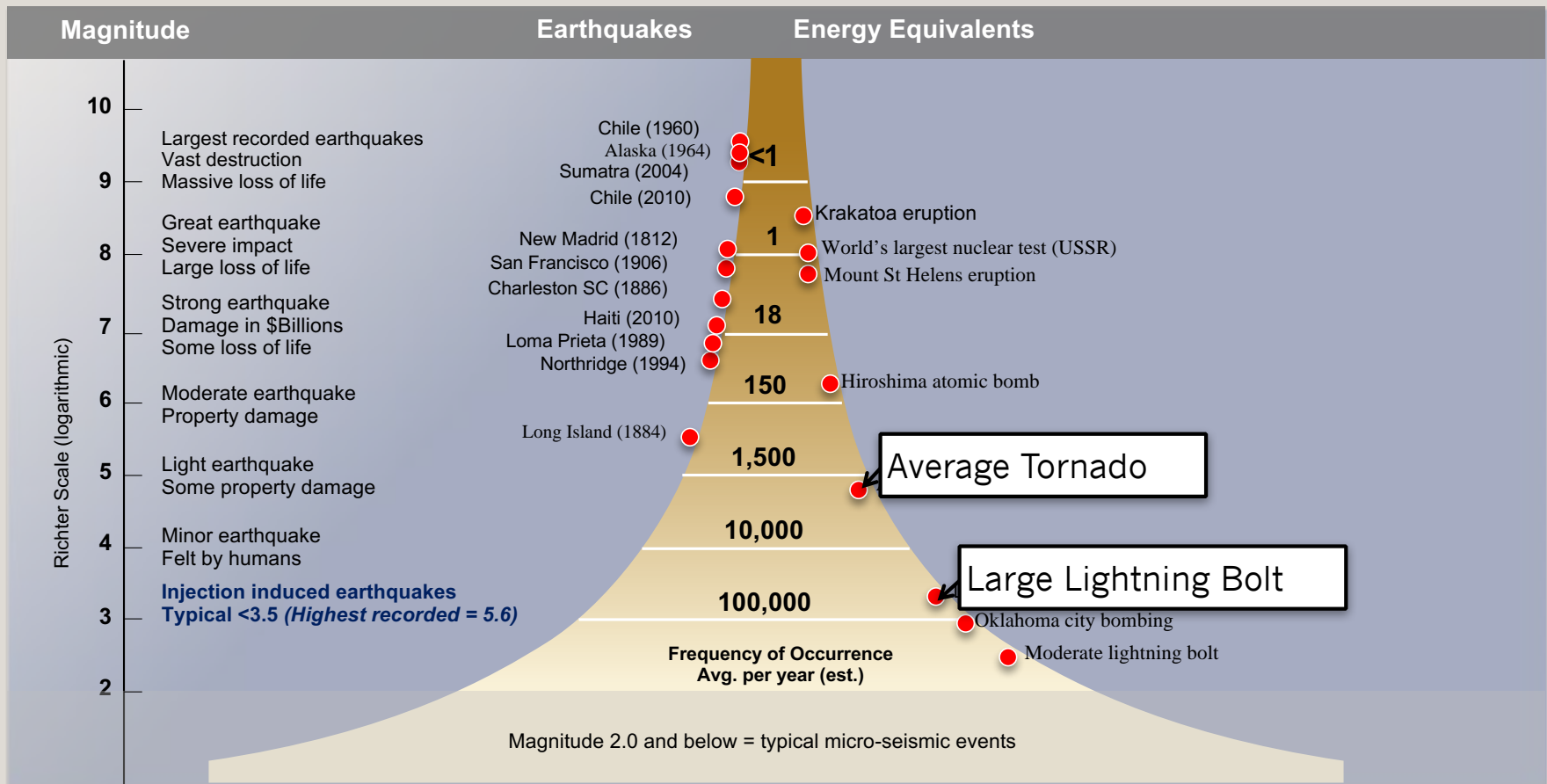


The Oklahoma Geological Survey is a state agency for research and public service located on the Norman Campus of the University of Oklahoma and affiliated with the OU College of Earth and Energy. The Survey is chartered in the Oklahoma Constitution and is charged with investigating the state's land, water, mineral, and energy resources and disseminating the results of those investigations to promote the wise use of Oklahoma's natural resources consistent with sound environmental practices.

