Managing the Risk of Earthquakes Triggered by Oil and Gas Development

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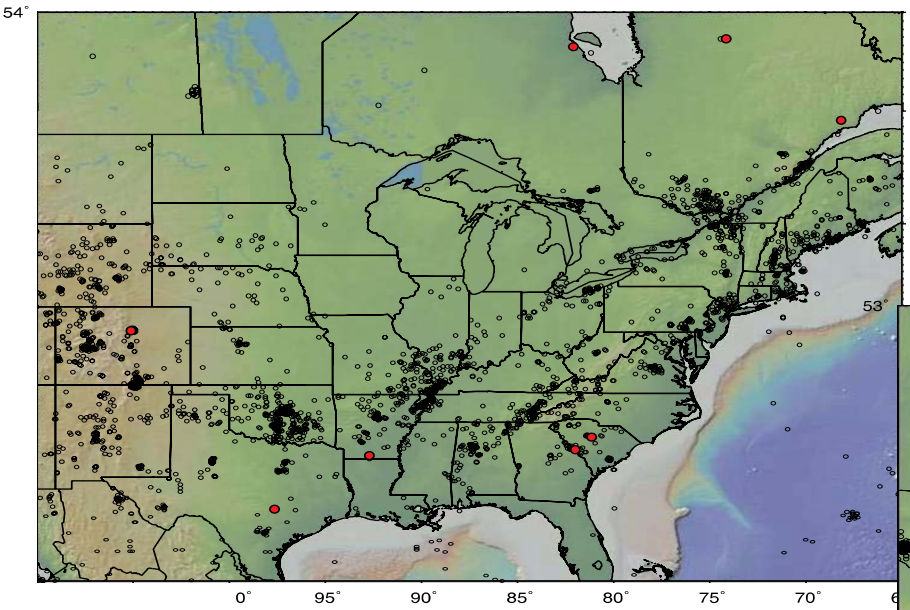
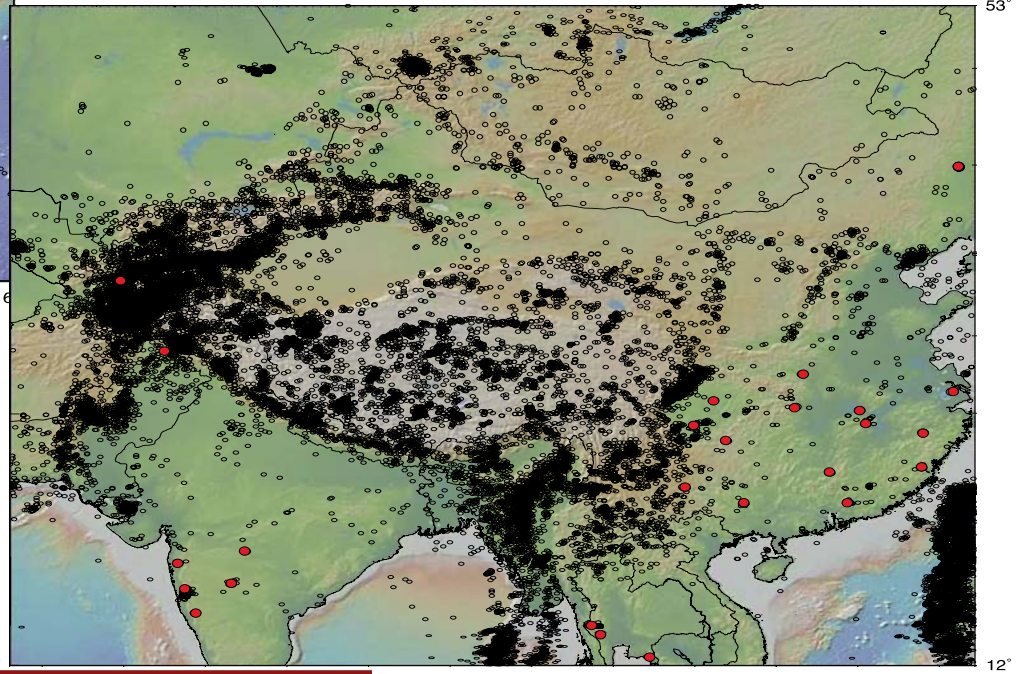
Topics on Induced Seismicity

