Earthquakes Triggered by Unconventional Oil and Gas Development

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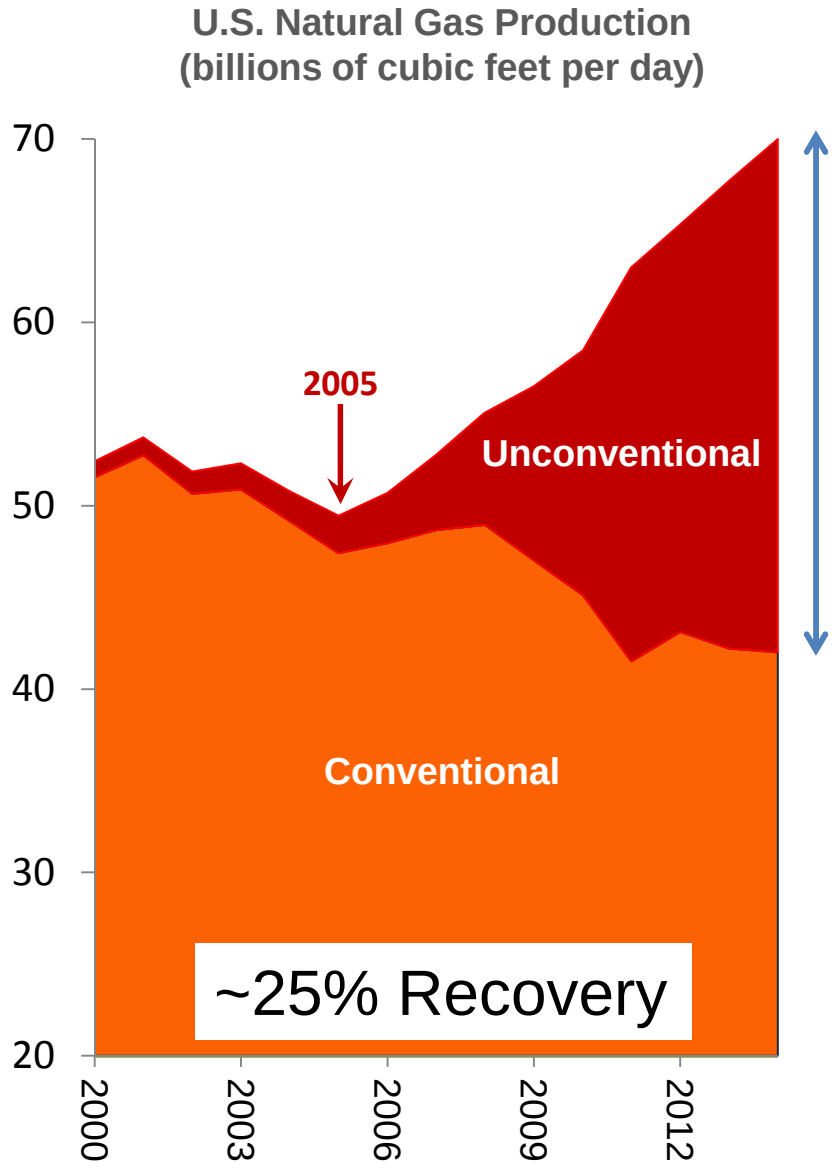
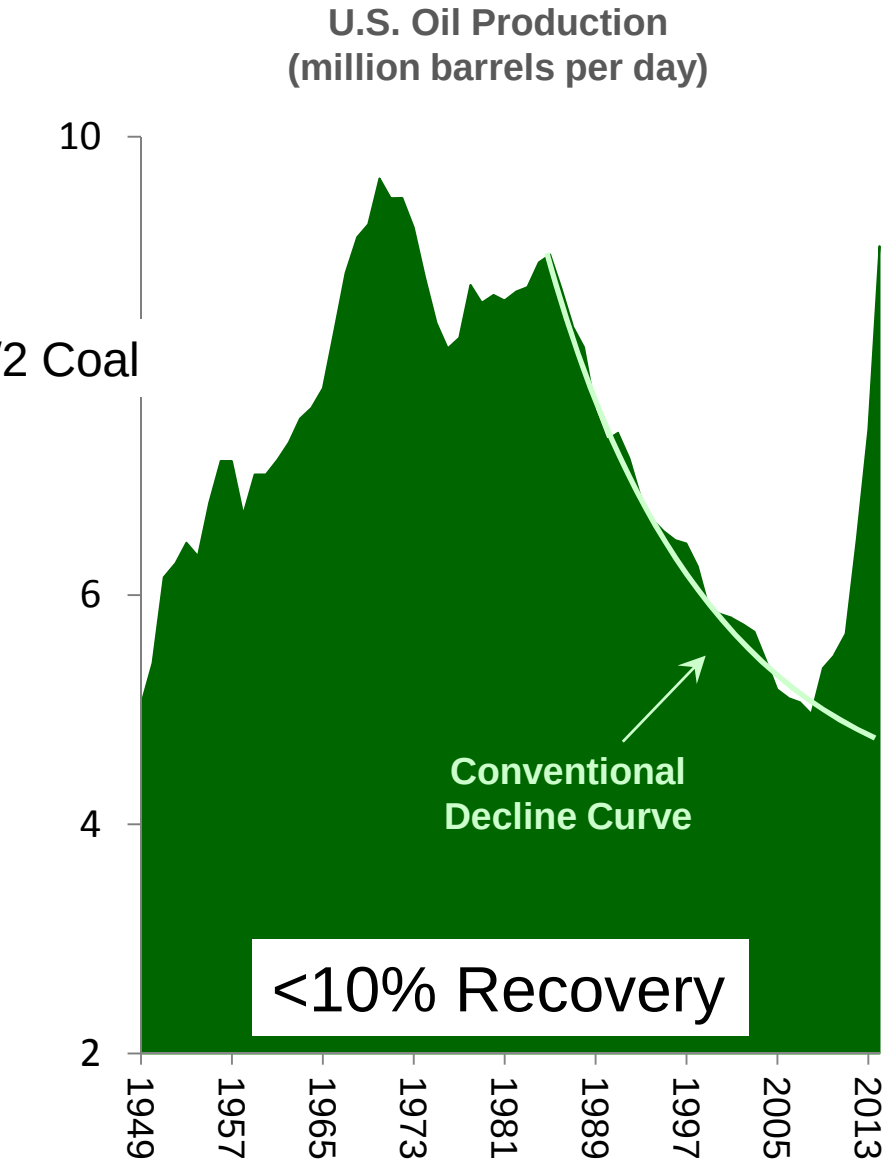
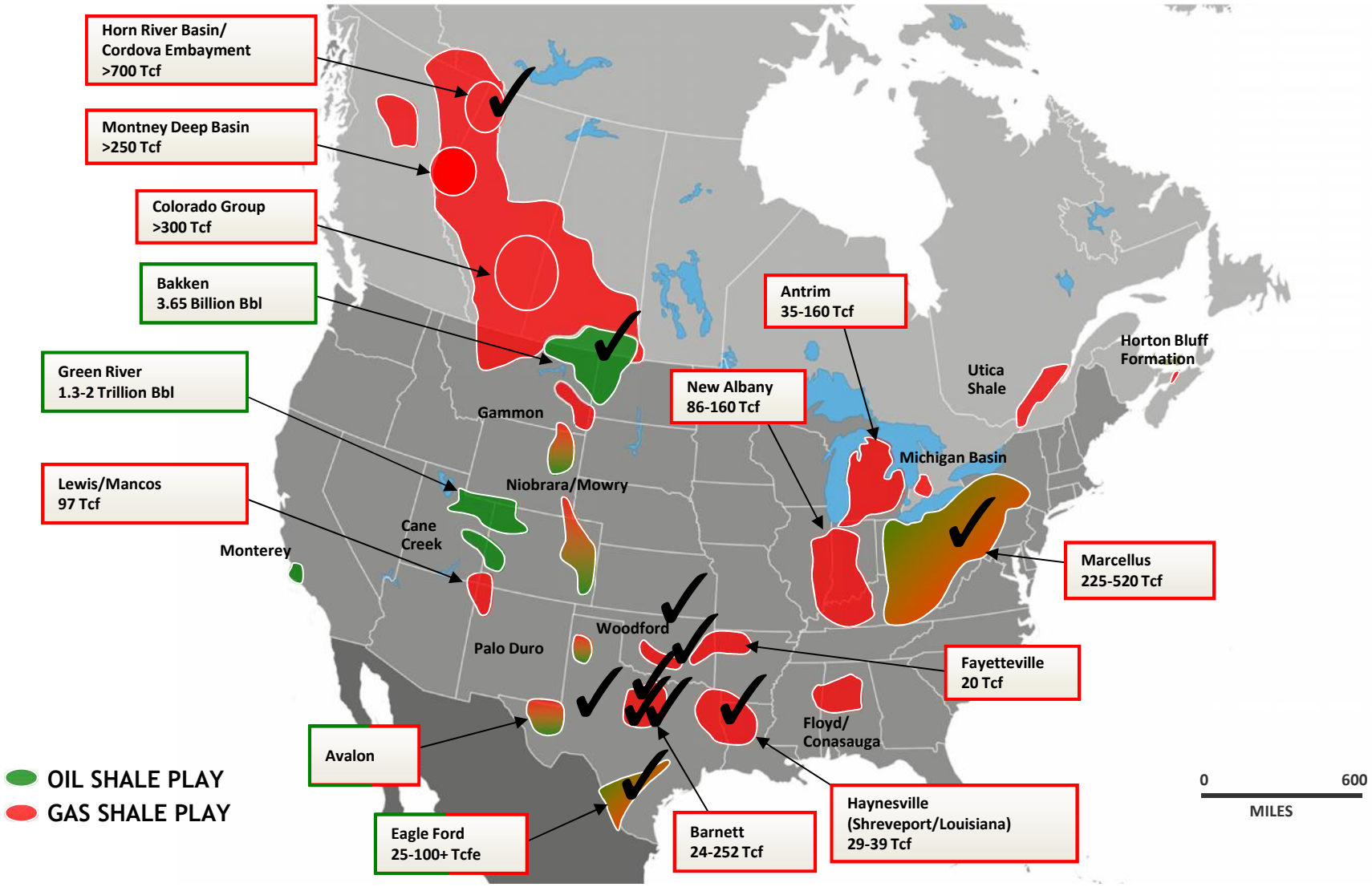
Unconventional Gas and Tight Oil Development



~1/2 Coal



Unconventional Gas, NG Liquids and Oil Development



Opportunities and Challenges of Shale Gas Production

The development of shale gas resources in an environmentally responsible manner presents a critical opportunity to move toward decarbonizing the global energy system.

