A Brief Primer on Induced Seismicity

Dr. George L. Choy
choy@usgs.gov
U. S. Geological Survey

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

Magnitude 5.6 5-Nov-2011
Shawnee, Oklahoma

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*.

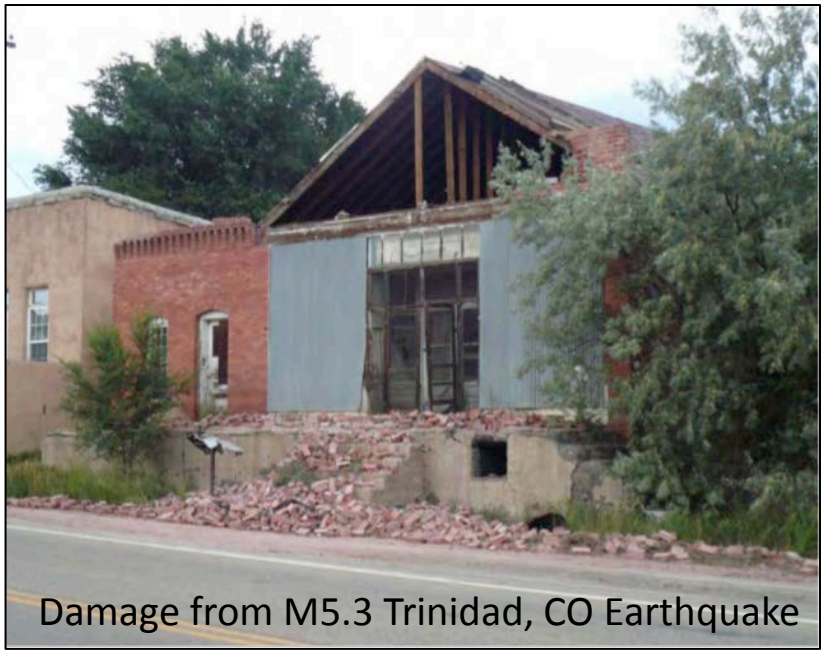
USGS
science for a changing world

SEJ

Conference of the Society of Environmental Journalists Conference October 7-11, 2015

- Why are earthquakes (especially induced) in CEUS suddenly an issue?
- What causes induced eq's
- What is the USGS response
  - Monitoring
  - Research
  - Hazard Communication