***We are not a regulatory authority***



### 3 Earthquake Magnitude & Frequency



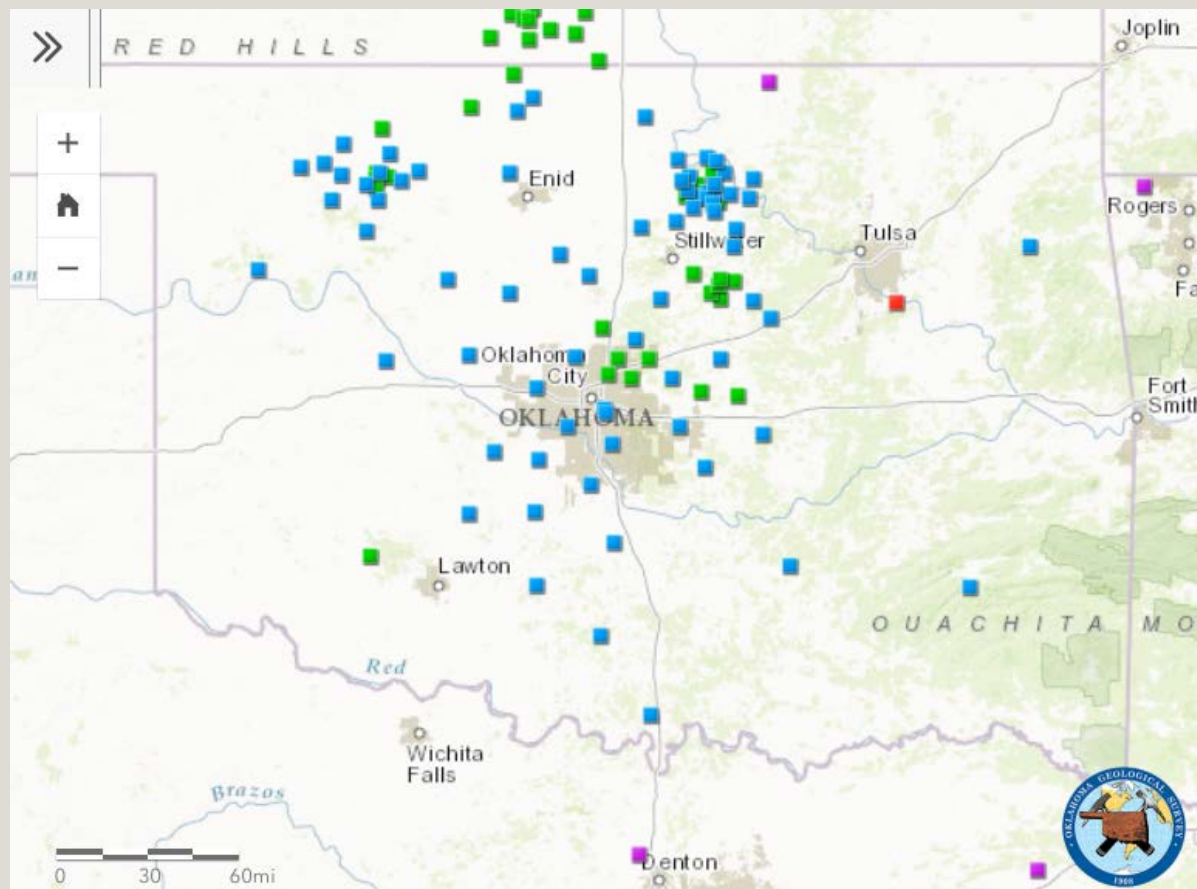


## 4 Measuring an Earthquake

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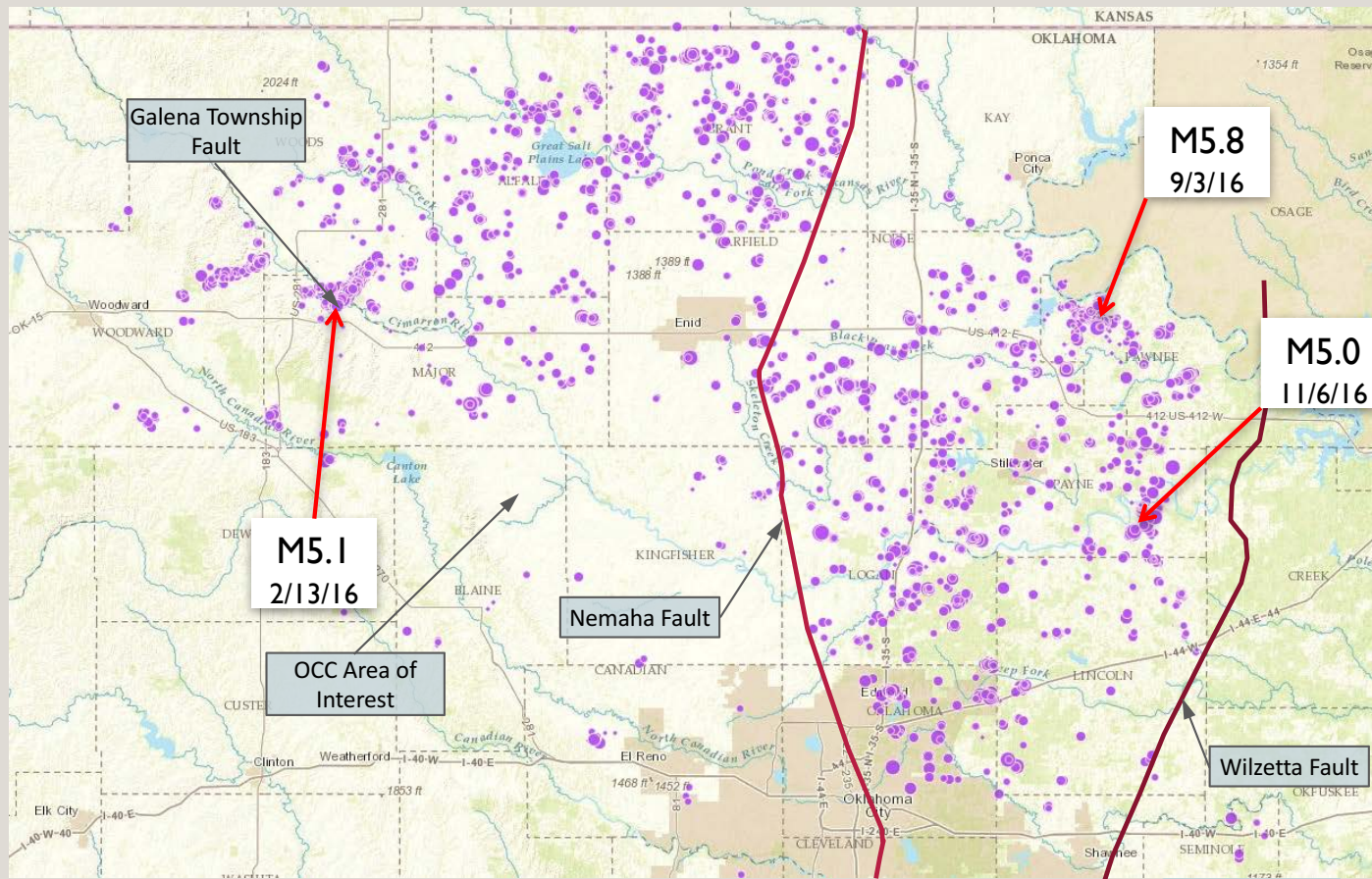
- Magnitude
  - Scaled **estimate** of energy released as seismic waves,
  - Proportional to rupture area
- Magnitude measured multiple ways ( $M_L$ ,  $m_b$ ,  $M_w$ ,  $M_o$ ,  $M_s$ )
  - Estimates are uncertain, and rarely the same between different methods
  - Scales logarithmic (+1 unit of magnitude = ~10 times shaking & ~32 times the energy release)
- Earthquake Intensity
  - Varies with distance from the earthquake
  - Qualitative estimate (using **Modified Mercalli scale** ranging from I-XII)

## 5 OGS Monitors ~100 Seismometer Stations





## 6 Oklahoma Earthquakes, 2016



Earthquake map available at OGS website:

<http://uok.maps.arcgis.com/apps/Minimalist/index.html?appid=3ebaf2b8de02406b94804cbdb5afbec8>

## 7 Human Activity Can Induce Earthquakes

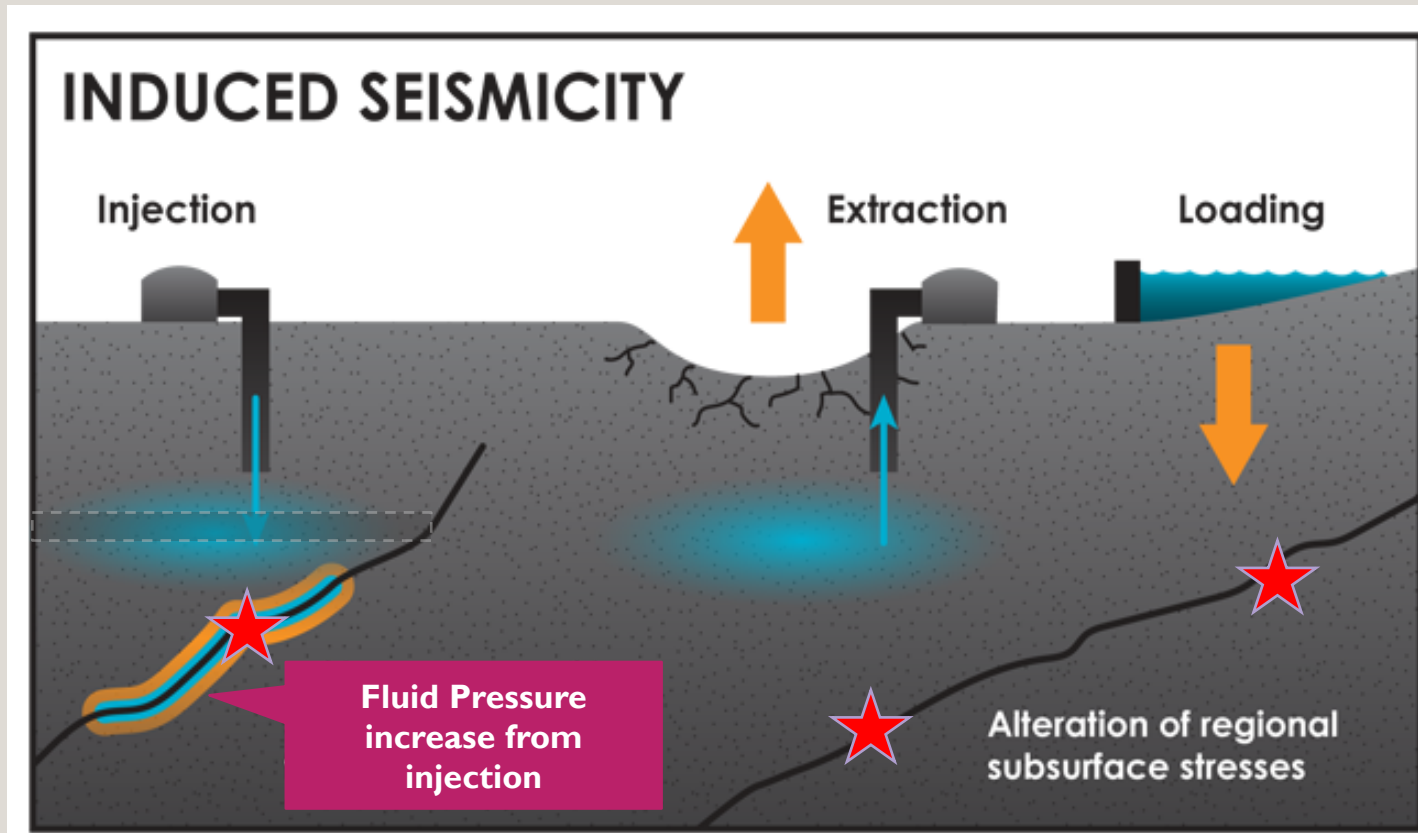
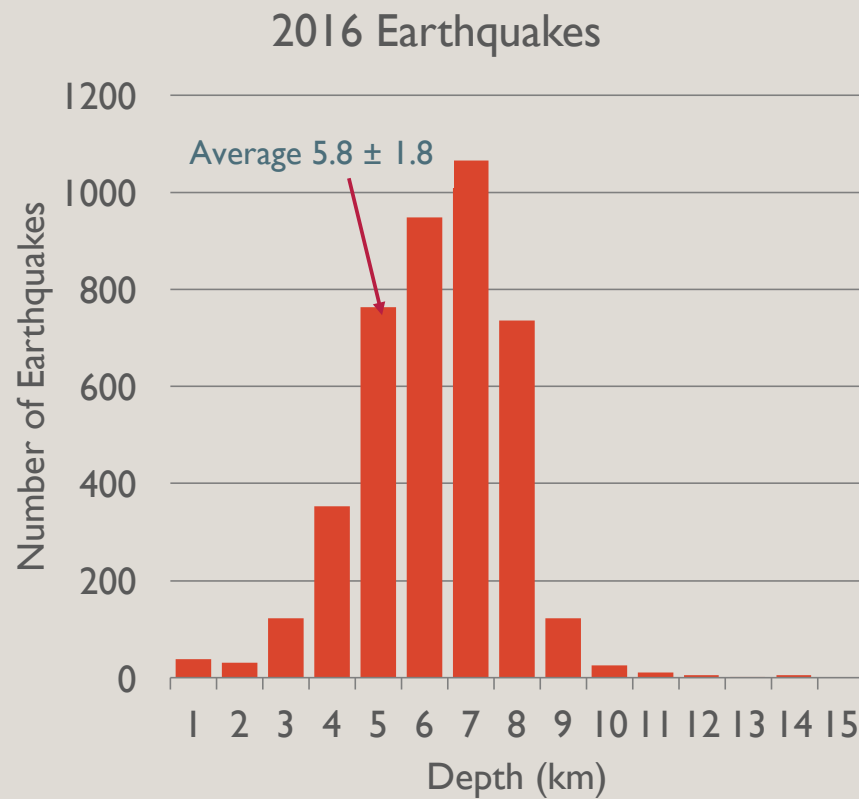


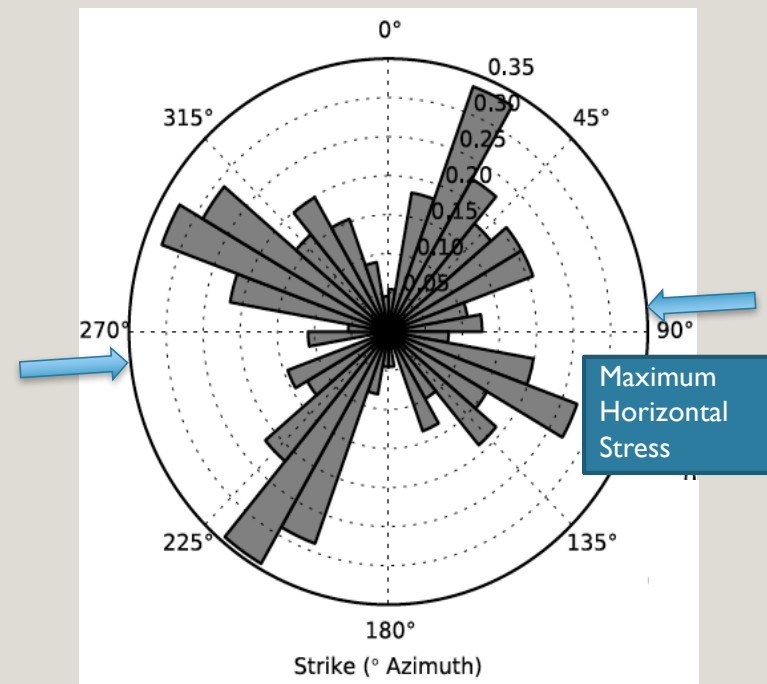
Figure modified from: <http://www.earthmagazine.org/article/ground-shaking-research-how-humans-trigger-earthquakes>



