Worldwide Seismic Activity and Recent Oklahoma Earthquakes*

Glen Brown[1]

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Abstract

Oklahoma seismic activity uptick in last 5 years is not unprecedented. During the 1950s a similar active earthquake period occurred in Oklahoma but was poorly measured as compared to today. From a global perspective, both earthquake-prone periods in Oklahoma were each coincident with 50% of the largest worldwide quakes over 8.8 Richter scale from 1900 to 2014. Oklahoma activity may be related to these large quakes despite being away from the actual plate boundaries. Earthquake locations in Oklahoma are inversely related to horizontal drilling, stimulation and/or salt water disposal. Unusual earthquake activity is also observed during the last 5 years in Virginia, South Carolina, Alaska, Mexico, and the Gulf of California--in areas where no oil and gas activity is present.

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Worldwide Seismic Activity

and Recent

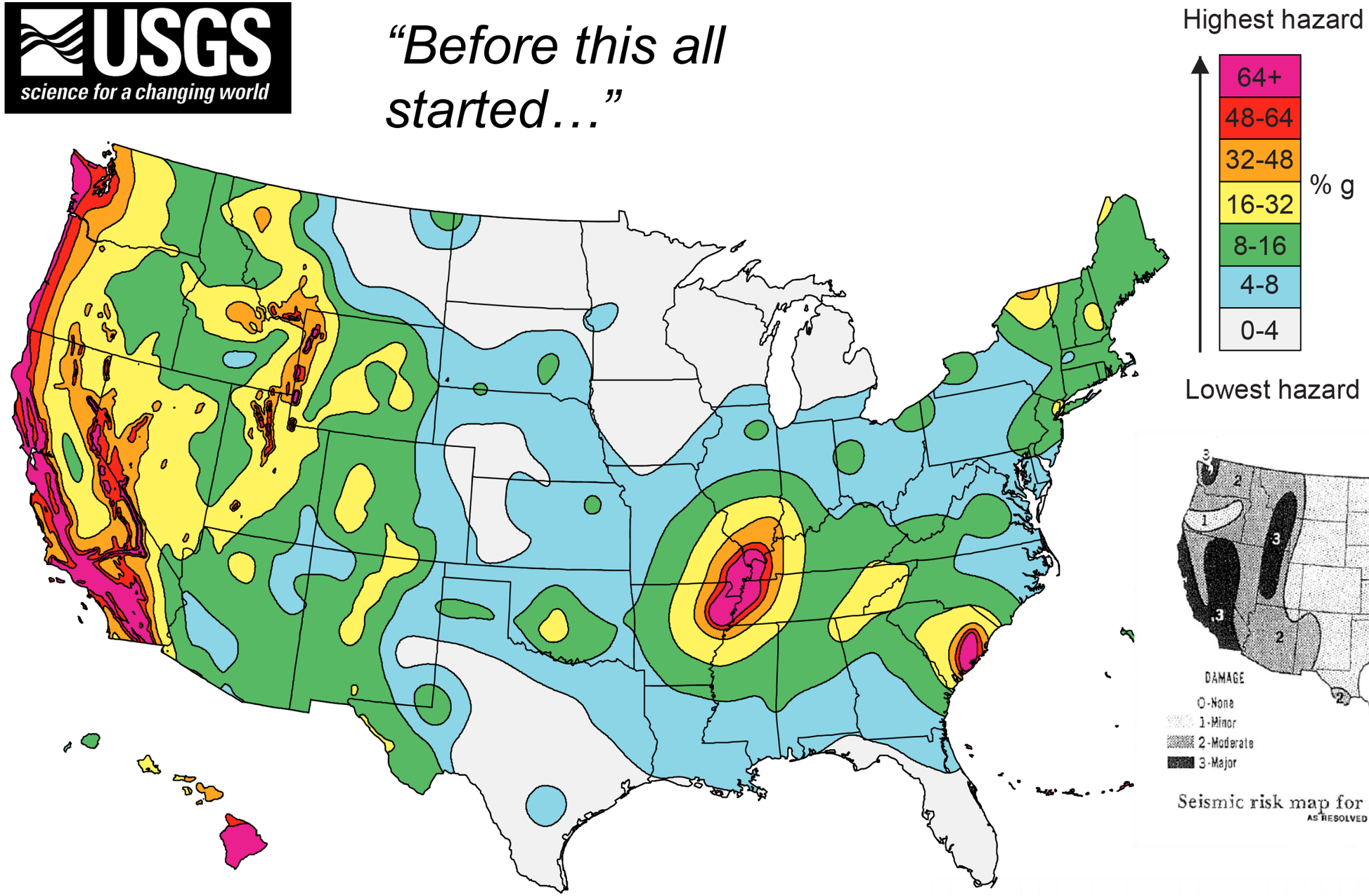
Oklahoma Earthquakes

Tulsa Geological Society Dec 16th ,2014
Glen Brown

Oklahoma seismic activity uptick in last 5 years is not unprecedented. During the 1950s another active earthquake period occurred in Oklahoma but was poorly measured as compared to today. From a global perspective, both earthquake prone periods in Oklahoma history were each coincident with 50% of the largest Worldwide quakes over 8.8 Richter Scale from 1900 to 2014. Oklahoma activity may be related to these large quakes despite being away from actual plate boundaries. Earthquake locations in Oklahoma are inversely related to horizontal drilling, stimulation and/or salt water disposal. Unusual earthquake activity is also observed during the last 5 years in Virginia, South Carolina, Alaska, Mexico, and the Gulf of California--in areas where no oil and gas activity is present.

2008 U.S. Event Hazards Rating Map

"Before this all started…"



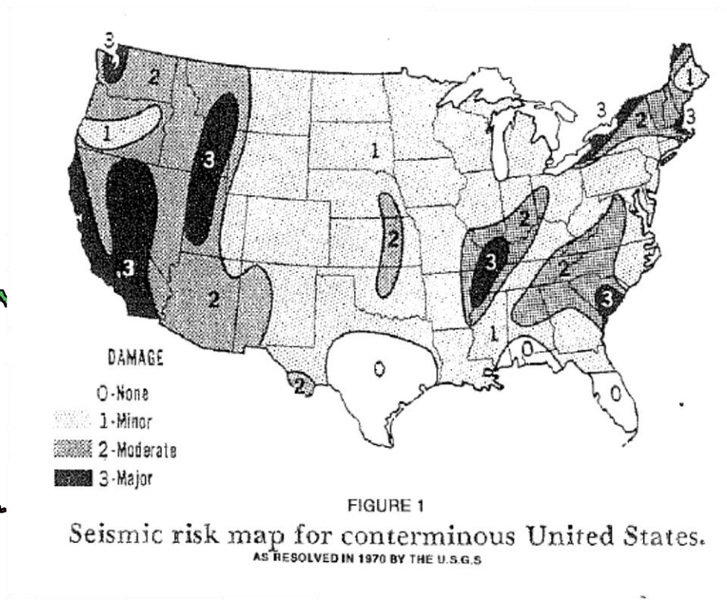


FIGURE 1

Seismic risk map for conterminous United States.