- Earthquake Fundamentals - A Context for Understanding Earthquake Triggering
- A Brief Update on Earthquakes in Oklahoma
- Managing Earthquake Risk

We Live on a Critically-Stressed Crust

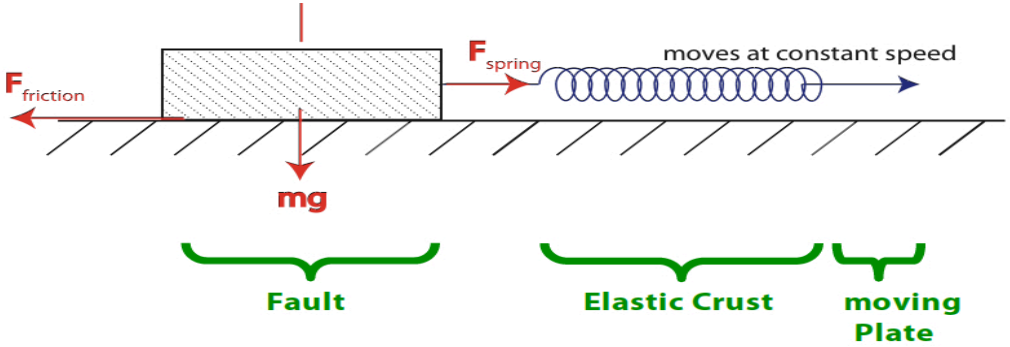




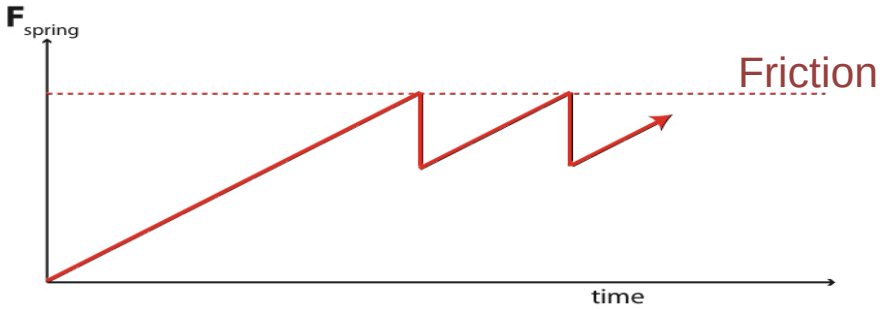
- Earthquakes Occur Nearly Everywhere in Intraplate Areas

- Small Perturbations <RIS> Capable of Triggering Seismicity, Even in "Stable Areas"