Shale Gas Development

Opportunities and Challenges

Mark D. Zoback

Douglas J. Arent

Mark D. Zoback and
Douglas J. Arent

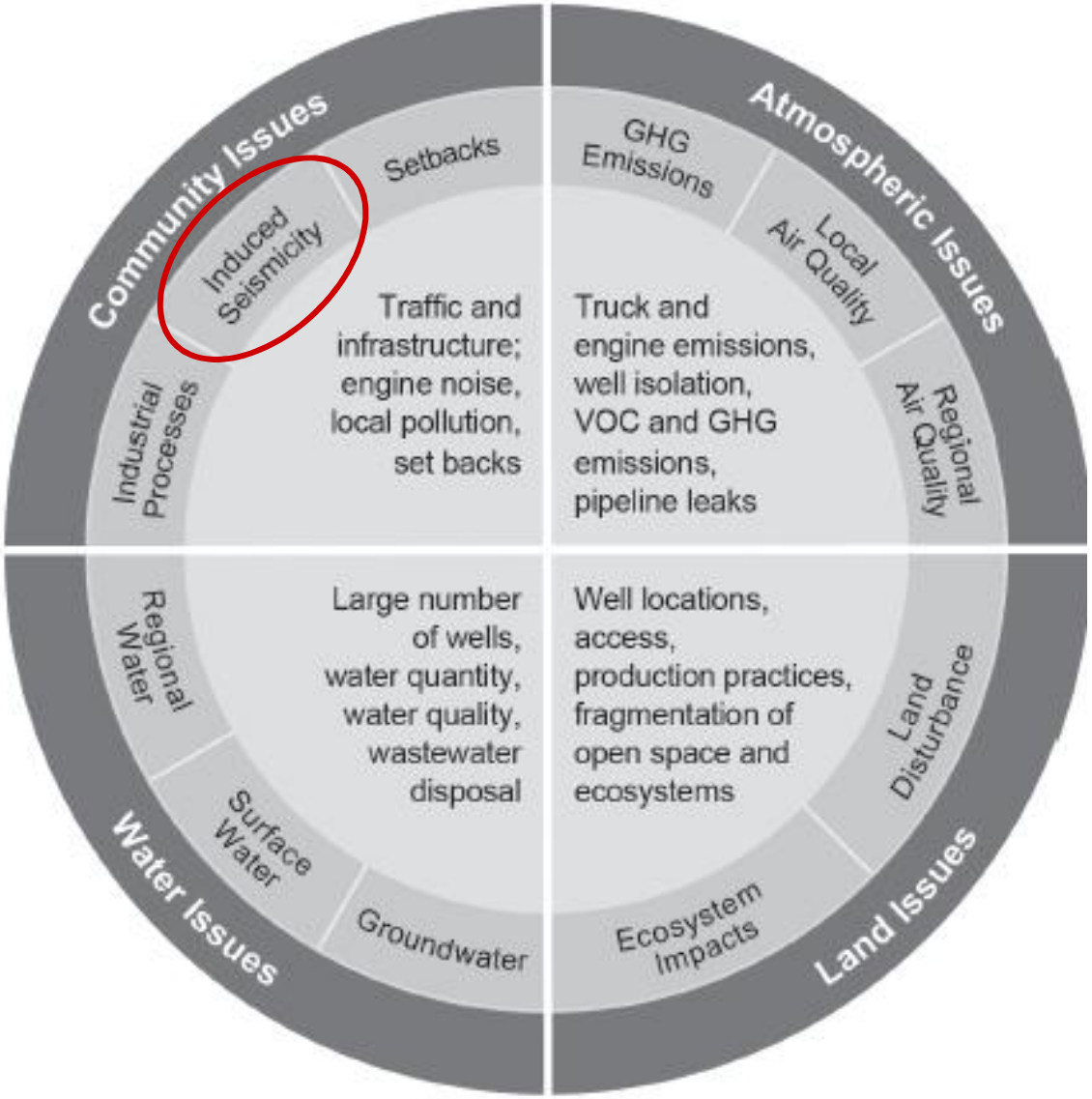
The use of horizontal drilling and multistage hydraulic fracturing technologies has enabled the production of immense quantities of natural gas, to date principally in North America but increasingly in other countries around the world. The global availability of this resource creates both opportunities and challenges that need to be addressed in a timely and effective manner.

There seems little question that rapid shale gas development, coupled with fuel switching from coal to natural gas for power generation, can have beneficial effects on air pollution, greenhouse gas emissions, and energy security in many countries. In this context, shale gas resources represent a critically important transition fuel on the path to a decarbonized energy future. For these benefits to be realized, however, it is imperative that shale gas resources be developed with effective environmental safeguards to reduce their impact on land use, water resources, air quality, and nearby communities.

Background

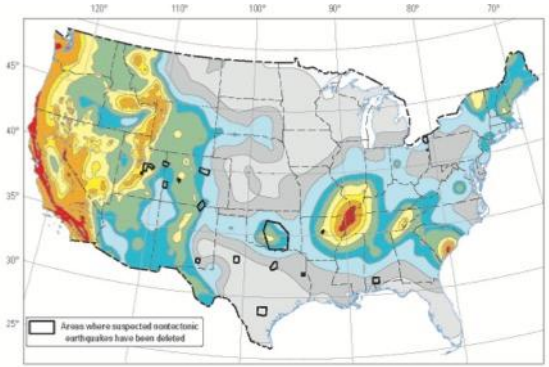
Geologists have long known that large amounts of organic matter and natural gas are trapped (usually by clay and other fine-grained minerals) in many

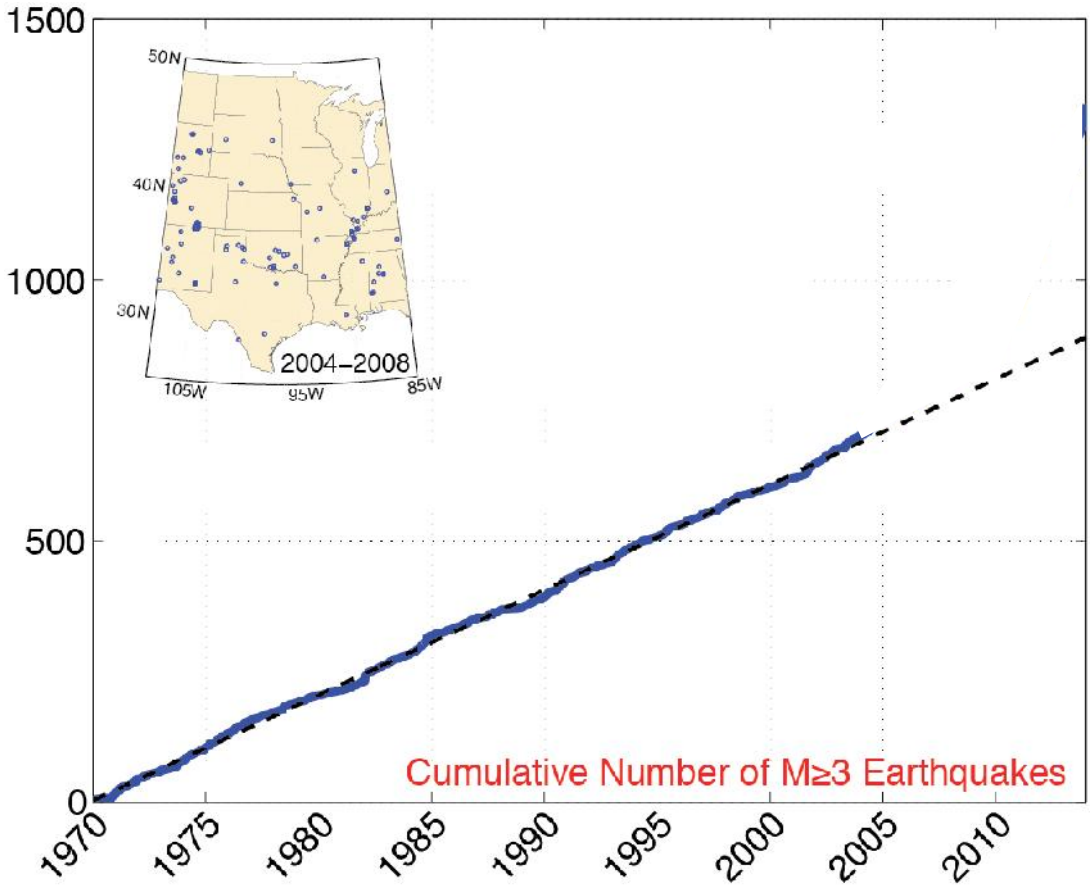
Mark D. Zoback (NAE) is a professor of geophysics at Stanford University. Douglas J. Arent is executive director of the Joint Institute for Strategic Energy Analysis at the National Renewable Energy Laboratory.



The Bridge (U.S. National Academy of Engineering), 2014

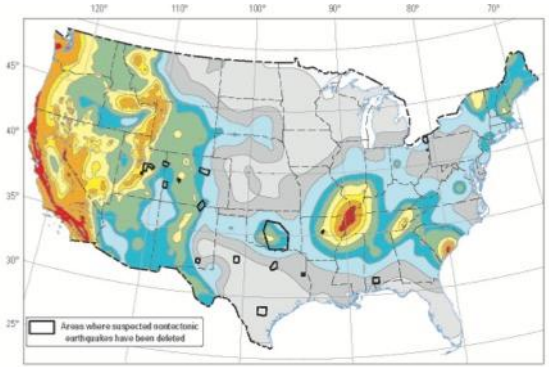
Earthquakes in the Mid-Continent

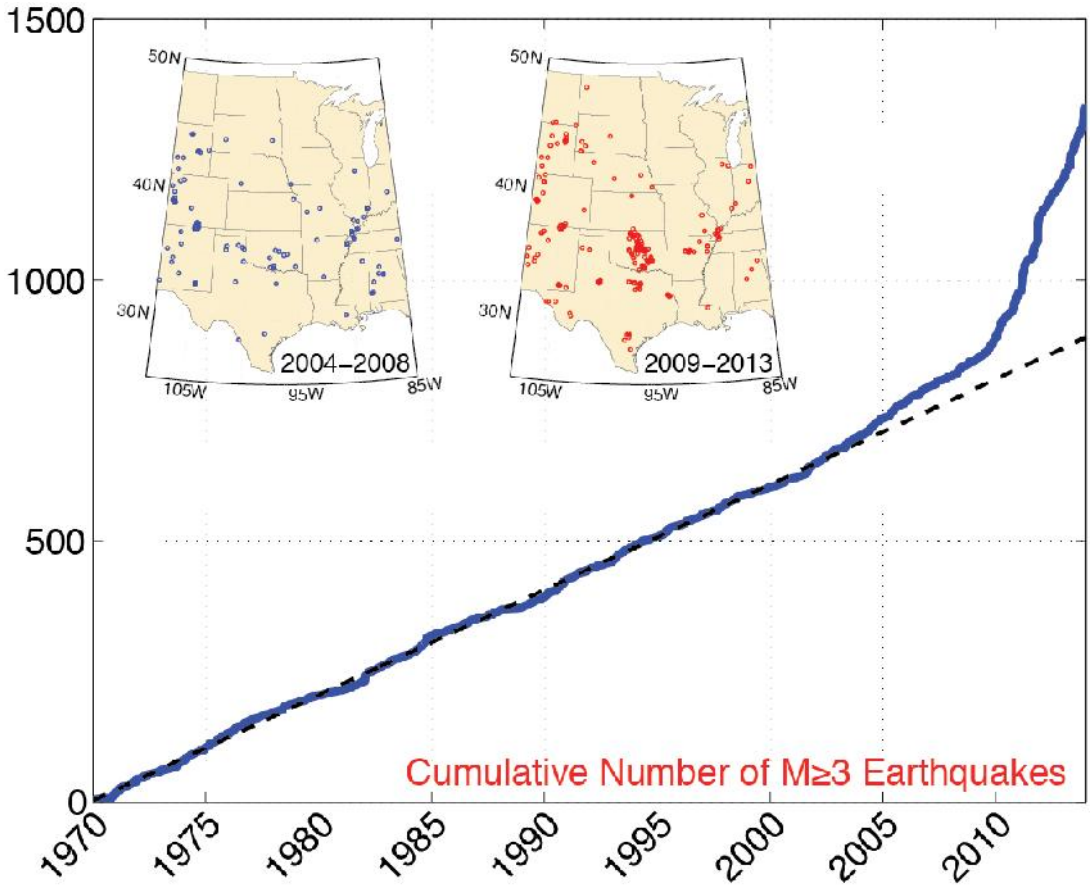




Ellsworth (2013)