AS RESOLVED IN 1970 BY THE U.S.G.S

Map source: http://earthquake.usgs.gov/hazards/products/

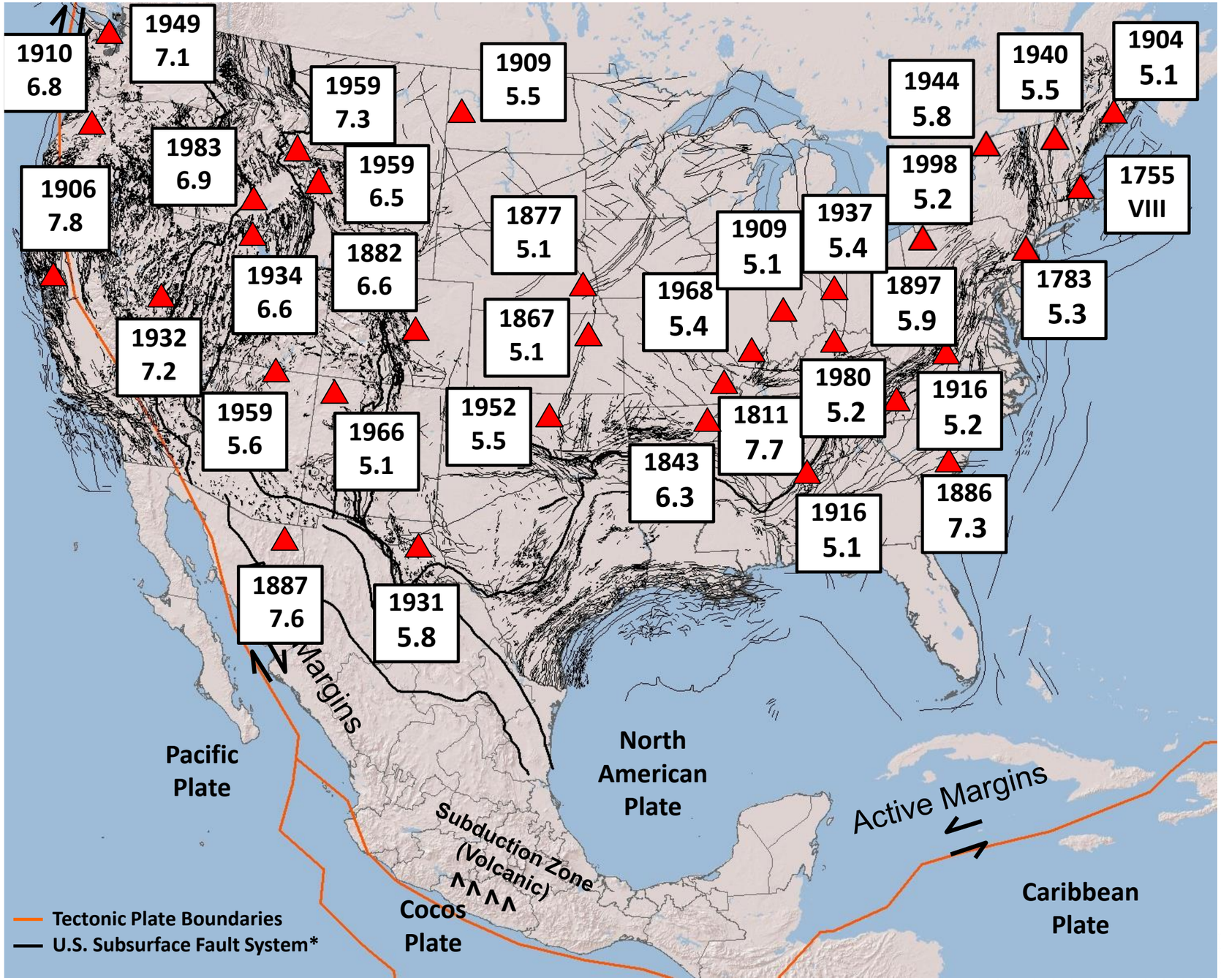
U.S. Tectonic Map with largest Earthquake events prior to 2000

In the lower 48:

46 states have documented earthquakes 96%

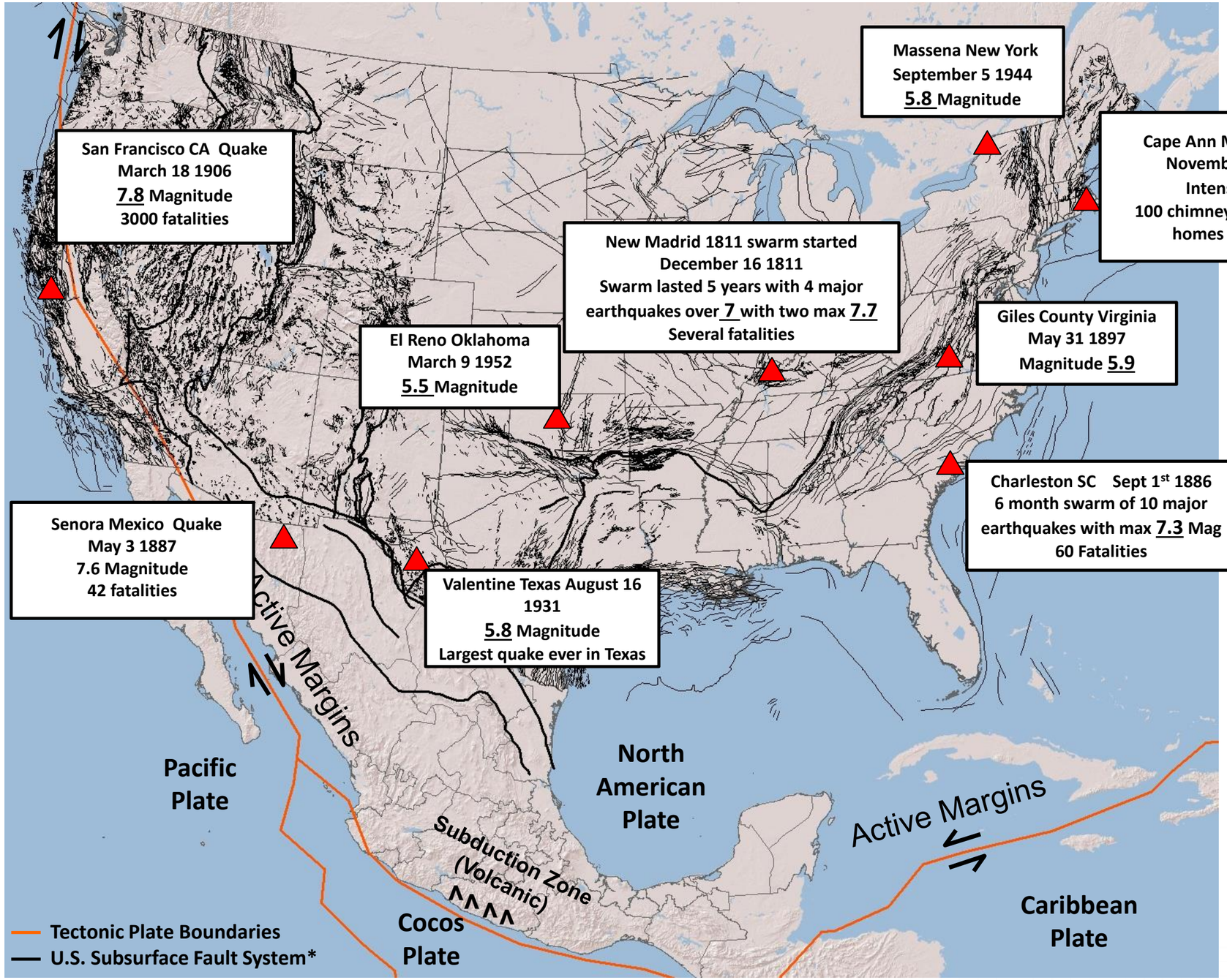
32 states have magnitude greater than 5 66%

