

LEARNING FROM INDUCED SEISMICITY IN THE DALLAS- FORT WORTH AREA

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Southern
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20 May 2015

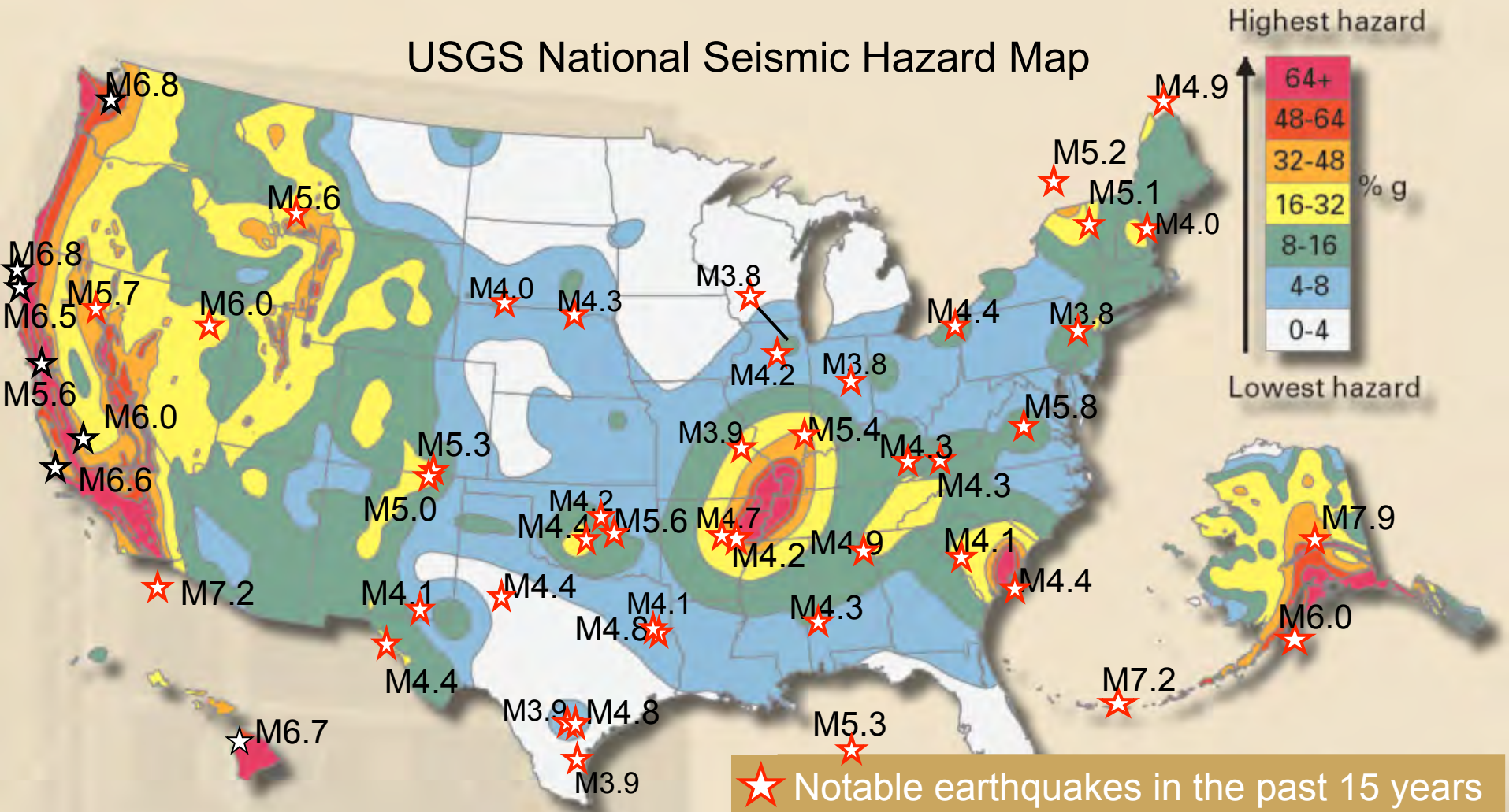
Power Plays
Conference

Acknowledgements:

Heather DeShon, Chris Hayward, Matt Hornbach, Beatrice Magnani, Cliff Frohlich, Jon Olson, North Texas Eqs Working Group, USGS

Earthquakes are a national hazard

USGS National Seismic Hazard Map



FEMA

NIST

National Institute of Standards and Technology

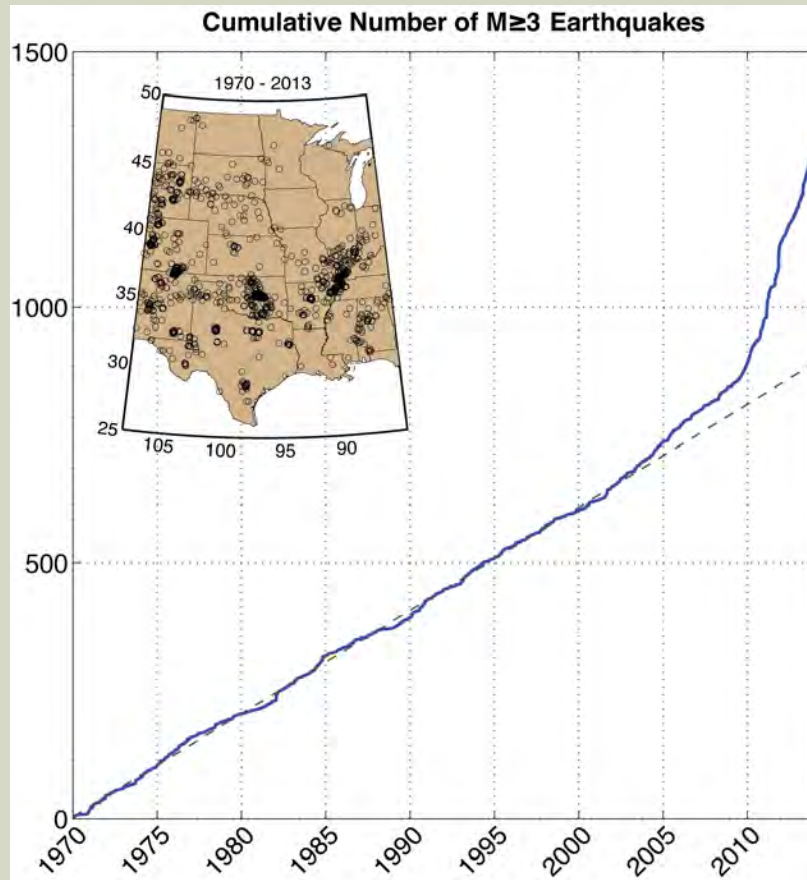


USGS
science for a changing world



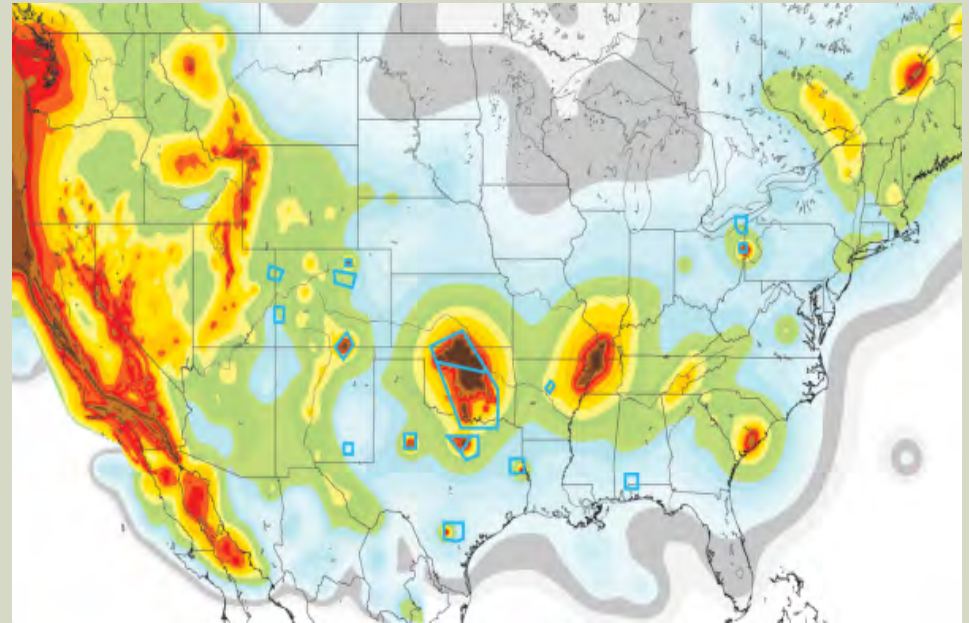
national earthquake hazards reduction program

INCREASE IN SEISMICITY IN CENTRAL AND EASTERN US



Recent increase in annual seismicity in Central and Eastern US. Ellsworth, 2013.