Earthquakes in the Mid-Continent



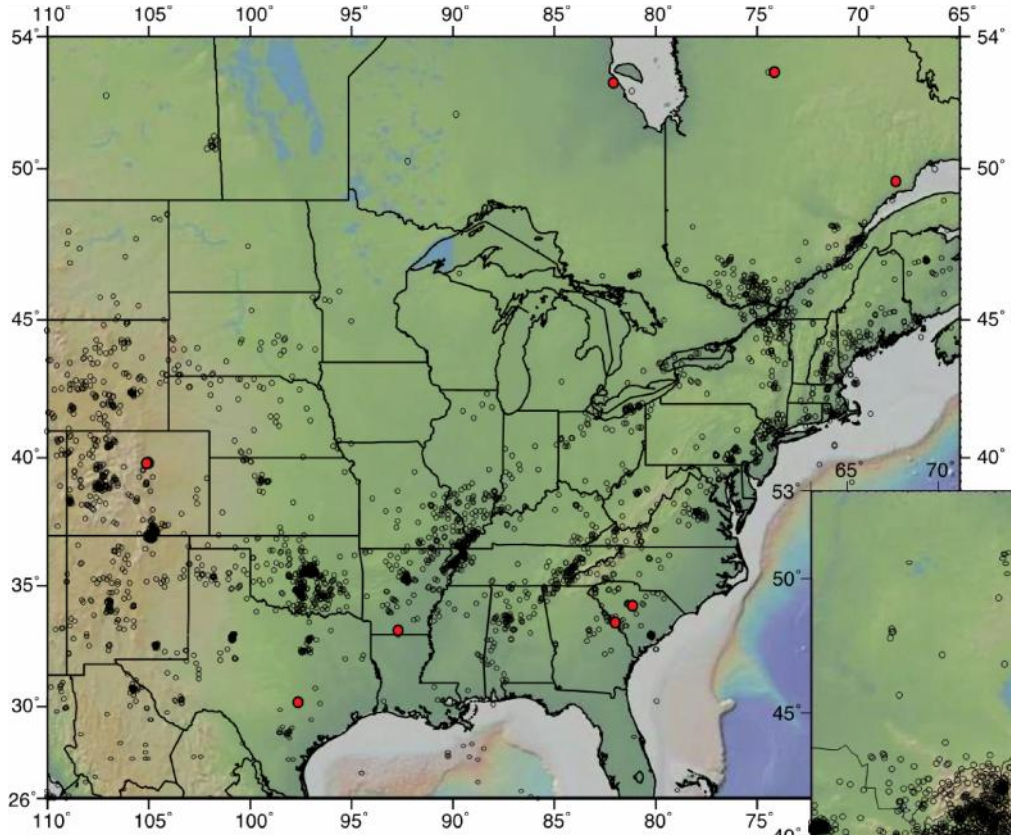


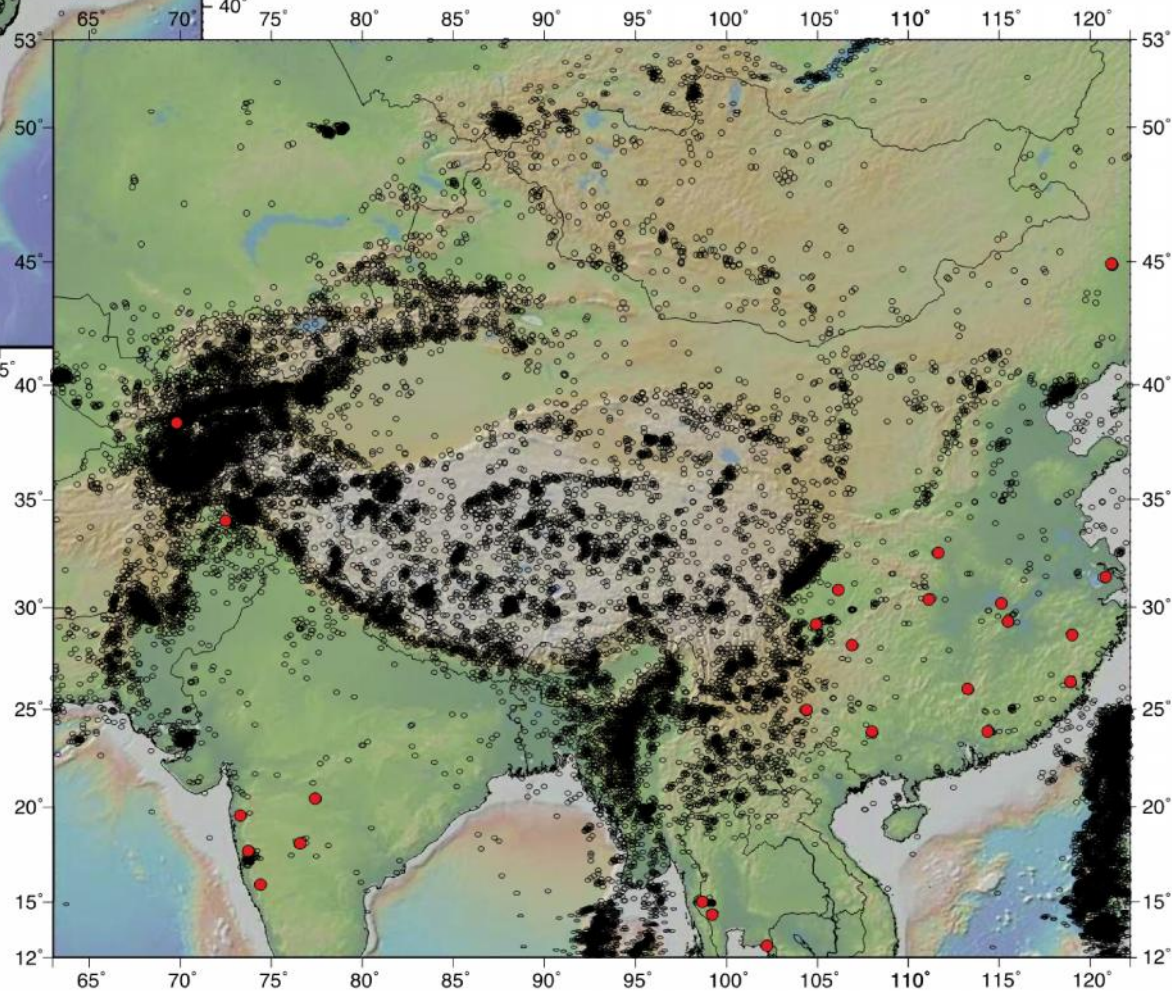
Ellsworth (2013)

Topics

- Earthquake Fundamentals - A Context for Understanding Earthquake Triggering
- More Earthquakes in Oklahoma Than California?
- Managing Earthquake Risk

I-We Live on a Critically-Stressed Crust



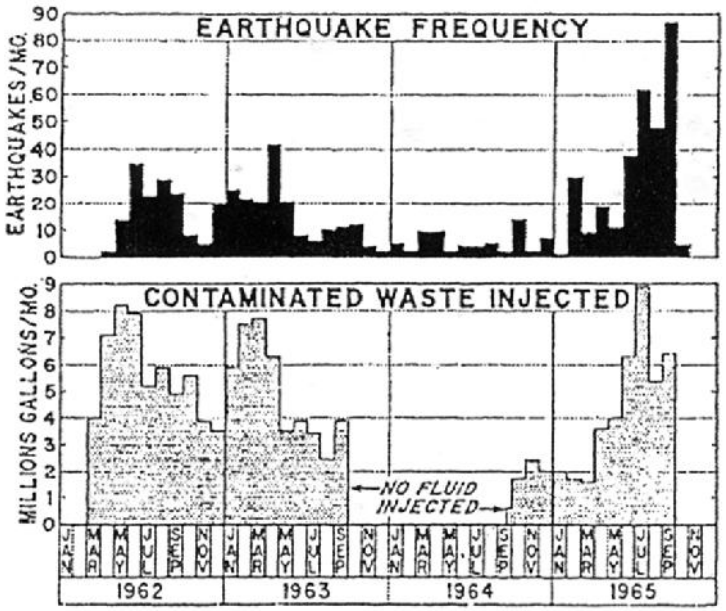


- Earthquakes Occur Nearly Everywhere in Intraplate Areas

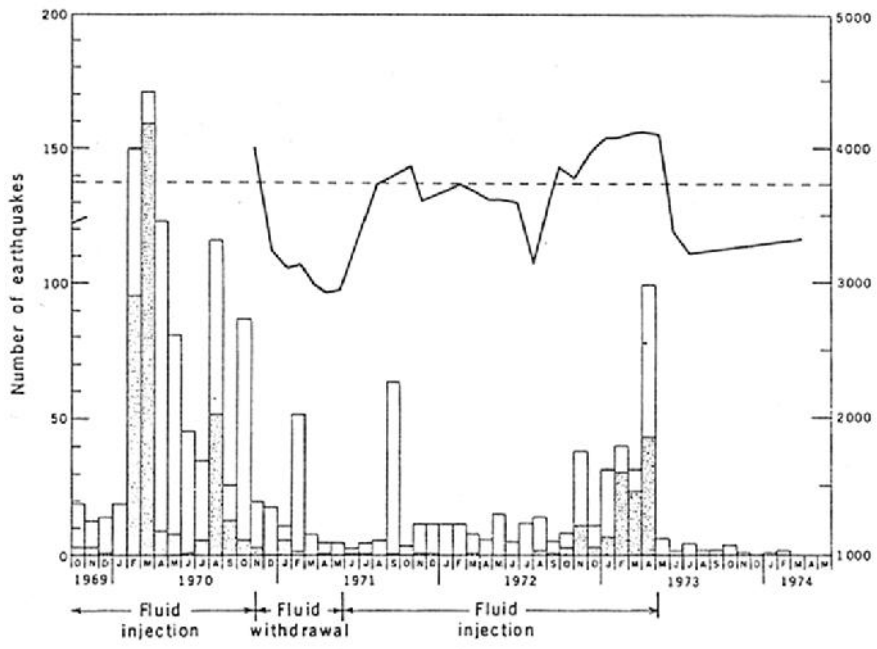
- Small Perturbations <RIS> Capable of Triggering Seismicity, Even in “Stable Areas”