## 8 Earthquakes occur in basement, on optimally aligned faults



Active Fault Orientations 2014

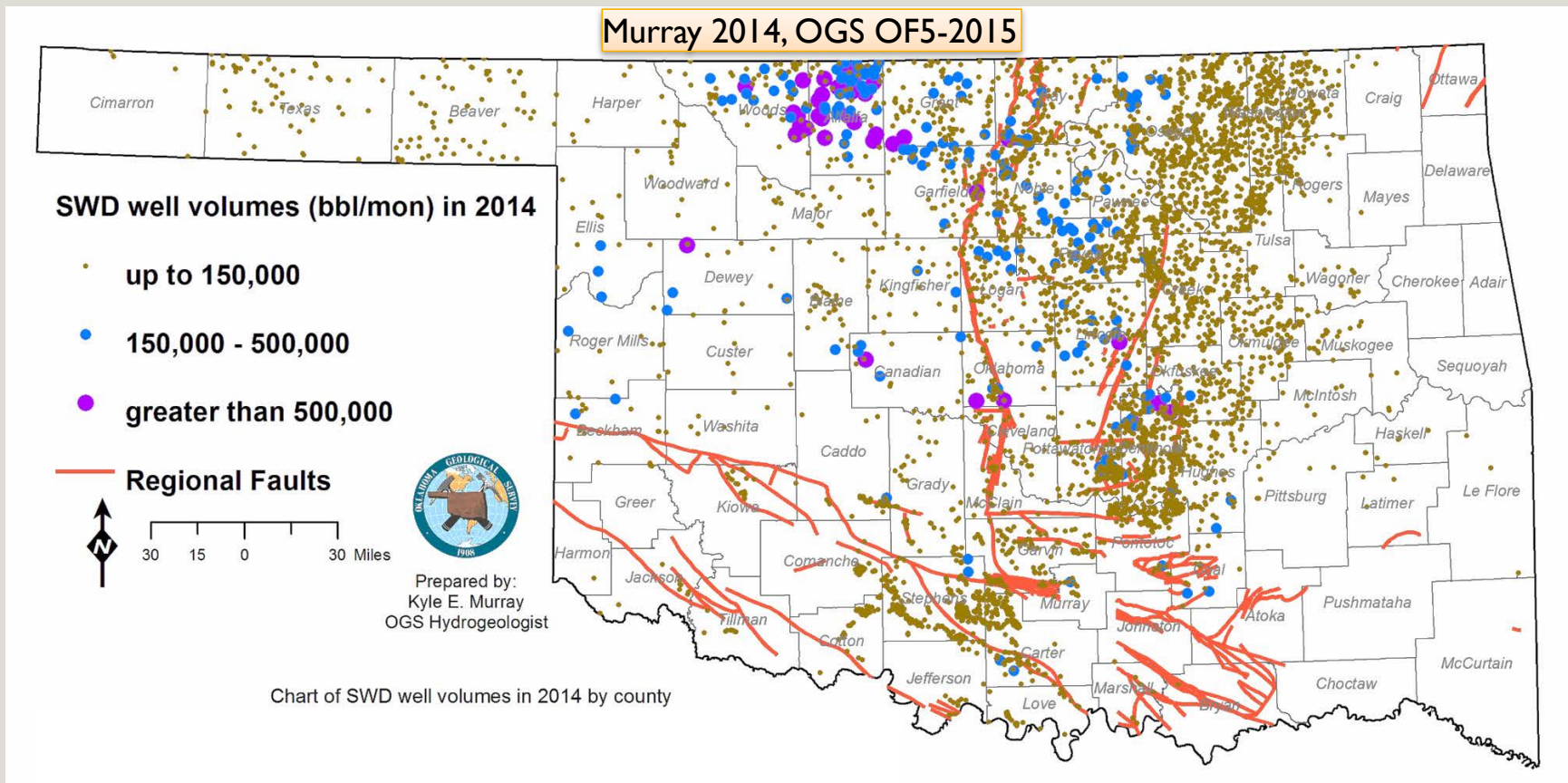


OGS OFI-2015



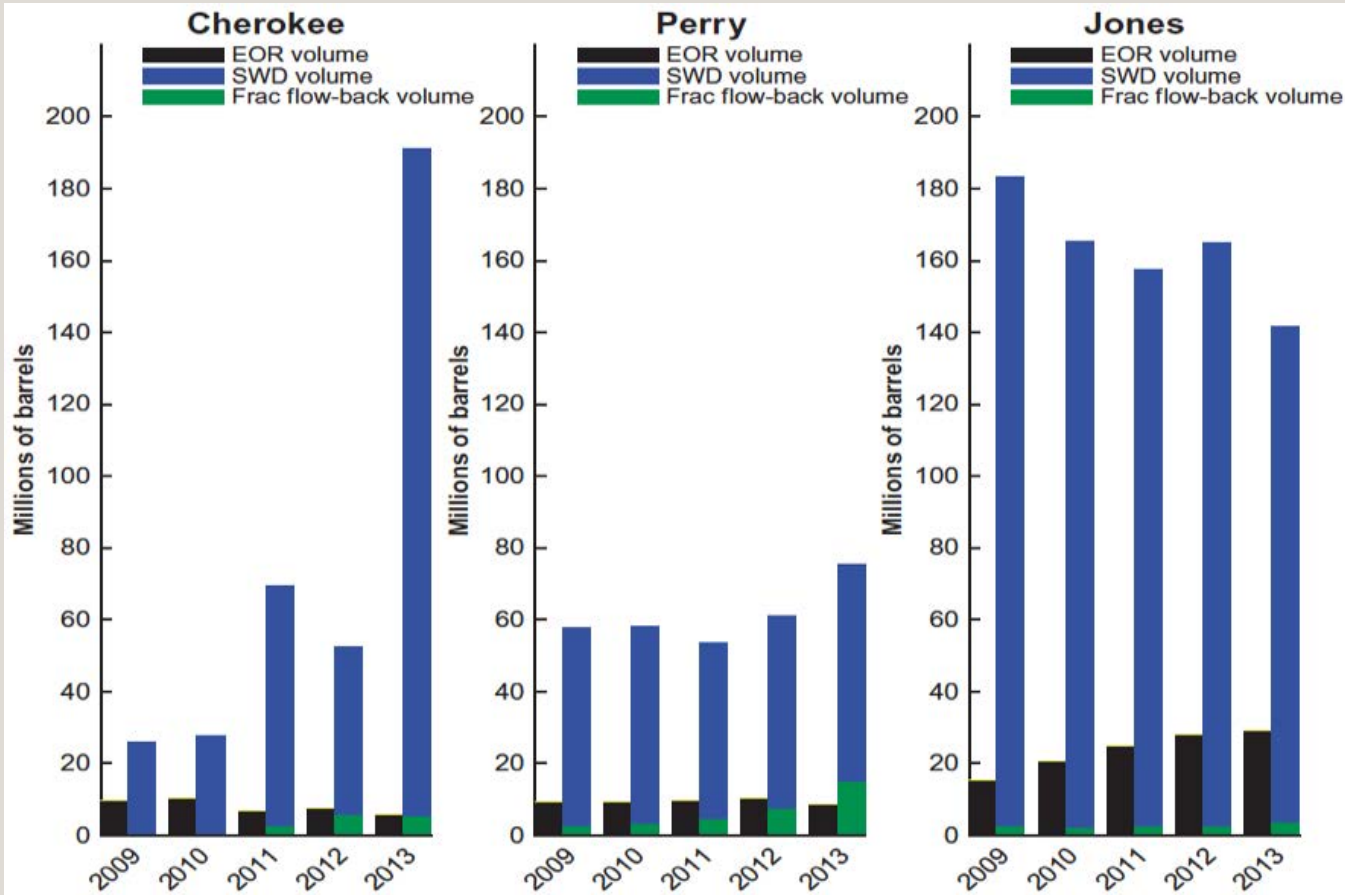


## 9 Earthquakes occur in areas of large volume disposal wells





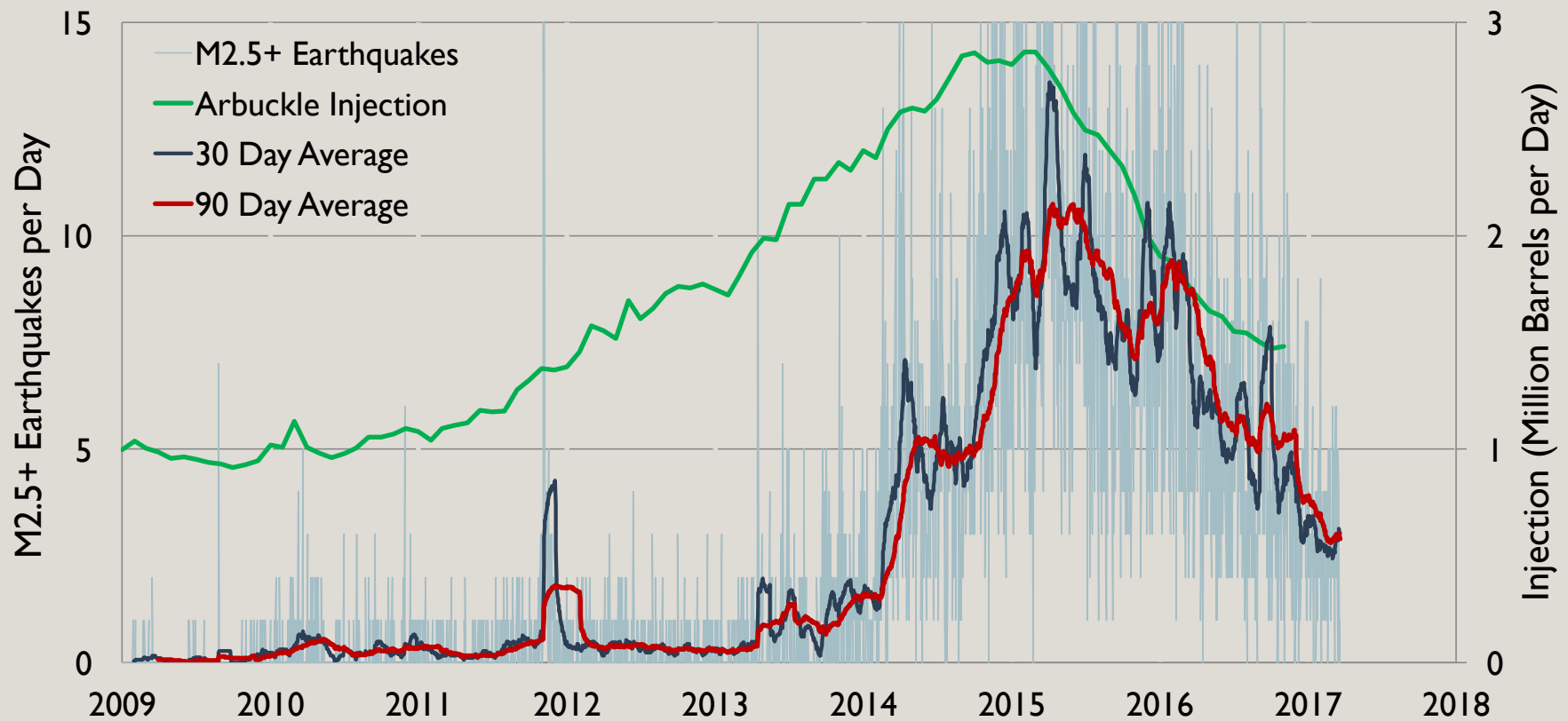
# 10 Disposal contains <5% flowback water from hydraulic fracturing



Source: Walsh, F. R., and Zoback, M. D. (2015) Oklahoma's recent earthquakes and saltwater disposal. *Sci. Adv.* 2015; 1:e1500195, 18 June 2015



## || Oklahoma M2.5+ earthquakes





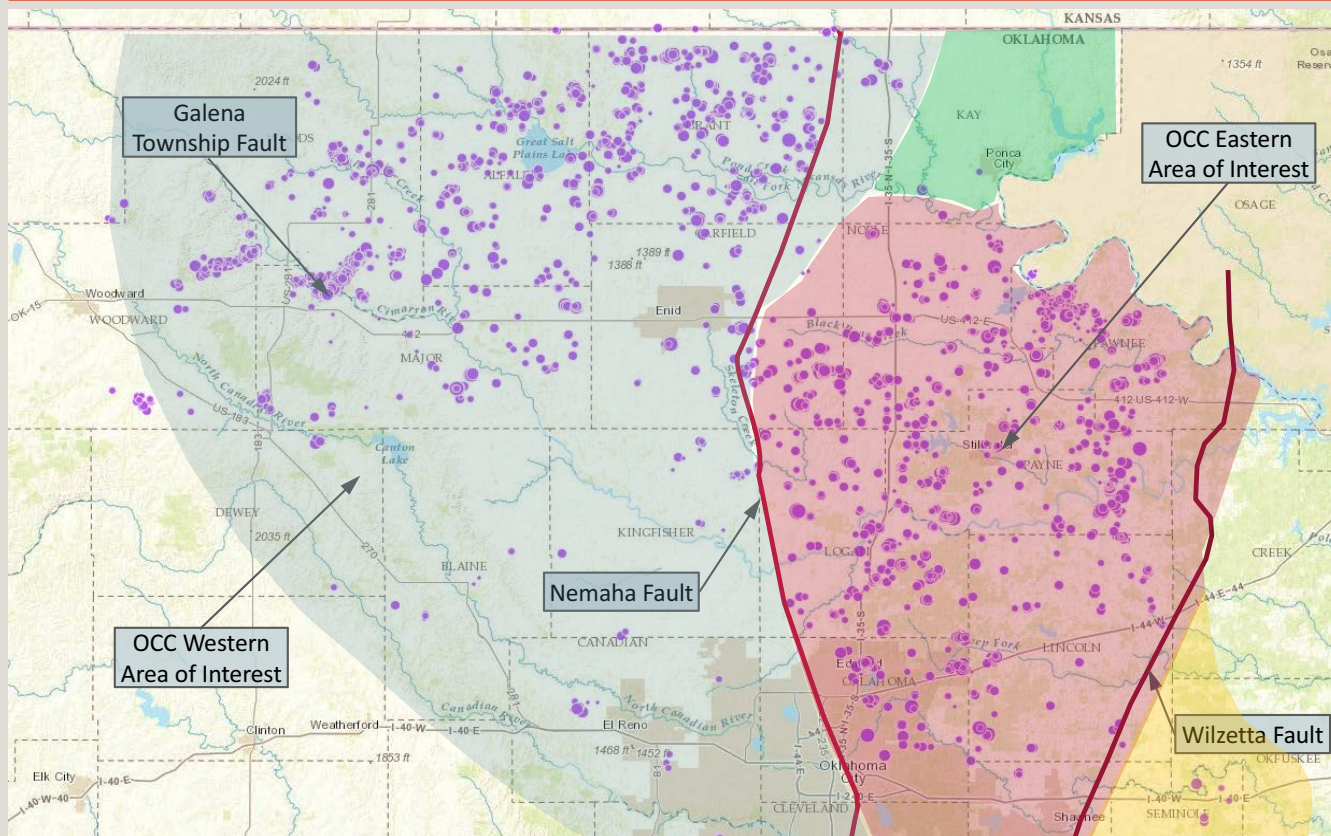
## 12 State Actions on Induced Seismicity

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- Governor creates Coordinating Council on Seismicity (2014)
- OCC directives reduce injection (2015)