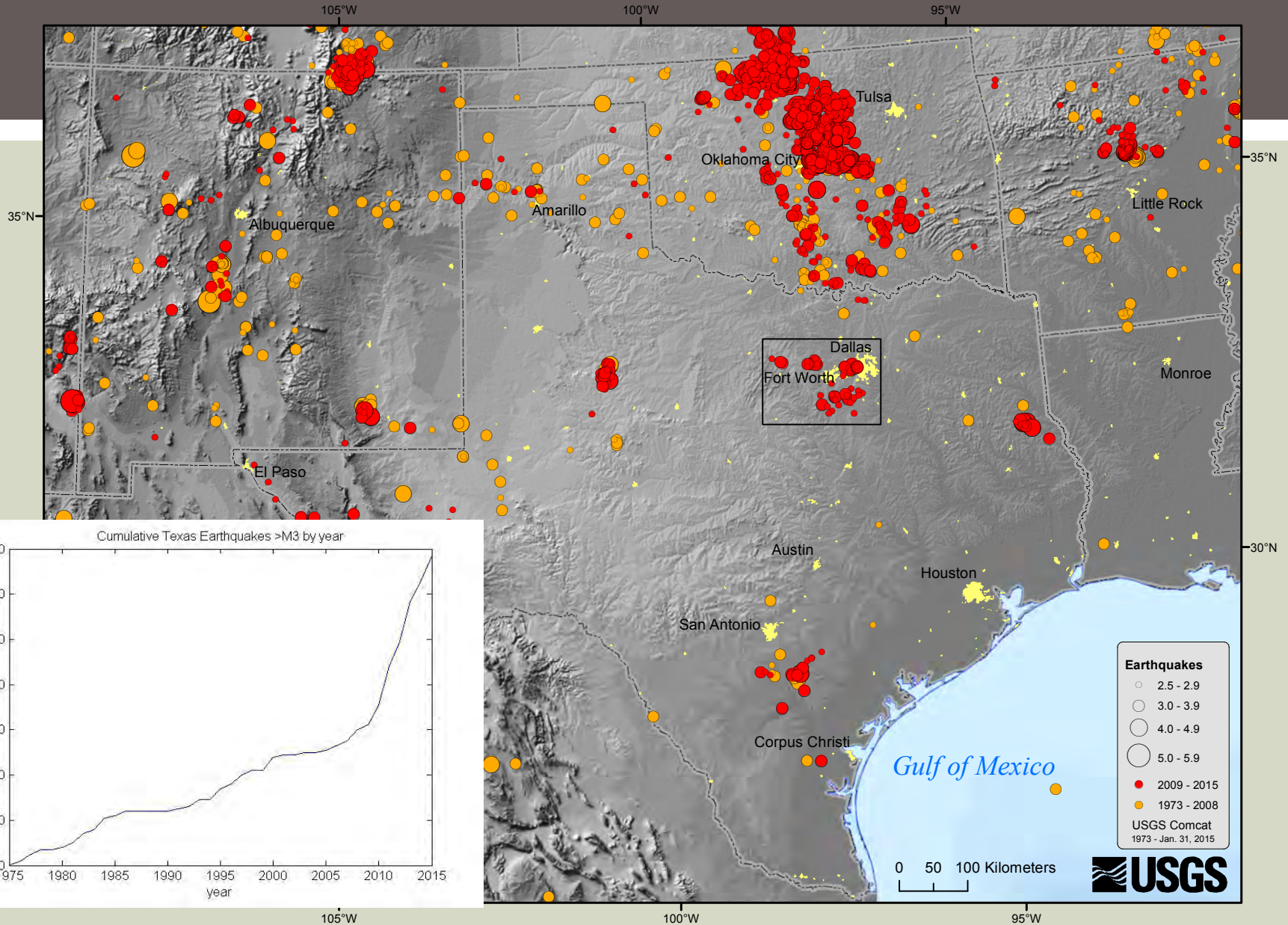
earthquake.usgs.gov/research/induced/



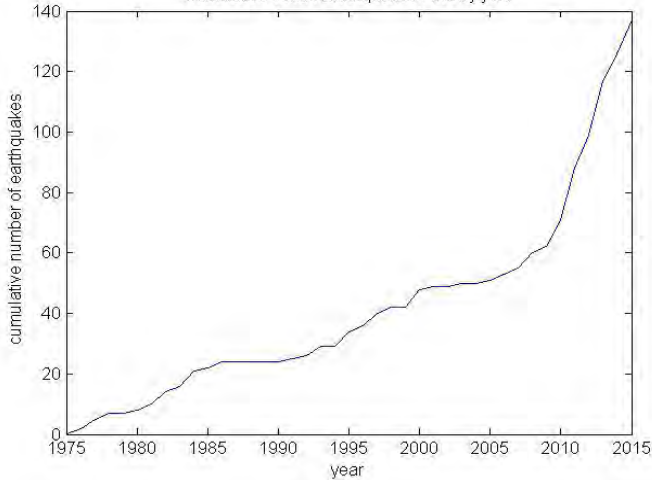
Incorporating Induced Seismicity in the 2014 United States National Seismic Hazard Model – Results of 2014 Workshop and Sensitivity Studies

[Pubs.usgs.gov/of/2015/1070/](http://pubs.usgs.gov/of/2015/1070/)

Recent Seismicity



Cumulative Texas Earthquakes >M3 by year

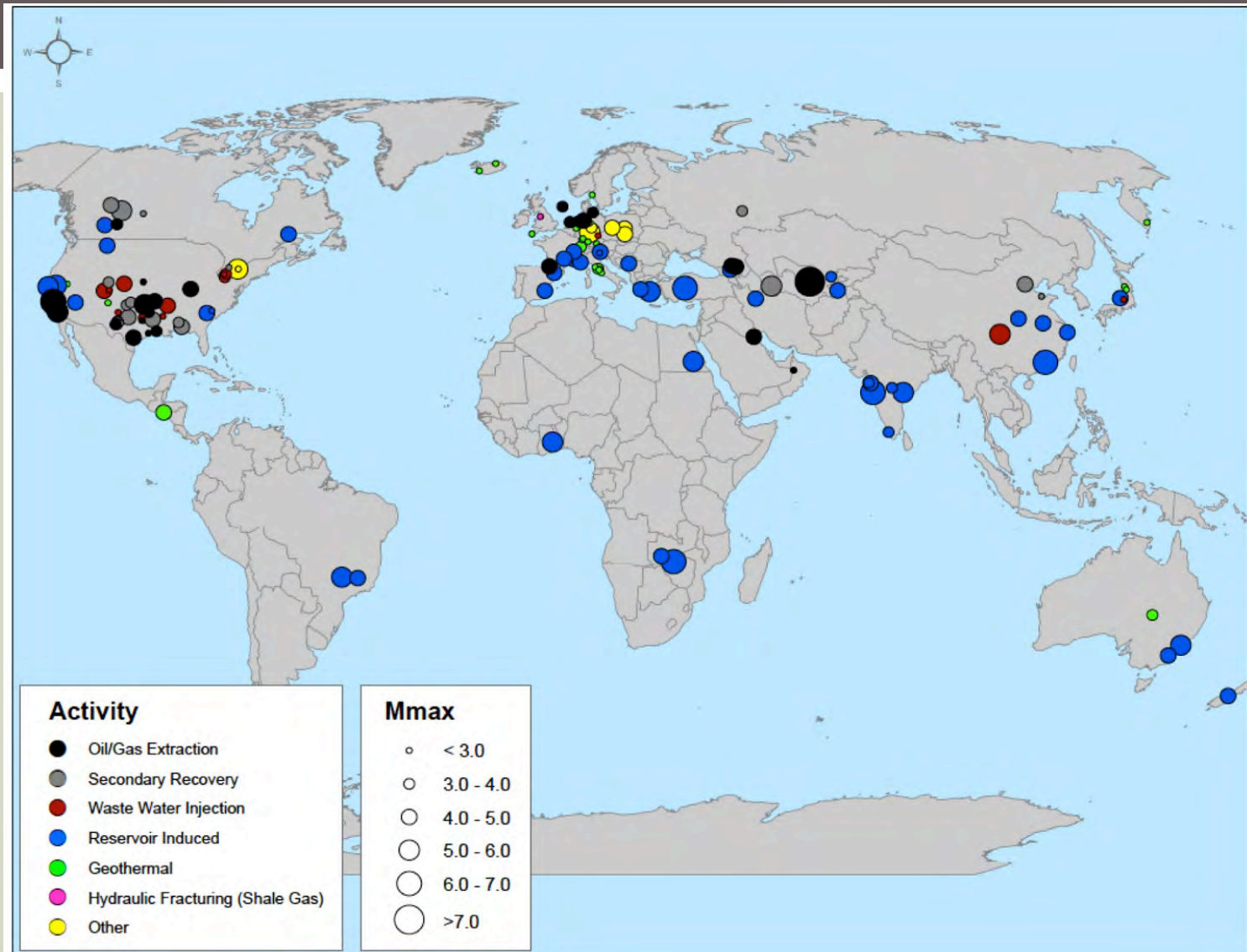


NATIONAL RESEARCH COUNCIL REPORT
***INDUCED SEISMICITY POTENTIAL IN ENERGY
TECHNOLOGIES, 2012***

Although only a very small fraction of injection and extraction activities at hundreds of thousands of energy development sites in the United States have induced seismicity at levels that are noticeable to the public, seismic events caused by or likely related to energy development have been measured and felt in Alabama, Arkansas, California, Colorado, Illinois, Louisiana, Mississippi, Nebraska, Nevada, New Mexico, Ohio, Oklahoma, and Texas.