II. Fluid Injection Can Induce Earthquakes

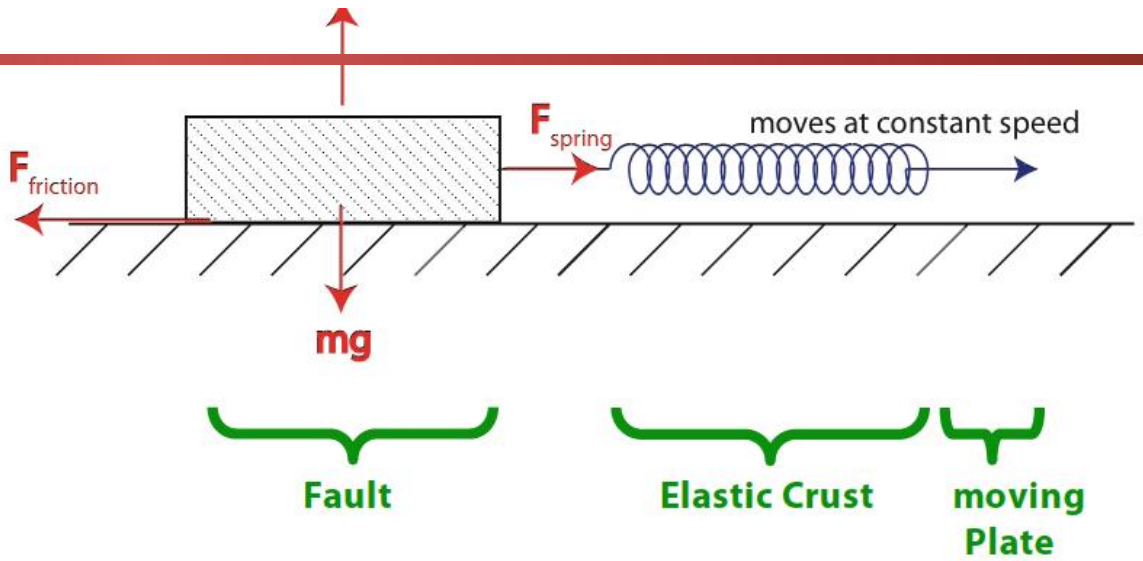
Waste Injection
Denver Arsenal



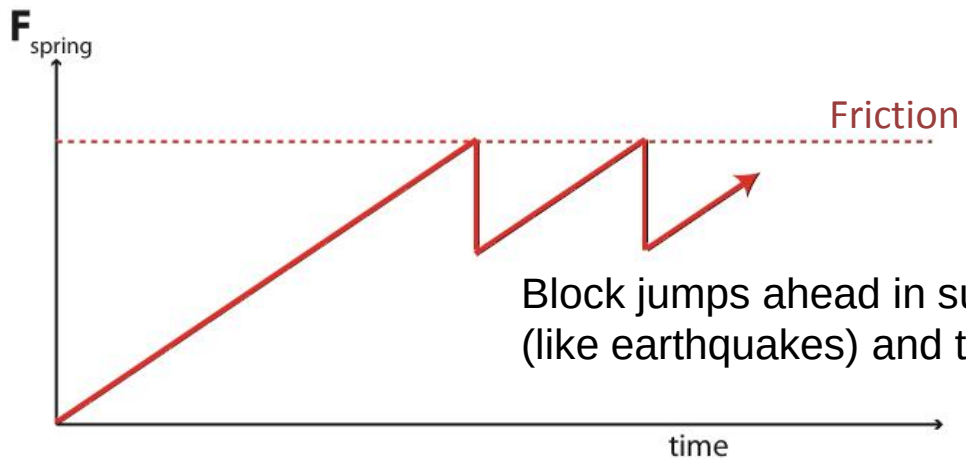
Fluid Injection
Rangely Oil Field



A Simple Earthquake Machine

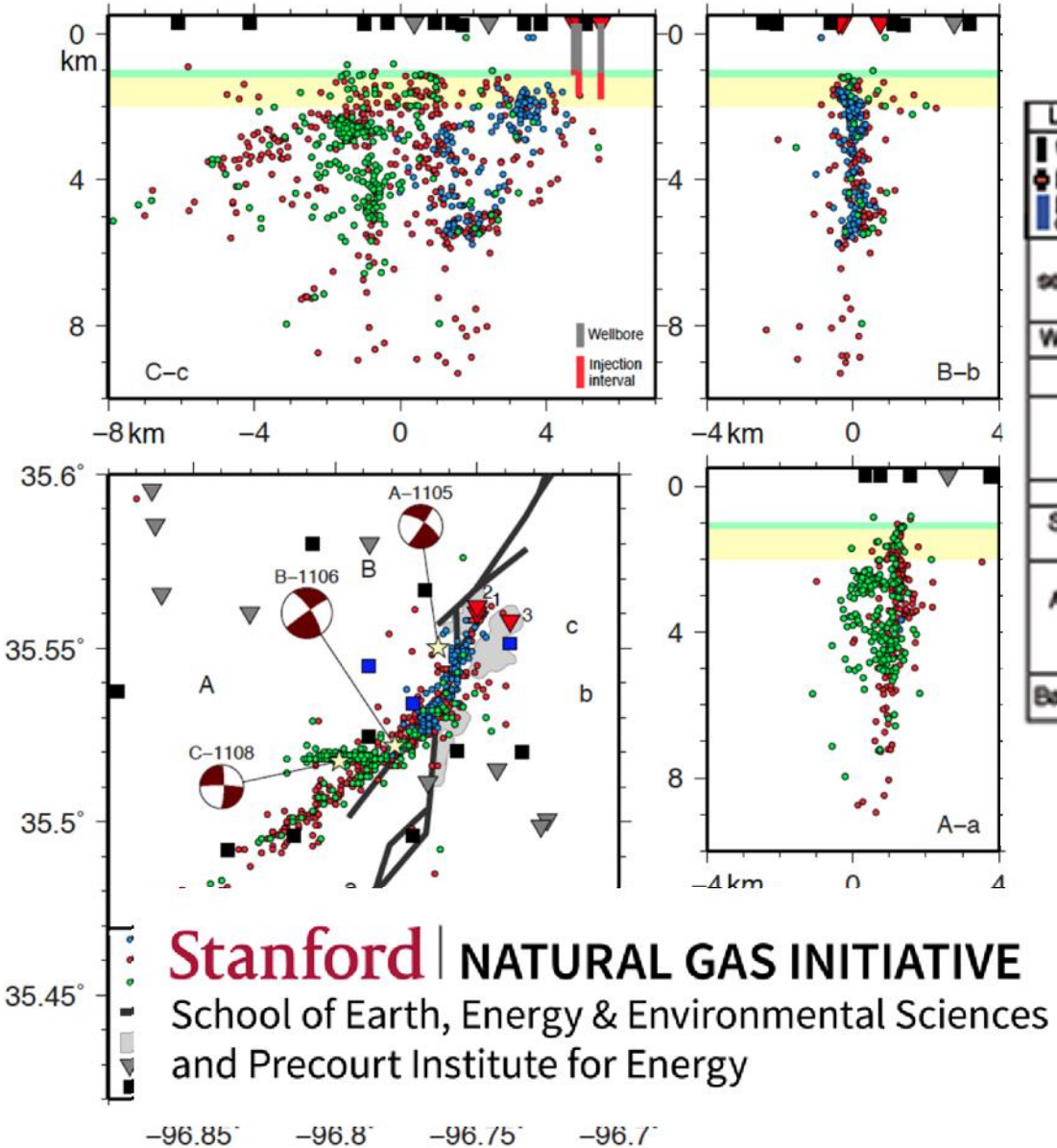


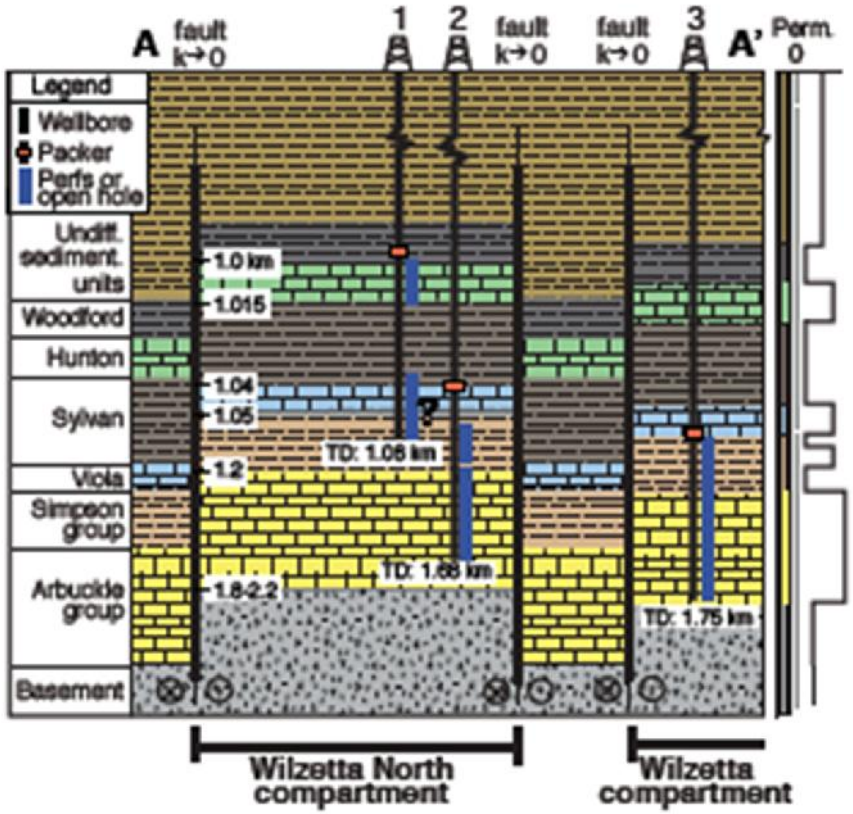
$$\tau = \mu_n \sigma \qquad \sigma_n = S_n - P_p$$