8 States have magnitude greater than 7 16%



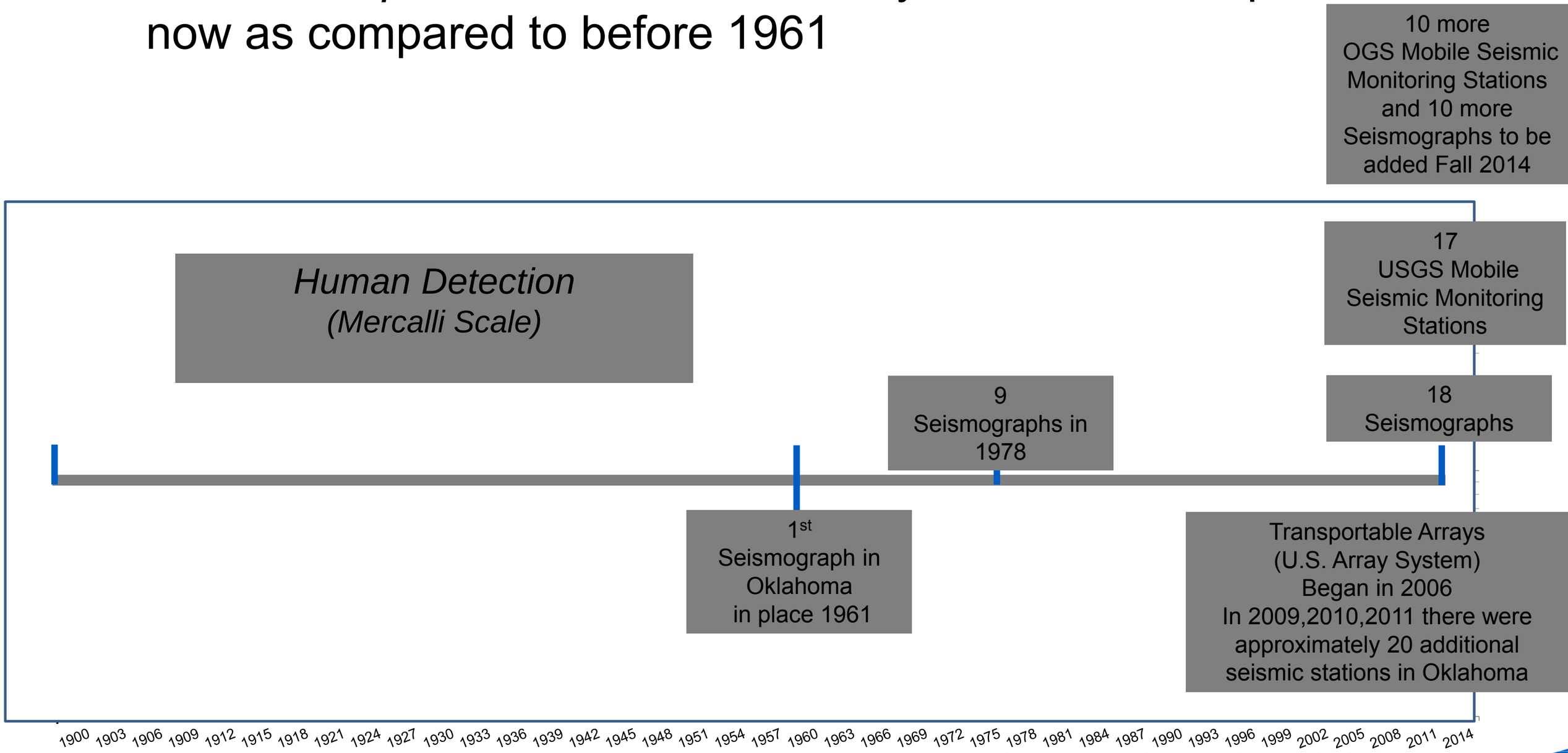
*Source: Geologic Data Systems

U.S. Tectonic Map with historic Earthquake events



*Source: Geologic Data Systems

Oklahoma detection of earthquakes has evolved
What is "*unprecedented*" is our ability to detect earthquakes now as compared to before 1961