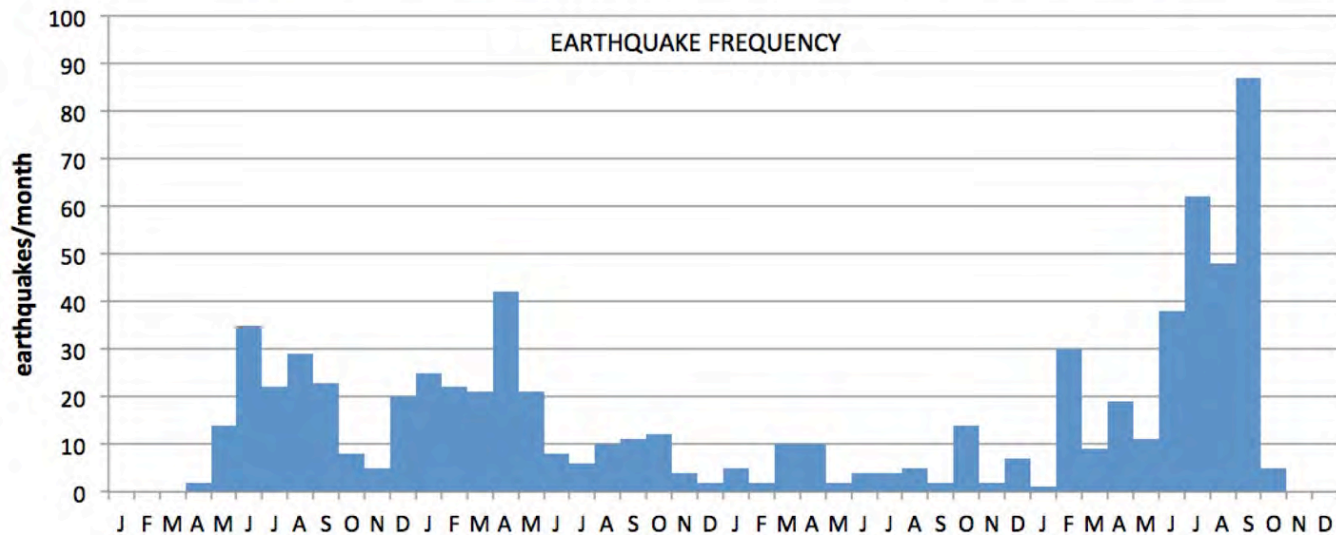
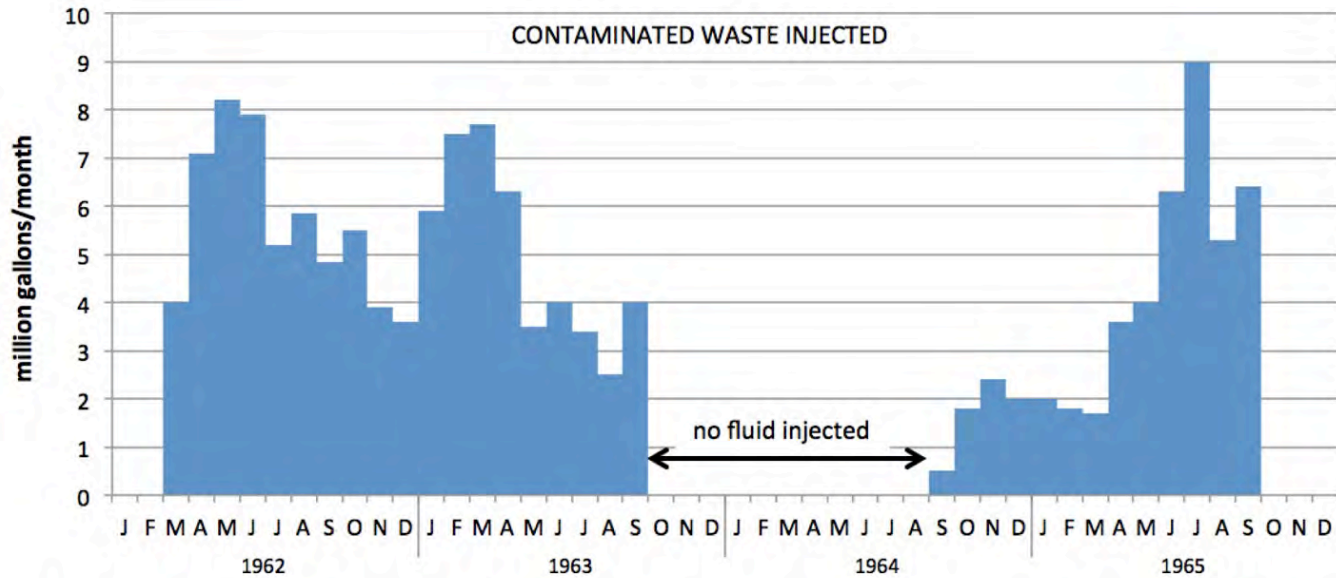
www.nap.edu/catalog.php?record_id=13355

“Seismicity Caused by or Likely Related to Human Activity” NRC, 2012



Little Linkage Between Hydraulic Fracturing and Felt Earthquakes

Rocky Mountain Arsenal Waste Water Disposal - 1962-1965



RMA CONCLUSION: THE PRESSURE OF THE FLUIDS LOWERED THE FRICTIONAL RESISTANCE ALONG AN EXISTING FAULT SYSTEM

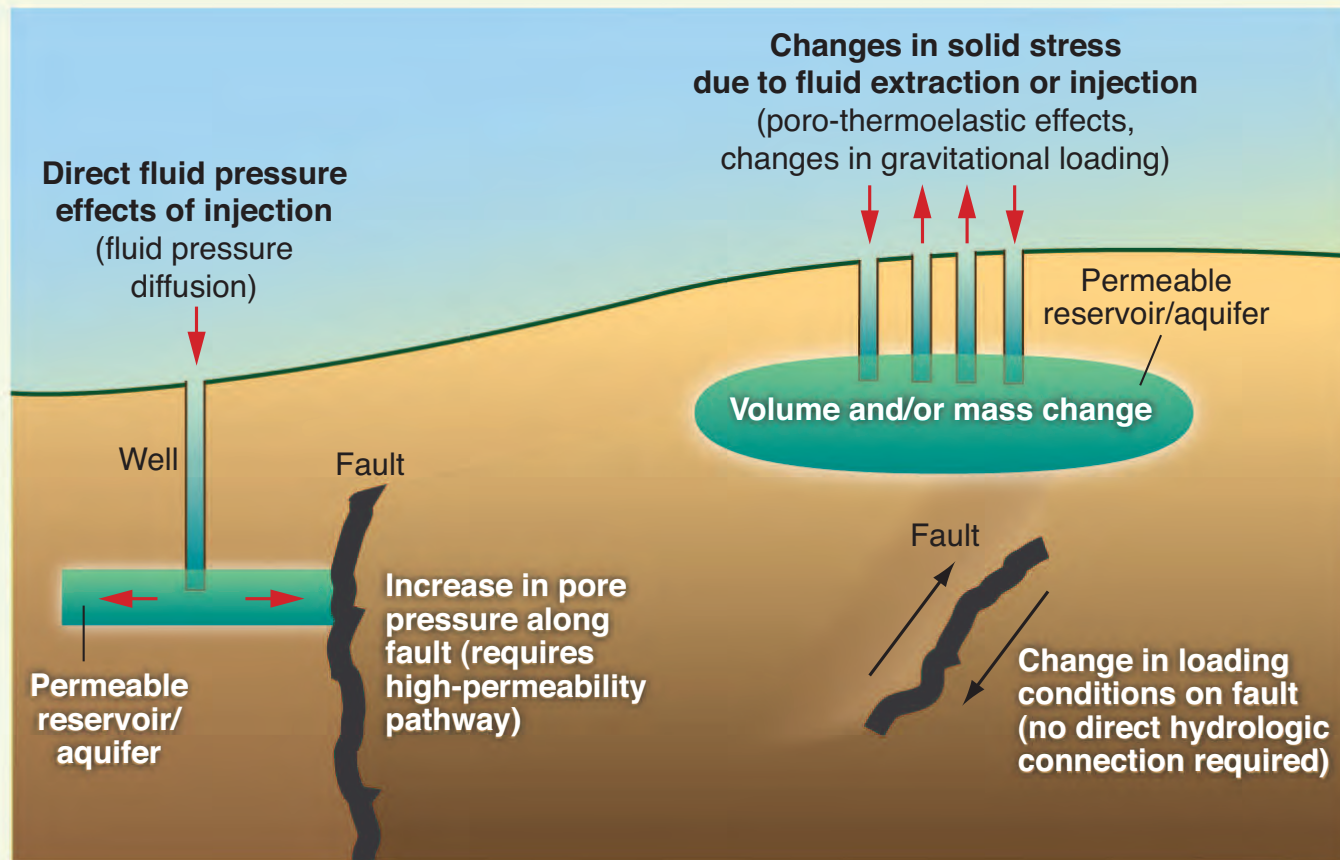
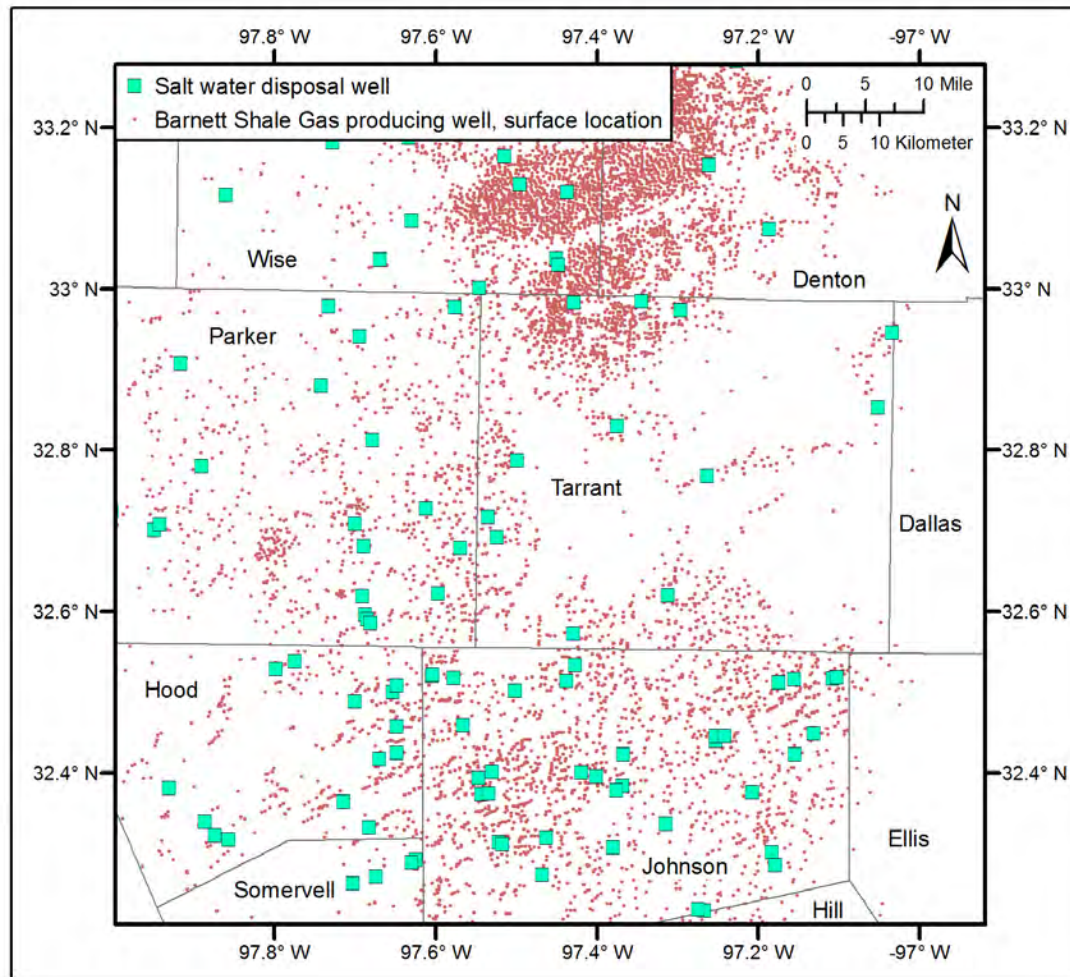


