Findings and Update on the National Research Council's Committee on Induced Seismicity Potential of Energy Production and Related Technologies*

David K. Dillon[1] and Don Clarke[2]

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Abstract

Earthquakes attributable to human activities, “induced seismic events”, have received heightened public attention in the United States over the past several years. Upon request from the U.S. Congress and the Department of Energy, the National Research Council was asked to assemble a committee of experts to examine the scale, scope, and consequences of seismicity induced during fluid injection and withdrawal associated with geothermal energy development, oil and gas development, and carbon capture and storage (CCS). The committee's report, publicly released in June 2012, indicates that induced seismicity associated with fluid injection or withdrawal is caused in most cases by change in pore fluid pressure and/or change in stress in the subsurface in the presence of faults with specific properties and orientations and a critical state of stress in the rocks. The factor that appears to have the most direct consequence in regard to induced seismicity is the net fluid balance (total balance of fluid introduced into or removed from the subsurface). Energy technology projects that are designed to maintain a balance between the amount of fluid being injected and withdrawn, such as most oil and gas development projects, appear to produce fewer seismic events than projects that do not maintain fluid balance. Major findings from the study include: (1) as presently implemented, the process of hydraulic fracturing for shale gas recovery does not pose a high risk for inducing felt seismic events; (2) injection for disposal of waste water derived from energy technologies does pose some risk for induced seismicity, but very few events have been documented over the past several decades relative to the large number of disposal wells in operation; and (3) CCS, due to the large net volumes of injected fluids suggested for future large-scale carbon storage projects, may have potential for inducing larger seismic events.

References Cited

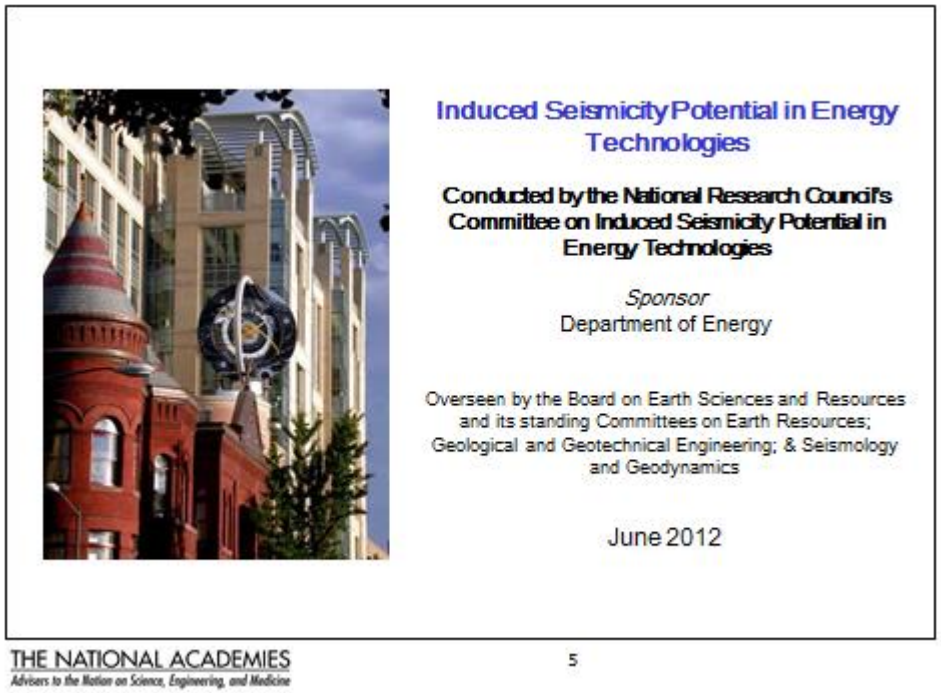
McGarr, A., 2014, Maximum Magnitude Earthquakes Induced by Fluid Injection: Journal of Geophysical Research, v. 119/2, p. 1008-1019.

Petersen, M.D., C.S. Mueller, M.P. Moschetti, S.M. Hoover, J.L. Rubinstein, A.L. Llenos, A.J. Michael, W.L. Ellsworth, A.F. McGarr, A.A. Holland, and J.G. Anderson, 2015, Incorporating Induced Seismicity in the 2014 United States National Seismic Hazard Model - Results of 2014 Workshop and Sensitivity Studies: U.S. Geological Survey Open-File Report 2015 - 1070, 69 p.

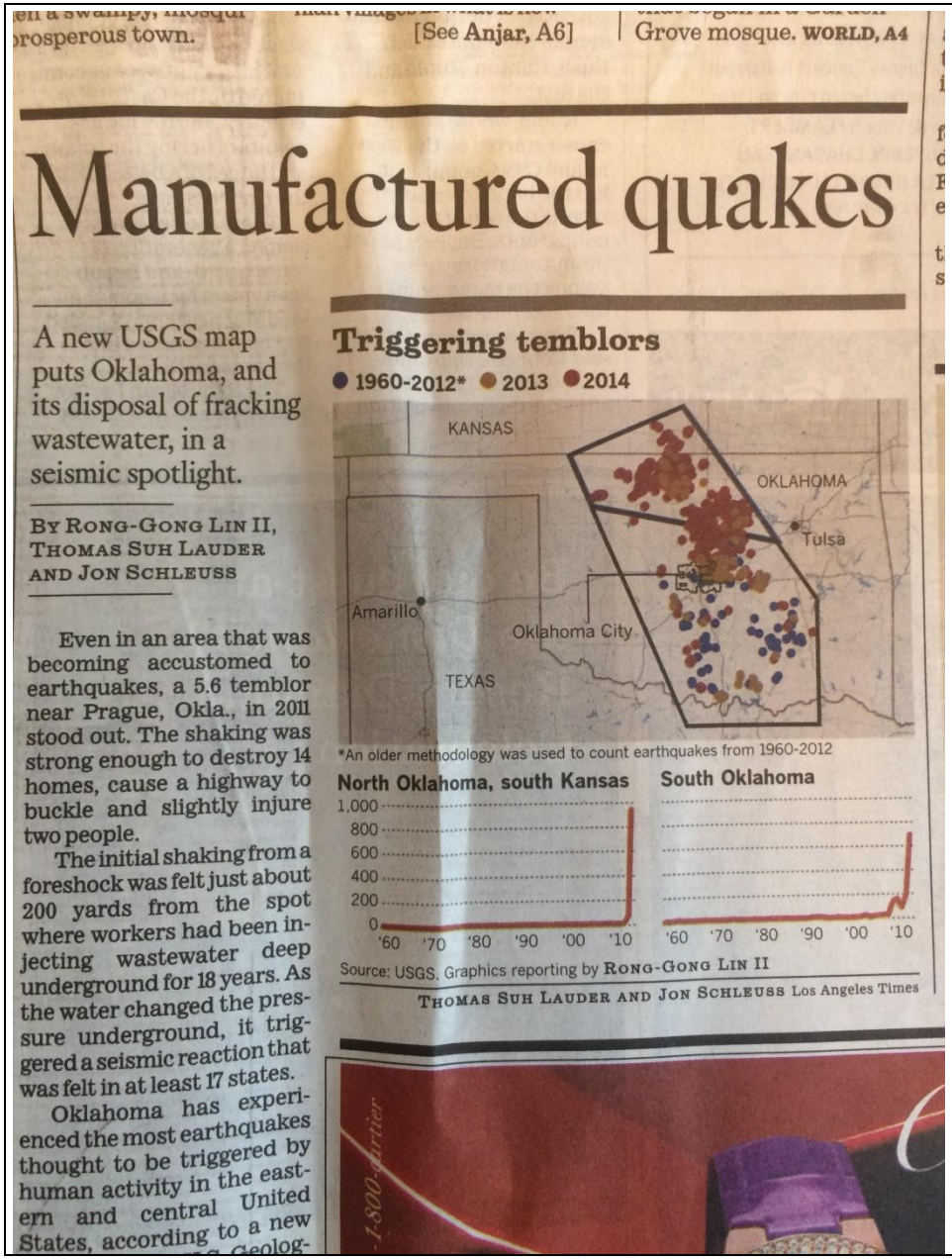
Findings and Update on the National Research Council's Committee on Induced Seismicity Potential of Energy Production and Related Technologies

By
D. K. Dillon and
Don Clarke
June 3, 2015

AAPG Annual Convention & Exhibition 2015




WE'RE GOING TO START FRACKING UNDER OUR BIGGEST COMPETITOR'S HEADQUARTERS.
Dilbert.com DilbertCartoonist@gmail.com
MY PLAN IS TO POLLUTE THEIR WATER AND GENERATE EARTH-QUAKES TO DESTROY THEIR CAMPUS.
3-2-12 ©2012 Scott Adams, Inc. / Dist. by Universal Uclick
THE PROJECT CODE NAME IS "FRACKING AWESOME."
CATCHY



prosperous town. [See Anjar, A6] | Grove mosque. WORLD, A4

Manufactured quakes

A new USGS map puts Oklahoma, and its disposal of fracking wastewater, in a seismic spotlight.