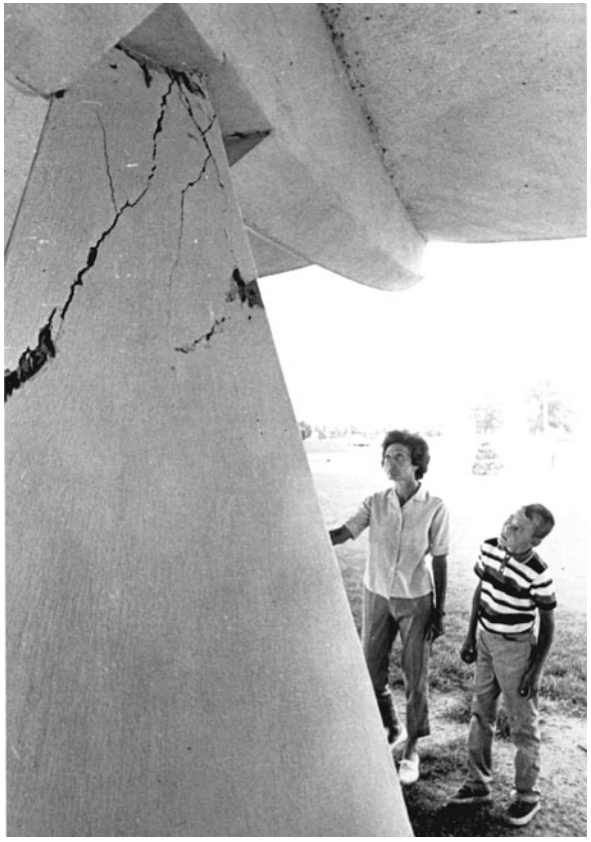
Damage from M5.7 Prague, OK Earthquake



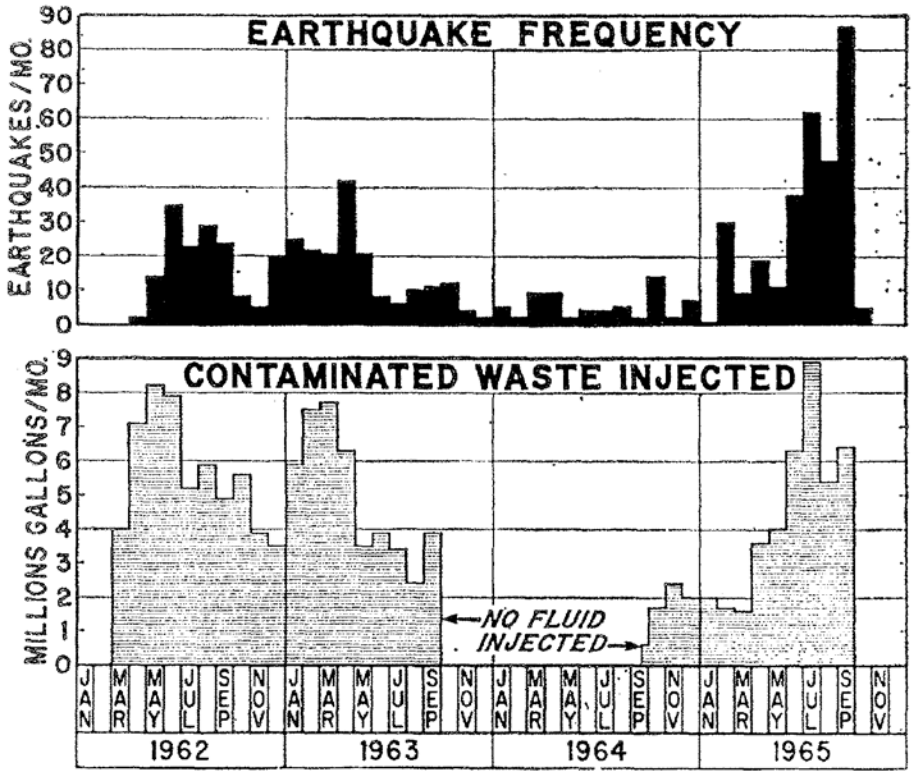
Damage from M5.3 Trinidad, CO Earthquake

USGS
science for a changing world

Rocky Mountain Arsenal Earthquakes 1962: Inducing earthquakes



Pillar of highway overpass.



Healy, 1968

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

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. Bredehoeft

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

locations and focal plane solutions for the earthquakes, and most important (iv) to be confident that the active phase of the experiment would not materially increase the

USGS
science for a changing world

Raleigh, 1976

Fracking vs. Waste Water Injection

- Short Term (hours-days)
- High pressure but low volume (5K-50K Bbls)
- Then well goes into production
- Typically microearthquakes are not felt -2≤M≤1
  - Rare exceptions:

    e.g., Ohio, Mag 3.0,

    OK, M 2.9

    Horn River, BC, M3.8

- Long Term (years)
- High volume (M's Bbl/mon)
- Most waste water is "produced" water
- Some faults reactivated
- Some damaging earthquakes