Fig. 3. Schematic diagram of mechanisms for inducing earthquakes. Earthquakes may be induced by increasing the pore pressure acting on a fault (**left**) or by changing the shear and normal stress acting on the fault (**right**). See (4).

Development of Shale Plays in Central and Eastern US



Oil and Gas Recovery from Shale Can Include Hydraulic Fracturing, Production and Waste Water Disposal



Barnett Shale

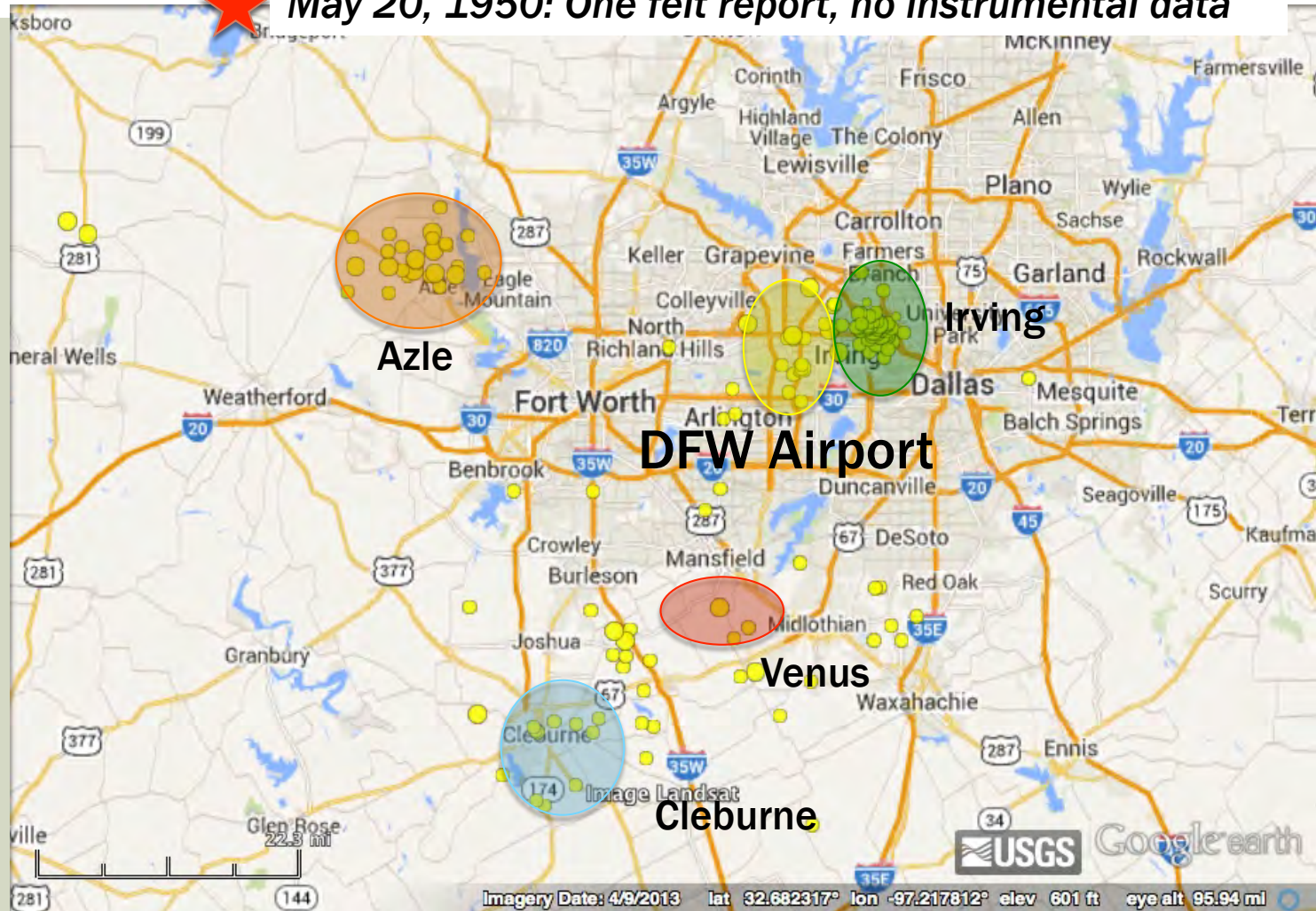
Regional gas production in the Fort Worth Basin and Waste Water Disposal sites.

Frohlich *et al.*, 2010.

Vast majority of injectors have no associated seismicity

1 Earthquake in Fort Worth Basin prior to 2008 & over 160 since

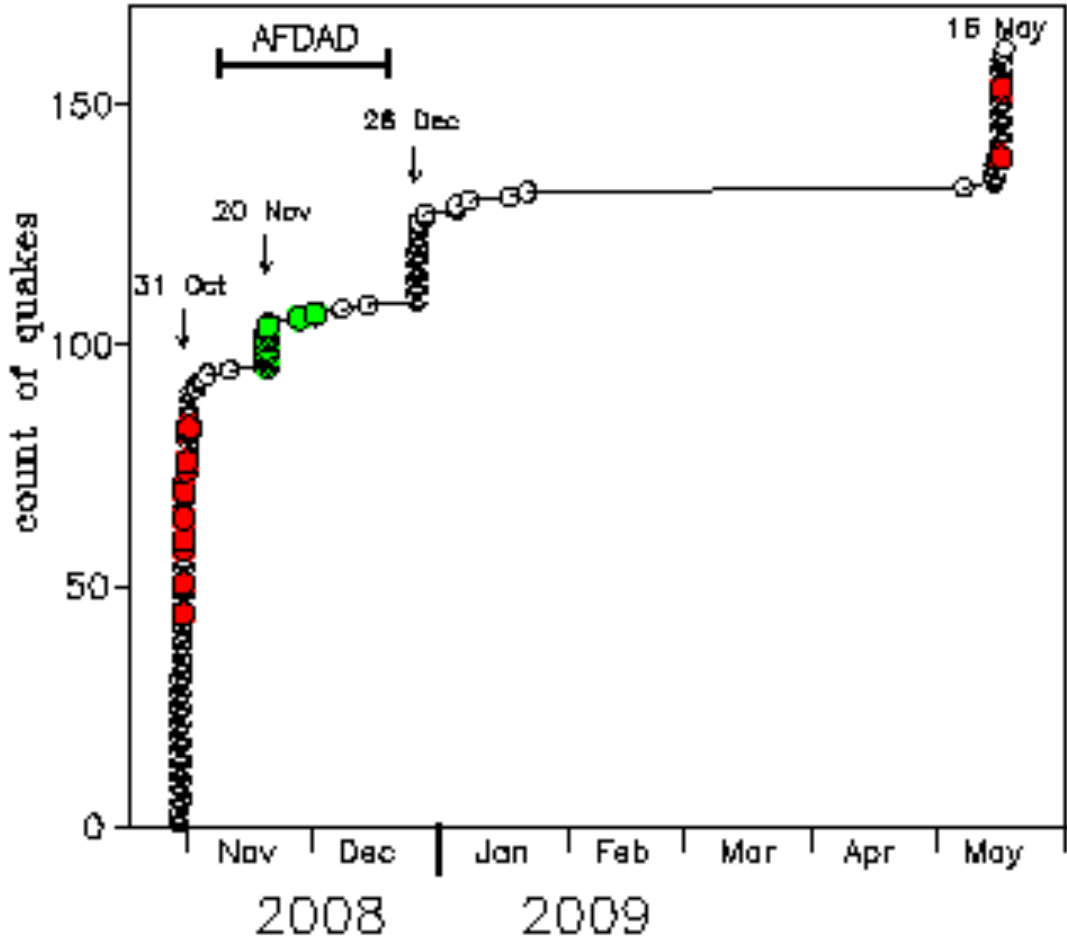
★ *May 20, 1950: One felt report, no instrumental data*