- Oklahoma Geological Survey (OGS) position paper (2015)
- Secretary of Energy funds \$200,000 seismicity projects (2015)
- Governor's Water for 2060 Produced Water Working Group (2015)
- RPSEA funded stations added to OGS network (2016)
- Governor's Emergency Fund \$1,387,000 to OCC, OGS (2016)
- New tracking system for earthquakes and injection for OCC (2016)

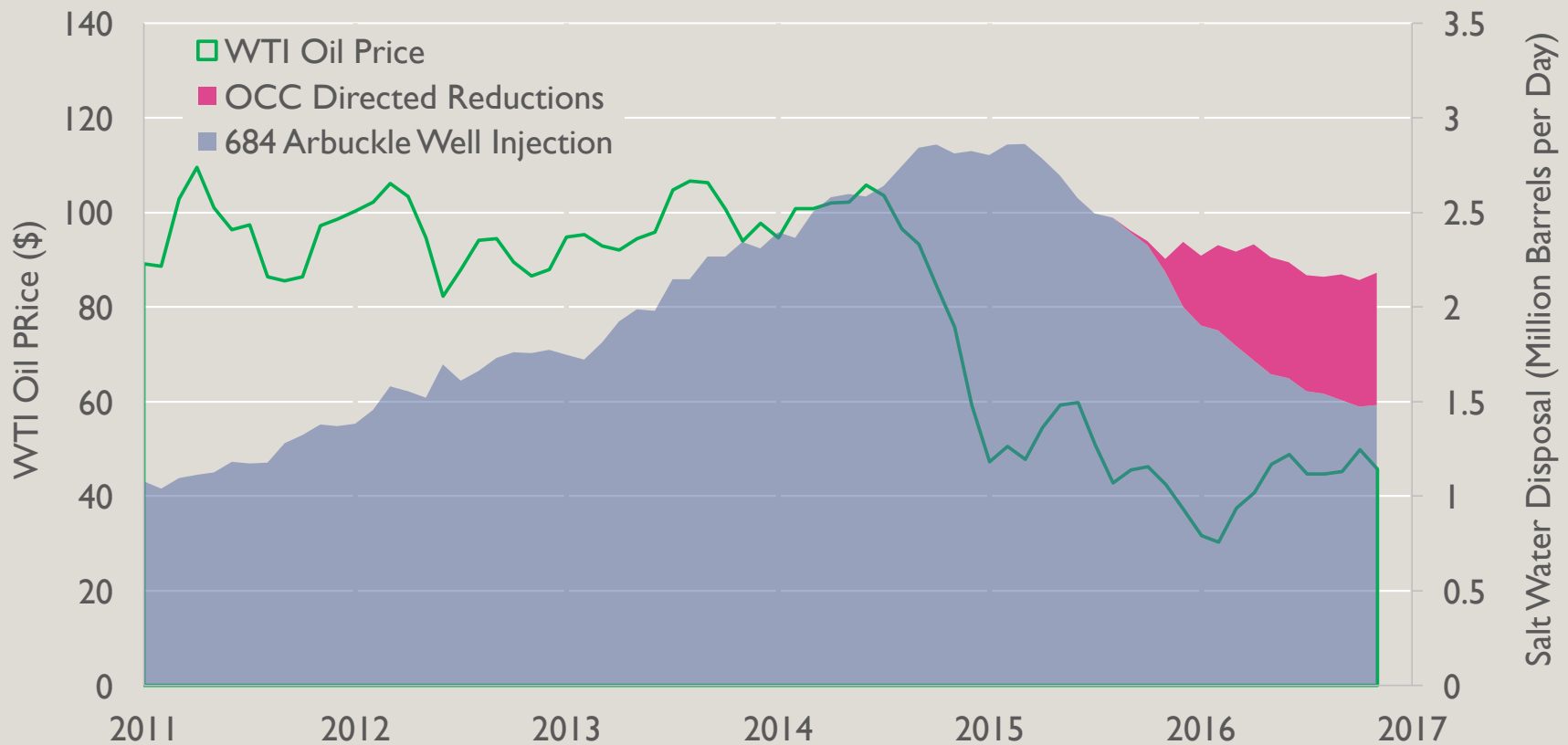


## 13 Oklahoma Corporation Commission (OCC) Actions



- Arbuckle Group injection wells in Area of Interest (AOI) submit **weekly** report of daily injection rate
- Wells in Precambrian basement **plugged back** or cut injection **50%**
- Reductions and shut-in wells **reduced overall injection by >900,000 BWPD** since mid-2015
- **Caps on injection rate** in Western and Eastern AOI