A Simple Earthquake Machine

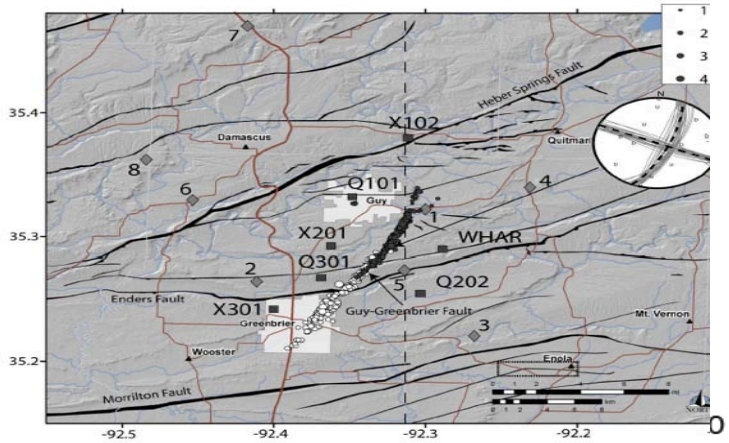


$$\tau = \mu\sigma_n \qquad \sigma_n = S_n - P_p$$



Block jumps ahead in sudden slip events (like earthquakes) and the stress drops

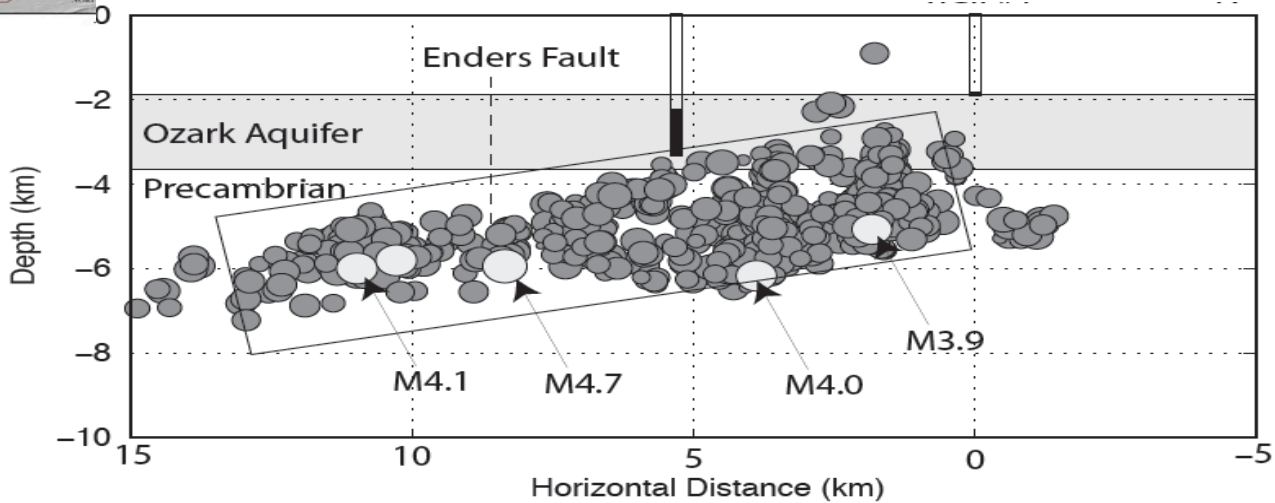
Earthquake Hazard Depends on Whether Injection Increases Pore Pressure in Potentially Active Basement Faults



Horton (2012)

Damaging Earthquakes Occur on Relatively Large Faults

Need to Prevent Faulting on Basement Faults in Response to Injection in Overlaying Sedimentary Formations