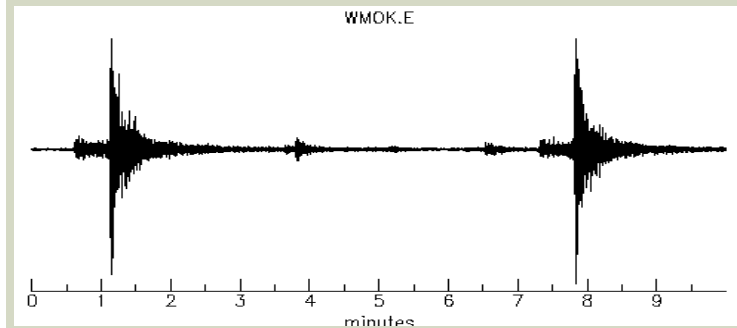
Earthquakes Report by National Earthquake Information Center since 2008 (2.0 – 4.0)

DFW EARTHQUAKE SEQUENCE

31 October 2008 – First Felt EQ in Recorded History



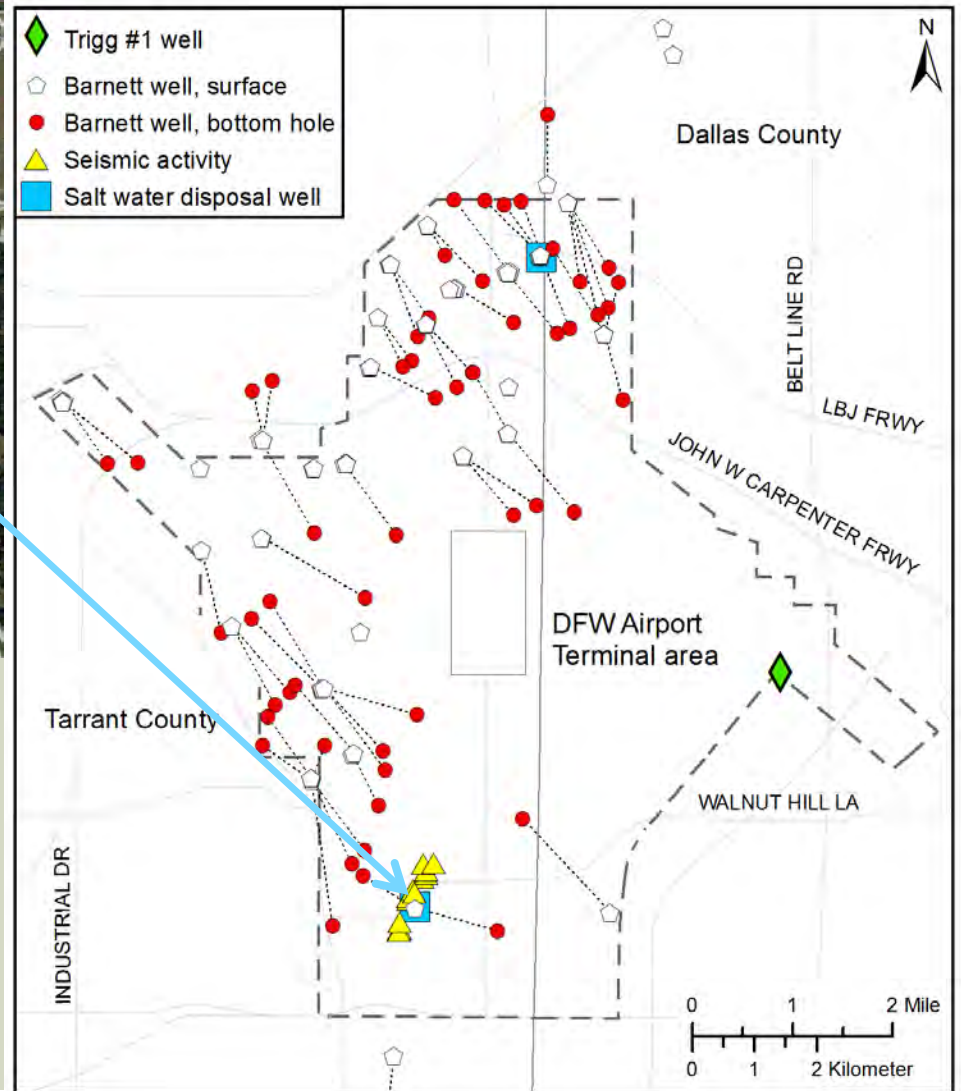
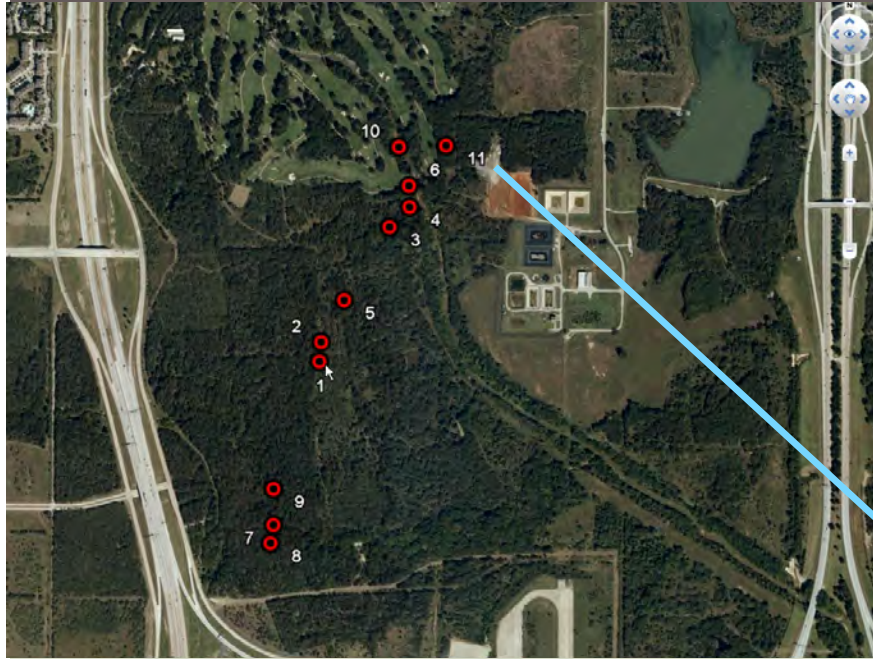
Most Sensitive Station is WMOK, in Oklahoma at 280 km



- USGS located 14 events but over 150 events identified using the sensitive station WMOK
- No events before 31 October 2008
- Ongoing sequence motivated a deployment of local instruments to improve locations

First Earthquake Sequence Begins – Recorded by seismometers hundreds of kilometers from the event