# 14 Oil Price, Injection Rate and OCC Directed Reductions



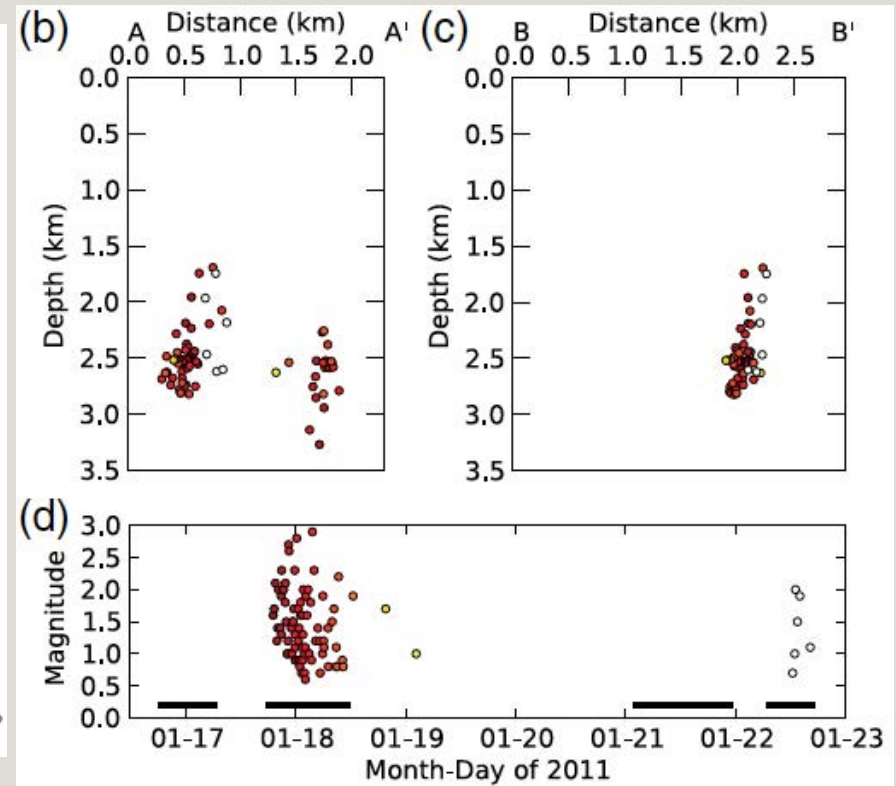
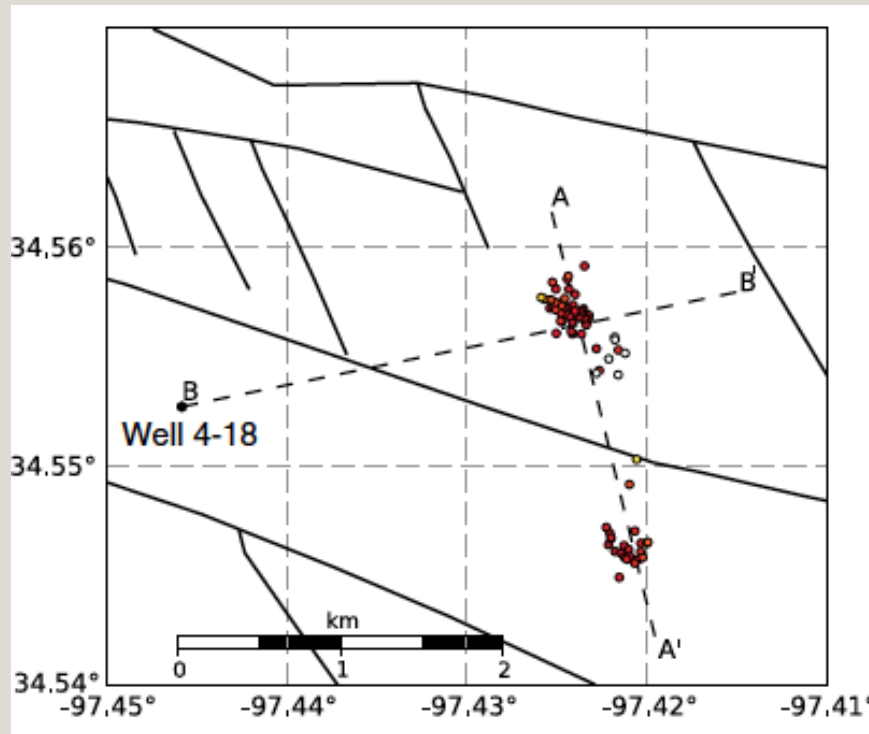


## 15 Recommendations of Produced Water Task Force

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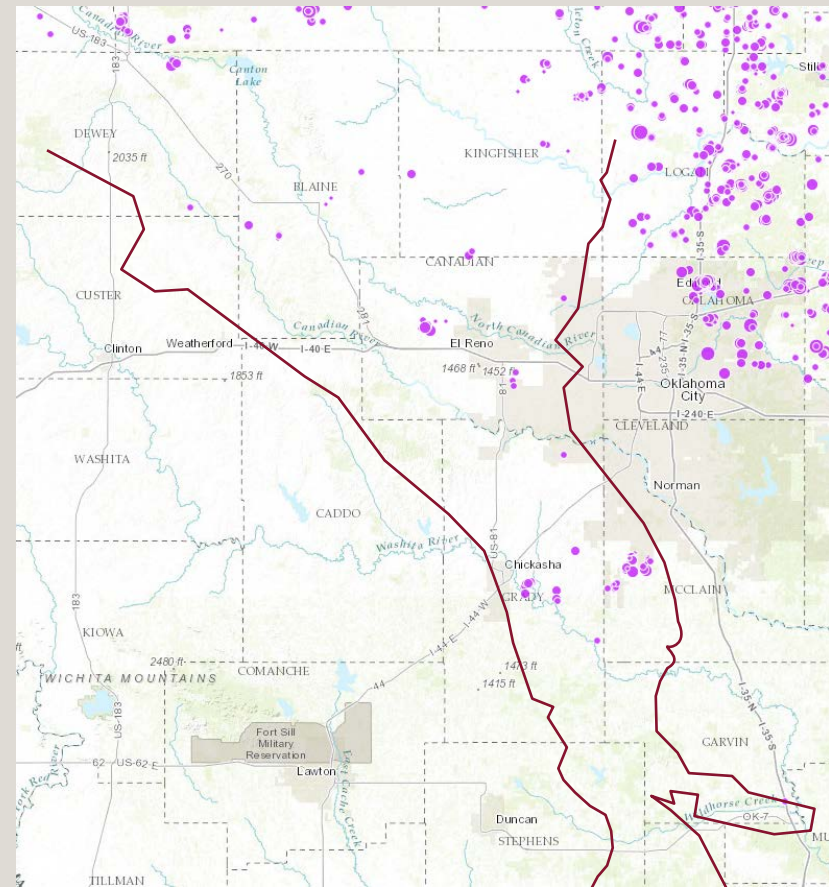
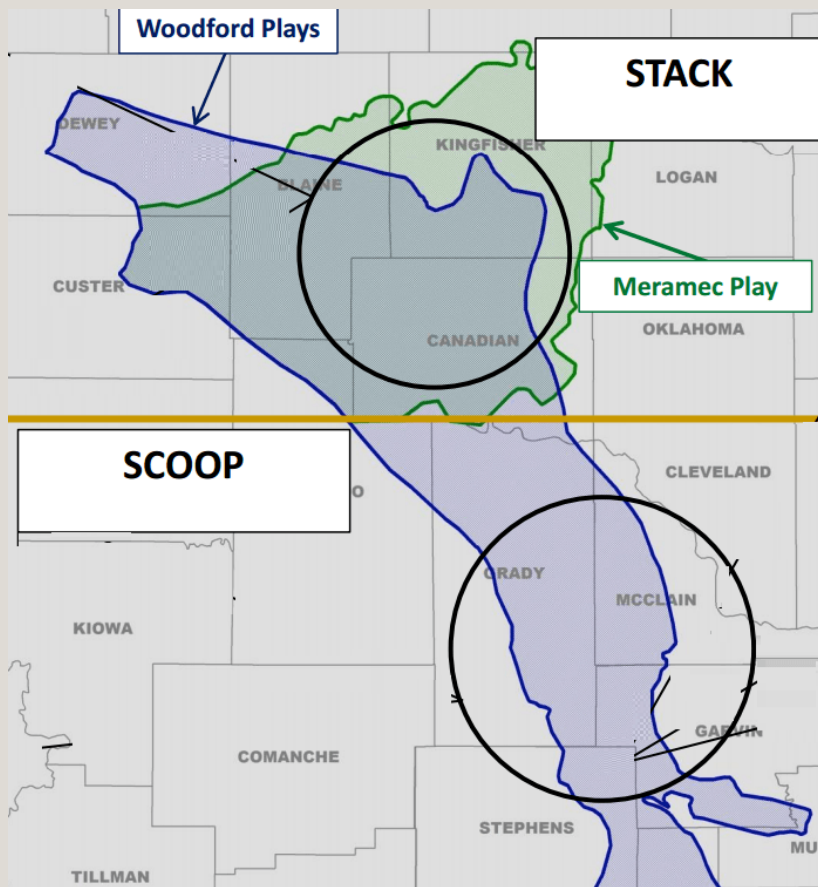
1. Reduce challenges to water re-use through **targeted regulations and legislation**:
  - Remove **legal ambiguity about ownership of produced water**
  - Establish **bonding requirements** for water impoundments without being an impediment
  - Make **right-of-way for pipelines** for recycled/re-used water easier to obtain
  - Request **delegation** from the U.S. EPA to Oklahoma for discharge permits
2. **Facilitate re-use of produced water** in oil and gas operations
3. Study feasibility of **transferring** Mississippi Lime produced water to STACK play.
4. Continue **evaluation of evaporation** as an alternative to injection.
5. **Consider all** environmental and stakeholder **impacts, and data gaps before** implementing long-term projects.