BY RONG-GONG LIN II, THOMAS SUH LAUDER AND JON SCHLEUSS

Even in an area that was becoming accustomed to earthquakes, a 5.6 temblor near Prague, Okla., in 2011 stood out. The shaking was strong enough to destroy 14 homes, cause a highway to buckle and slightly injure two people.

The initial shaking from a foreshock was felt just about 200 yards from the spot where workers had been injecting wastewater deep underground for 18 years. As the water changed the pressure underground, it triggered a seismic reaction that was felt in at least 17 states.

Oklahoma has experienced the most earthquakes thought to be triggered by human activity in the eastern and central United States, according to a new

Triggering temblors

● 1960-2012* ● 2013 ● 2014

*An older methodology was used to count earthquakes from 1960-2012

North Oklahoma, south Kansas

South Oklahoma

Source: USGS, Graphics reporting by RONG-GONG LIN II

THOMAS SUH LAUDER AND JON SCHLEUSS Los Angeles Times

Los Angeles Times
April 24, 2015

California's New Seismic Monitoring Network

ENVIRONMENTAL HAZARDS

BRIAN VAN DER BRUG Los Angeles Times

DRILLING EQUIPMENT in Kern County, where the majority of California's oil and gas production is centered. Water coming out of fracked wells had high concentrations of benzene, a carcinogen.

A 'SHOCKING' DISCOVERY

Benzene is found in fracking waste water at up to 700 times the federal standard, data analysis shows

By Julie Cart

Hoping to better understand the health effects of oil fracking, the state in 2013 ordered oil companies to test the chemical-laden waste water extracted from wells.

Data culled from the first year of those tests found significant concentrations of the human carcinogen benzene in this so-called "flowback fluid." In some cases, the fracking waste liquid, which is frequently reinjected into groundwater, contained a Times analysis of the state data.

The presence of benzene in fracking waste water is raising alarm over potential public health dangers amid admissions by state oil and gas regulators that California for years inadvertently allowed companies to inject fracking flowback water into protected aquifers containing drinking water.

The federal Environmental Protection Agency called the state's ermounting list of problems at the state Division of Oil, Gas and Geothermal Resources, which regulates the oil and gas industry.

State officials attribute the agency's errors to chaotic record-keeping and antiquated data collection. And they emphasize that preliminary tests on nine drinking water wells have found no benzene or other contaminants.

"The problem is foundational and

Groundwater Quality is the Issue

This Article in the *Long Beach Press Telegram* dated September 10, 2013 questions hydraulic fracturing.

Sadly the interviews were with uninformed people from both sides of the argument.

PRESS-TELEGRAM

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Tuesday, September 10, 2013 75 CENTS FACEBOOK.COM/PRESSTELEGRAM TWITTER.COM/PRESSTELEGRAM

SYRIA CRISIS

Protesters rally against

Opposition: LB demonstrators, many in Congress resist Obama's call for intervention

By Brenda Gazzar and Josh Dulaney
Staff Writers

LONG BEACH » Melanie Hiller supported President Barack Obama's presidential campaign in part because she saw him as an anti-war candidate.

Hiller said she was disappointed Monday, on the eve of Obama addressing the nation in an effort to rally support for military strikes on Syria.

"I don't understand killing (in order) to punish killing," Hiller said, as she led a vigil against the effort in front of her home at Fourth Street and Temple Avenue.

More than 50 protesters gathered on the sidewalk, holding candles and asking passers-by to sign a petition against U.S. military

OPPONENTS » PAGE 6

STEPHEN CLARK
STAFF PHOTOGRAPHER

Sisters Tasneem, left, and Bushra Shukairy, who are from Syria, both attend Cal State Long Beach.

Cal State Long Bea
support military action

By Grace Wong
grace.wong@presstelegram.com
@graceg67 on Twitter

Once a week, the Shukairy fam
ily huddles around an iPhone, iPad
or iPod to talk to their family mem
bers in Syria. At first, they would
dialogue in code, worried that the
government was listening to their
conversations.

"My son went off in a wedding

ENVIRONMENT

FRACTURED STATE

Controversy: Injection method of extracting oil deposits is called risky but necessary

Black gold rush: Untapped reserves could produce 15.1 billion barrels of crude oil

"In Pennsylvania, the closer you live to a well used to hydraulically fracture underground shale for natural gas, the more likely it is that your drinking water is contaminated with methane". **Robert Jackson** from Duke University in the Proceedings of the *National Academy of Sciences USA*, July 2013

Mark Fischetti of *Scienticic American*, September 2013 points out that Jacksons work does not prove the point but also says that the oil industry's denials undermine their own credibility.

TOXICOLOGY

Fracking and Tainted Drinking Water

Well water in Pennsylvania homes within a mile of fracking sites is found to be high in methane

In Pennsylvania, the closer you live to a well used to hydraulically fracture underground shale for natural gas, the more likely it is that your drinking water is contaminated with methane. This conclusion, in a study published in the *Proceedings of the National Academy of Sciences USA* in July, is a first step in determining whether fracking in the Marcellus Shale underlying much of Pennsylvania is responsible for tainted drinking water in that region.

Robert Jackson, a chemical engineer at Duke University, found methane in 115 of 141 shallow, residential drinking-water wells. The methane concentration in homes less than one mile from a fracking well was six times higher than the concentration in homes farther away. Isotopes and traces of ethane in the methane indicated that the gas was not created by microorganisms living in groundwater but by heat and pressure thousands of feet down in the Marcellus Shale, which is where companies fracture rock to release gas that rises up a well shaft.

Most groundwater supplies are only a few hundred feet deep, but if the protective metal casing and concrete around a fracking well are leaky, methane can escape into them. The study does not prove that fracking has contaminated specific drinking-water wells, however. "I have no agenda to stop fracking," Jackson says. He notes that drilling companies often construct wells properly. But by denying even the possibility that some wells may leak, the drilling companies have undermined their own credibility.

The next step in proving whether or not fracking has contaminated specific drinking-water wells would be to figure out whether methane in those wells came from the Marcellus Shale or other deposits. Energy companies claim that the gas often rises naturally from deep formations through rock fissures and that determining a source is therefore problematic. Yet some scientists maintain that chemical analysis of the gas can reveal whether it slowly bubbled up through thousands of feet of rock or zipped up a leaky well. Jackson is now analyzing methane samples in that way.

Another way to link a leaky fracking well to a tainted water well is to show that the earth between them provides pathways for the gas to flow. Leaky wells have to be identified first, however. Anthony Ingraffea, a fracking expert at Cornell University, is combing through the inspection reports for most of the 87,911 gas wells drilled in Pennsylvania since January 2000. Thus far, he says, it appears that "a higher percentage" of Marcellus Shale fracking wells are leaking than conventional oil and gas wells drilled into other formations. Stay tuned. —*Mark Fischetti*

Some Perspective

Since 1947 over one million wells have been hydraulically fractured.

Moment magnitude (M) is used for earthquakes. It is the energy released not the amount of shaking.