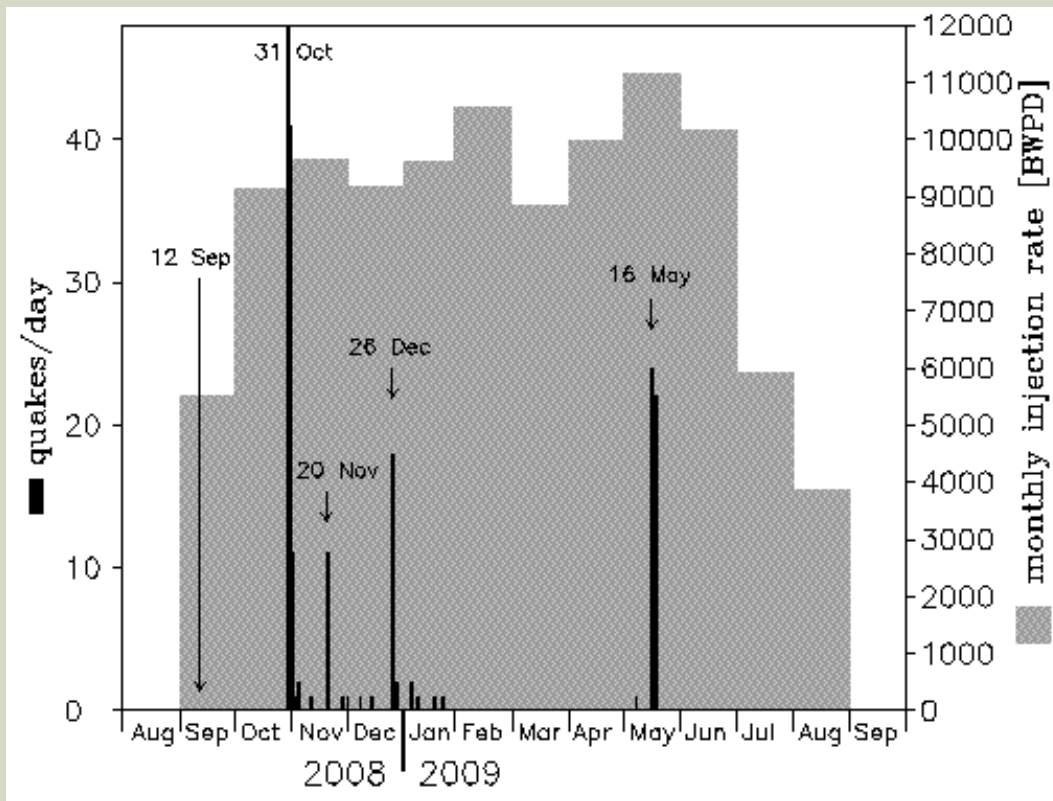
Refined Locations Provided Opportunity to Explore Cause of Earthquakes



Earthquakes occur:

- Along linear trend about 2 km long
- Common depth of ~4.4 km

Texas Railroad Commission Disposal Well Data



- Earthquakes located within hundreds of meters of disposal well
- Earthquakes began shortly after the injector was initiated
- A mapped fault crosses the area
- No subsurface data on geology or material properties was made available
- Earthquakes continued into 2010 and moved away from injector

Were Earthquakes Induced or Triggered?

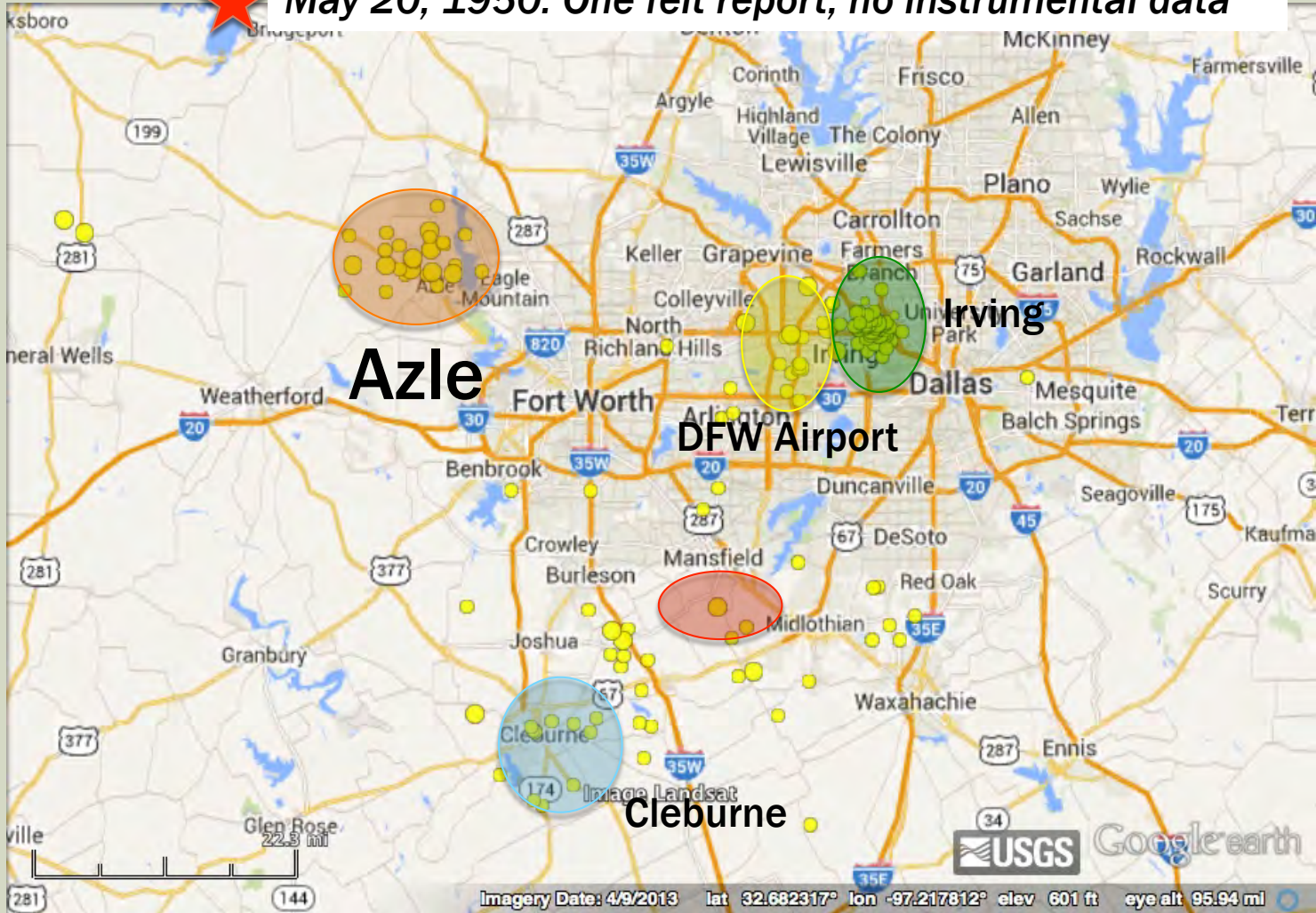
Questions from Davis and Frohlich, 1993	DFW Answers
1. Are the events the first known earthquakes of this character in the region?	YES
2. Is there a clear correlation between injection and seismicity?	YES
3. Are epicenters within 5 km of wells?	YES
4. Do some earthquakes occur at or near injection depth?	YES
5. Are there known geologic structures that may channel flow to sites of earthquakes?	YES
6. Are changes in fluid pressure at well bottoms sufficient to encourage seismicity?	UNKNOWN
7. Are changes in fluid pressure at hypocentral distances sufficient to encourage seismicity?	UNKNOWN

Little subsurface data to constrain structures, faults and material properties. This type of data needed to produce physical models to assess the cause of earthquakes.

AZLE Earthquake Sequence 2014-2015



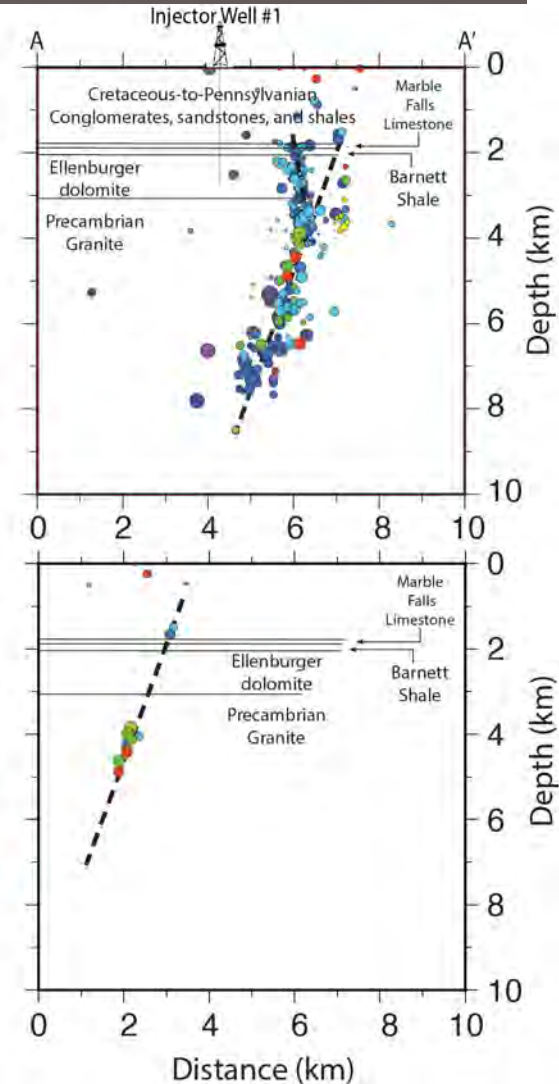
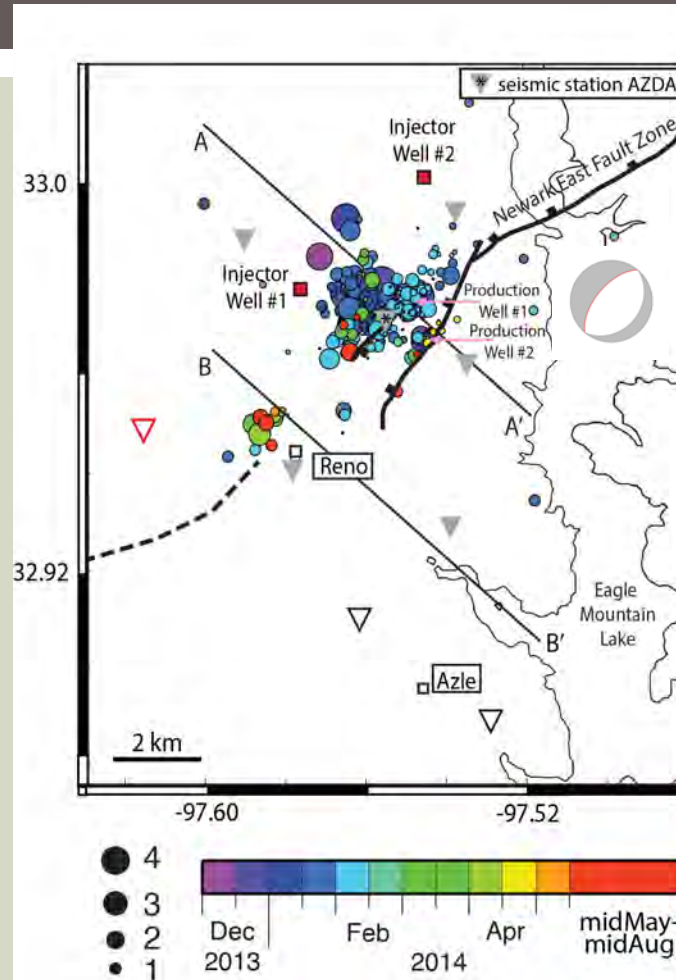
May 20, 1950: One felt report, no instrumental data