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

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





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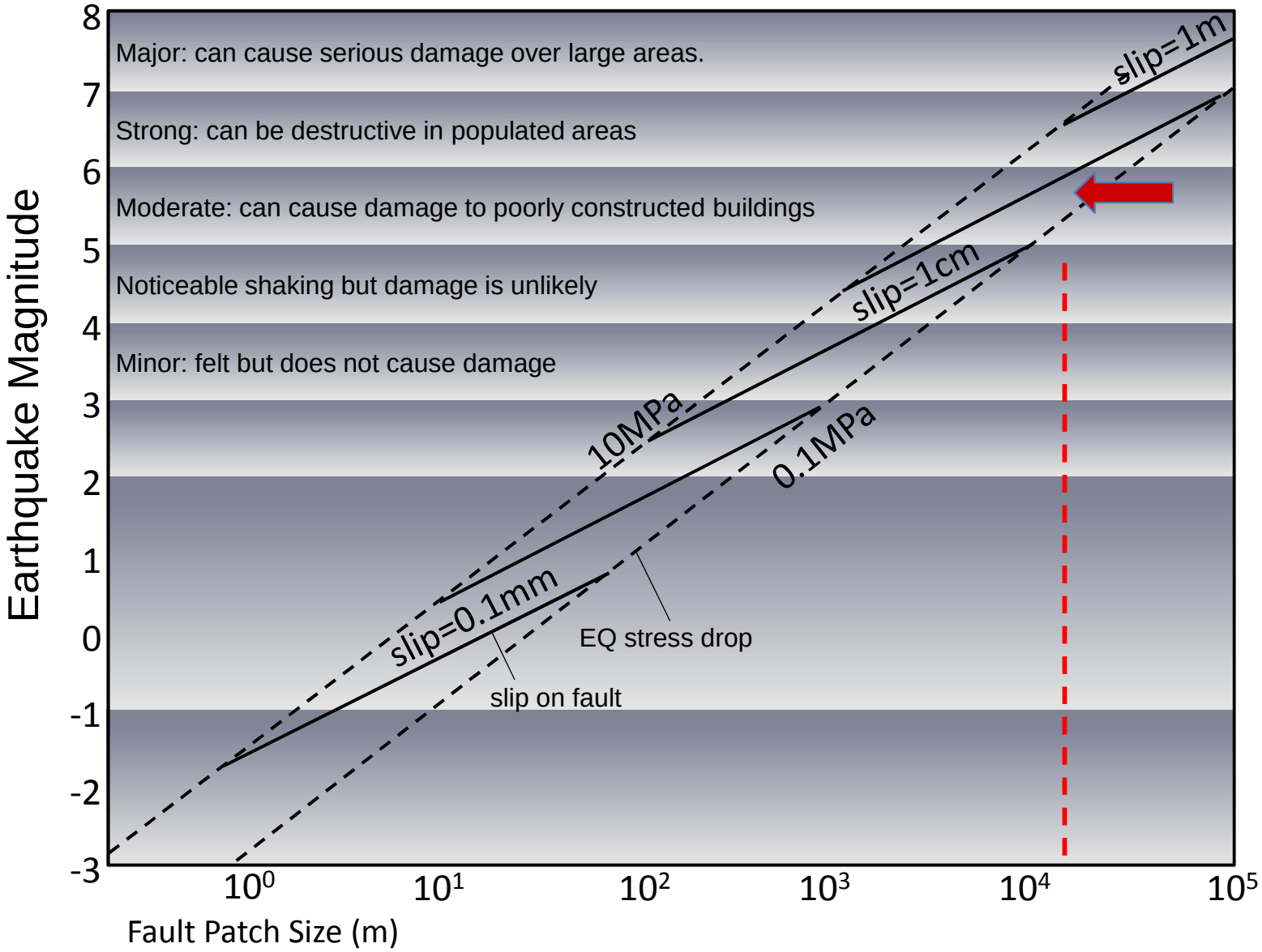
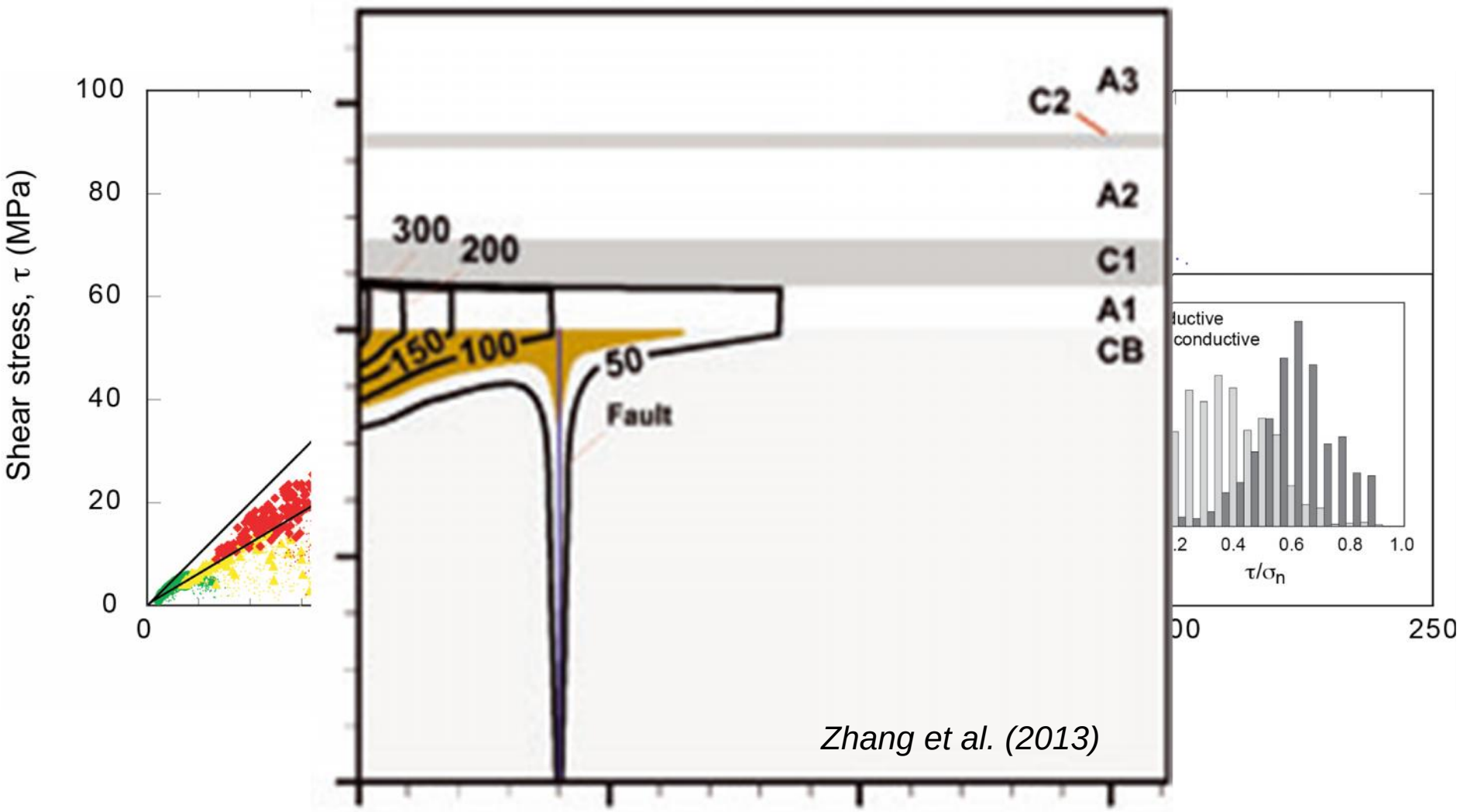
Prague Earthquakes
M ~5.7

Keranen et al. (2013)

Damaging Earthquakes Require Big Faults

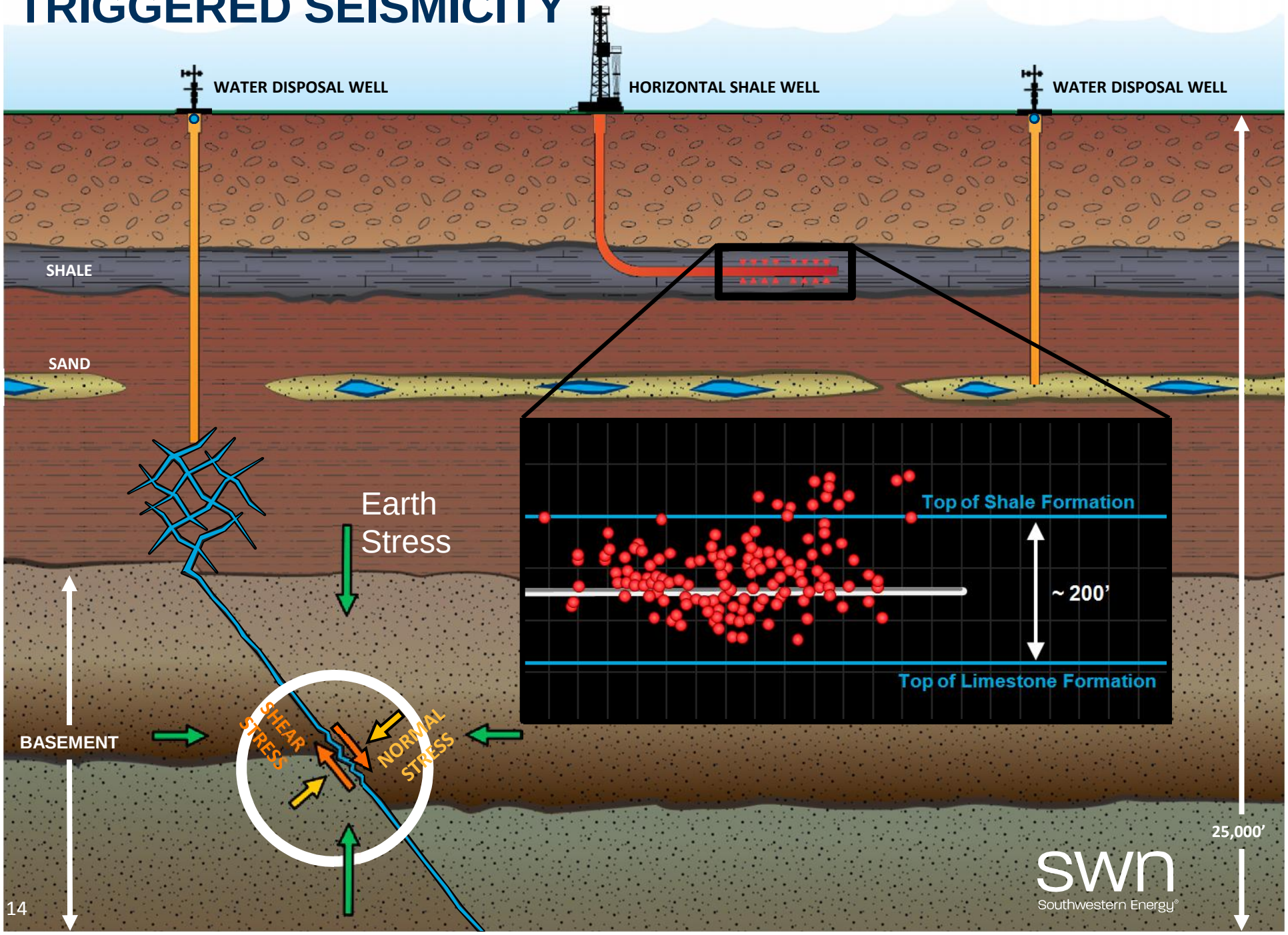


IV. Basement Faults That are *Potentially Active* in the Current Stress Field Are Also *Hydraulically Conductive*



Zoback and Townend (2001)

TRIGGERED SEISMICITY



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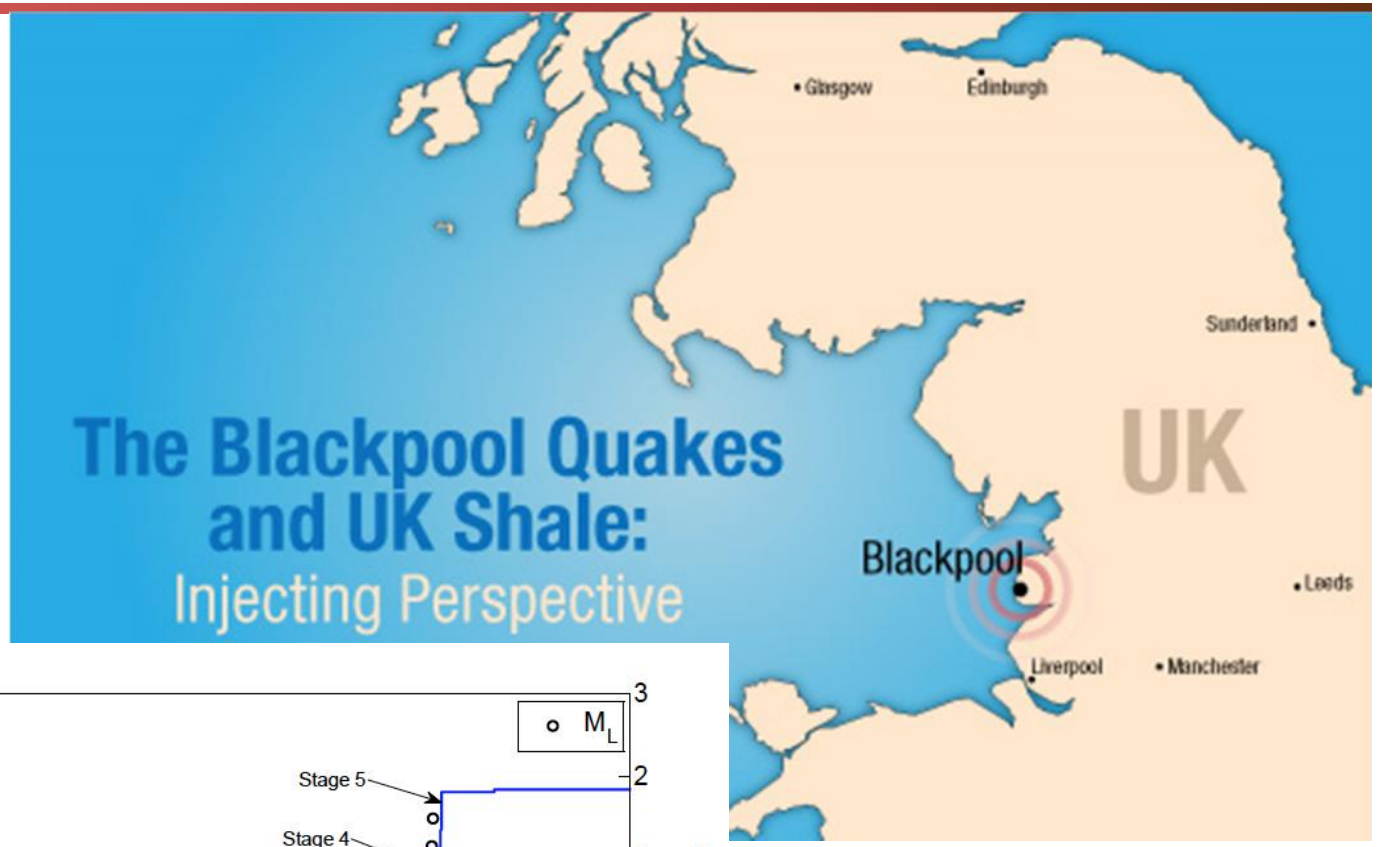
M 2.3 Earthquake During HF in Bowland Basin