M -2 =1m^2 rupture

M 3 = 15 acres rupture

M 4 = ½ mi^2 rupture with a displacement of 0.4 inches

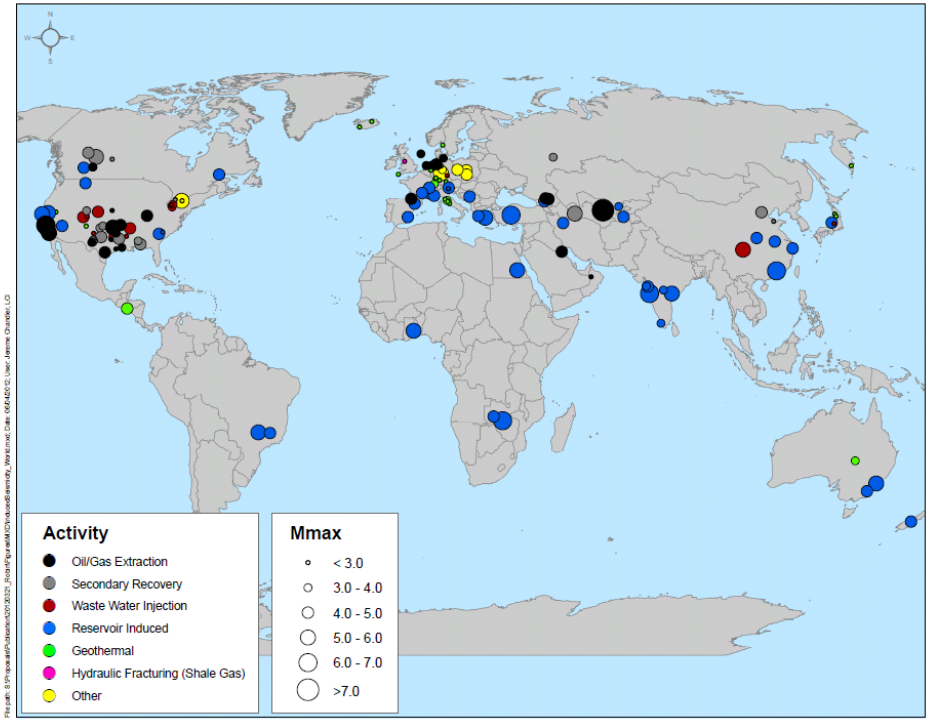
M 5 = 4.2 square miles rupture with a 1.8 inch displacement

M 8 = a rupture the size of Delaware

Report Overview

- Introduction to induced seismicity and its history
- Types and causes of induced seismicity
- Induced seismicity of energy technologies
  - Geothermal
  - Oil and gas (including EOR and shale gas recovery)
  - Waste water injection
  - Carbon capture and sequestration (CCS)
- Government roles and responsibilities
- Understanding hazard and risk assessment to manage induced seismicity
- Steps toward best practices
- Findings, gaps, proposed actions, and research recommendations

Background



- A number of seismic events apparently related to fluid injection for energy development occurred during the past 7 years, for example:

  - Basel, Switzerland, 2006, Enhanced geothermal system (M 3.4)

  - Dallas-Ft. Worth airport area, 2008-09, Waste water disposal from shale gas development (M 3.3)

  - Blackpool, England, 2011, Hydraulic fracturing (shale gas) (M 2.3)

- Public concern about these kinds of events prompted Senator Bingaman to ask Secretary Chu to request a study by the National Research Council on “Induced Seismicity in Energy Technologies”

Statement of Task

This study will address the potential for felt induced seismicity of geothermal systems, oil and gas production including enhanced oil recovery and hydraulic fracturing for shale gas production, and carbon capture and storage (CCS) and specifically will:

- **summarize the current state-of-the-art knowledge on the possible scale, scope and consequences of seismicity induced during the injection of fluids related to energy production;**

- **identify gaps in knowledge and the research needed to advance the understanding of induced seismicity, its causes, effects, and associated risks;**

- **identify gaps and deficiencies in current hazard assessment methodologies for induced seismicity and research needed to close those gaps;**

- **identify and assess options for interim steps toward best practices, pending resolution of key outstanding research questions.**

Types and Causes of Induced Seismicity

- **Induced seismic activity has been attributed to a range of human activities including:**
  - **Impoundment of large reservoirs behind dams**
  - **Controlled explosions related to mining or construction**
  - **Underground nuclear tests**
  - ***Energy technologies that involve injection or withdrawal of fluids from the subsurface***

Types and Causes of Induced Seismicity in Fluid Injection/Withdrawal for Energy Development

- **The general mechanisms that create induced seismic events are well understood.**

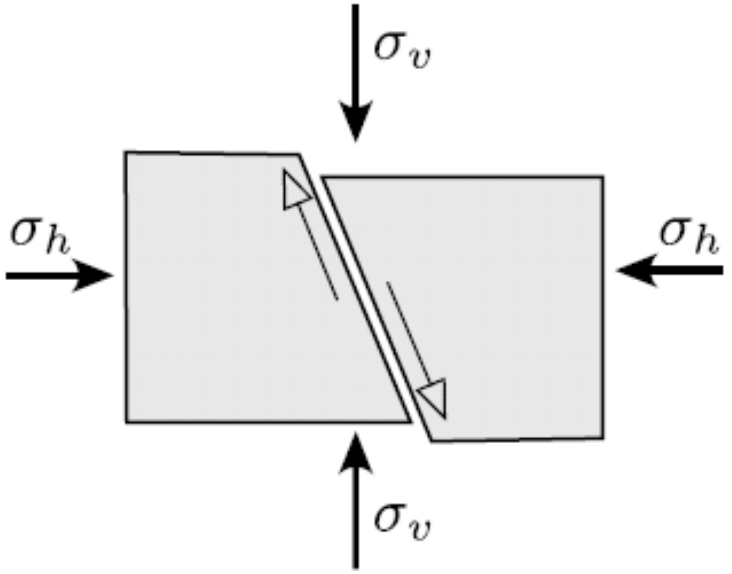
- **However, we are currently unable to accurately predict the occurrence or magnitude of such events due to the lack of comprehensive data on complex natural rock systems and the lack of validated predictive models.**

Types and Causes of Induced Seismicity in Fluid Injection/Withdrawal for Energy Development

- Induced seismicity is caused in most cases by change in pore fluid pressure and/or change in stress in the subsurface in the presence of:
  - faults with specific properties and orientations;
  - a critical state of stress in the crust.

- The factor that appears to have the most direct correlation in regard to induced seismicity is the net fluid balance — *the total balance of fluid introduced into or removed from the subsurface*.

- Additional factors may also influence the way fluids affect the subsurface.



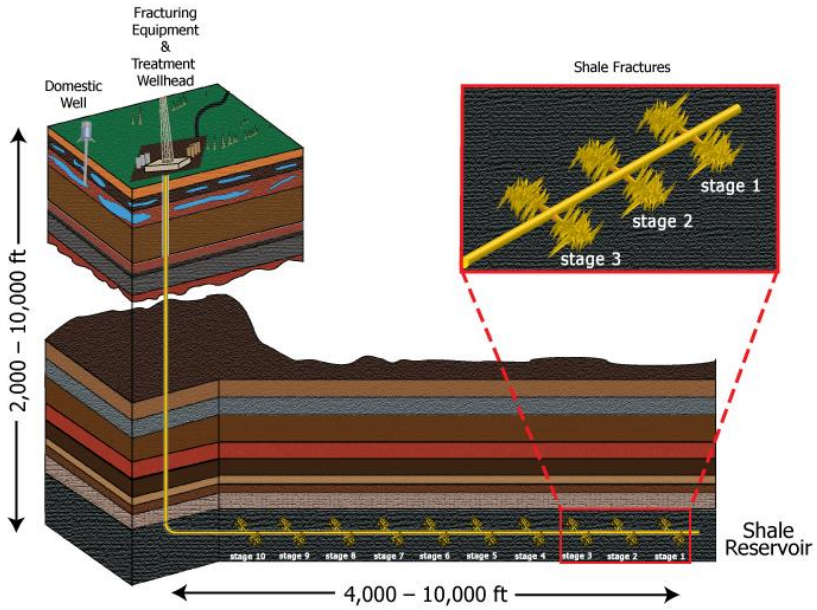
Normal fault

$\sigma_v > \sigma_H > \sigma_h$

Energy Technologies

- Geothermal energy development
  - *Vapor-dominated*
  - *Liquid-dominated*
  - *Enhanced geothermal systems (EGS)*
- Oil and gas development
  - *Oil and gas extraction (fluid withdrawal)*
  - *Secondary recovery (waterflooding)*
  - *Tertiary recovery (CO_2 flooding)*
  - *Hydraulic fracturing for shale gas*
- Waste water disposal wells
- Carbon capture and storage (CCS)