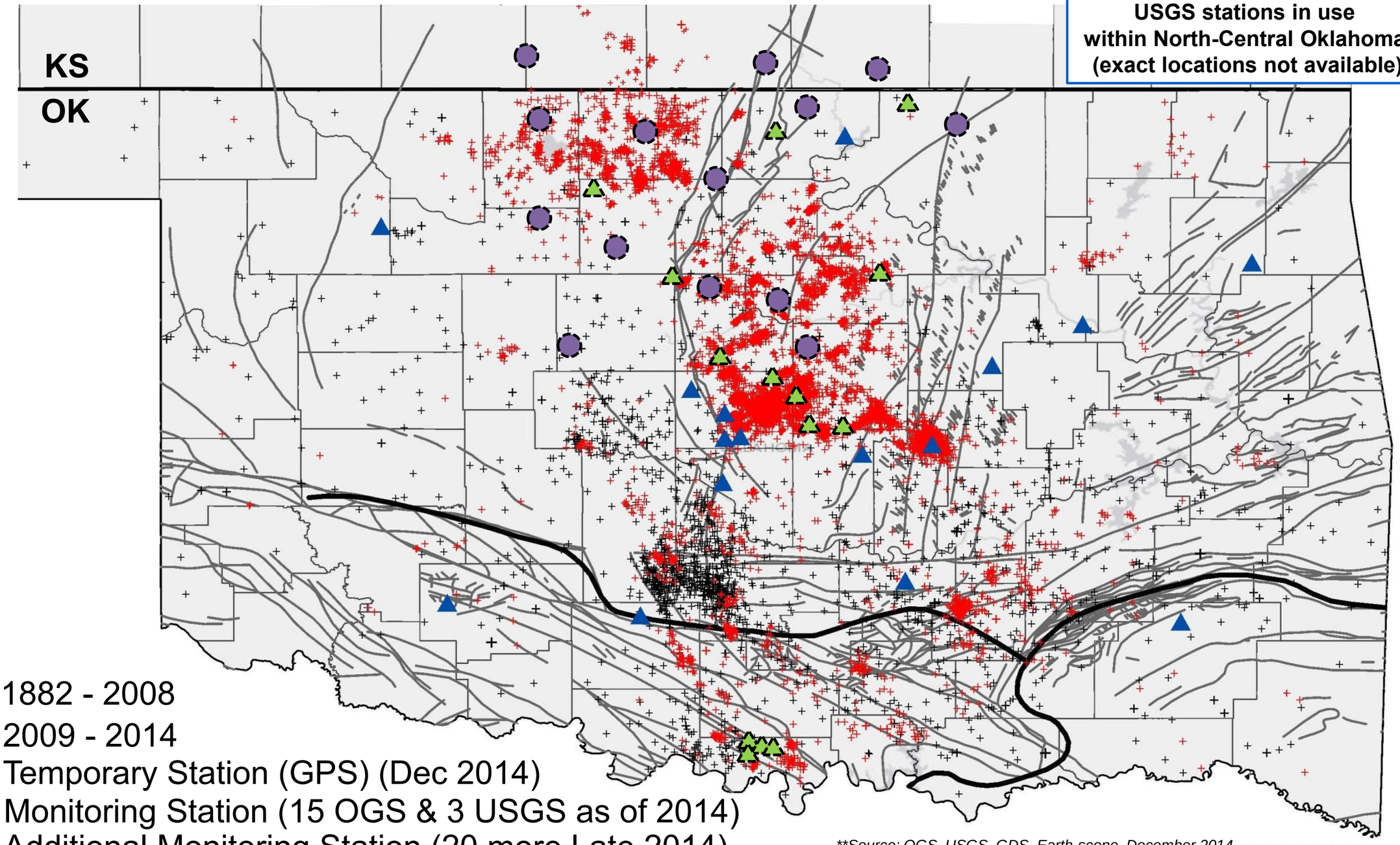
**Source: OGS/USGS, 2014*

Oklahoma Earthquakes

55 total stations in late 2014 planned (20 in OK & 6 additional in South-Central KS)

Installing 10 new Seismographs fall 2014

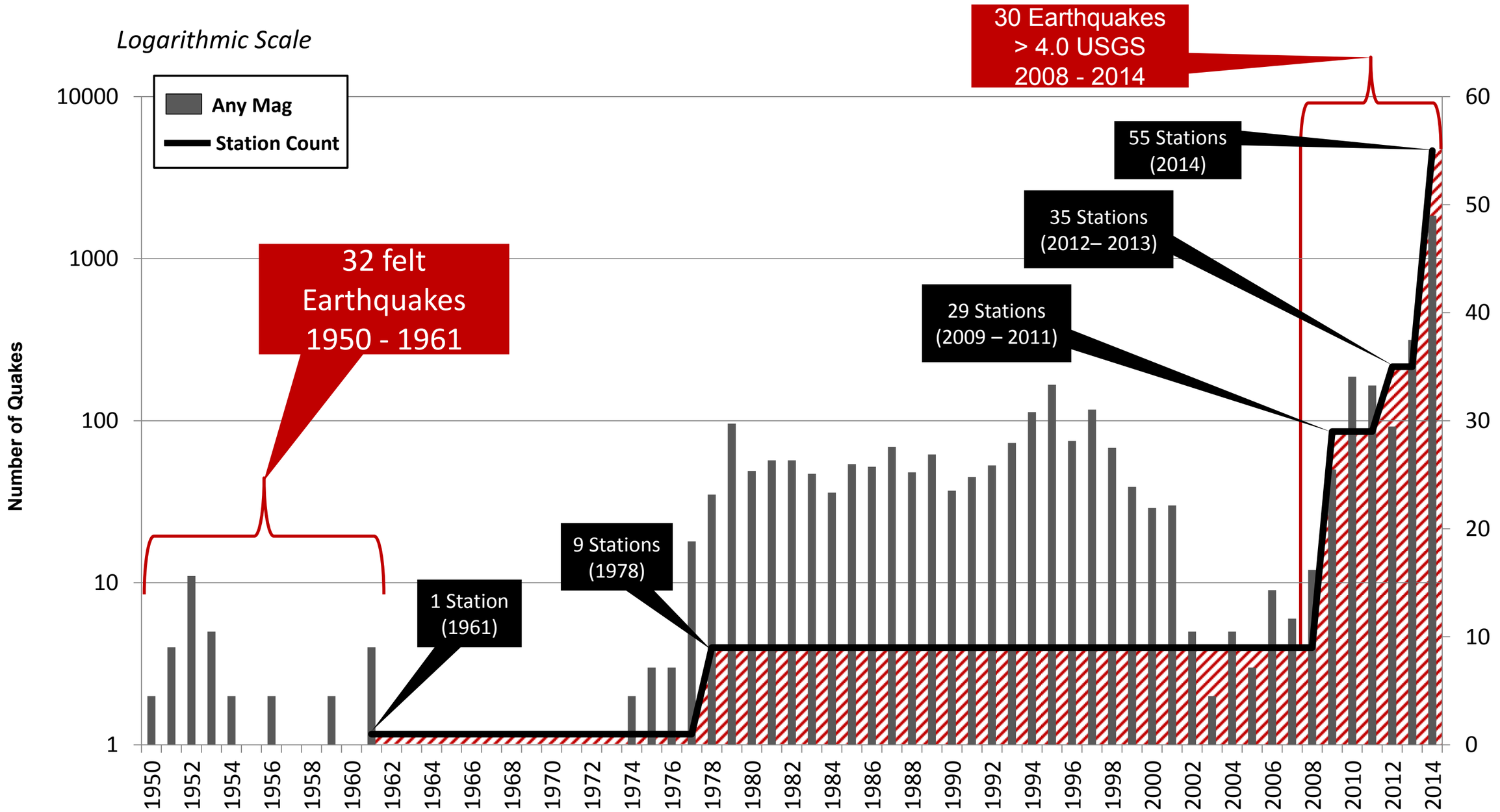
27 additional mobile/temp USGS stations in use within North-Central Oklahoma (exact locations not available)