# 16 Earthquakes associated with hydraulic fracturing





# 17 STACK & SCOOP Play Areas



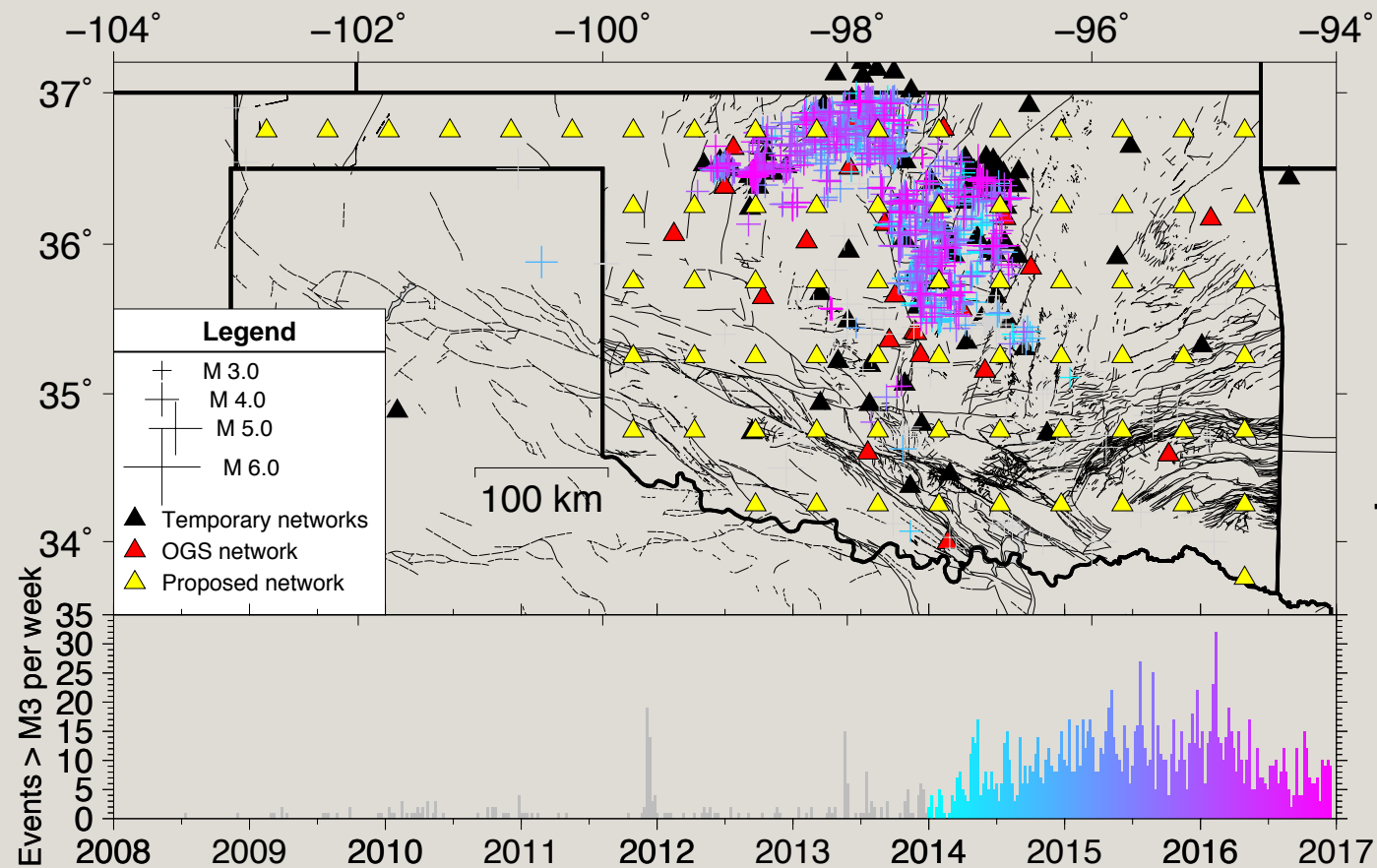


## 18 OCC well completion guidance on seismicity

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- Action following anomalous **seismic activity  $\leq 2$  km from completion operations**
- Stoplight system, if Oklahoma Geological Survey reports magnitude  **$\geq 2.5$ ;  $\geq 3.0M$ ;  $\geq 3.5M$**  earthquake
- Escalating review of operator's internal mitigation procedures by Oil & Gas Conservation Division of Oklahoma Corporation Commission
- Operations may resume if seismicity stops and mitigation approach considered adequate

# 19 The vision: a comprehensive high-quality seismic network



~\$4 million total cost



## 20 Acknowledgments

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- **OGS Staff Engaged on the Seismicity Issue**
  - **Seismology:** Jacob Walter, Jefferson Chang, Fernando Ferrer, Andrew Thiel, Isaac Woelfel
  - **Hydrogeology, Geology, Geophysics:** Kyle Murray, Ella Walker, Jordan Williams, Kevin Crain, Steve Holloway,
  - **Publications & Outreach:** Ted Satterfield
- **Major Additional Funding Sources**
  - Research Partnership to Secure Energy for America (RPSEA)
  - Secretary of Energy and Environment (through Recovery Act)
  - Oklahoma Governor's Emergency Fund





## Backup Material

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## 22 Summary: Induced Seismicity in Oklahoma

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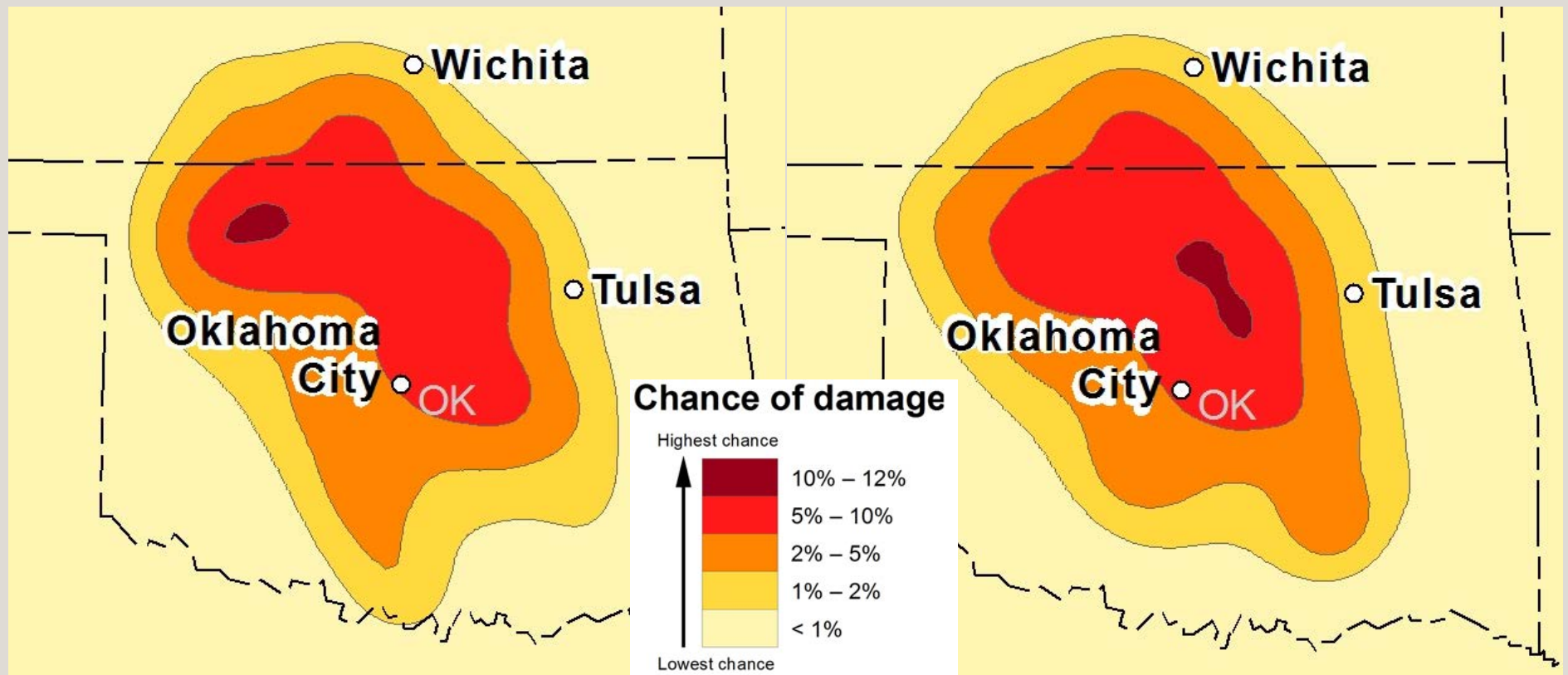
- No documented case of induced seismicity close to Oklahoma in earthquake rate or affected area
- Only 34% of earthquakes occur within 2 km of any known fault.
- It is not clear the density of faulting is greater in Oklahoma than elsewhere in the mid-continent
- Majority of recent earthquakes in central and north-central Oklahoma likely triggered by injection of produced water in SWD wells
- Hydraulic fracturing flowback water <5% of SWD volume in Arbuckle
- Drop in earthquake frequency since mid-2015 likely results from decreases in injection in Area of Interest driven by oil price and Corporation Commission directives
- Small number of lower magnitude earthquakes apparently associated with hydraulic fracturing manageable through a stoplight system