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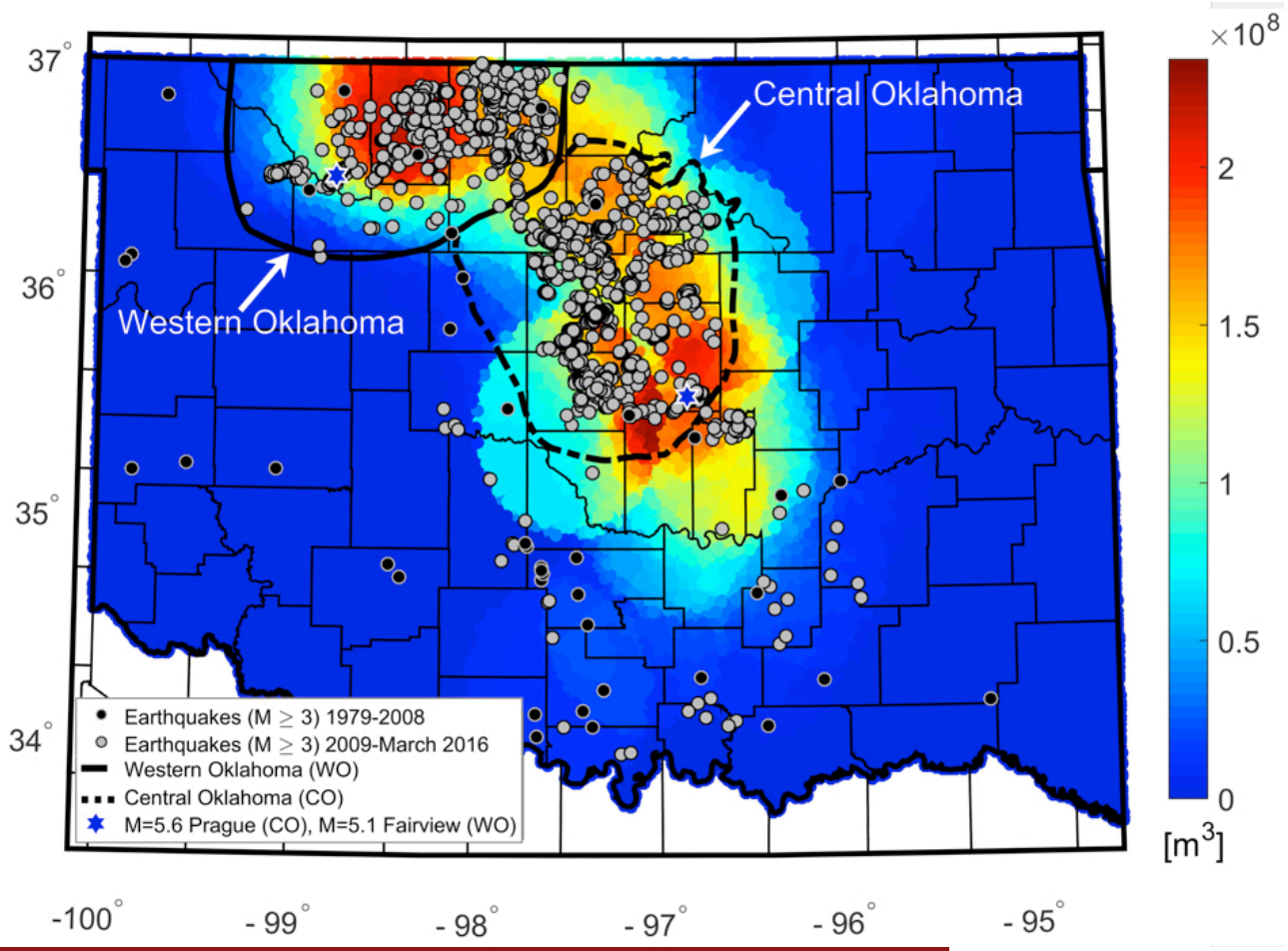
RESEARCH ARTICLE

SEISMOLOGY

Oklahoma's recent earthquakes and saltwater disposal

F. Rall Walsh III* and Mark D. Zoback

Over the past 5 years, parts of Oklahoma have experienced marked increases in the number of small- to moderate-sized earthquakes. In three study areas that encompass the vast majority of the recent seismicity, we show that the increases in seismicity follow 5- to 10-fold increases in the rates of saltwater disposal. Adjacent areas where there has been relatively little saltwater disposal have had comparatively few recent earthquakes. In the areas of seismic activity, the saltwater disposal principally comes from "produced" water, saline pore water that is coproduced with oil and then injected into deeper sedimentary formations. These formations appear to be in hydraulic communication with potentially active faults in crystalline basement, where nearly all the earthquakes are occurring. Although most of the recent earthquakes have posed little danger to the public, the possibility of triggering damaging earthquakes on potentially active basement faults cannot be discounted.