- 1882 - 2008
- 2009 - 2014
- Temporary Station (GPS) (Dec 2014)
- Monitoring Station (15 OGS & 3 USGS as of 2014)
- Additional Monitoring Station (20 more Late 2014)

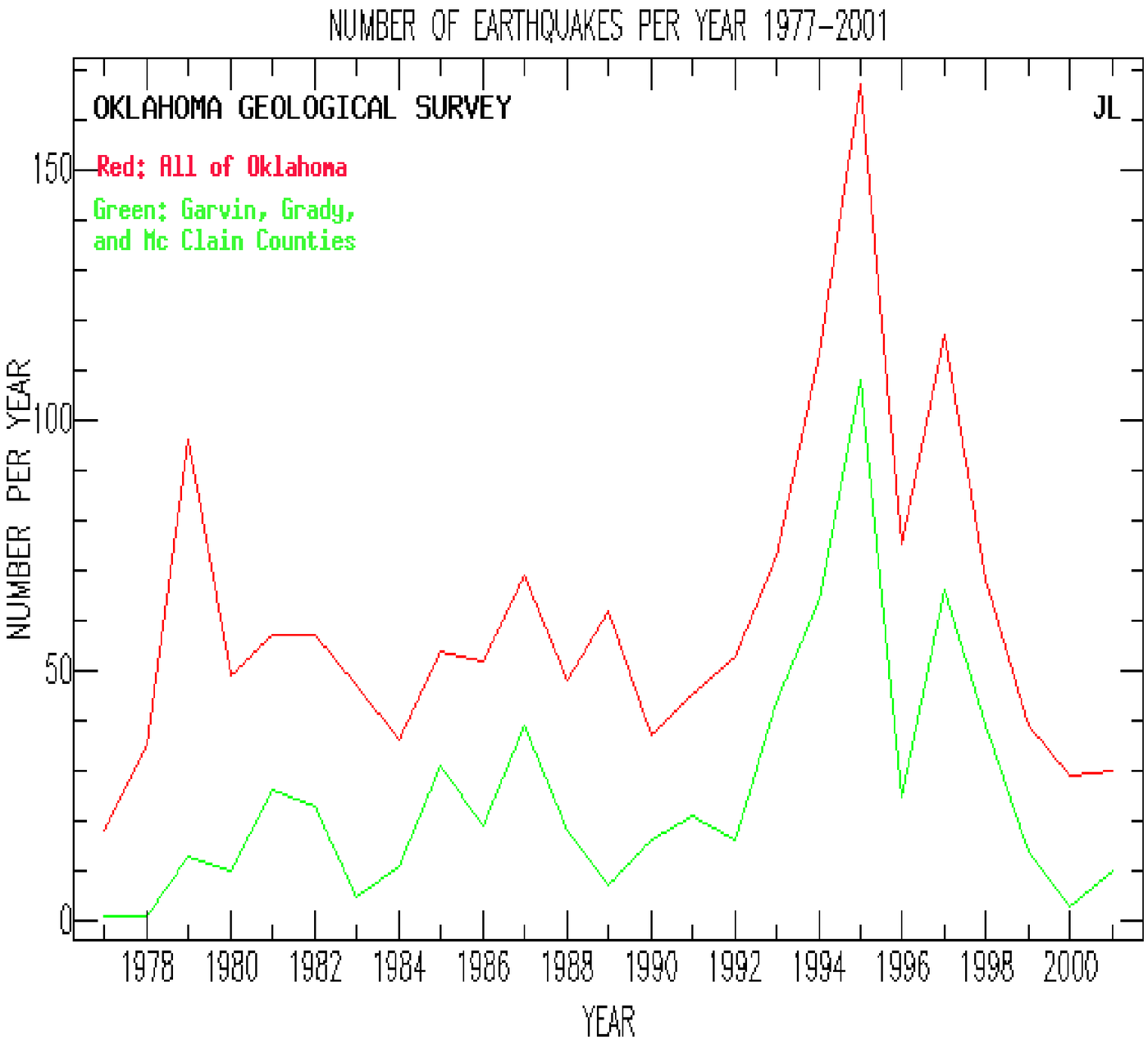
***Source: OGS, USGS, GDS, Earth-scope, December 2014*

Oklahoma and Kansas Quakes: Any Magnitude



Source: USGS, December 2014
OGS (from 1977-2001)

