Earthquakes and human activities to induce them in Oklahoma

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State Seismologist

Seismic Team: Fernando Ferrer, Andrew Thiel, Isaac Woelfel

Oklahoma Geological Survey
November 2011 – Magnitude 5.7 earthquake near Prague, Oklahoma
September 2016 – Magnitude 5.8 earthquake near Pawnee, Oklahoma

Risk analysis suggests similar earthquake in Dallas … ~$5 billion damage

Number of \( M \geq 3 \) Earthquakes

- Blue line: 855 \( M \geq 3 \) Earthquakes 1973 - 2008
- Red line: 2310 \( M \geq 3 \) Earthquakes 2009 - Jan 2016
Download our scientific products: ogs.ou.edu
Arbuckle Formation in Oklahoma

Rubinstein and Mahani, 2015
Kevin Crain’s basement topography (m below sea level)
If earthquakes are a static process, then failure occurs when whole fault reaches failure threshold.

Several lines of evidence suggest that faults are weaker than would be predicted by Coulomb failure.

Once static stress is overcome on a portion of the fault the dynamic stress can overwhelm other areas.
Meers Fault, Oklahoma

100s of meters

Mitchell and Faulkner, 2009
As we deal with repercussions of Mississippi Lime production ... SCOOP/STACK enters the picture
FracNotice available since Oct 2016
Comparison of FracNotice and OGS Catalog – earthquakes within Distance and Time of start of frac job (May 2018)

5 km
5 days 4%
10 days 7%

10 km
5 days 8%
10 days 13%
Oklahoma Corporation Commission Protocol for earthquakes associated with well completions (issued Dec 20, 2016, since updated, with more updates likely)

SUMMARY OF WELL COMPLETION SEISMICITY GUIDANCE

Terms: Oil and Gas Conservation Division (OGCD)
       Oklahoma Geological Survey (OGS)

Action following anomalous seismic activity within 1.25 miles of hydraulic fracturing operations:

- If magnitude, as determined by the OGS, is greater than or equal to 2.5M:
  - OGCD contacts designated representative for the operator with active completion operations within a 2 km radius of located seismic events.
  - Implementation of the operator’s internal mitigation practices commences.
  - Operation continues.

- If magnitude is greater than or equal to 3.0M:
  - Operator initiates a pause of operations for no less than 6 hours.
  - Technical conference/call held between the OGCD staff and operator about operator mitigation practices.
  - Upon agreement between operator and OGCD regarding mitigation practices and reduced seismic activity, operator permitted to resume with revised completion procedure.

- If magnitude is greater than or equal to 3.5M:
  - Operator suspends operations
  - In-person technical conference held with OGCD staff and operator to examine whether operation can resume with changes.
Seismicity de-clustering drives seismic hazard maps

Time and space windowing

Too aggressive?

P-values lower for induced earthquakes?

Zach Rosson (OU MS student)
Early 2017 – broad restrictions
10,000 bbl/day in Central
15,000 bbl/day in Western

Coordinating Council currently evaluating geologically distinct sub-regions
### Age Chart

<table>
<thead>
<tr>
<th>Age (Ma)</th>
<th>Period</th>
<th>Global Standard</th>
<th>British Series</th>
<th>North American Series</th>
<th>Oklahoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>445</td>
<td>Upper Ordovician</td>
<td>Katian</td>
<td>Cincinnatian</td>
<td>Viola Group</td>
<td>Seminole</td>
</tr>
<tr>
<td>460</td>
<td>Lower/Middle Ordovician</td>
<td>Sandbian</td>
<td>“Lower Mohawkian”</td>
<td>Bromide</td>
<td>Wild</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Llanvirn</td>
<td>“Upper Chazy”</td>
<td>Tulip Creek</td>
<td>McLish Fm.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dapingian</td>
<td>“Lower Chazy”</td>
<td>“Lower Simpson Group”</td>
<td>McLish (Pruitt Ranch/Birdseye)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floian</td>
<td>“Canadian”</td>
<td>“Arbuckle Group”</td>
<td>Kindblade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cambrian</td>
<td>Tremadoc</td>
<td>“Arbuckle Group”</td>
<td>Lower West Slope Creek</td>
</tr>
</tbody>
</table>

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**Ray Suhm, OGS Open File Report 3-2016**
Oklahoma Geological Survey Earthquake Catalog Download Tool

This API returns OGS earthquake catalog information for download in the user-desired format.

Starting Date: 08/13/2018
Ending Date: 08/13/2018
Magnitude: ≥ 2
Download Format: csv

https://ogsweb.ou.edu/api/earthquake?
start=201808130000&end=201808132359&mag=2&format=csv
### Oklahoma City Metro

### Tulsa Metro

#### Soil Profile Site Classification for Seismic Amplification

<table>
<thead>
<tr>
<th>Soil Profile Type</th>
<th>General Site Profile Description</th>
<th>Average Shear Wave Velocity (ft/sec)</th>
<th>Possible Amount of Amplification</th>
<th>Standard Penetration Tests (SPT) Average Blow Counts</th>
<th>Average Shear Strength (lbs/sq ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hard Rock</td>
<td>&gt;6,000</td>
<td>0.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>B</td>
<td>Rock</td>
<td>2,500-5,000</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>C</td>
<td>Regolith, weathered shales, cemented gravels, hard and/or stiff/very stiff soils</td>
<td>1,200-2,500</td>
<td>1.3-1.7</td>
<td>&gt;50</td>
<td>2,000</td>
</tr>
<tr>
<td>D</td>
<td>Sands, silts, and/or stiff/very stiff clays, loess, gravels</td>
<td>6000-1,200</td>
<td>1.5-2.4</td>
<td>15-50</td>
<td>1,000-2,000</td>
</tr>
<tr>
<td>E</td>
<td>Soil profile with more than 10 ft (3m) of soft clay defined as soil with Plasticity Index &gt; 20, water content &gt; 40</td>
<td>&lt;600</td>
<td>1.2-3.5</td>
<td>&lt;15</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>F</td>
<td>Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible, weakly cemented soils</td>
<td>N/A</td>
<td>Site Specific Investigation should be conducted- can be &lt; 1 to as high as 10 x</td>
<td>&lt;15</td>
<td>&lt;1,000</td>
</tr>
</tbody>
</table>
$4.5 claims paid out out of $278 million value of properties with active claims – data from Oklahoma Insurance Commission
Download our scientific products: ogs.ou.edu

• OGS Staff engaged on induced seismicity
  – **Seismology**: Jake Walter, Fernando Ferrer, Andrew Thiel, Isaac Woelfel, Zach Rosson
  – **Hydrogeology, Geology, Geophysics**: Kyle Murray
  – **Publications & Outreach**: Ted Satterfield, Molly Yunker