Oil and Gas



Shale gas development

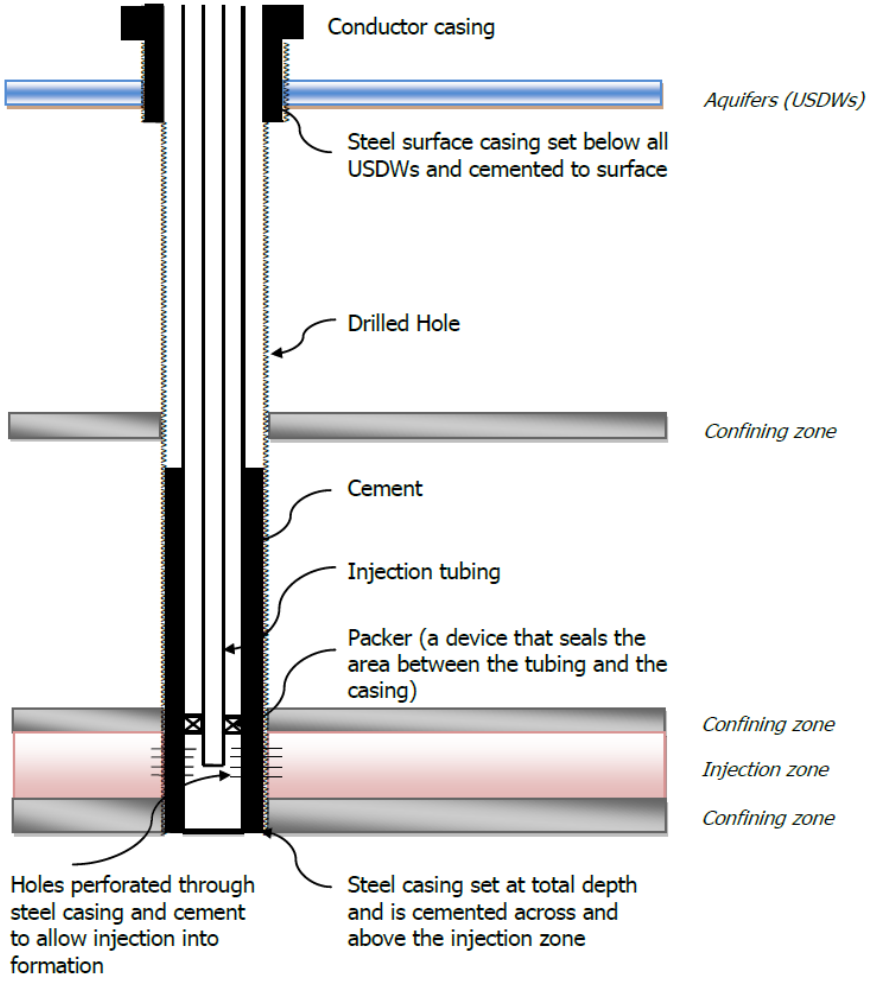
- Oil and gas withdrawal—removes large volumes of fluids over decades, usually with accompanying fluid injection

- Enhanced recovery—inject fluids (water, steam, CO_2, etc.) to extract remaining oil and gas
  - secondary recovery (often 'waterflooding')
  - tertiary recovery (enhanced oil recovery)

- Hydraulic fracturing a well for shale gas development—use horizontal drilling and hydraulic fracturing to create fractures for gas to migrate to a well

- Oil and gas operators attempt to balance the fluid volumes produced with fluid injection to maintain reservoir pressure

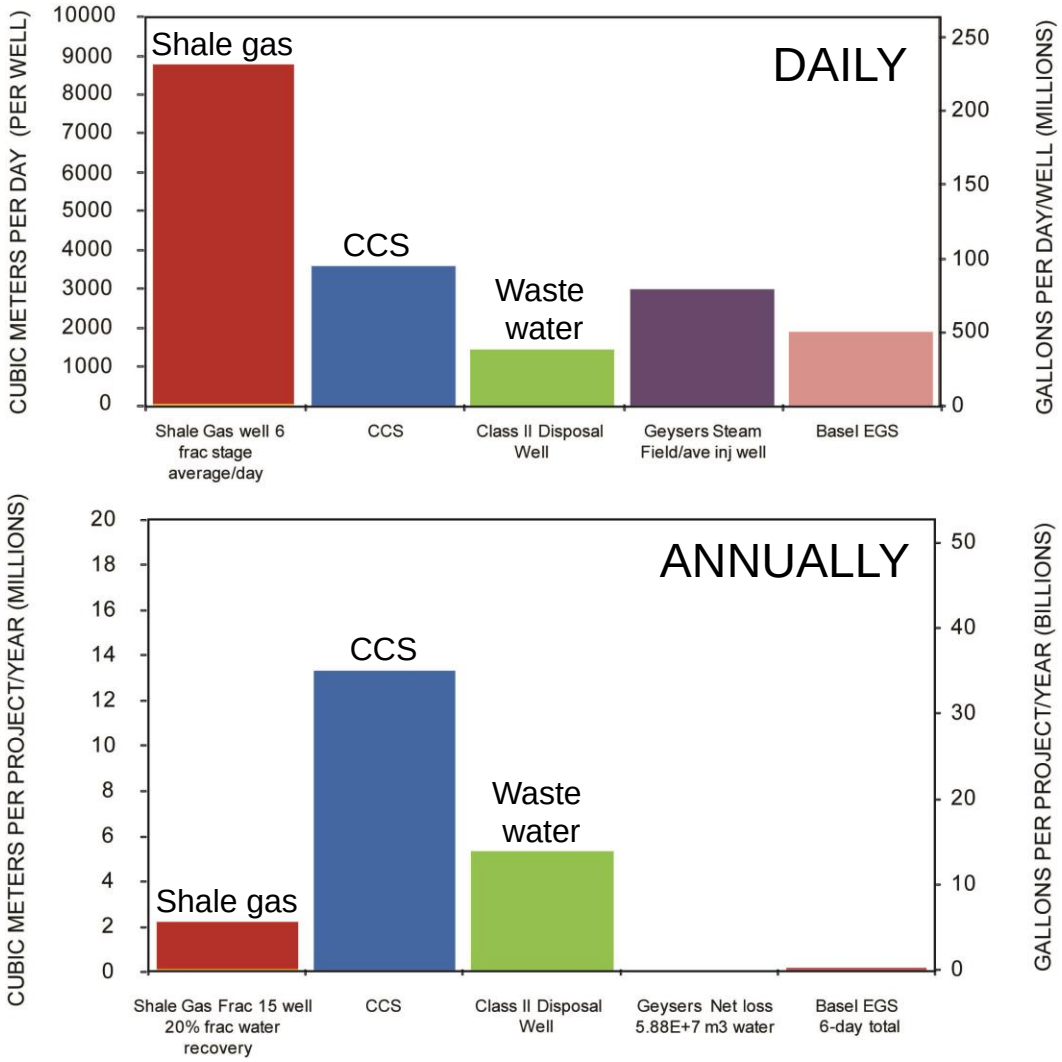
Waste Water Disposal Wells



- Fluid from flow back after hydraulic fracturing and waste fluid produced from conventional oil and gas production in the United States = over 800 billion gallons a year

- More than one third of the volume is managed through underground injection for permanent disposal in “Class II” wells, permitted by EPA and states with delegated authority

Comparative Estimated Fluid Volumes for Energy Technologies



- Daily fluid volumes injected are highest for hydraulic fracturing — 8,500 m^3
- Annual fluid volumes injected are highest for proposed CCS projects (13,000,000 m^3) and then Class II waste water disposal wells (4,000,000 m^3)
- Geysers geothermal field records net fluid loss annually

Conventional Oil & Gas Production

- **Generally, withdrawal associated with conventional oil and gas recovery has not caused significant seismic events, however several major earthquakes have been associated with conventional oil and gas withdrawal.**

- **Relative to the large number of waterflood projects for secondary recovery, the small number of documented instances of felt induced seismicity suggests such projects pose small risk for events that would be of concern to the public.**

- **The committee did not identify any documented, felt induced seismic events associated with EOR (tertiary recovery); the potential for induced seismicity is low.**

Unconventional Oil & Gas Production (Shale Gas)

- **The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events.**

- **~35,000 wells have been hydraulically fractured for shale gas development to date in the United States.**

- **Only one case of demonstrated induced seismicity from hydraulic fracturing for shale gas has been documented worldwide (Blackpool, England – 2011).**

Induced Seismicity Potential — Energy Waste Water Disposal

- The US currently has approximately 30,000 Class II waste water disposal wells (water from energy production). Very few felt induced seismic events reported as either caused by or likely related to these wells. Rare cases of waste water injection have produced seismic events, typically less than **M** 5.0.