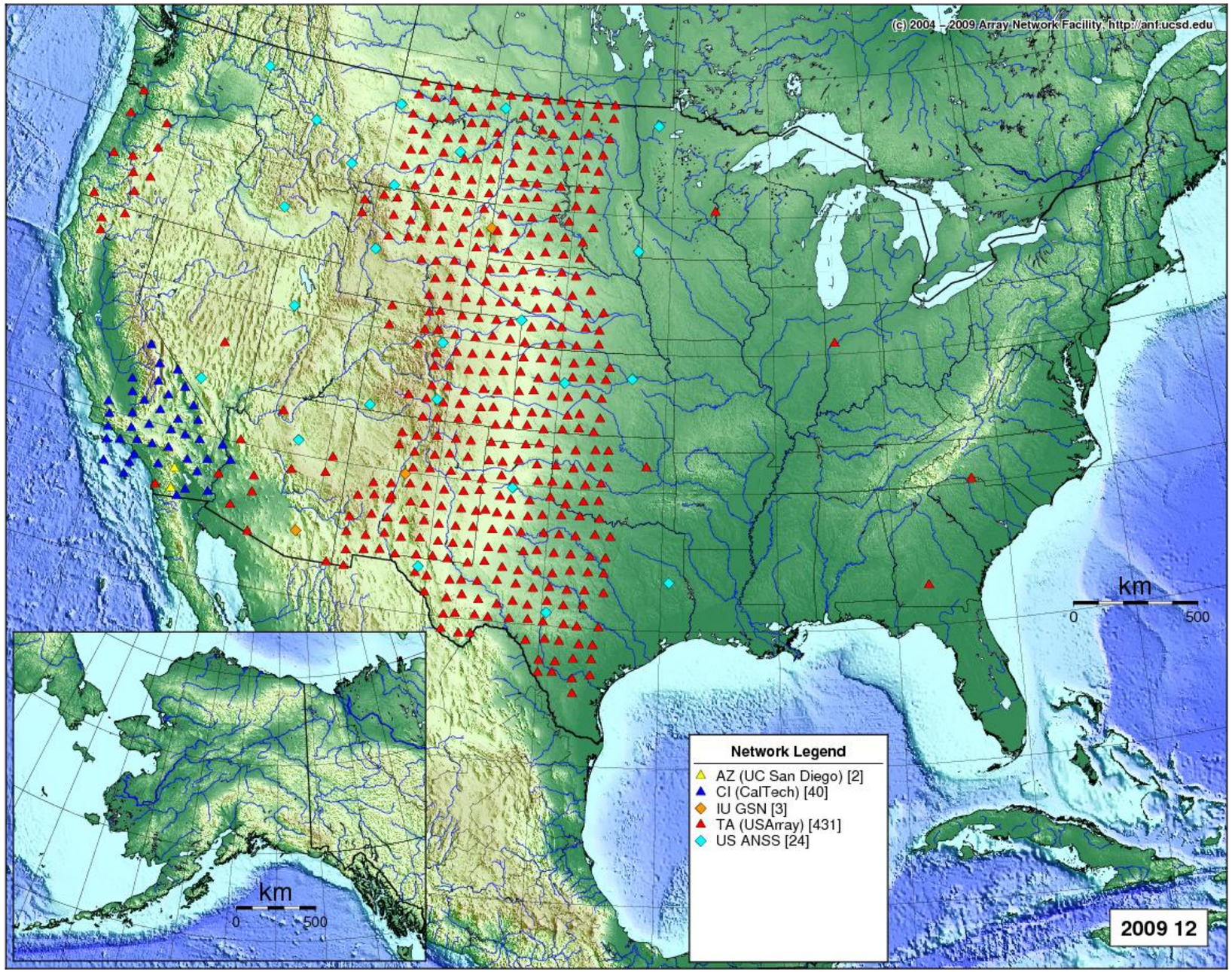
OKLAHOMA GEOLOGICAL OBSERVATORY
NUMBER OF EARTHQUAKES PER YEAR FOR THE ENTIRE STATE AND SELECTED COUNTIES



Source OGS

The Oklahoma Geological Survey's statewide seismograph network started
operation in late 1976. Because many earthquakes which are located by the
network are much smaller than those known before 1977, years before 1977
are not listed.

In 2009 the NSF EarthScope U.S. Array program deployed stations at 70-km spacing across Oklahoma.



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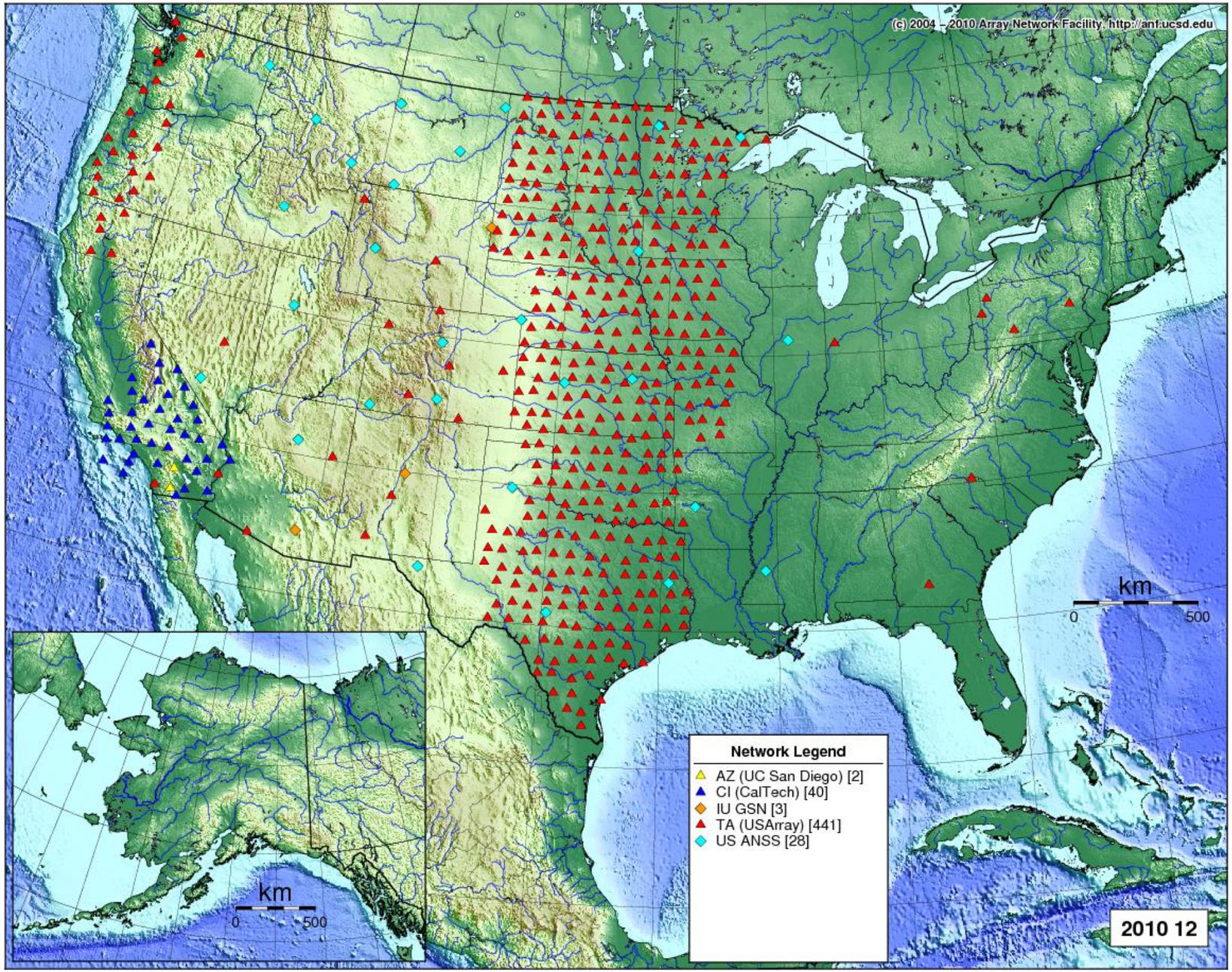