## 23 USGS One-Year Hazard Forecast

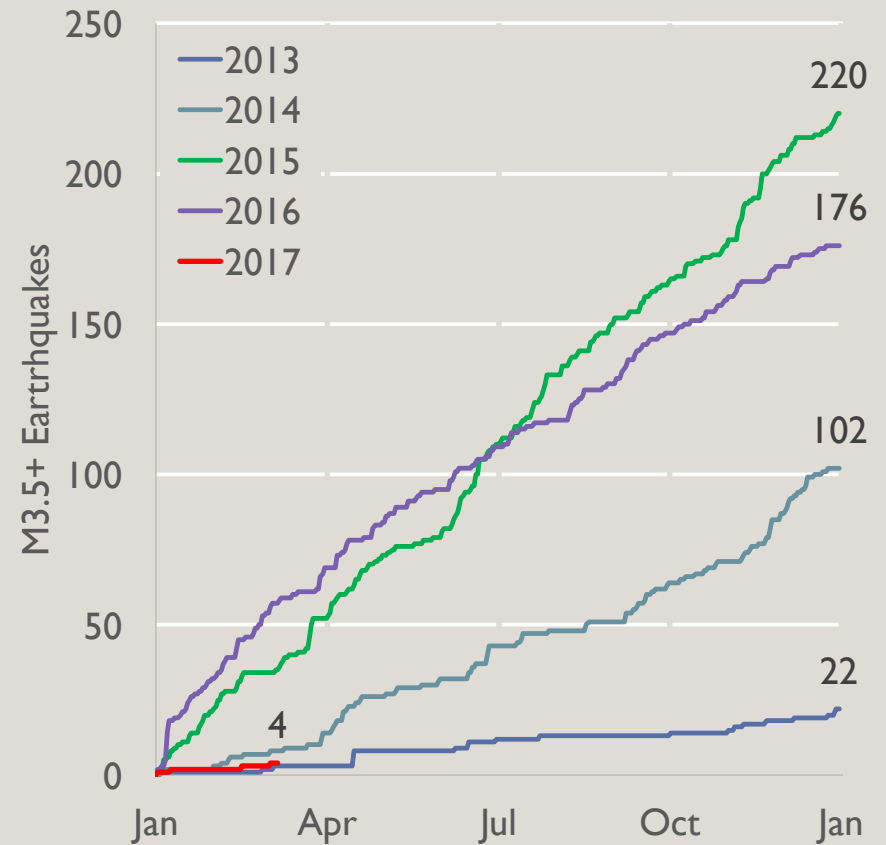
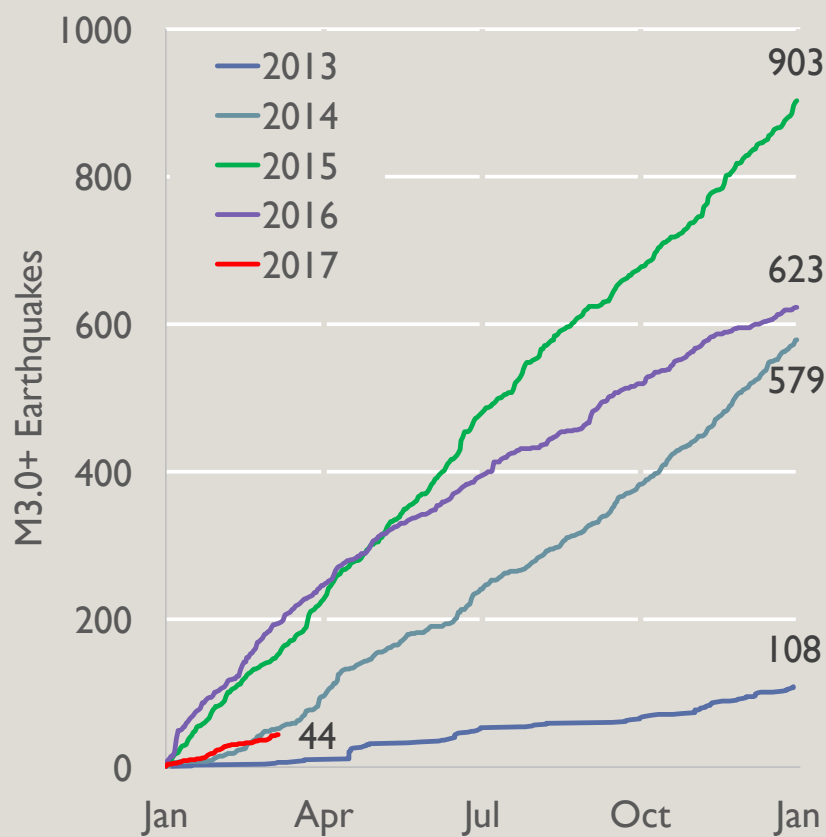