  e.g., Prague, OK, Mag 5.6,

  Raton Basin, CO, M5.3

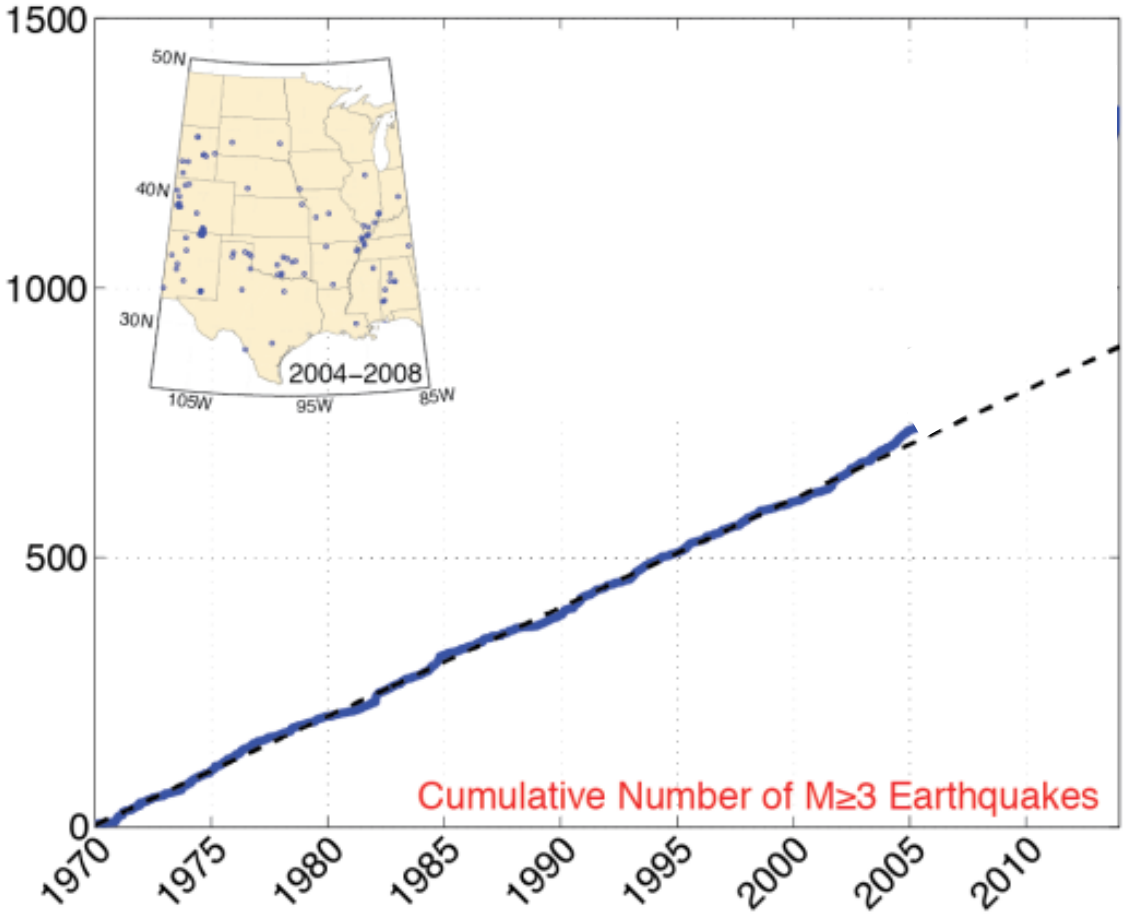
  Timpson, TX,M4.8,

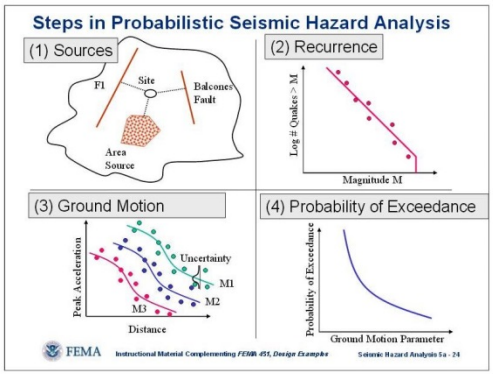
  Guy-Greenbrier, AR, M4.7,

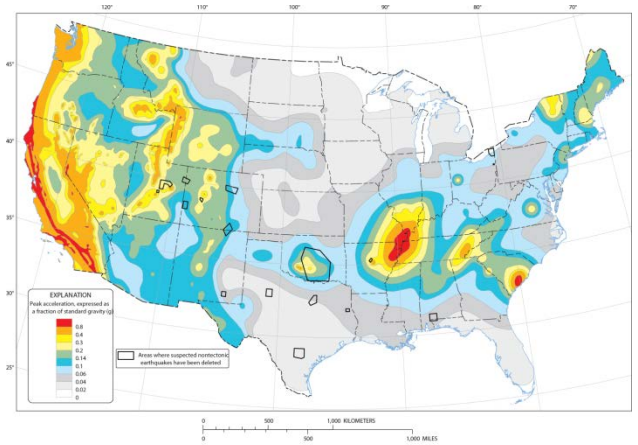
  …etc.

USGS
science for a changing world

Central & Eastern US Seismicity before 2005
from which a hazard model can be derived