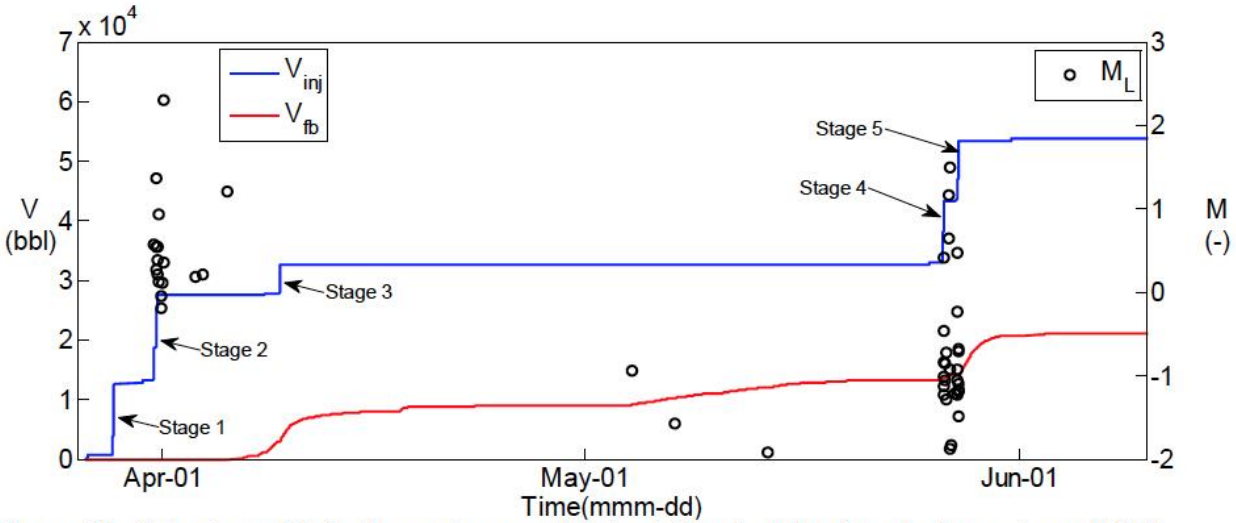


Figure 24: Overview of injection volume and seismicity of all treatment stages in well PH1. More small events were recorded in May because the monitoring system was improved with local stations.

Topics

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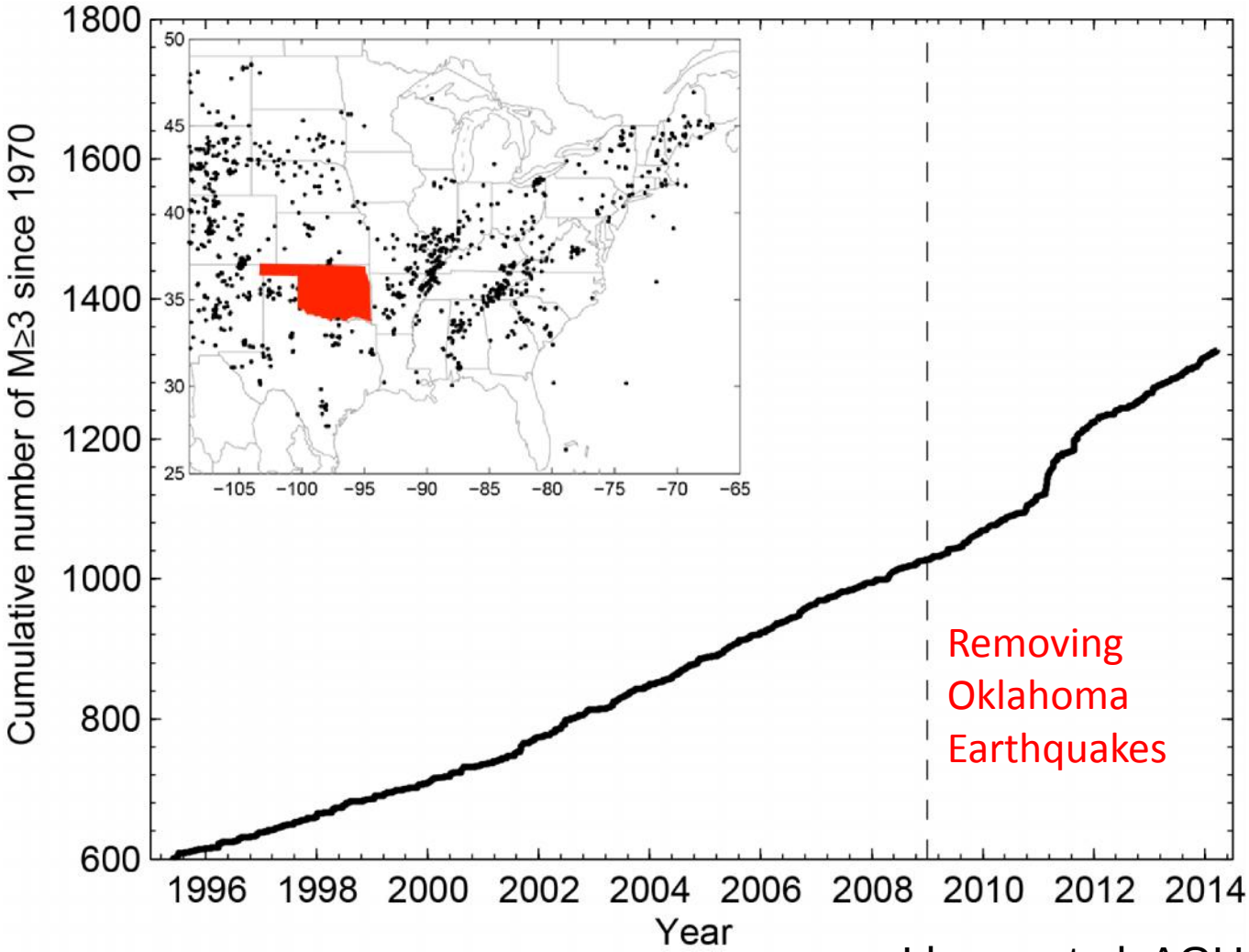
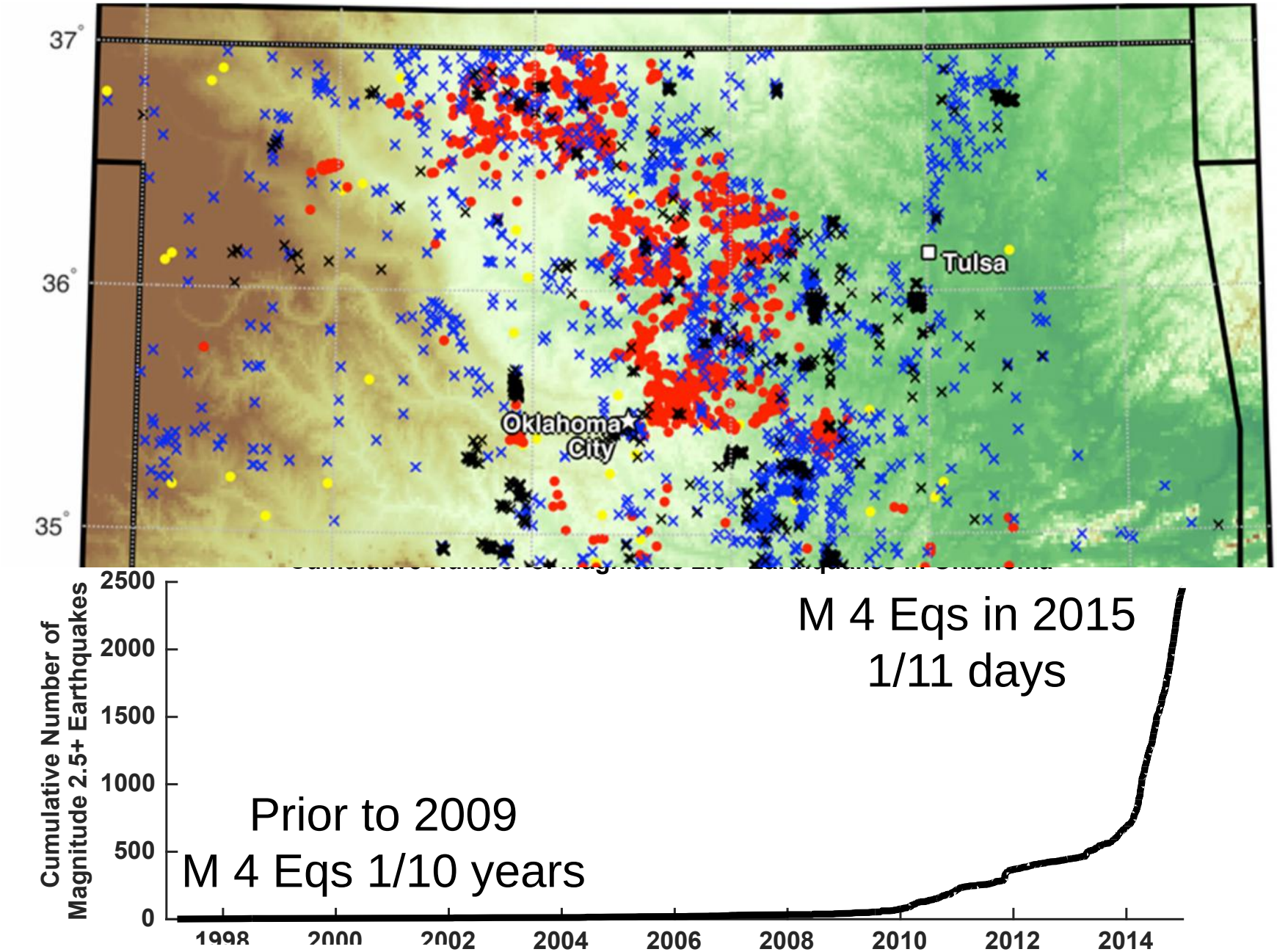
Oklahoma Has Had 69% of the Recent Earthquakes