- High injection volumes may increase pore pressure and in proximity to existing faults could lead to an induced seismic event.

- The area of potential influence from injection wells may extend over several square miles.

- Induced seismicity may continue for months to years after injection ceases.

- Evaluating the potential for induced seismicity in the location and design of injection wells is difficult because there are no cost-effective ways to locate faults and measure in situ stress.

Induced Seismicity Potential — Carbon Capture and Sequestration (CCS)

- The only long-term (~15 years) commercial CO_2 sequestration project in the world at the **Sleipner field offshore Norway** is small scale relative to commercial projects proposed in the US. Extensive seismic monitoring has not indicated any significant induced seismicity.

- There is **no experience** with the proposed injection volumes of liquid CO_2 in large-scale sequestration projects (> 1 million metric tonnes per year). If the reservoirs behave in a similar manner to oil and gas fields, these large volumes have the potential to increase the pore pressure over large areas and may have the potential to cause significant seismic events.

- CO_2 has the potential to react with the host/adjacent rock and cause mineral precipitation or dissolution. The effects of these reactions on potential seismic events are not understood.

Potential for Induced Seismicity Summary Points

The factors important for understanding the potential to generate felt seismic events are complex and interrelated and include:

- the rate of injection or extraction
- volume and temperature of injected or extracted fluids
- pore pressure
- permeability of the relevant geologic layers
- faults, fault properties, fault location
- crustal stress conditions
- the distance from the injection point
- the length of time over which injection and/or withdrawal takes place

Understanding Hazard and Risk to Manage Induced Seismicity — Proposed Actions

1. A detailed methodology should be developed for quantitative, probabilistic hazard assessments of induced seismicity risk. The goals in developing the methodology would be to:
   - make assessments before operations begin in areas with a known history of felt seismicity
   - update assessments in response to observed induced seismicity

2. Data related to fluid injection (well locations coordinates, injection depths, injection volumes and pressures, time frames) should be collected by state and federal regulatory authorities in a common format and made accessible to the public (through a coordinating body such as the USGS).

3. In areas of high-density of structures and population, regulatory agencies should consider requiring that data to facilitate fault identification for hazard and risk analysis be collected and analyzed before energy operations are initiated.

Government Roles and Responsibilities (Findings)

1. Responsibility for oversight of activities that can cause induced seismicity is dispersed among a number of federal and state agencies.

2. Recent, potentially induced seismic events in the US have been addressed in a variety of manners involving local, state, federal agencies, and research institutions. These agencies and research institutions may not have resources to address unexpected events; more events could stress this ad hoc system.

3. Currently the EPA has primary regulatory responsibility for fluid injection under the Safe Drinking Water Act; ***this act does not address induced seismicity***.

4. The USGS has the capability and expertise to address monitoring and research associated with induced seismic events. However, their mission does not focus on induced events. Significant new resources would be required if their mission is expanded to include comprehensive monitoring and research on induced seismicity.

Potential for Induced Seismicity Summary Points Continued

- The net fluid balance (*total balance of fluid introduced and removed*) appears to have the most direct consequence on changing pore pressure in the subsurface over time.

- Energy technology projects designed to maintain a balance between the amount of fluid being injected and the amount of fluid being withdrawn, such as geothermal and most oil and gas development, may produce fewer induced seismic events than technologies that do not maintain fluid balance.

Steps Toward Best Practices (Findings & Gap)

Findings

1. The **DOE Protocol for EGS provides a reasonable initial model** for dealing with induced seismicity that can serve as a template for other energy technologies.
2. Based on this model, two matrix-style protocols illustrate the manner in which activities can ideally be undertaken concurrently (rather than only sequentially), while also illustrating how these activities should be adjusted as a project progresses from early planning through operations to completion.

Gap

No best practices protocol for addressing induced seismicity is in place for each of these technologies, with the exception of the EGS protocol. The committee suggests that best practices protocols be adapted and tailored to each technology.

Study Research Recommendations

1. **Collect field and laboratory data** on active seismic events possibly caused by energy development and on specific aspects of the rock system at energy development sites (for example, on fault and fracture properties and orientations, crustal stress, injection rates, fluid volumes and pressures).

2. **Develop instrumentation** to measure rock and fluid properties before and during energy development projects.

3. **Hazard and risk assessment** for individual energy projects.

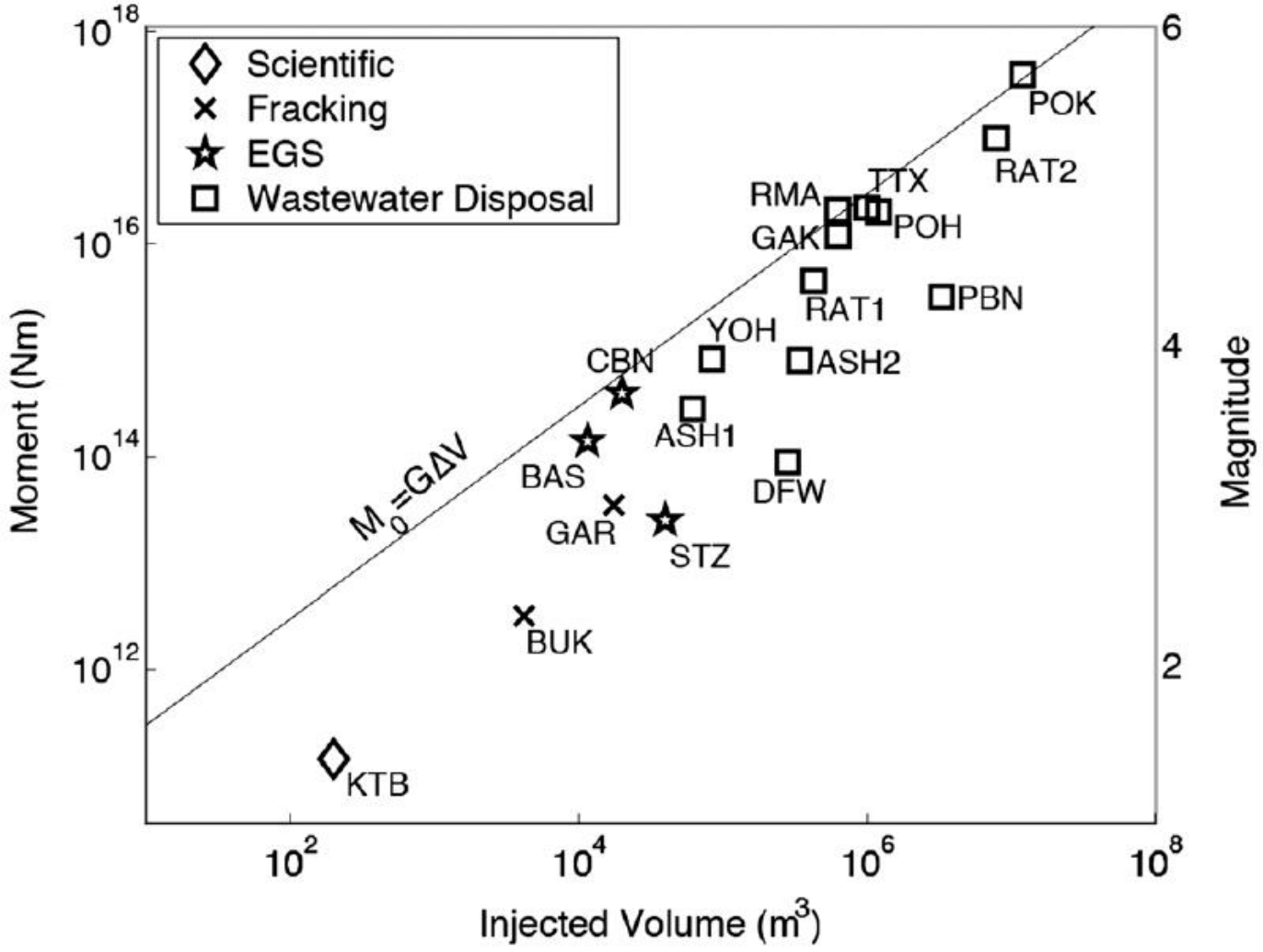
4. **Develop models,** including codes that link geomechanical models with models for reservoir fluid flow and earthquake simulation.