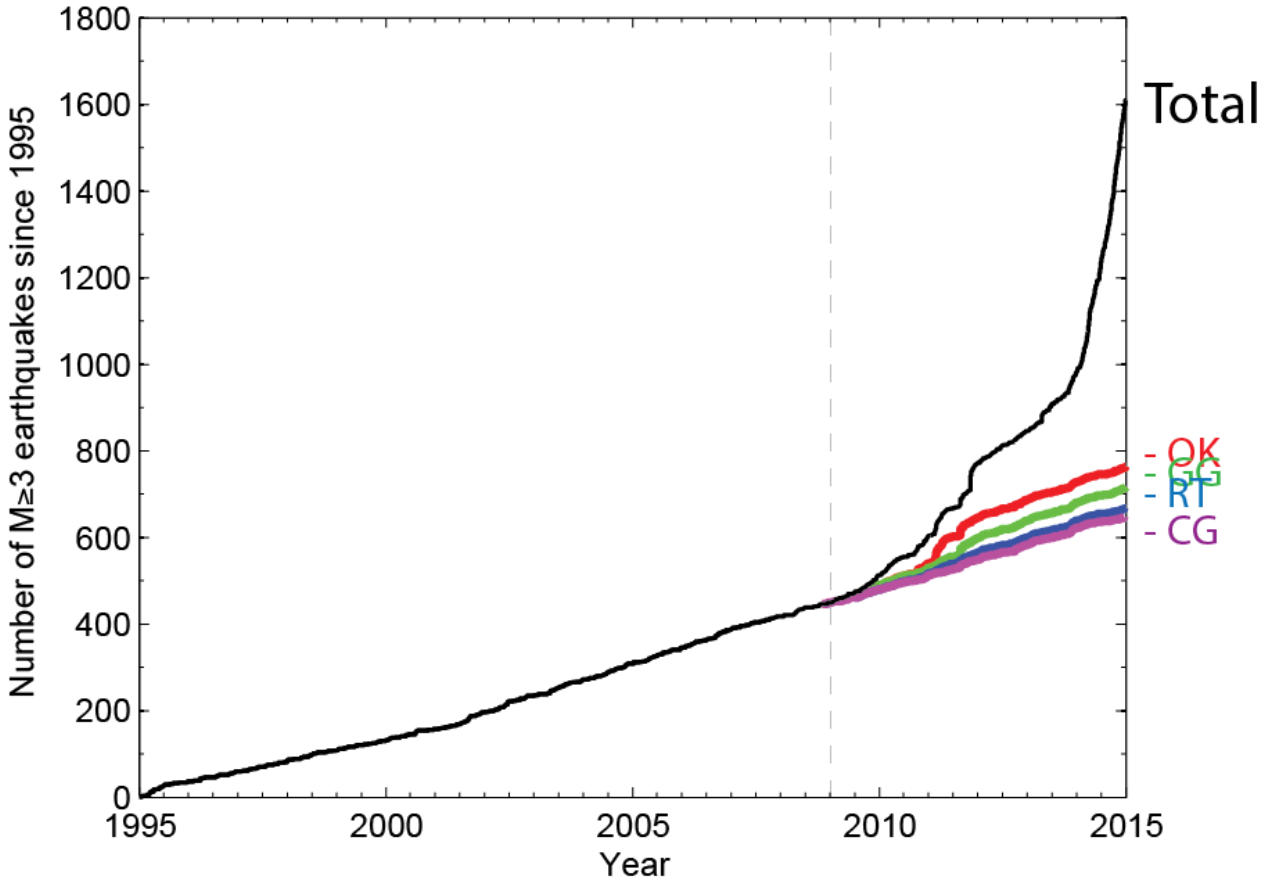


Two-percent probability of exceedance in 50 years map of peak ground acceleration

USGS
science for a changing world

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?

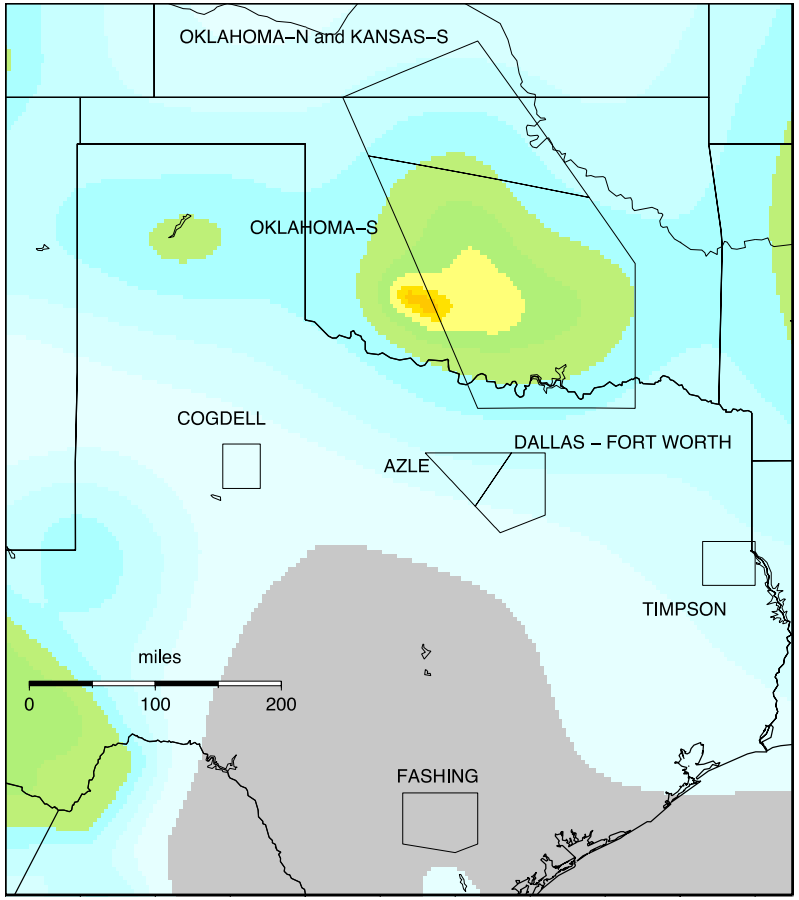
How long will the higher hazard last?