2016

2017

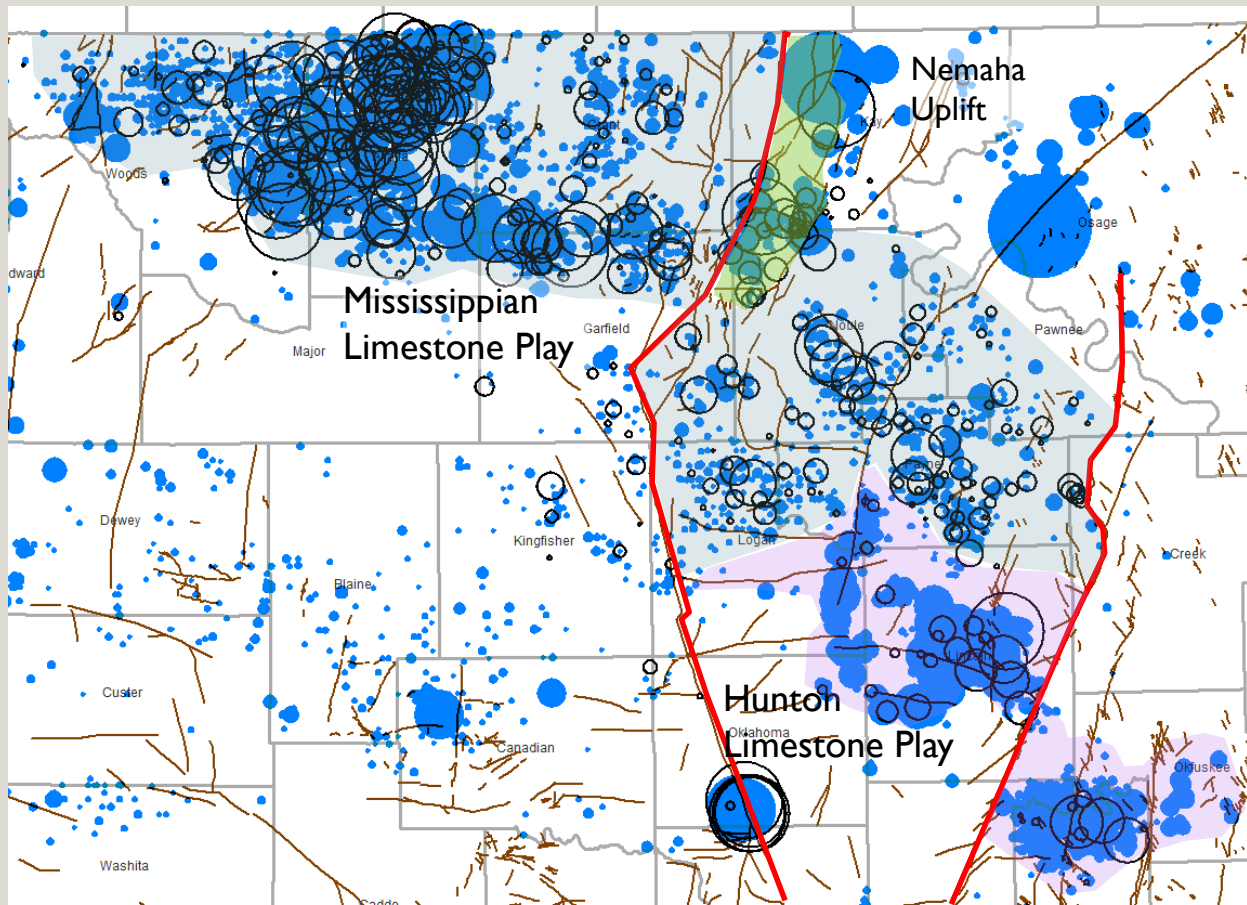


# 24 Earthquake Comparison | Year-to-Year





## 25 Different plays have different seismic history





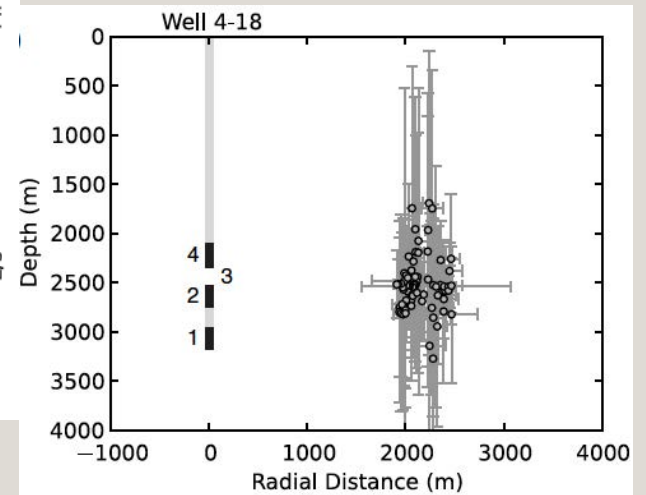
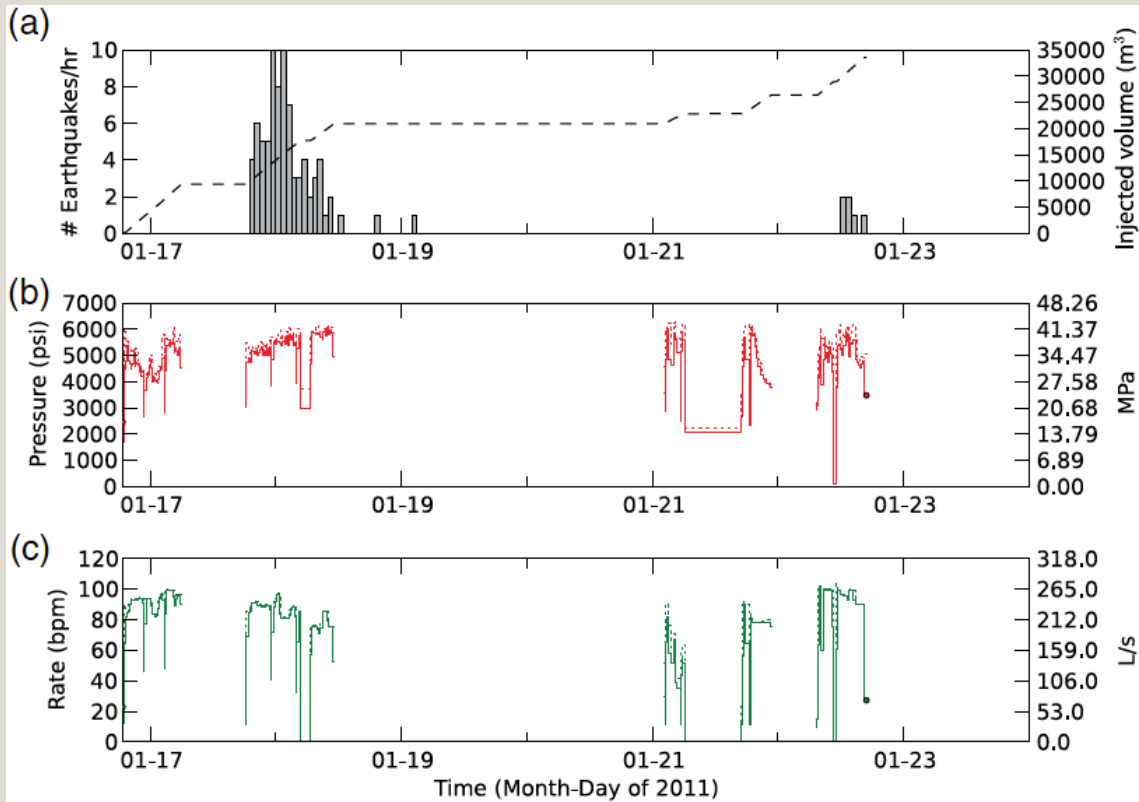
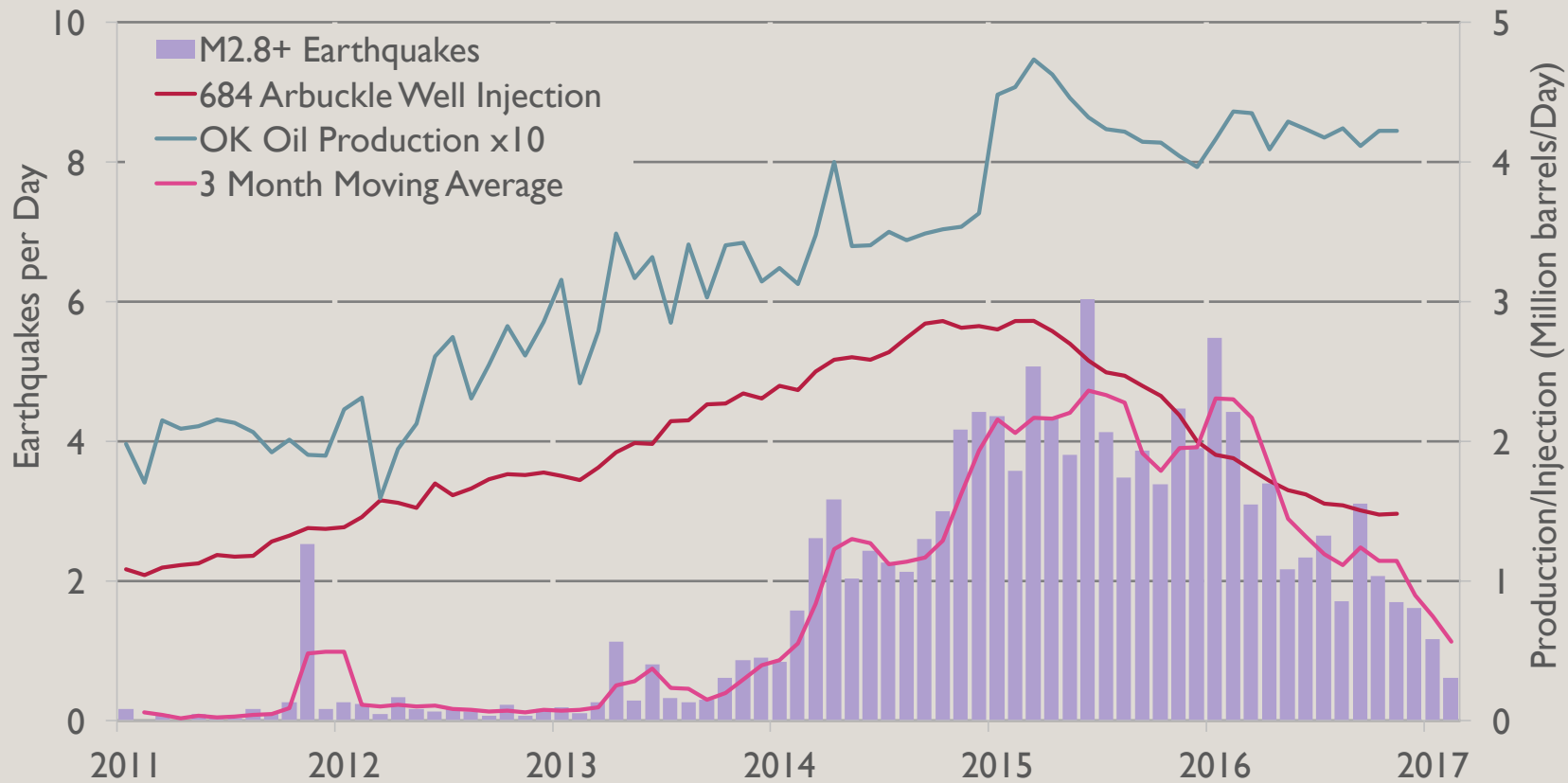
-  Initial Water Production
-  Cumulative Injection

Figure Courtesy of  
Anna Stafford, IPA LLC

# 26 Timing of Earthquakes and Hydraulic Fracturing Stages

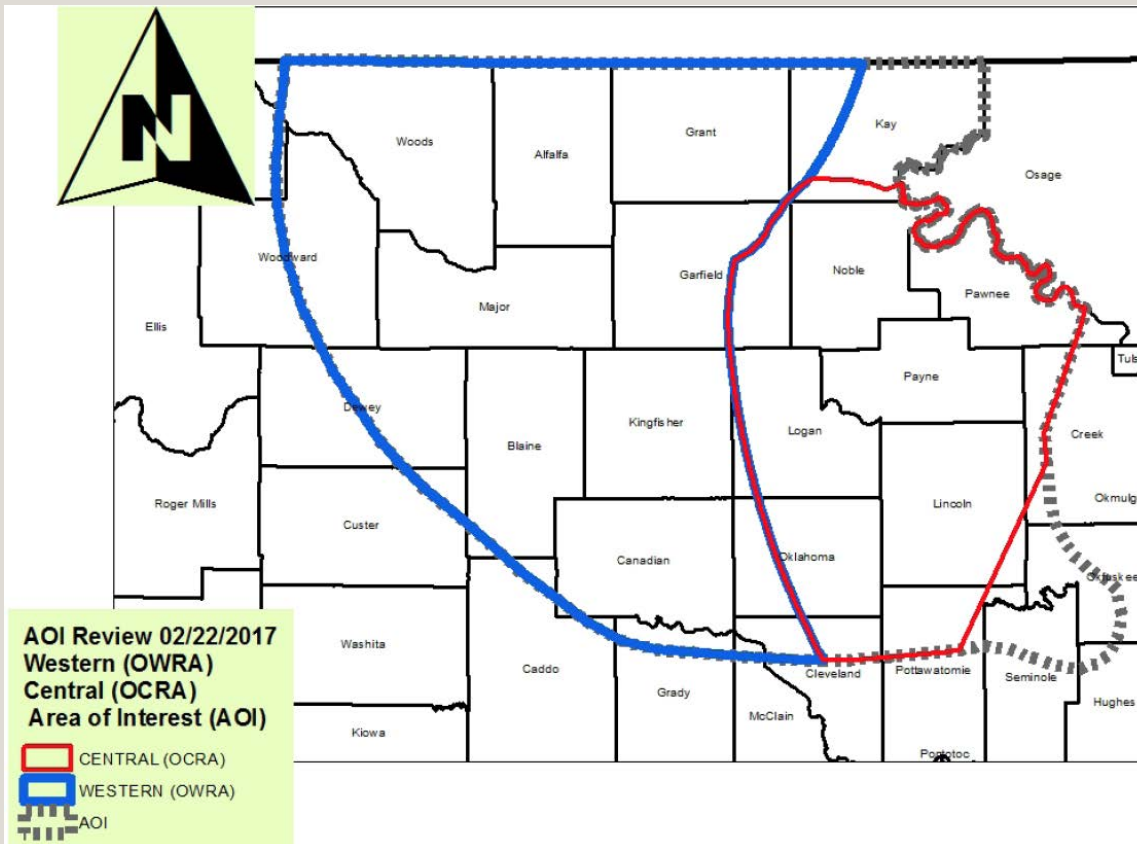


# 27 Earthquakes, Oil and Water





## 28 Oklahoma Corporation Commission (OCC) Actions



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