5. **Conduct research on carbon capture and storage,** incorporate data from existing sites where carbon dioxide is injected for enhanced oil recovery, and develop models to estimate the potential magnitude of seismic events induced by the large-scale injection of carbon dioxide for storage.

Conclusion

Although induced seismic events have not resulted in loss of life or major damage in the United States, their effects have been felt locally, and they raise some concern about additional seismic activity and its consequences in areas where energy development is ongoing or planned.

Further research is required to better understand and address the potential risks associated with induced seismicity.



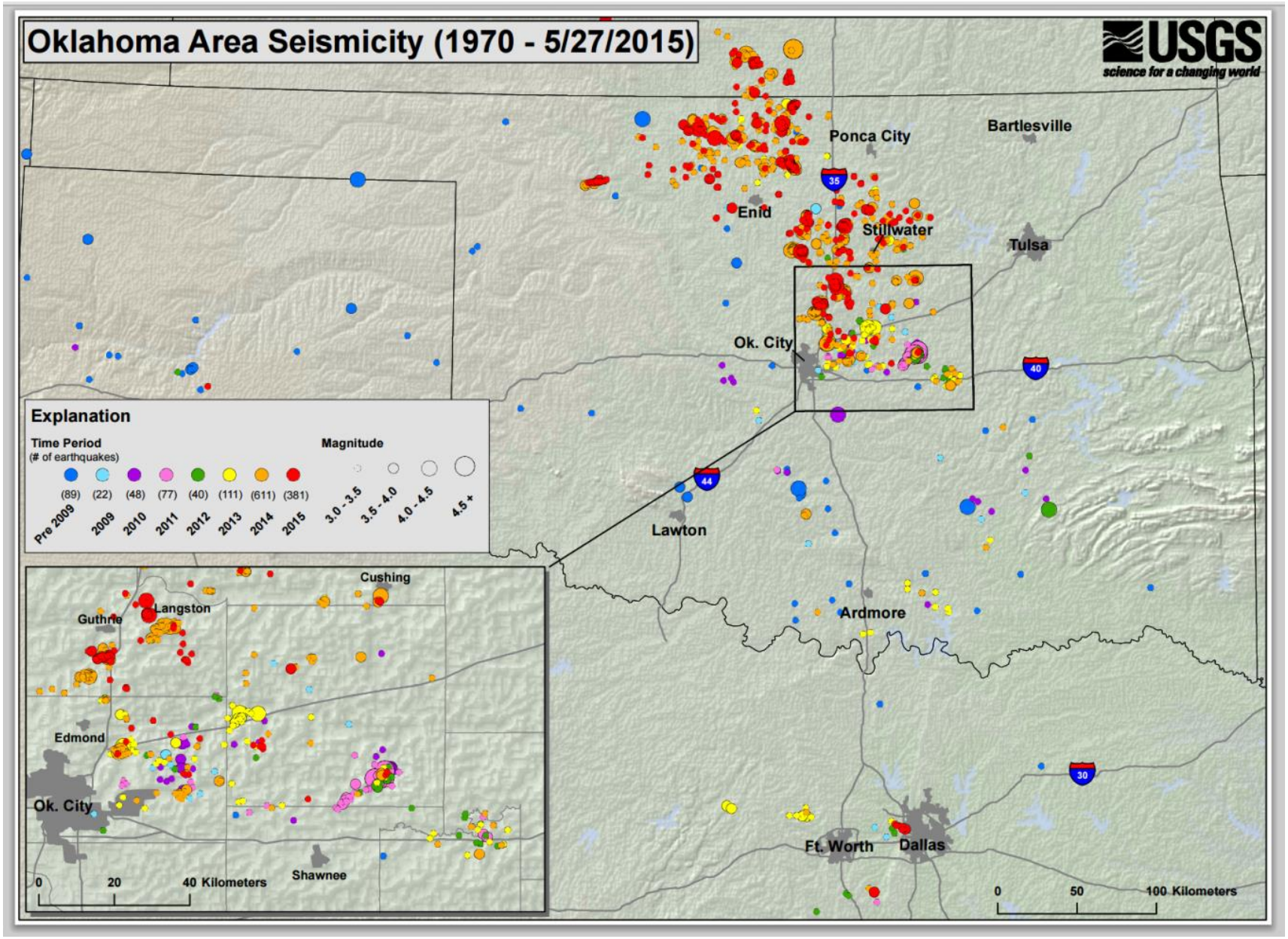
Maximum Seismic Moment and Magnitude

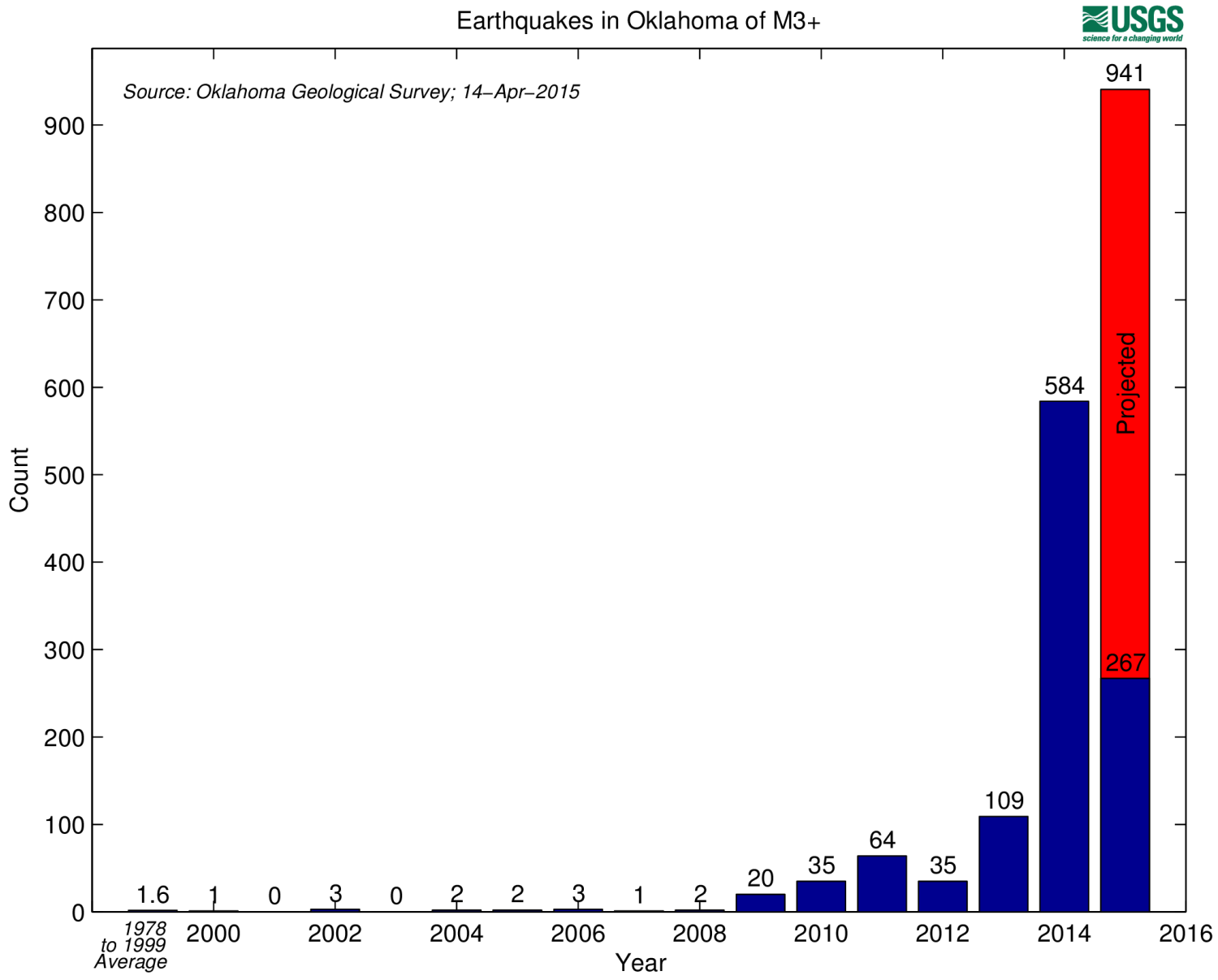
From A. McGarr, 2014

Social License to Operate

- **The term "Social License to Operate" (SLO) was originally adopted for use by the Canadian mining industry in the late 1990s, and referred to the concept that social permission was needed for a mining company to conduct its operations, for example from local communities or indigenous people. Since