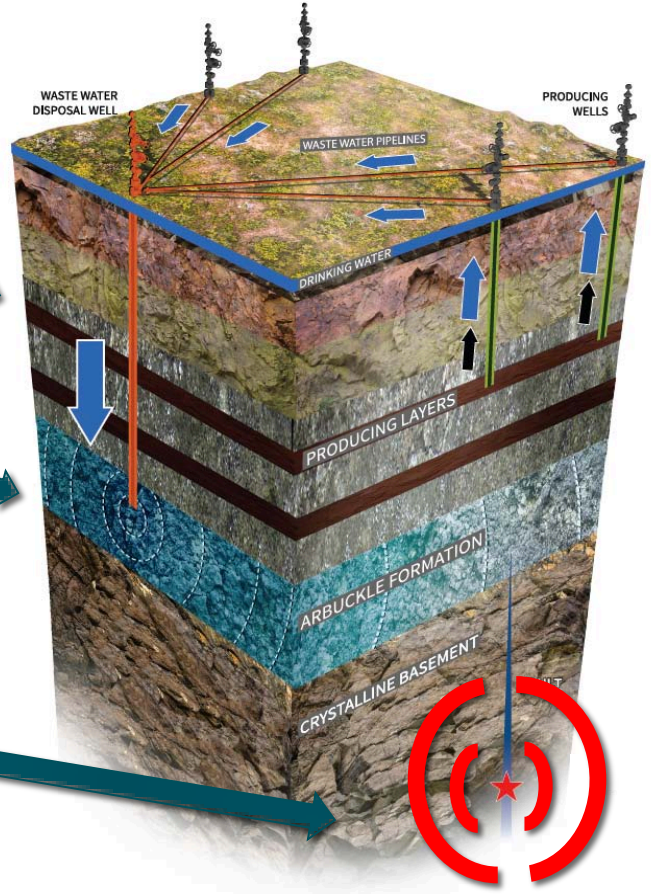

Central Oklahoma
Western Oklahoma
37°
36°
35°
34°
-100°
- 99°
- 98°
- 97°
- 96°
- 95°
Earthquakes (M ≥ 3) 1979-2008
Earthquakes (M ≥ 3) 2009-March 2016
Western Oklahoma (WO)
Central Oklahoma (CO)
M=5.6 Prague (CO), M=5.1 Fairview (WO)
×10^8
2
1.5
1
0.5
0
[m^3]

Saltwater Disposal Well Is Triggering Earthquakes

Oil production with and large saltwater saltwater cut

Saltwater Injection at 2 – 2.5 km into the Arbuckle Fm
~80 Million bbls/mo
≤1-2 MPa Pressure Change

Earthquakes at 5-6 km depth in granitic basement



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Be Proactive

Characterizing and Responding to Seismic Risk Associated with Earthquakes Potentially Triggered by Fluid Disposal and Hydraulic Fracturing

