A Brief Primer on Induced Seismicity

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Magnitude 5.6 5-Nov-2011
Shawnee, Oklahoma

Magnitude 4.8, Timpson, TX, 17-May-2012

Slides from the research of: Robert Williams USGS, Bill Ellsworth USGS, Justin Rubinstein USGS, Dan McNamara USGS, Arthur McGarr USGS, Mark Petersen USGS, Chuck Mueller USGS, Austin Holland OGS, Cliff Frohlich UT, Katie Keranen CU, William Barnhardt IU, Heather DeShon SMU.
• Why are earthquakes (especially induced) in CEUS suddenly an issue?
• What causes induced eq’s
• What is the USGS response
  - Monitoring
  - Research
  - Hazard Communication

Damage from M5.7 Prague, OK Earthquake

Damage from M5.3 Trinidad, CO Earthquake
Rocky Mountain Arsenal

Earthquakes 1962:
Inducing earthquakes

Largest earthquake occurred 2 years after injection stopped and 10 km away from initial site.

Pillar of highway overpass.

Healy, 1968

USGS

science for a changing world
Induced Earthquakes at the Rangely Oil Fields, 1969-1973: Seismicity Management

An Experiment in Earthquake Control at Rangely, Colorado

C. B. Raleigh, J. H. Healy, J. D. Bredchoeft

The discovery in 1966 that injection of fluid underground at high pressure was responsible for the triggering of earthquakes near Denver, Colorado, led to speculations about the locations and focal plane solutions for the earthquakes, and most important, to be confident that the active phase of the experiment would not materially increase the...
<table>
<thead>
<tr>
<th>Fracking</th>
<th>vs.</th>
<th>Waste Water Injection</th>
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<tbody>
<tr>
<td>Short Term (hours-days)</td>
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<td>Long Term (years)</td>
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<td>High pressure but low volume (5K-50K Bbls)</td>
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<td>High volume (M’s Bbl/mon)</td>
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<td>Then well goes into production</td>
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<td>Most waste water is “produced” water</td>
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<td>Typically microearthquakes are not felt -2≤M≤1</td>
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<td>Some faults reactivated</td>
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<td>– Rare exceptions:</td>
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<td>Some damaging earthquakes</td>
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<td>e.g., Ohio, Mag 3.0,</td>
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<td>e.g., Prague, OK, Mag 5.6,</td>
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<td>OK, M 2.9</td>
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<td>Raton Basin, CO, M5.3</td>
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<td>Horn River, BC, M3.8</td>
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<td>Timpson, TX, M4.8,</td>
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<td></td>
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<td>Guy-Greenbrier, AR, M4.7,</td>
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<td>...etc.</td>
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Central & Eastern US Seismicity before 2005 from which a hazard model can be derived

Ellsworth, 2013
After 2009, accelerated activity
But rate increase is limited to a few areas

Higher rate of earthquakes implies higher hazard.

But how much higher?

How long will the higher hazard last?

Ellsworth, 2013
Impact on Seismic Hazard Models

2014 USGS National Seismic Hazard Model
No induced earthquakes

One of several models from the 2015 Report
Includes induced earthquakes
USGS Open File Report 2015-1017:17 Areas of Known/Suspected Induced Earthquakes (but most other areas remain aseismic)

- Greeley, CO
- RMA, CO
- Paradox, CO
- Rangely, CO-UT
- Raton, CO-NM
- Dagger Draw, NM
- Fashing, TX
- Cogdell, TX
- Timpson, TX
- Brewton, AL-FL
- Dallas-Fort Worth, TX
- Azle, TX
- Oklahoma N and Kansas S
- Oklahoma-S
- Guy-Greenbrier, AR
- Ashtabula, OH
- Youngstown, OH

Red text = the associated polygon has had earthquakes within the last two years (6/30/13- 6/23/15)
How do we determine whether earthquakes are induced?

• Are these earthquakes the first known earthquakes or if the increased rate of seismicity is statistically improbable to be due random activity.
• Is there temporal correlation between injection time. Response can range from immediate to years.
• Is there a spatial correlation with the injection site. *Up to 35 km.*

**What are the long-term and long-range effects of dispersed water injection?**
• Do changes in injection practice (e.g., changing fluid volume, pressure or rate) encourage or discourage seismic activity.
• Are there geologic structures that could be affected by fluid or stress change. *Most faults are unknown, must be inferred from seismic data.*
Jones Swarm, OK 2009-2012: Regional Waste Water Injection & Remote Triggering

Keranen et al (2014)

Hydrogeological model showing migrating pore pressure from high-rate wells corresponds to growth of the largest swarm in OK.

- Waste water-induced earthquakes often not directly beneath a well.
- Volume expansion enhances chances of encountering a fault.
- Hydraulic connection level and basement likely important.
Azle, TX earthquakes 2013-2014: Complex faulting

Hornback & Deshon (2015)

• Injection on side of the fault and extraction on the other sympathetically combined to create a differential pressure.
• The pressure differential was of sufficient size and orientation to trigger conjugate faulting.
• Basement faulting by channeling of fluid or change in loading condition.


W.-Y. Kim, Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio. J. Geophys. Res. 10.1002/jgrb.50247 (2013)
Takeaways

• Increased earthquake activity may not be related to a single disposal well – could be caused by multiple wells over a larger area.

• Most disposal and fracking wells (in the thousands) do not produce felt earthquakes.

• Need to have a good understanding of earthquake fault network before well operations begin: fault lengths, depths, orientations.

• More seismic and hydrogeological data can constrain seismic hazard.

• Monitoring, research, hazards, communication earthquake.usgs.gov
Outlook

• High earthquake rates continue, but regulations appear to be having some effect

• Managing seismicity **may** be possible

• No large earthquakes yet, but they are still possible

• Earthquakes in the central US are potentially more dangerous due to less stringent building codes