Industry Cooperation in Study

AZLE EVENT LOCATIONS THROUGH 26 AUG, 2014

- The last widely felt event was Jan 28th, 2014
- Seismicity rate was highly variable
- The sequence has slowed, last recorded event January 2015
- Faulting appears complex



CAUSAL FACTORS

- Natural Tectonic Stress Changes

- Ground Water

<1 kPa on the fault

- Lake Level Changes

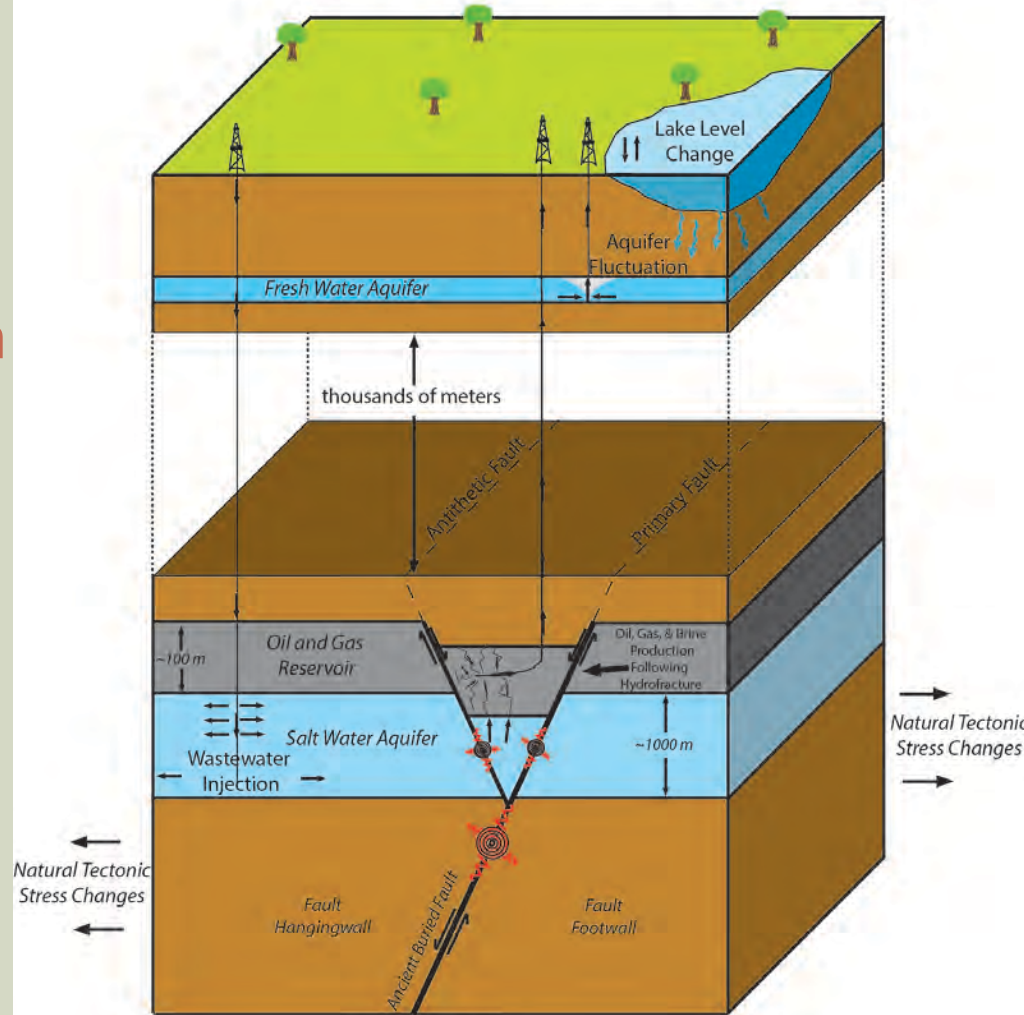
- Industry Activity

- SWD Injection

- Brine Production

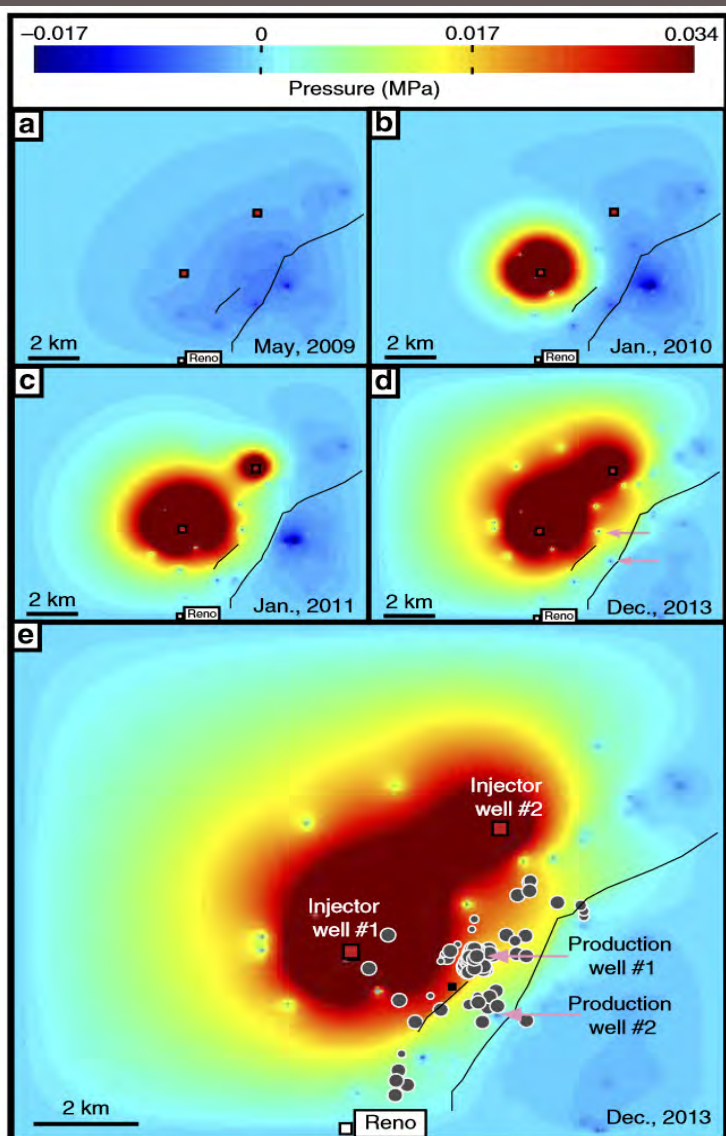
Hornbach et al., 2015, Nature Comm.

Natural and Human-Made Stress Changes that Cause Earthquakes



NOT TO SCALE

SWD INJECTION AND BRINE PRODUCTION MOST LIKELY CAUSE



- Pressure modeling confirms it is plausible injection/production caused pressure changes sufficient to trigger earthquakes.
- Pressure modeling indicates pressure changes associated with drought were orders of magnitude lower
- Faults near Azle/Reno area though historically inactive, appear near-critically stressed
- Currently, industry activities appear to represent the largest quantifiable stress driver on the fault system.

LINKAGE TO PRODUCTION ACTIVITIES?