USGS
science for a changing world

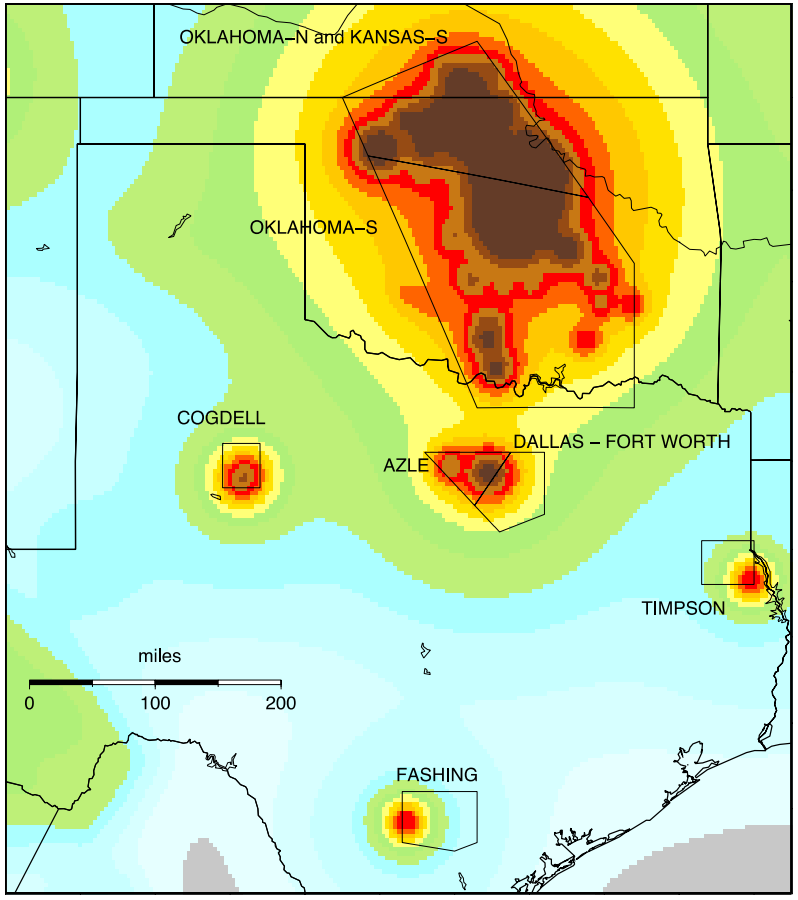
Ellsworth, 2013

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

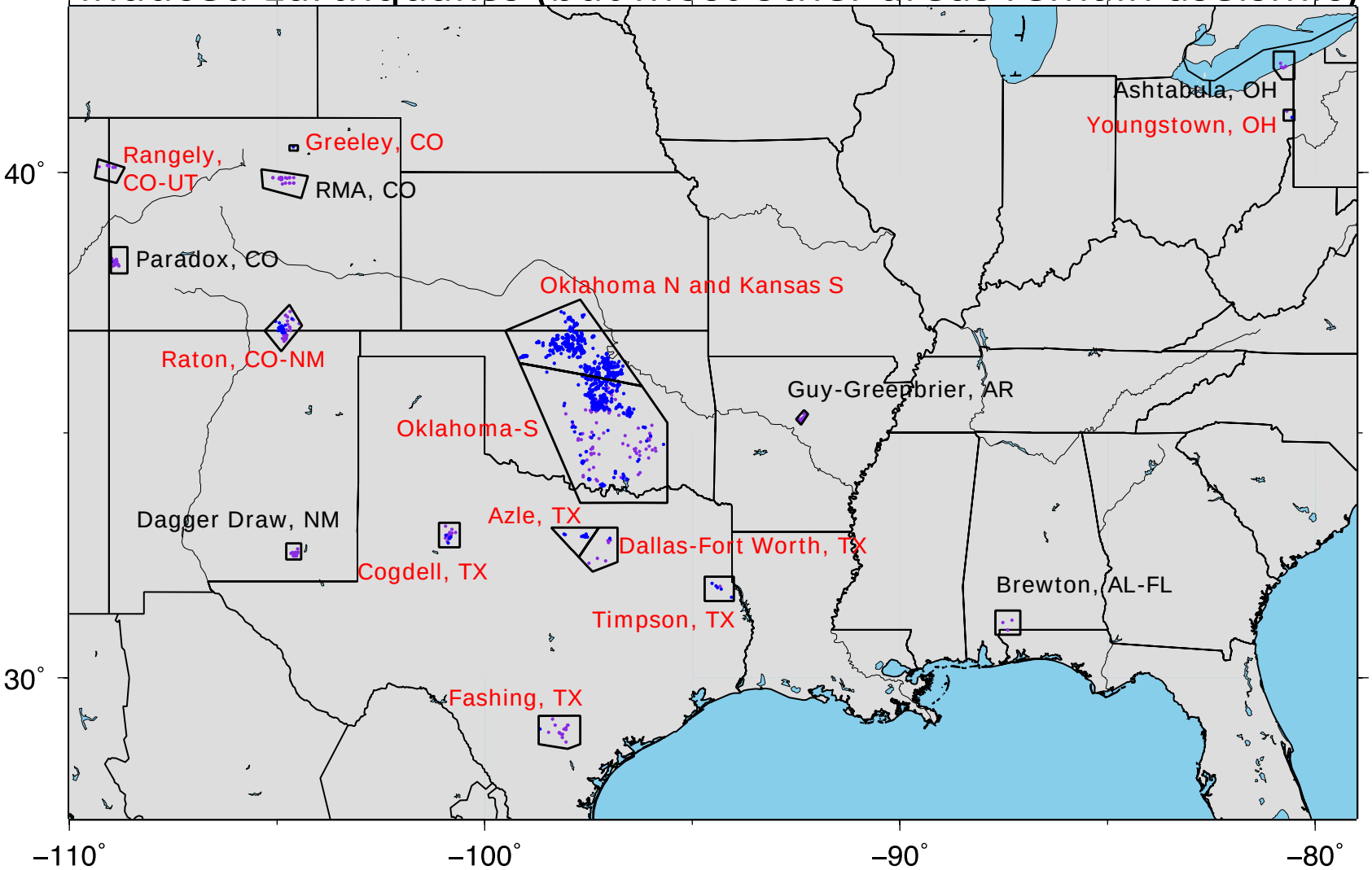


1.19 1.62 2.21 3.00

5 Hz spectral acceleration

USGS science for a changing world

USGS Open File Report 2015-1017:17 Areas of Known/Suspected Induced Earthquakes (but most other areas remain aseismic)



Red text = the associated polygon has had earthquakes within the last two years (6/30/13- 6/23/15)

