Potential Relationships Between Deep Underground Injection of Liquids/Wastes and Earthquakes

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AAEE/NJWEA Workshop on Appalachian Shale Gas Environmental Policy, Development Activities And Management Practices

May 14, 2012

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Key Points

Injection or extraction of fluid at depth carries a risk of inducing earthquakes.

Hydrofracking, by itself, rarely triggers small earthquakes, and has not caused earthquakes large enough to be a safety concern.

The rate of earthquakes in the U.S. midcontinent has increased significantly in recent years, but few injection wells are triggering earthquakes.

The risk can be managed.

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Examples of Induced Earthquakes

- Rangely, CO, injection experiments (M4.9, 1995), 1945-1995
- Rocky Mountain Arsenal (M5.3, 1967), waste injection, 1962-1966
- Gazli, Uzbekistan, gas recovery (M7.2), 1976-1984
- Water Reservoirs: Lake Mead (M5), Koyna (M6.3), Oroville (6.1) Tadjikistan, Italy and many others
- Geysers Geothermal Field (M4.6), injection-enhanced production
- Dallas Airport (M3.3), waste injection, 2008-2009
- Arkansas (M4.7), waste injection, 2010-2011
- Youngstown, Ohio (M4.0),waste injection, 2011

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Activities Entailing Fluid Injection at Depth

- **Waste liquid disposal of all types**
- **Geothermal production and Enhanced Geothermal Systems (EGS)**
- **Tight shale gas, tight sand and coal-bed methane production**

  (for disposing of "formation water")
- **Carbon dioxide sequestration**

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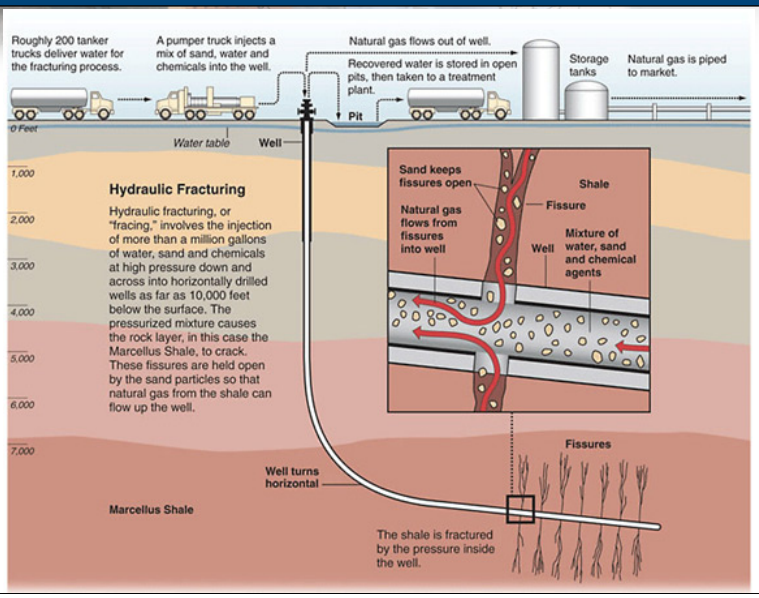
Hydrofracking and Earthquakes