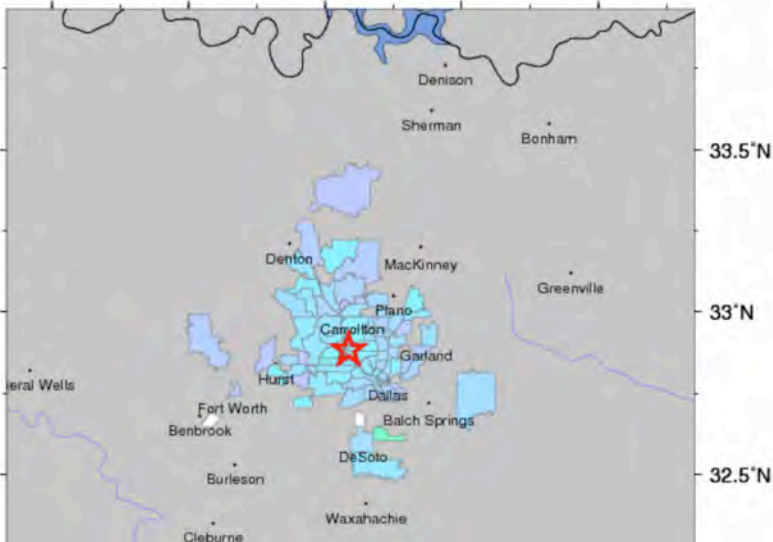
Questions from Davis and Frohlich, 1993	Cleburne Answers
1. Are the events the first known earthquakes of this character in the region?	YES
2. Is there a clear correlation between injection and seismicity?	YES
3. Are epicenters within 5 km of wells?	YES
4. Do some earthquakes occur at or near injection depth?	YES
5. Are there known geologic structures that may channel flow to sites of earthquakes?	YES
6. Are changes in fluid pressure at well bottoms sufficient to encourage seismicity?	YES
7. Are changes in fluid pressure at hypocentral distances sufficient to encourage seismicity?	YES

Better subsurface data to constrain structures, faults and material properties. This type of data needed to produce physical models to assess the cause of earthquakes.

EVENTS CONTINUE

Magnitude 3.3 (18 May) and 4.0 (7 May)

USGS Community Internet Intensity Map
NORTHERN TEXAS
May 18 2015 01:14:29 PM local 32.8833N 96.9147W M3.3 Depth: 5 km ID:us10002a93

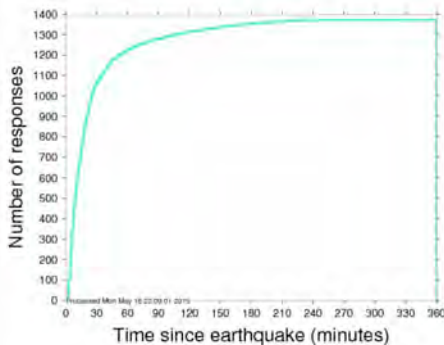


1340 responses in 86 ZIP codes (Max

	98°W	97.5°W	97°W
INTENSITY	I	II-III	IV
SHAKING	Not felt	Weak	Light
DAMAGE	none	none	none

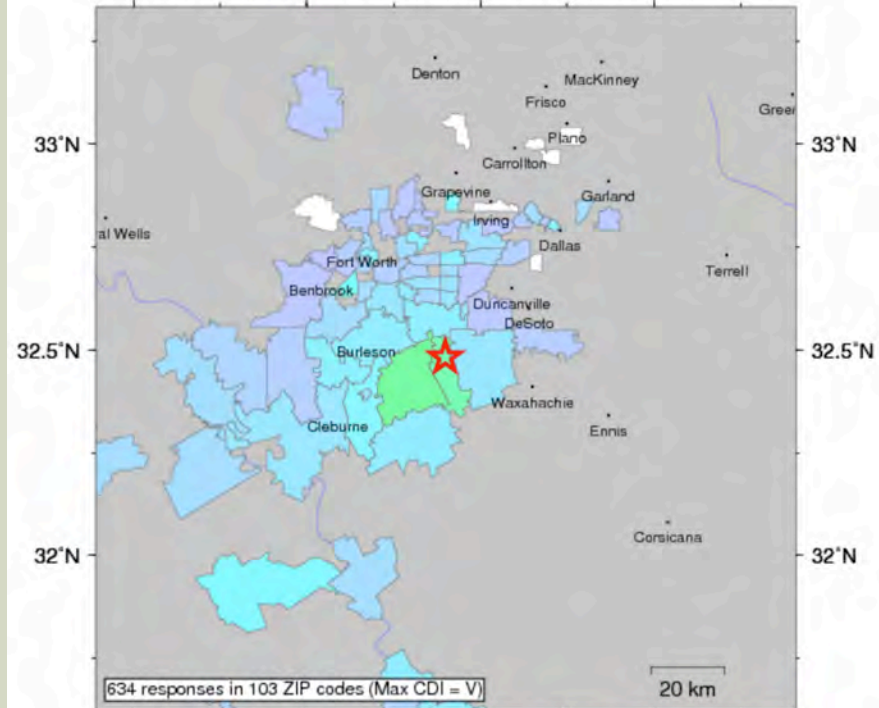
Processed: Mon May 18 22:08:55 2015

Responses vs. Time Plot (ID us10002a93)



USGS Community Internet Intensity Map
NORTHERN TEXAS

May 7 2015 05:58:05 PM local 32.4817N 97.1006W M4.0 Depth: 2 km ID:us20002dm8



634 responses in 103 ZIP codes (Max CDI = V)

	98°W	97.5°W	97°W	96.5°W
INTENSITY	I	II-III	IV	V
SHAKING	Not felt	Weak	Light	Moderate
DAMAGE	none	none	none	Very light

Processed: Sun May 17 23:38:14 2015

PATH FORWARD

NRC, 2012

Current models employed to understand the predictability of the size and location of earthquakes through time in response to net fluid injection or withdrawal require calibration from data from field observations.

The success of these models is compromised in large part due to the lack of basic data at most locations on the interactions among rock, faults, and fluid as a complex system.

CONCLUDING REMARKS

- ***Proof of Induced Seismicity may be difficult to obtain.*** Absolute proof may not be necessary for consideration of prudent operational changes.
- ***No agreed upon physical model for linkage between commercial activities and earthquakes.*** A range of physical models may be in operation depending on individual conditions.
- ***Need for reservoir engineers, geologists and geophysicists to work together to attack these problems.*** Data sharing provides a step in assessment of these issues. Seismic monitoring is only one part of this assessment.



NORTH TEXAS EARTHQUAKES

Featured News & Experts / Faculty and News Issues / Earthquake Study

UNDERSTANDING RECENT NORTH TEXAS EARTHQUAKES

Scientific investigations of earthquake clusters are being conducted by seismologists from SMU's Huffington Department of Earth Sciences in Dedman College

A recent series of earthquakes near the site of the old Cowboys Stadium in Irving are renewing scientific questions about the nature of these events and heightened local and national concerns about the impact of activities related to shale gas production on geological infrastructure and subsurface structures.

The Irving earthquakes are the latest in a series of four clusters that have hit the North Texas area since 2008. The first group hit near DFW International Airport between October 30, 2008, and May 16, 2009. It was followed by a series of quakes in Cleburne between June 2009 and June 2010 and a third series in the Reno-Azle area between November 2013 and January 2014.

The SMU seismology team includes Prof. Brian Stump, SMU's Albritton Chair of Geological Sciences, Heather DeShon, associate professor of geophysics, Beatrice Magnani, associate professor of geophysics, and Matt Hornbach, associate professor of geophysics, as well as Chris Hayward, research scientist.

SMU seismologists say more than 120 earthquakes have been reported in the North Texas area since 2008. Prior to 2008, a felt earthquake had not been reported in the North Texas area since 1950. Peer-reviewed publications have been issued by the SMU team on the Cleburne and DFW clusters, and another is pending on the Reno-Azle cluster.

If a member of the public feels an earthquake, he or she is asked to report it to the U.S. Geological Survey "Did You Feel It?" site.

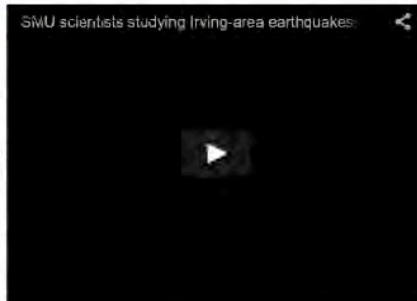
"I think the more important thing for people in the Dallas-Fort Worth area to remember is that since we don't have a lot of seismic stations, it is incredibly important when you feel an earthquake to report it to the U. S. Geological Survey," DeShon said. "This is very valuable information to us. It helps us to really understand how the ground moved and how it accelerated over the metropolitan area."

While all North Texas events to date have been small (less than magnitude 4) and at a depth of about three miles, seismologists are unable to determine the potential maximum magnitude for the region. Rapid deployment of seismographs to locate events is done to characterize subsurface faults and help define the hazard. For the Irving cluster, scientists at SMU have installed and are operating a seismic network to acquire data that may be used to determine the location and possible cause of the earthquakes.



Report before House Committee
SMU seismologists Matt Hornbach and Brian Stump testified before the Texas House of Representatives Committee on Energy Resources May 4, 2015. Watch the hearing or read their report on increased seismicity in Texas.

[Report an Earthquake to the USGS "Did You Feel It?" site.](#)



Scientists brief the media Jan. 6.

EARTHQUAKE STUDY

- [Contact Us](#)
- [Frequently Asked Questions](#)
- [Monitor Installation Process](#)
- [Sites for Seismic Monitors](#)
- [Study Team Members](#)
- [Report to Texas House Committee on May 4, 2015](#)
- [PowerPoint presentation to Texas House Subcommittee on May 12, 2014](#)
- [Progress Report May 7, 2014](#)

Related Links

- [Media Briefing Jan. 6, 2015](#)
- [Irving Quakes](#)
- [Media Briefing Feb. 7, 2014](#)
- [Cleburne Quakes Study](#)
- [DFW Quakes Study](#)
- [Reno-Azle Quakes Study](#)

Data collected in real-time and made publically available

smu.edu/News/NewsIssues/EarthquakeStudy/