USGS science for a changing world

How do we determine whether earthquakes are induced?

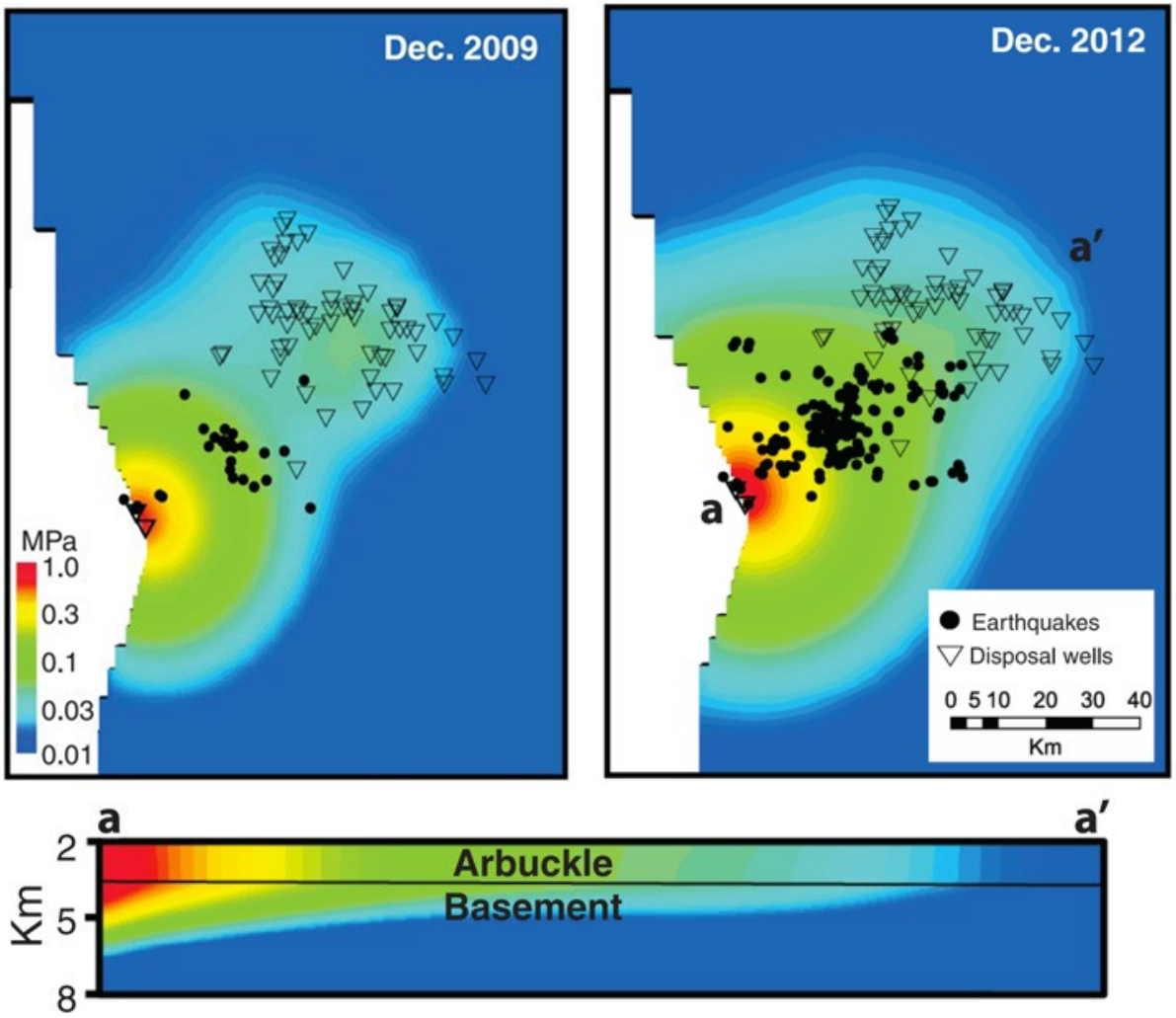
- Are these earthquakes the first known earthquakes or if the increased rate of seismicity is statistically improbable to be due random activity.
- Is there temporal correlation between injection time. Response can range from immediate to years.
- Is there a spatial correlation with the injection site.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