then, the premise of the SLO has been extended to other geological challenges faced by society, such as fracking for oil and gas development, radioactive waste disposal, carbon capture and storage, geologic hazards, and deep-well injection of wastewater.**

Dimock, PA


Oklahoma Area Seismicity (1970 - 5/27/2015)
USGS
science for a changing world
Ponca City
Bartlesville
Enid
Stillwater
Tulsa
Ok. City
Lawton
Ardmore
Ft. Worth
Dallas
Explanation
Time Period
(# of earthquakes)
Pre 2009 (89)
2009 (22)
2010 (48)
2011 (77)
2012 (40)
2013 (111)
2014 (611)
2015 (381)
Magnitude
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 +
Cushing
Guthrie
Langston
Edmond
Ok. City
Shawnee
0 20 40 Kilometers
0 50 100 Kilometers

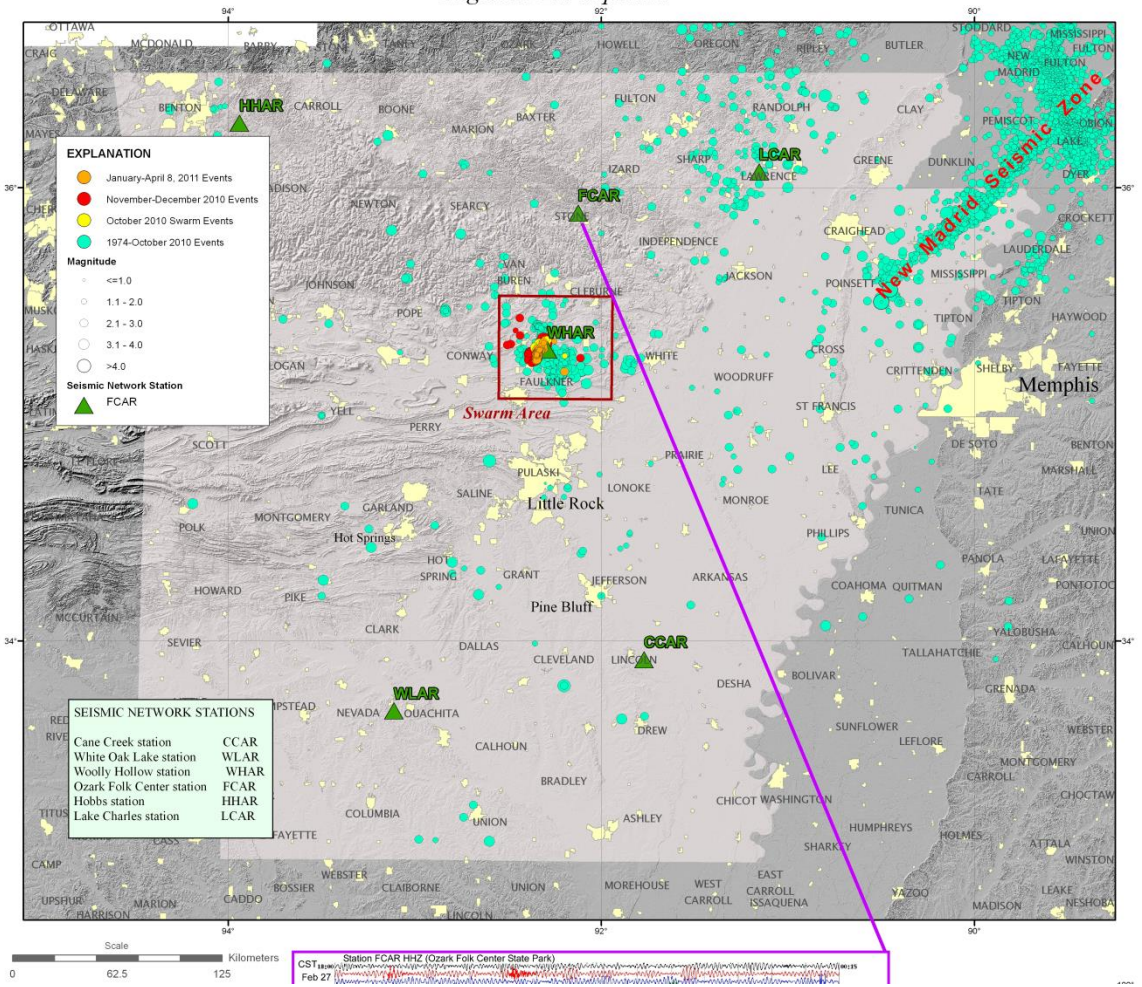

Earthquakes in Oklahoma of M3+
USGS
science for a changing world
Source: Oklahoma Geological Survey; 14–Apr–2015
Count
Year
Projected
941
584
267
109
64
35
35
20
3
2
2
3
1
2
0
3
0
1.6
1
0
1978 to 1999 Average
2000
2002
2004
2006
2008
2010
2012
2014
2016
0
100
200
300
400
500
600
700
800
900

USGS
science for a changing world

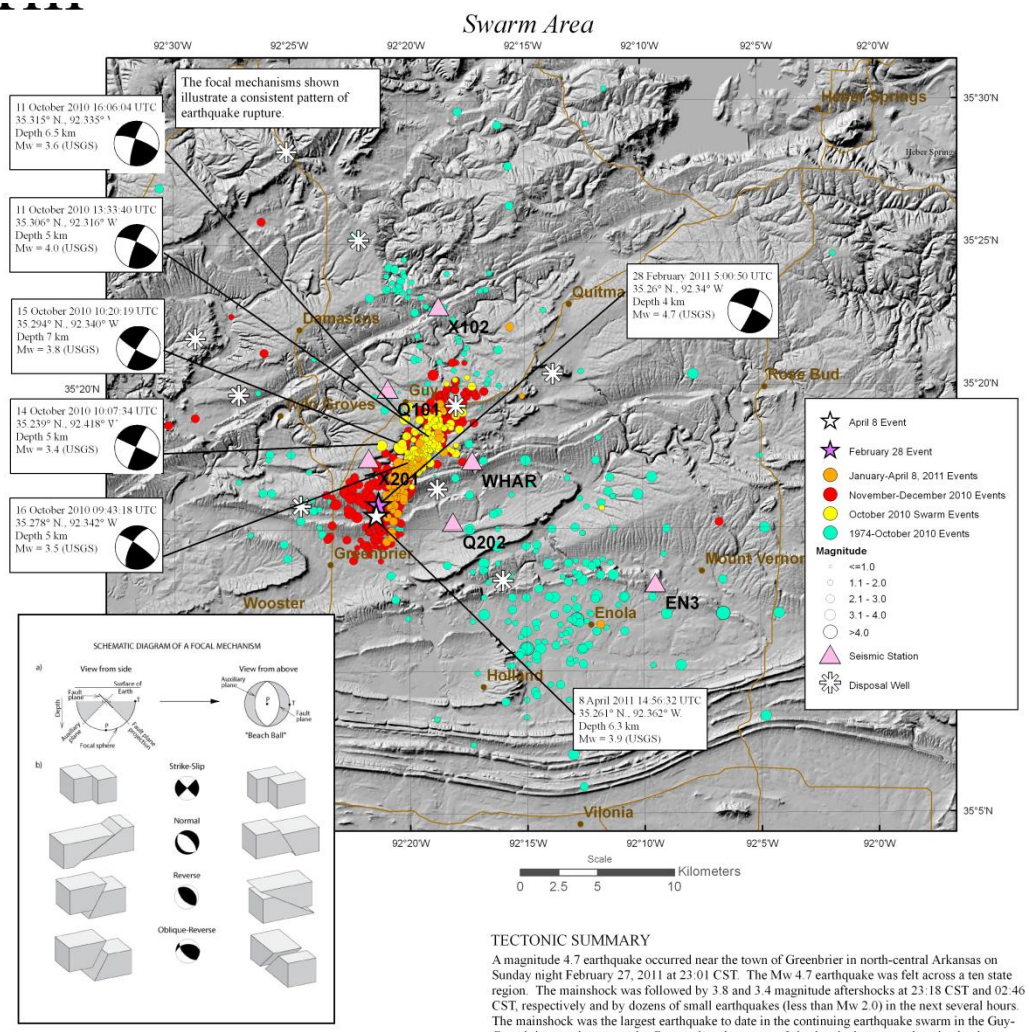
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