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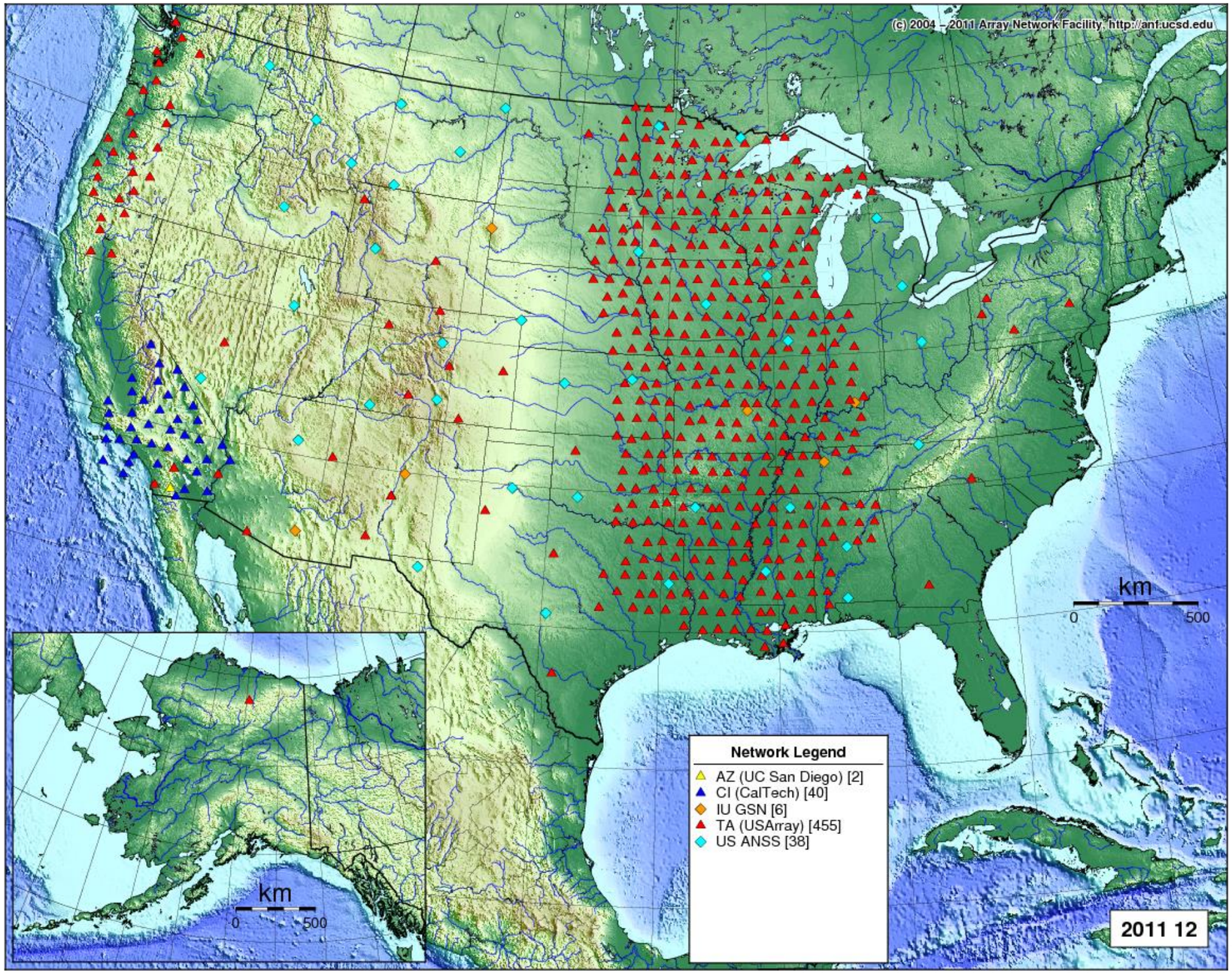
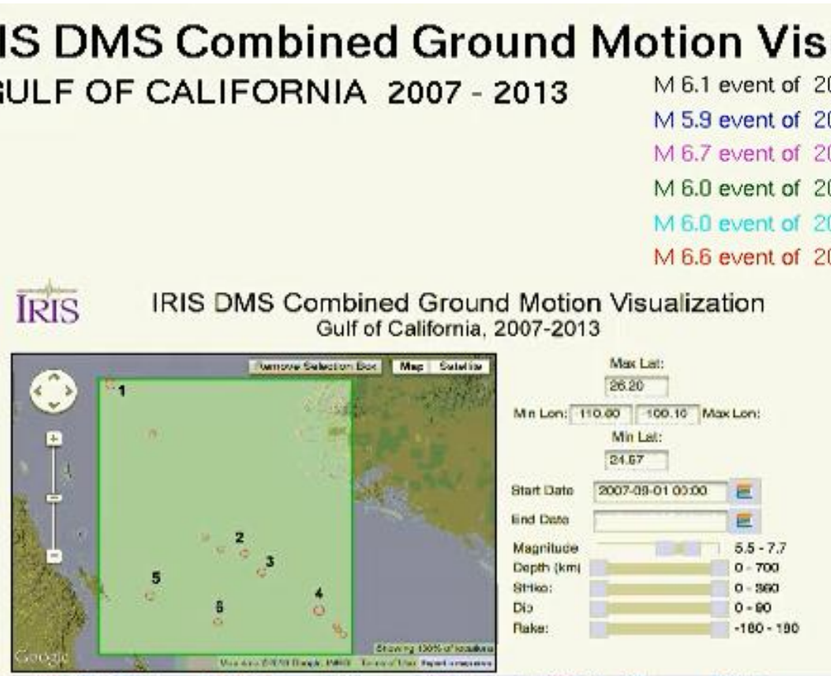