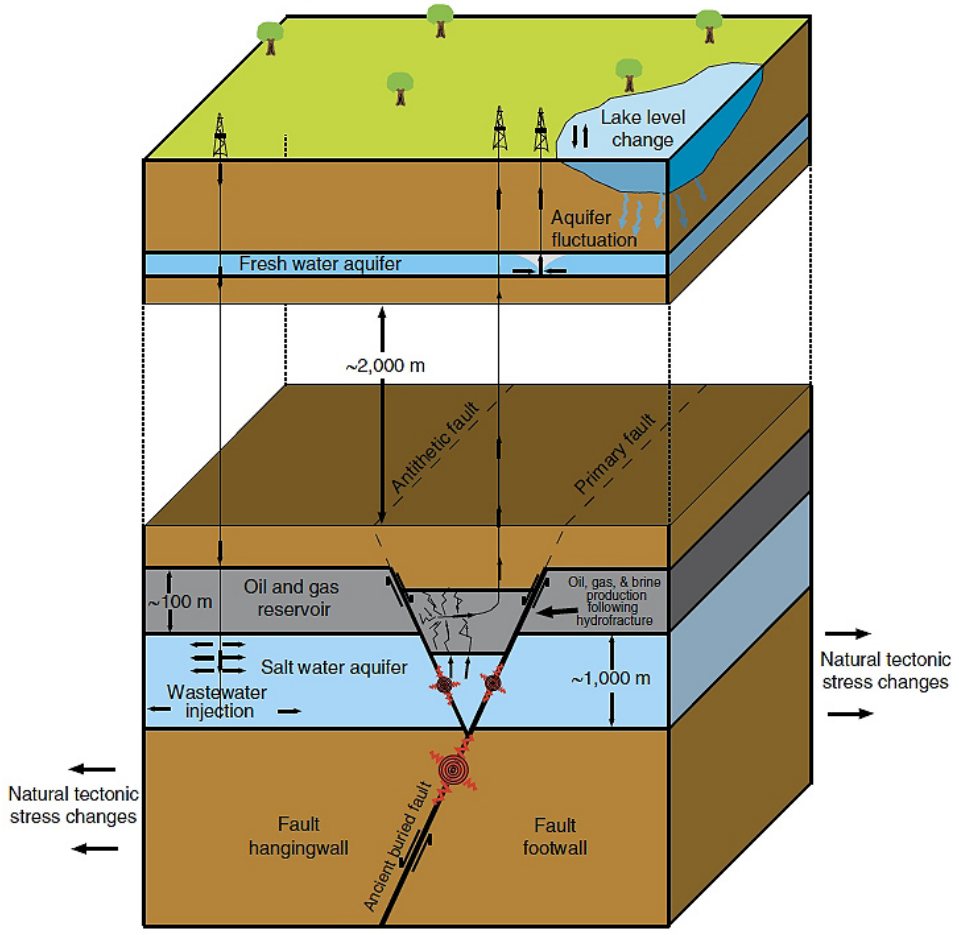
- Waste water-induced earthquakes *often not directly beneath a well.*
- Volume expansion enhances chances of encountering a fault.
- Hydraulic connection level and basement likely important.



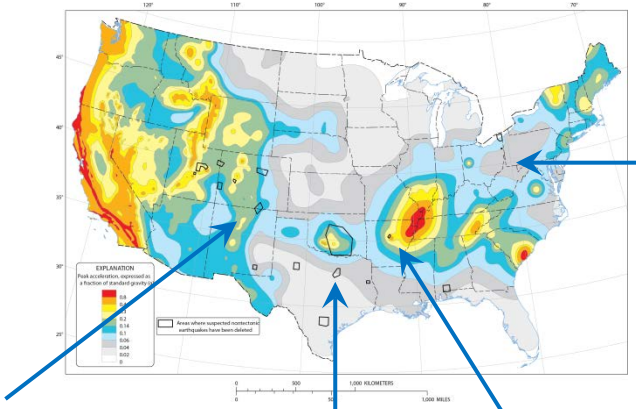
Azle, TX earthquakes 2013-2014: Complex faulting