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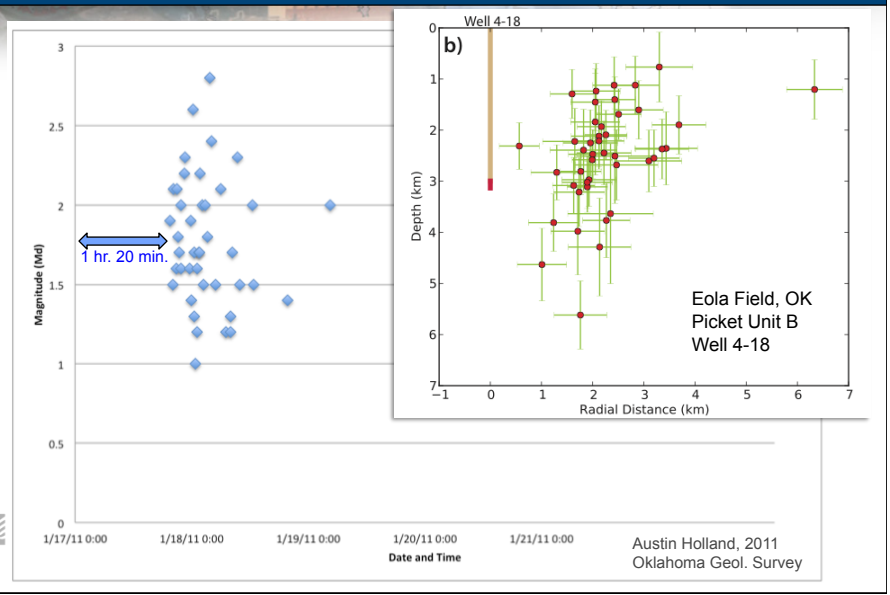
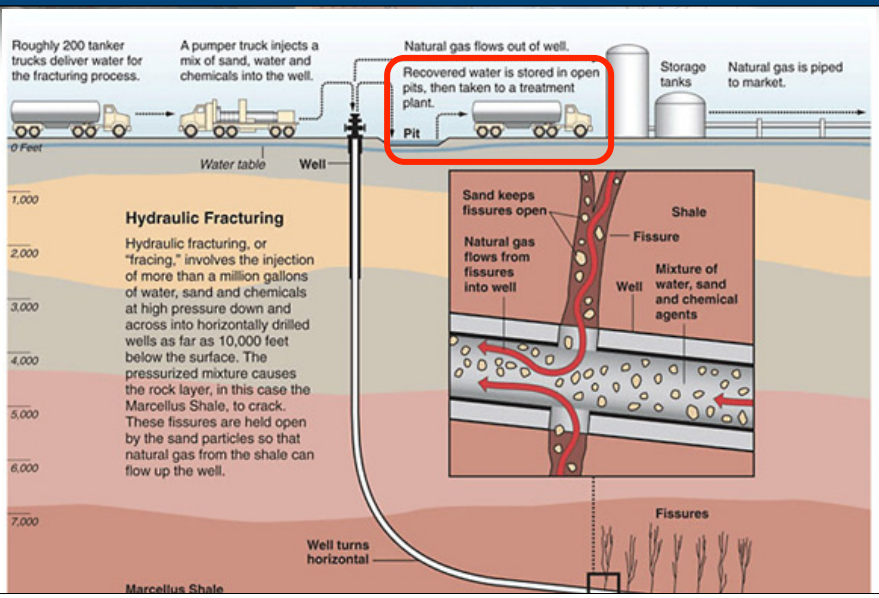
Example of Fracking-Triggered Quakes



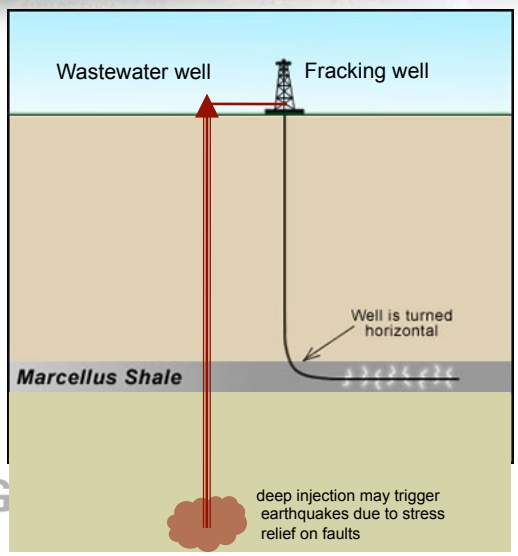
Austin Holland, 2011
Oklahoma Geol. Survey

Hydrofracking and Earthquakes



A by-product of the fracking operation is "produced water" (natural brine and fracking flowback)

Disposal of Fluids from Fracking



adapted from geology.com

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Wastewater (brine) injection depths are usually deep, in rocks naturally stressed with faults capable of generating earthquakes

Induced Seismicity and Enhanced Recovery

- Below a few kilometers depth, the Earth's crust is everywhere stressed. Stress measurements across the U.S. indicate that those natural stresses put faults and fractures at close to failure.
- The injection activity, which forces fluid along faults and fractures at high pressure relieves the effective stress on those faults, making triggered earthquakes more likely
- The formation of new fractures –i.e. the *hydrofrac* itself, actually doesn't release much energy compared to the triggered quakes.
- But large volumes of fluid are injected as waste, these flow along faults, reducing the effective stress on them and potentially triggering earthquakes

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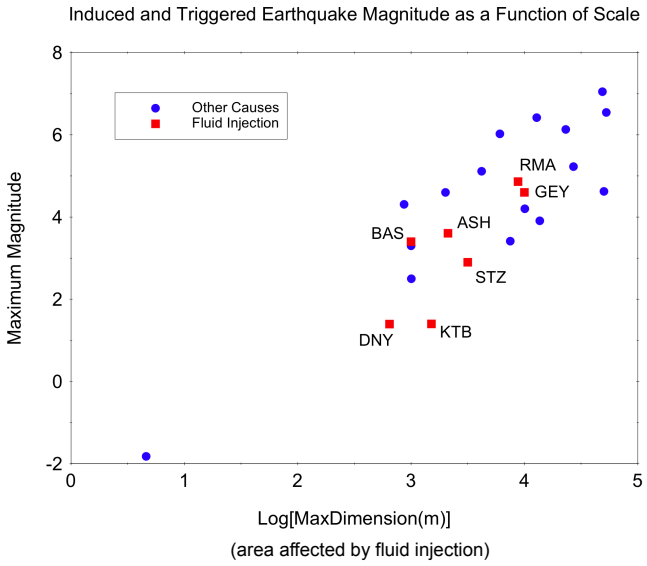
How large can a triggered earthquake be?