2010-2011 Arkansas Earthquake Swarm

Regional Earthquakes



Guy-Greenbrier Swarm in Arkansas



TECTONIC SUMMARY

A magnitude 4.7 earthquake occurred near the town of Greenbrier in north-central Arkansas on Sunday night February 27, 2011 at 23:01 CST. The Mw 4.7 earthquake was felt across a ten state region. The mainshock was followed by 3.8 and 3.4 magnitude aftershocks at 23:18 CST and 02:46 CST, respectively and by dozens of small earthquakes (less than Mw 2.0) in the next several hours. The mainshock was the largest earthquake to date in the continuing earthquake swarm in the Guy-Greenbrier area known as the Guy earthquake swarm. It is also the largest earthquake that has

Events that occurred after publication

- Youngstown Northstar 1 M-4 on Dec. 31, 2011 Steve Holtcamp
- Guy Greenbrier, Arkansas EQ's in pC basement 1,300 EQ's 2010-now
- Dimock, PA Gasland
- Ashtabula, OH Researchers use it as a good example of for and against Induced EQ's

Hydrofracturing Earthquakes

- Horn River Basin, BC Hydrofracturing shale play M3.8 largest Dec. 2013 16 events in 5 days Problem is moving into Alberta

Terry Engelder's 6 Oil Industry Mistakes

- Failure to establish baseline water chemistry prior to drilling
- The extent of cementing in casing
- Should not have used air-drilling in the vertical legs of the Marcellus gas wells
- Should not have lobbied for elements of the Energy Policy Act of 2005 to keep additaves secret

Terry Engelder cont.

- Flowback from large hydrofracture was in large enough volumes to induce seismicity
- Water management issues associated with potentially leaking pits led to worries of groundwater contaminated

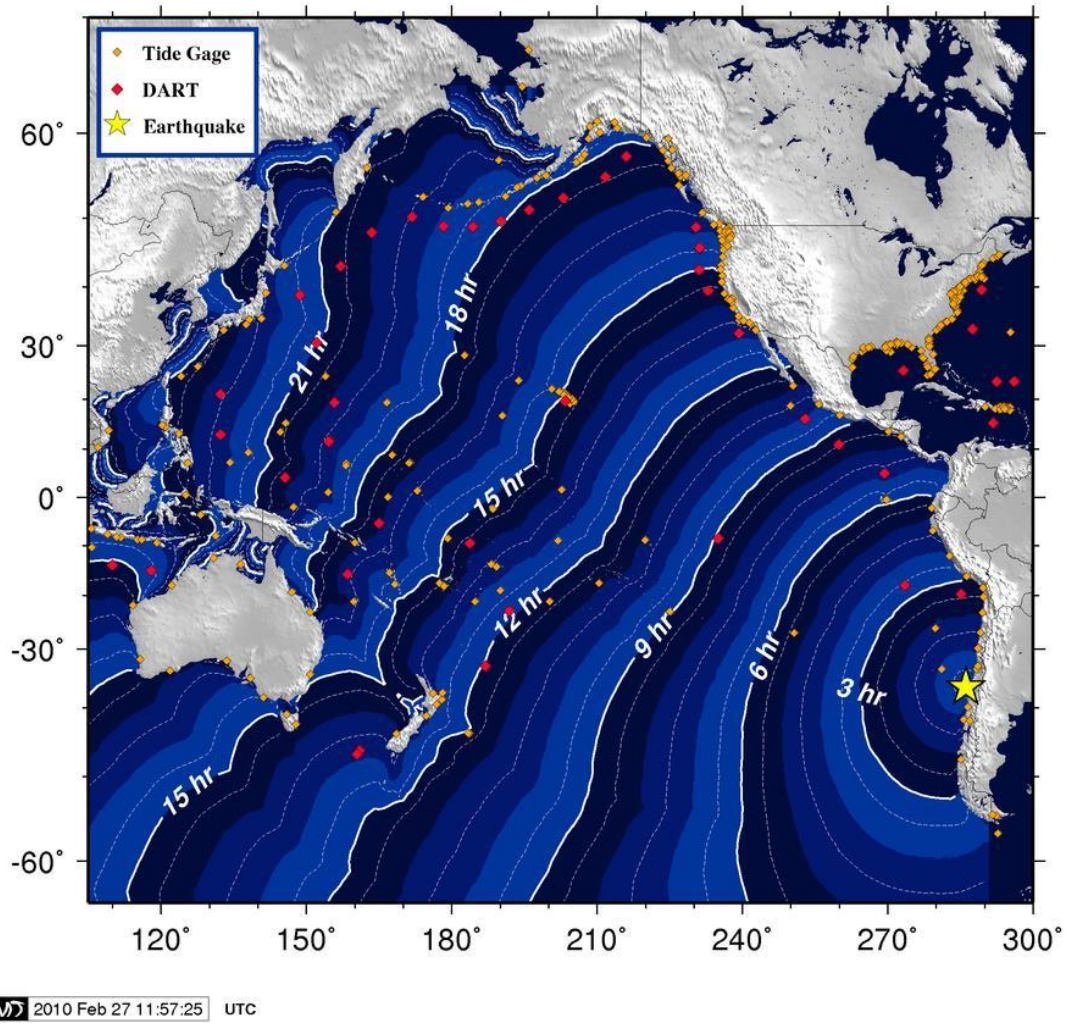
More post publication events

- Central OK EQ Swarm, (Prague M5.6 Nov. 2011) Huge increase in EQ's starting in 2009 Induced and triggered EQ's Danielle Sumy
- **M4 EQ in Cushing, OK**, Oct. 2014
- **Maule EQ** may have triggered OK events
- Wilzetta Fault increase in Columb stress

Maule Earthquake

- The **2010 Chile earthquake** occurred off the coast of central Chile on Saturday, 27 February 2010, at 03:34 local time (06:34 UTC), having a magnitude of 8.8 on the moment magnitude scale, with intense shaking lasting for about three minutes. It ranks as the sixth largest earthquake ever to be recorded by a seismograph.

Tsunami Travel Times



"2010 Chile earthquake NOAA tsunami travel time projection 2010-02-27" by National Oceanic and Atmospheric Administration - http://wcatwc.arh.noaa.gov/2010/02/27/725245/06/ttvu725245-06.jpg. Licensed under Public domain via Wikimedia Commons

International Breaking News

- Italian report claims oil activities (500 bopd) may have induced M5.9 &M5.8 EQ's
- Remember the L'Aquila EQ,s 5years ago. The seismologists are in jail (6 years)
- A judge overturned the convictions of the seismologists late 2014.

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Incorporating Induced Seismicity in the 2014 United States National Seismic Hazard Model—Results of 2014 Workshop and Sensitivity Studies

By Mark D. Petersen, Charles S. Mueller, Morgan P. Moschetti, Susan M. Hoover, Justin L. Rubinstein, Andrea L. Llenos, Andrew J. Michael, William L. Ellsworth, Arthur F. McGarr, Austin A. Holland, and John G. Anderson

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