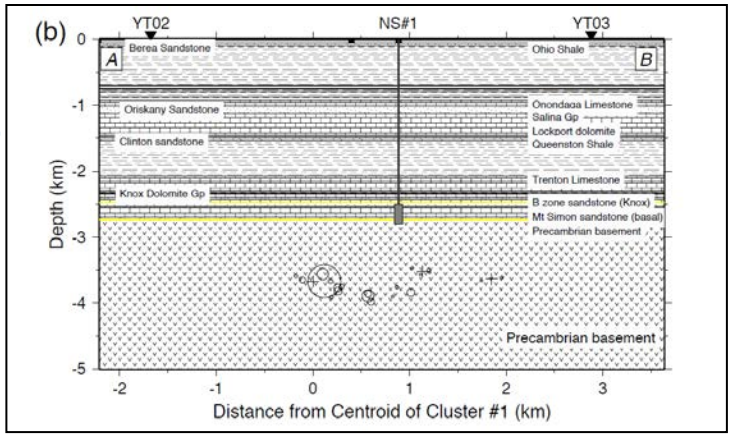
Hornback & Deshon (2015)

- 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.

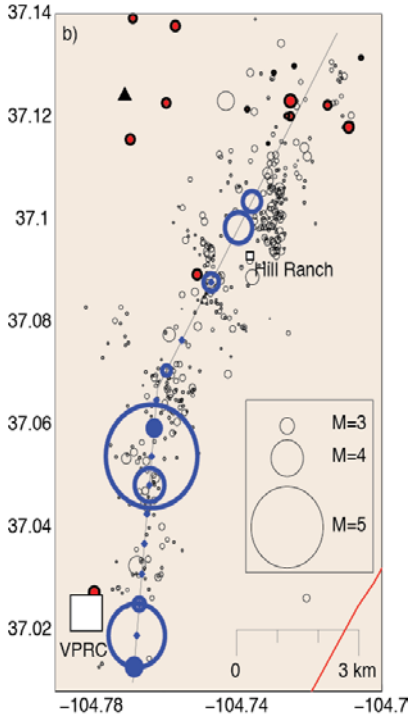


Peer-reviewed publications

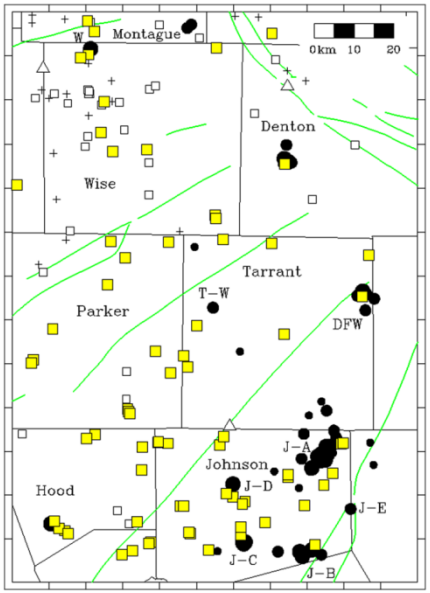




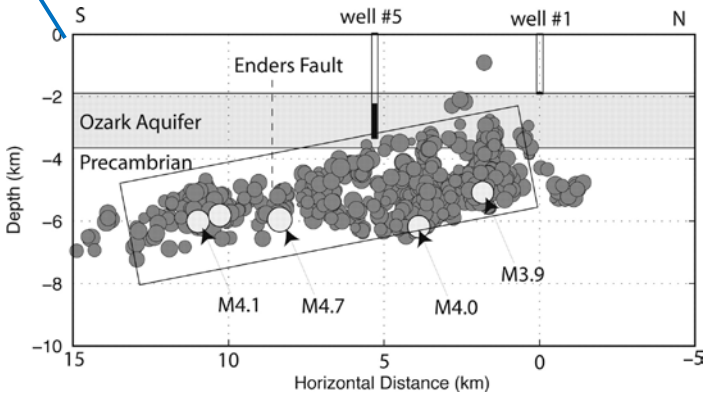
W.-Y. Kim, Induced seismicity associated with fluid injection into a deep well in Youngstown, Ohio. J. Geophys. Res. 10.1002/jgrb.50247 (2013)



Rubinstein, J. L., Ellsworth, W. L., McGarr, A., and Benz, H., 2014, The 2001 – Present Triggered Earthquake Sequence in the Raton Basin of Northern New Mexico and Southern Colorado, *Bull. Seismol. Soc. Am.*



Frohlich, C., 2012, *Two-year survey comparing earthquake activity and injection-well locations in the Barnett Shale, Texas*. Proc. Natl. Acad. Sci.



Horton, S., 2012, *Disposal of Hydrofracking Waste Fluid by Injection into Subsurface Aquifers Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquake; Seismological Research Letters*, v. 83.

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

The End

USGS
science for a changing world