Llenos et al. AGU (2014)



Walsh and Zoback (2015)

Science Advances

RESEARCH ARTICLE

SEISMOLOGY

Oklahoma's recent earthquakes and saltwater disposal

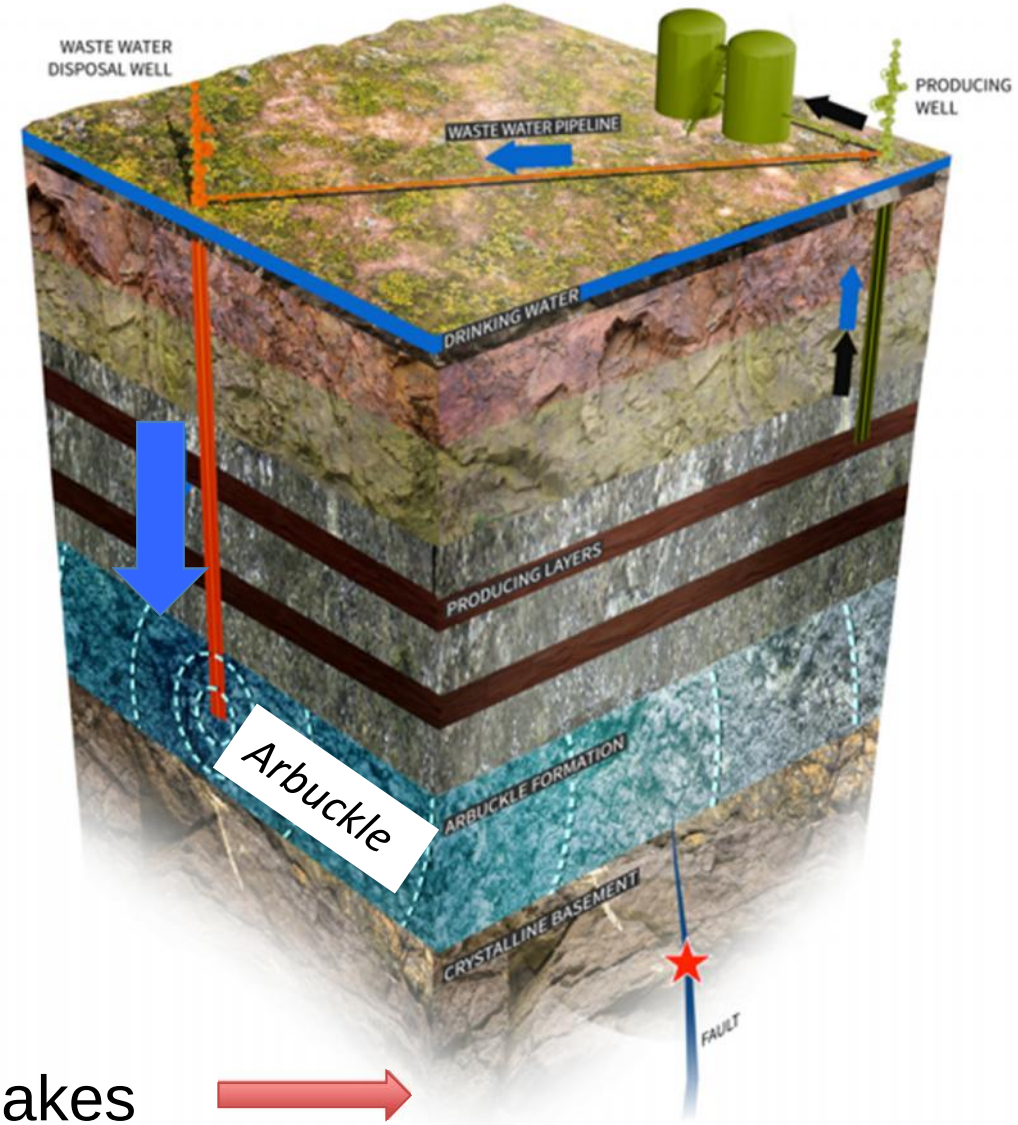
F. Rall Walsh III* and Mark D. Zoback

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.

Massive Injection of Produced Water

Oil and Saltwater Production

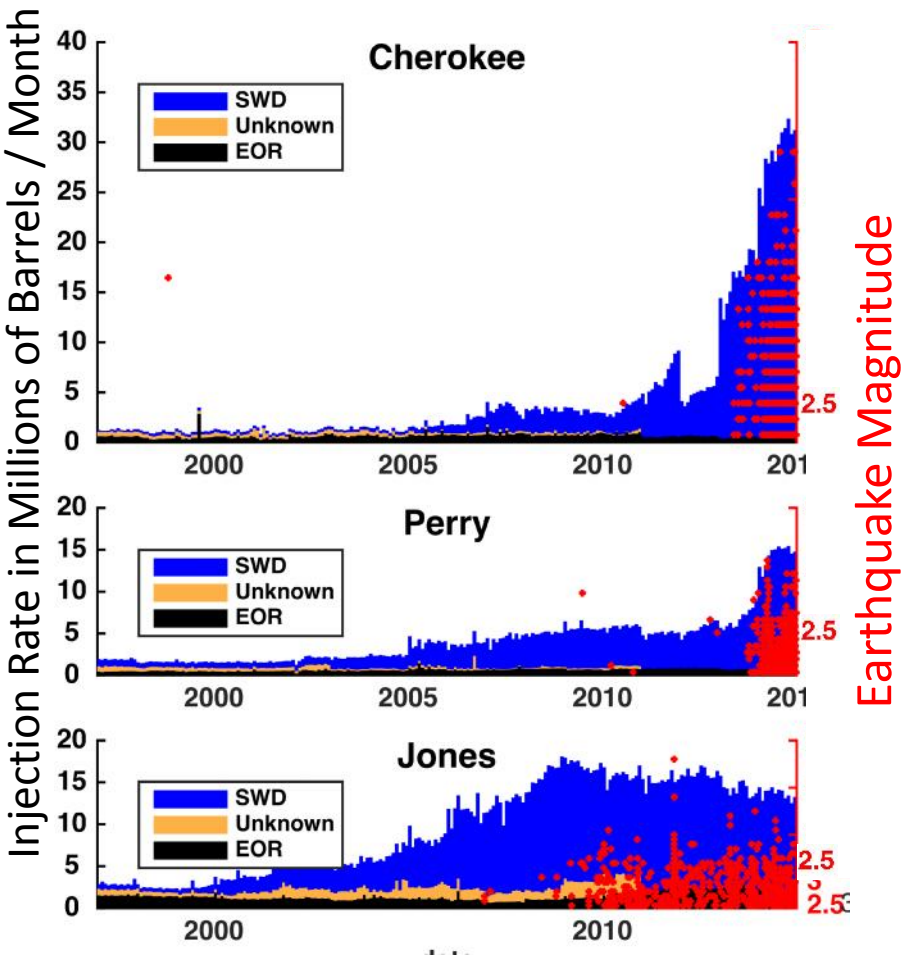
Salt Water Injection at 2 – 2.5 km
~700 Million Barrels
<1 MPa Pressure Change



