Understanding Injection Seismicity: Status and Progress

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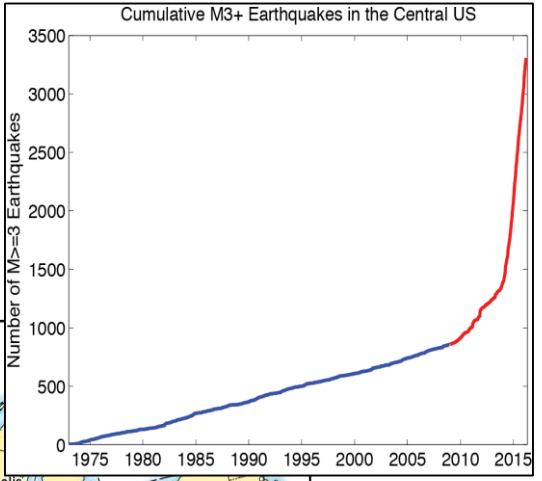

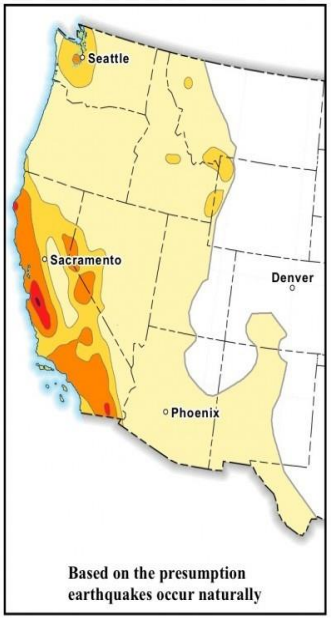

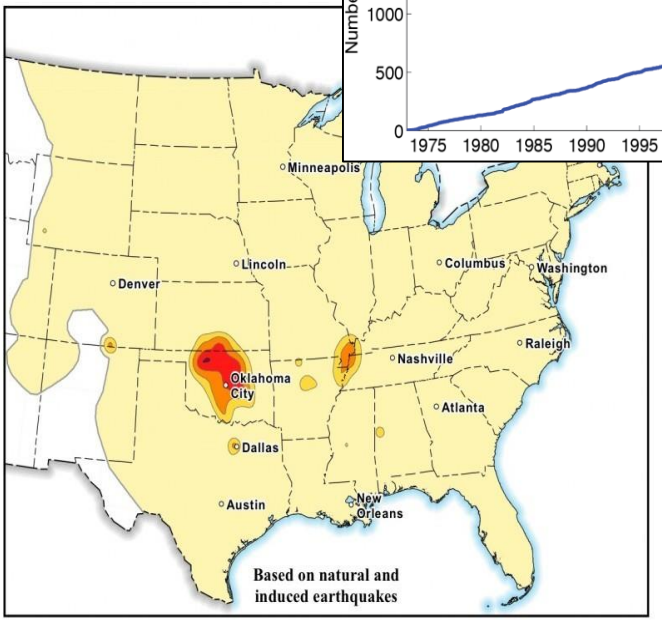

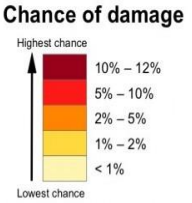

USGS Induced Seismicity Activities

- Ongoing seismic monitoring in Oklahoma, Kansas, Texas and Illinois, partnered with states.
- Includes seismic monitoring of the DOE-ADM carbon sequestration site at Decatur, Illinois
- New induced seismic hazard assessment product: a one-year forecast of ground motion probabilities in 21 areas.
- Ongoing technology development to improve the monitoring and characterization of small earthquakes.
- Research defining the variables that may be used to reduce risk (volume, injection rate, stress, etc.)
- Recent NODAL field deployment in Grant County, Oklahoma
- Integration of research results from Oil & Gas, geothermal and carbon sequestration
- Risk communication for induced seismicity (e.g. using earthquake scenarios, etc.)

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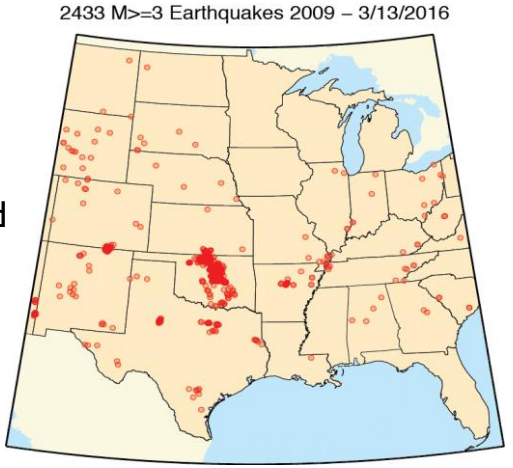
Progress: What we've learned in 5 years