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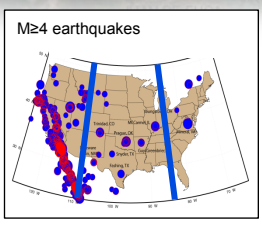
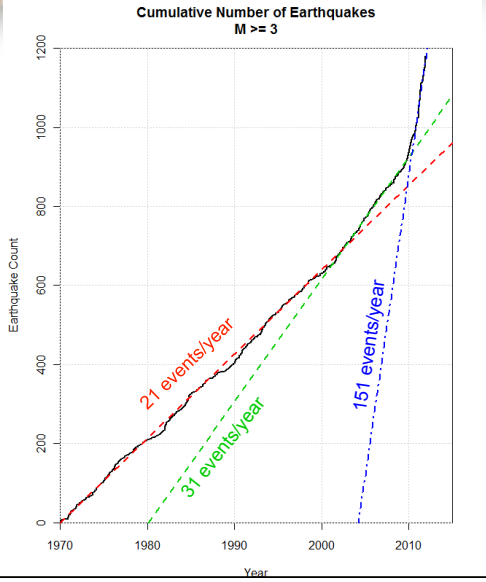
Rate of Earthquakes in the Midcontinent



Earthquake frequency in the central U.S. increased 50% in 2000, and then over seven-fold in 2008

Ellsworth and others, 2012



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Arkansas: Wastewater Injection at Shale Gas Play

- As part of an enhance recovery operation (shale gas play), large volumes of wastewater are being injected at depths of 2-4 km.
- Hundreds of shallow earthquakes have been triggered, the largest, M4.7, causing damage in nearby towns. These quakes are at about the same depth of the injections.
- In April, 2011, the Arkansas oil and gas commission halted injection activities at two main disposal wells, and earthquakes were dramatically reduced in number and magnitude.

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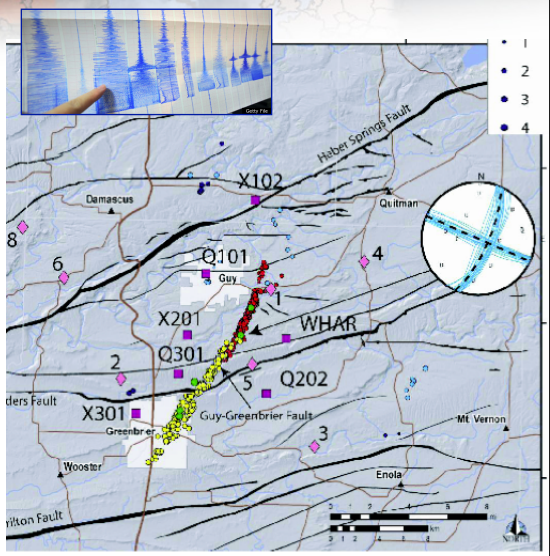

Research Questions

Why do triggered earthquakes occur in some places and not others?

Can injection practices be altered to minimize the risk of triggered earthquakes?

Once a significant earthquake occurs, what process changes should be implemented?

How do the answers to these questions relate to regulation and permitting?

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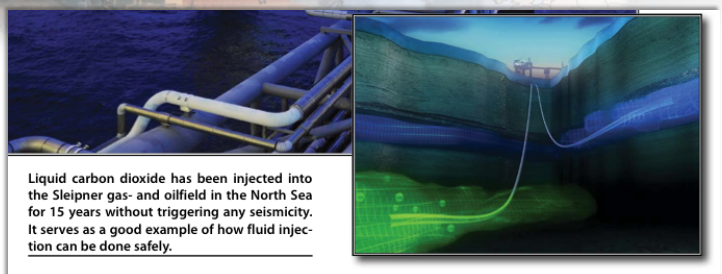
Can injection-induced quakes be controlled?

Earth Magazine
April 2012



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, 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,

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Can injection-induced quakes be controlled?

The Experiment at Rangely, Colorado (1960s)

- "Experiments in an oil field at Rangely have demonstrated the feasibility of earthquake control. Variations in seismicity were produced by controlled variations in the fluid pressure in a seismically active zone.
- "Fluid pressure was controlled by alternately injecting and recovering water from wells that penetrated the seismic zone. Fluid pressure was monitored in observation wells, and a model of the reservoir was used to infer the fluid pressure distributions in the vicinity of the injection wells.
- "The results of this experiment confirm the predicted effect of fluid pressure on earthquake activity and indicate that earthquakes may be controlled through manipulating the fluid pressure in a fault zone."

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Need more information?

See our FAQ on
Earthquakes Triggered by Fluid Injection

http://earthquake.usgs.gov

and blog on recent earthquake rate changes

http://www.doi.gov/news/doinews/Is-the-Recent-Increase-in-Felt-Earthquakes-in-the-Central-US-Natural-or-Manmade.cfm

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