by Randi Jean Walters, Mark D. Zoback, Jack W. Baker, and Gregory C. Beroza

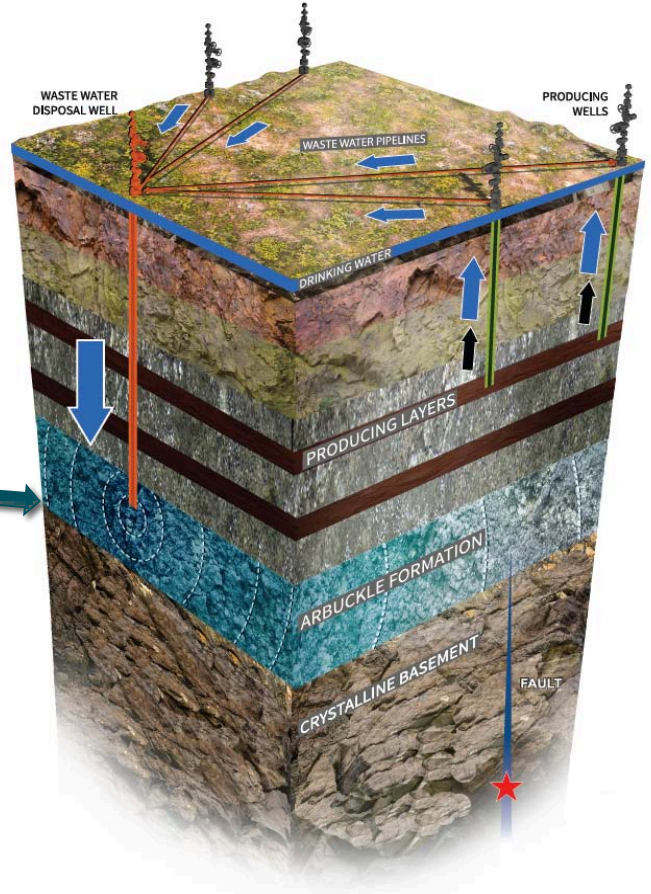
Seismological Research Letters, 2015

Reducing Saltwater Disposal Well Risk

Limit injection into basal aquifers

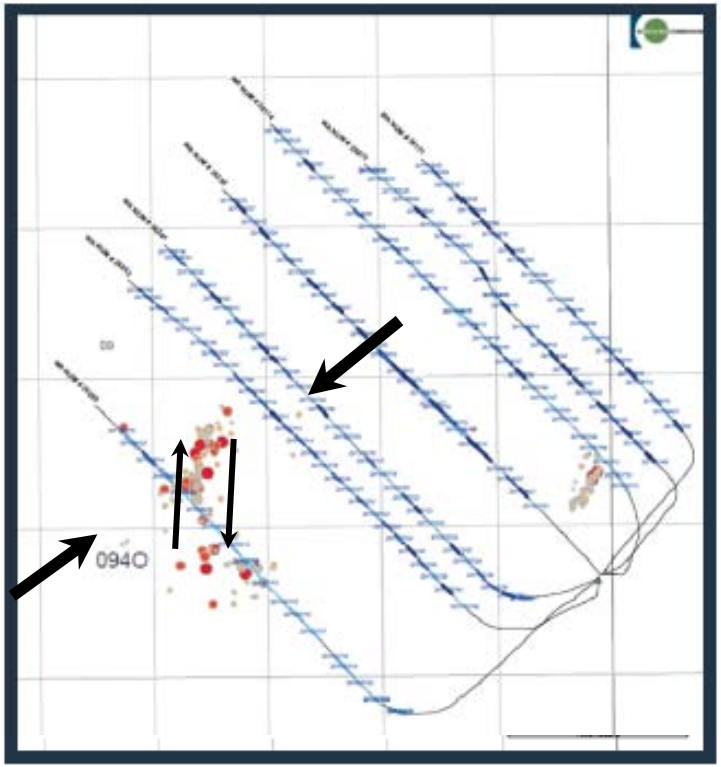
Re-inject in production zone as is typically done with produced water

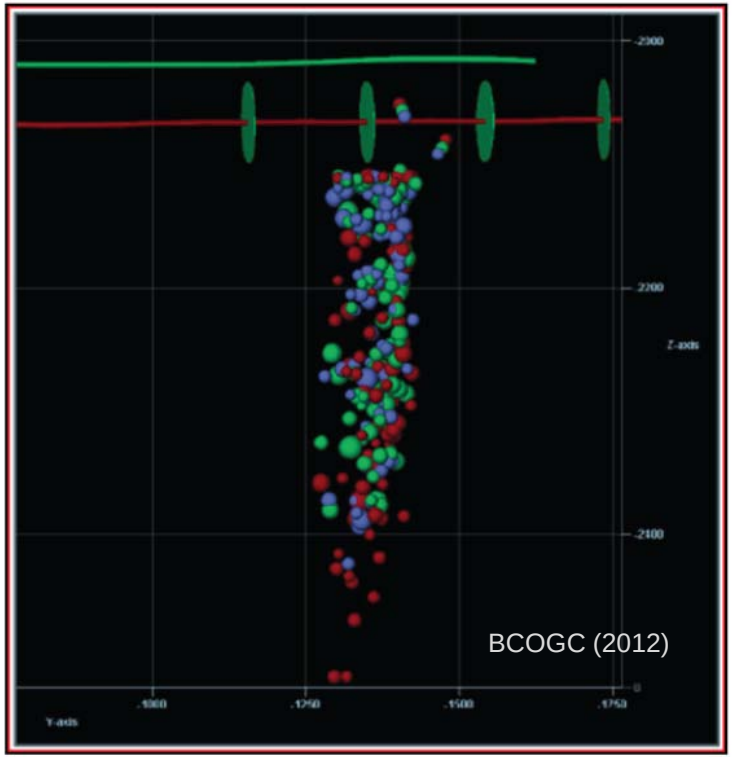
Seek injection zones with “bottom seals”



Consider Water Recycling Where the Injection of Flow-Back Water Triggers Earthquakes

Avoid Injection Near Potentially Active Faults During Hydraulic Fracturing





Distribution of earthquakes indicates slip along a pre-existing fault at the Horn River Basin hydraulic fracturing project in British Columbia


Thank you