- Most of the anomalous seismicity in the CEUS is induced by injection
  - Catalog & statistical studies
  - "Smoking gun" cases: Injections halted in Arkansas, Ohio and elsewhere
- Tectonics of Induced Seismicity
  - Larger earthquakes occur in the crystalline basement
  - Faults being triggered are well-oriented for failure in the tectonic stress field
- Geophysics of Induced Seismicity
  - Ground motion is strong but peaked above the earthquakes
  - Hazard may temporarily increase at shut-in

"We find the entire increase in earthquake rate is associated with fluid injection wells"
Weingarten and others, 2015



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Progress: What we've learned in 5 years

Hydraulics of Induced seismicity

- Triggering is statistically linked to injection rate (Weingarten et al. 2015)
  - but gravity-fed wells can also induce earthquakes
- Maximum magnitudes appear to be related to total volume injected
- Pressure changes move fast and far (with implications for natural earthquake tectonics)
- Seismicity dies down quickly when injections are halted
- Small earthquakes are more likely to be foreshocks of larger quakes.

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Progress: What we've learned in 5 years

- Politics of Induced Seismicity

"Myths & Facts", Rubenstein & Mahani, 2015

- ✓ Fracking is rarely the cause of damaging earthquakes! (but can generate mod.-size earthquakes…)
- ✓ Not all wastewater wells produce earthquakes!
- ✓ Wastewater is not just produced at fracking sites!
- ✓ Wastewater content varies greatly!
- ✓ Earthquake triggering can be at large distances and varying depths!
- ✓ Gravity-fed wells can induce quakes!

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What we still don't know…

Important questions for earthquake science, and also for regulation, and therefore also for business

- Forensics: which well(s) caused that earthquake?
- Which faults are most likely to trigger?
- What injection rates, pressure changes and/or total volumes are critical for triggering? How does that vary?
- How fast and how far can injection-caused pressure changes move?
- Does lowering injection volume just delay the time-to-next damaging earthquake?
- Prediction: are there observable signals, surface or subsurface prior to triggering

QUANTIFY

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What's needed now?

Field experiments: we can't get to the answers to these questions without:

- detailed geology, well characterized
- subsurface stress, hydrology, geophysics
- controlled injections
- tomographic imaging—dense 3-D seismic deployments, acoustic sensing, pressure monitoring...

…all in someplace of low risk to people & infrastructure

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backup slides

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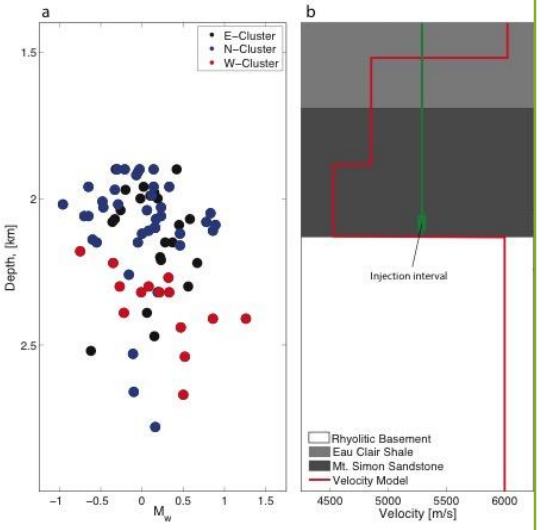
Ongoing analysis of seismicity at Decatur

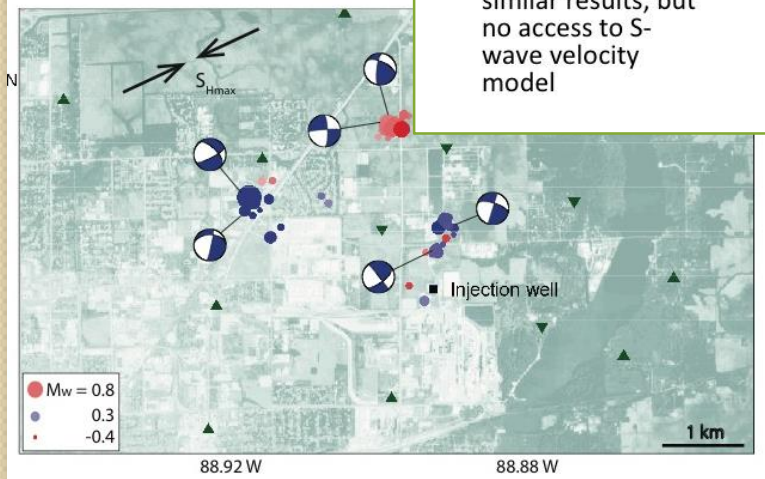
Next: analysis of microseisms on fiber DAS to increase detections

Decatur CCS Site

- East cluster near injection well appears slightly shallower, but still in basement
- All events are well below Eau Claire Shale
- Comparison of velocity models with SCS yielded similar results, but no access to S-wave velocity model



see Kaven et al, SRL, 2016



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