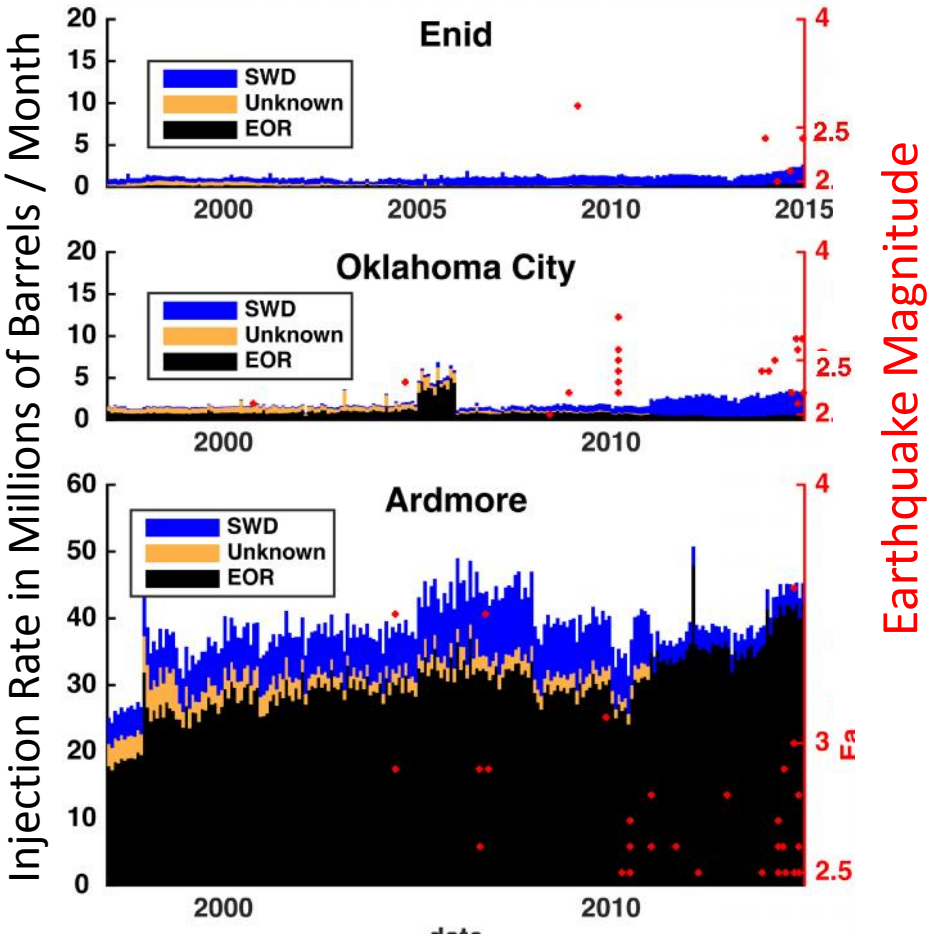
Earthquakes
5-6 km Depth

Areas With Increased Disposal Have Earthquakes

3 Areas with 71% of Oklahoma's Earthquakes

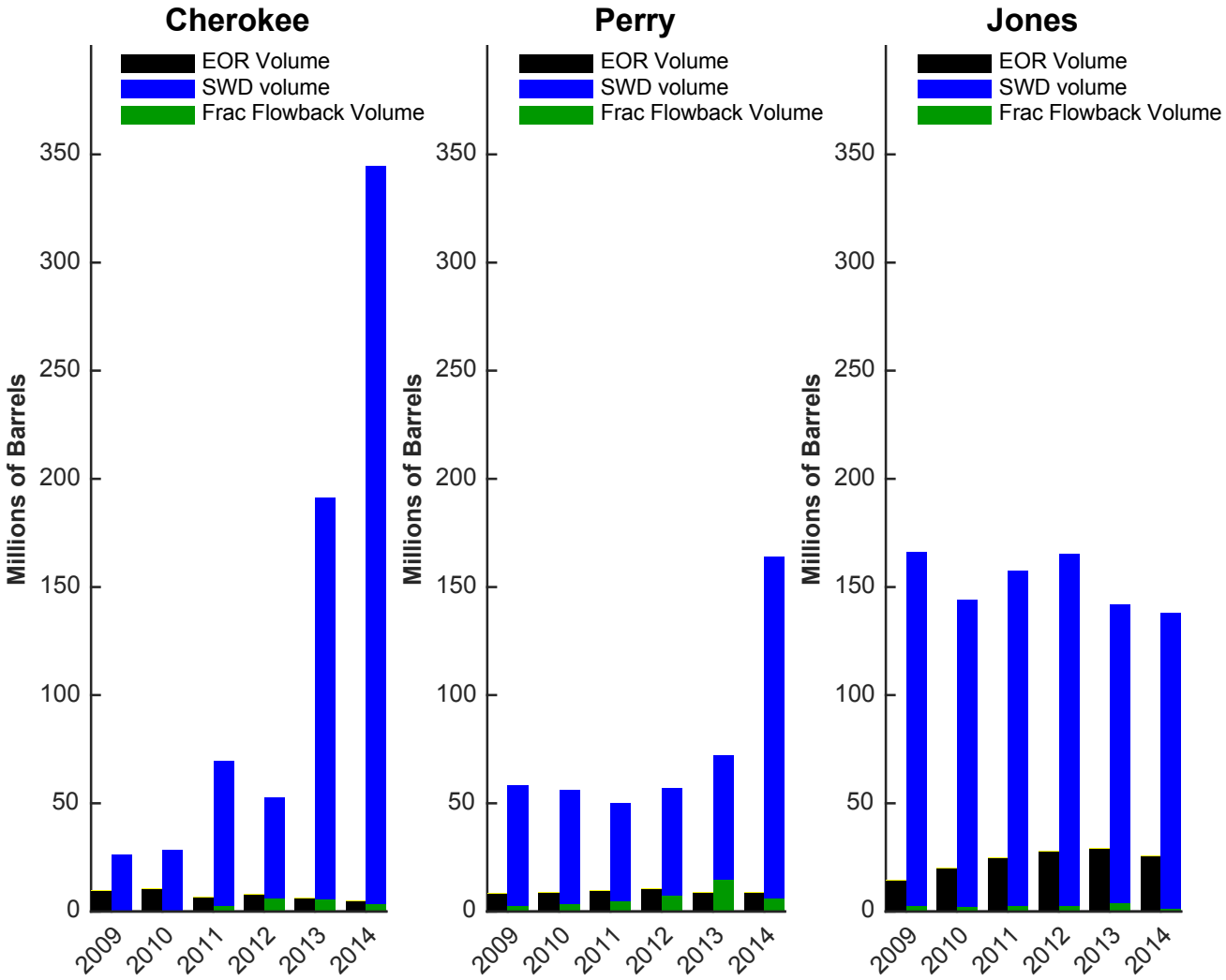


3 Areas with Few Earthquakes:



Map

Where Does the Wastewater Come From?



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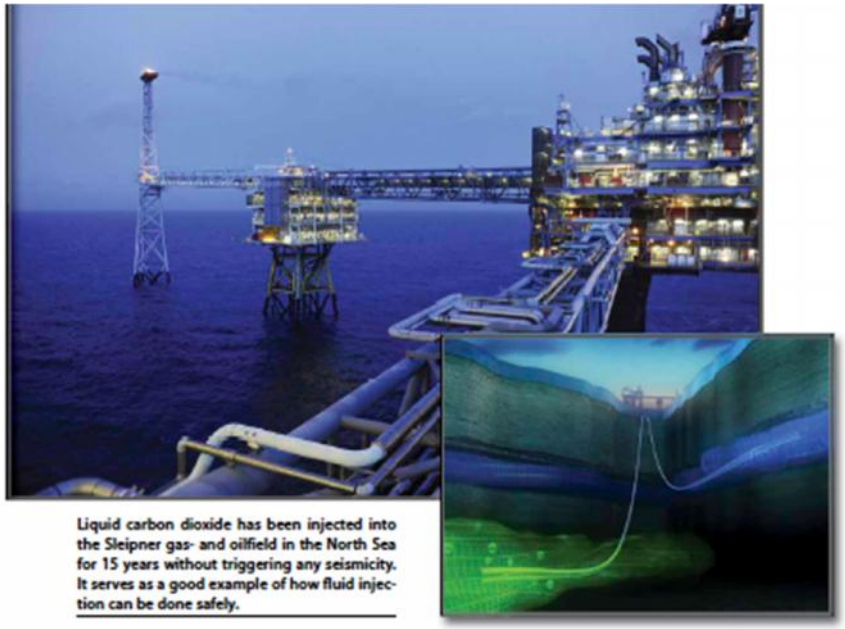
I. Be Proactive



Liquid carbon dioxide has been injected into the Sleipner gas- and oilfield in the North Sea for 15 years without triggering any seismicity. It serves as a good example of how fluid injection can be done safely.

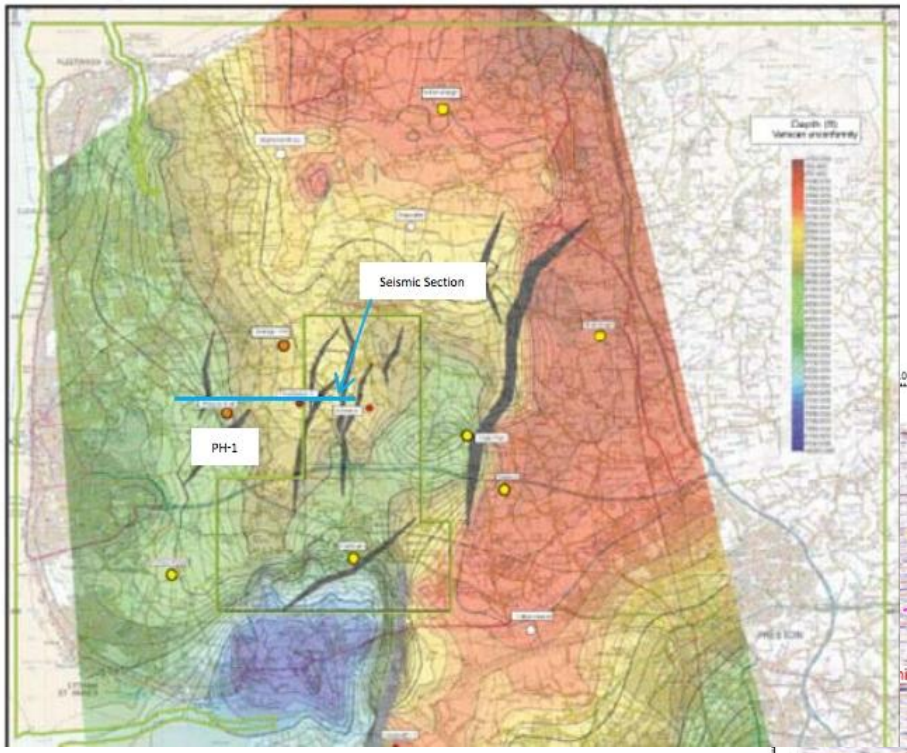
Managing the Seismic Risk Posed by Wastewater Disposal

Mark D. Zoback

From an earthquake perspective, 2011 was a remarkable year. While the devastation accompanying the magnitude-9.0 Tohoku earthquake that occurred off the coast of Japan on March 11 still captures attention worldwide, the relatively stable interior of the U.S. was struck by a somewhat surprising number of small-to-moderate earthquakes that were widely felt. Most of these were natural events, the types of earthquakes that occur from time to time in all intraplate regions. For example, the magnitude 5.8 that occurred in central Virginia on Aug. 23 was felt throughout the northeast, damaged the Washington Monument, and caused the temporary shutdown of a nuclear power plant. This earthquake occurred in the Central Virginia Seismic Zone, an area known to produce relatively frequent small earthquakes.

However, a number of the small-to-moderate earthquakes that occurred in the U.S. interior in 2011 appear to be associated with the disposal of wastewater, at least in part related to natural gas production. Several small earthquakes were apparently caused by injection of wastewater associated with shale gas production near Guy, Ark.; the largest earthquake was a magnitude-4.7 event on Feb. 27. In the Trinidad/Raton area near the border of Colorado and New Mexico, injection of wastewater associated with coalbed methane production seems to be associated with a magnitude-5.3 event that occurred on Aug. 22, and small earthquakes that appear to have been triggered by

II. Avoid Injection Near Potentially Active Faults



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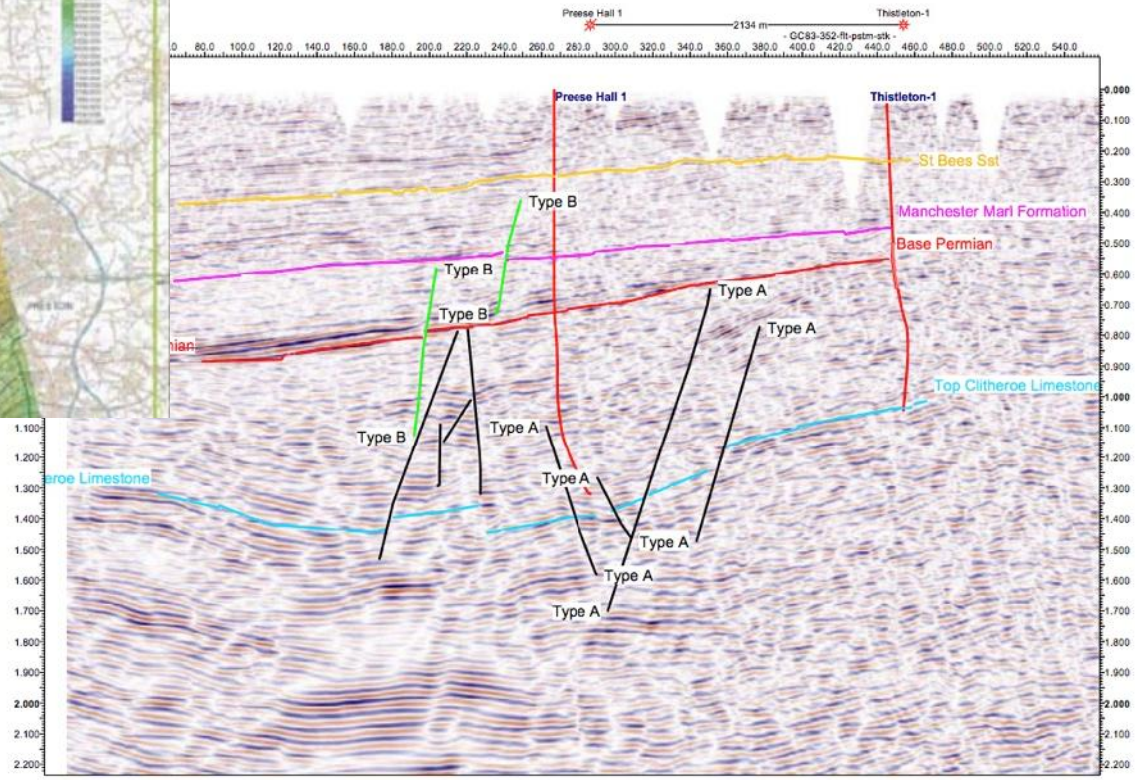

Figure 8: Reprocessed seismic section showing the two fault types, A and B in the proximity of Preese Hall-1 and Thistleton-1. The seismicity was caused by a type A fault that is contained in the Carboniferous.

Consider Water Recycling As in Pennsylvania


Thank you