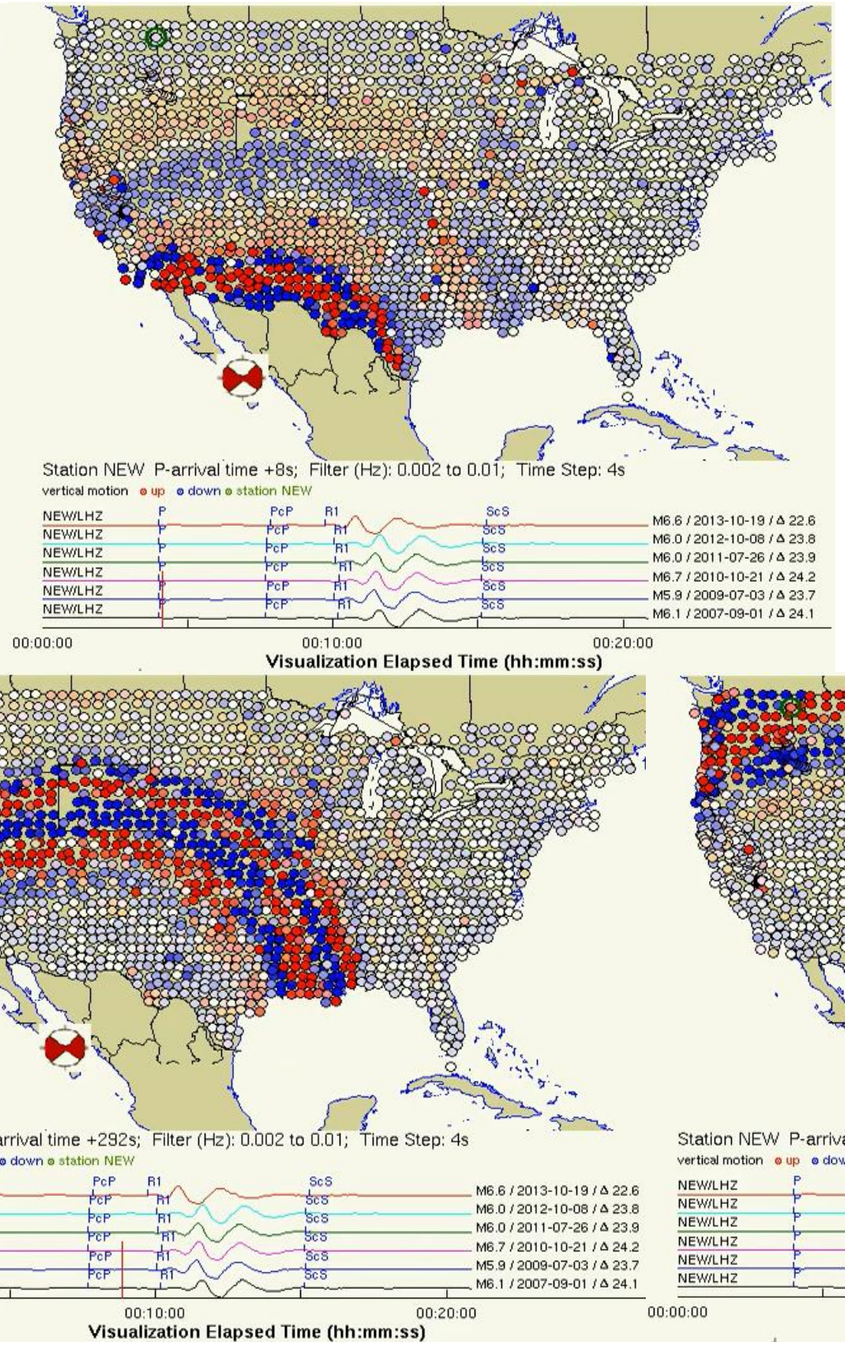
IRIS DMS Combined Ground Motion Visualization

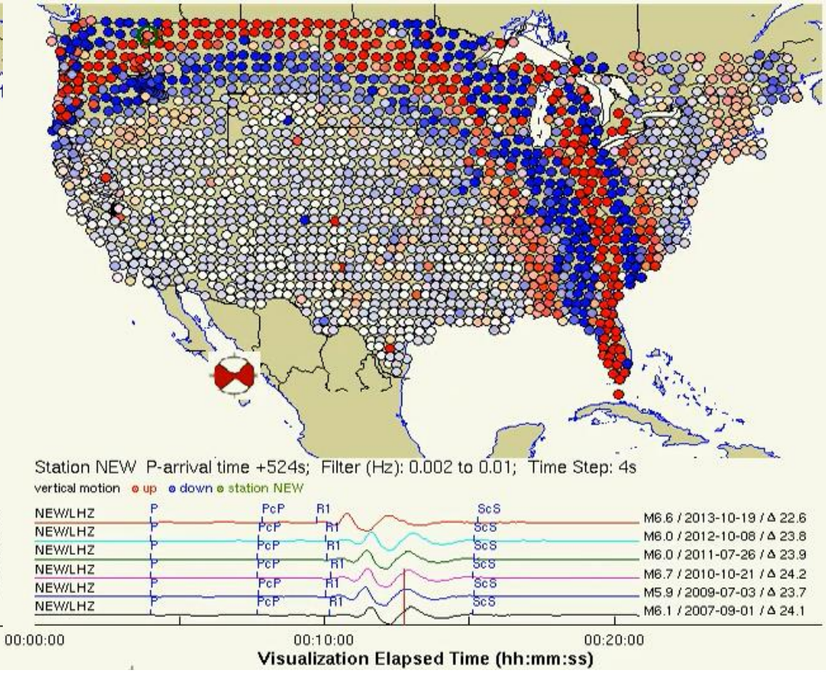
GULF OF CALIFORNIA 2007 - 2013

M 6.1 event of 2007-09-01 19:14:26
M 5.9 event of 2009-07-03 11:00:17
M 6.7 event of 2010-10-21 17:53:19
M 6.0 event of 2011-07-26 17:44:22
M 6.0 event of 2012-10-08 06:26:25
M 6.6 event of 2013-10-19 17:55:03



	Event Time (UTC)	Depth (km)	Mag	Latitude	Longitude	FM	Region
1	2013-10-19 17:55:03	15.1	6.6	25.17	-110.53		GULF OF CALIFORNIA
	2013-01-15 16:28:27	18.4	5.7	25.88	-110.28		GULF OF CALIFORNIA
2	2012-10-08 06:26:25	19.7	6.0	25.17	-109.73		GULF OF CALIFORNIA
	2012-09-25 23:45:27	12.0	5.3	21.92	-110.29		BAJA CALIFORNIA, MEXICO
3	2011-07-26 17:44:22	17.5	6.0	25.06	-109.68		GULF OF CALIFORNIA
	2011-08-12 13:26:32	20.6	5.6	25.27	-109.07		GULF OF CALIFORNIA
4	2010-10-21 17:53:19	14.2	6.7	24.83	-109.29		GULF OF CALIFORNIA
	2010-10-20 06:59:16	15.5	5.9	24.72	-109.16		GULF OF CALIFORNIA
	2010-10-20 04:15:36	17.4	5.7	24.89	-109.16		GULF OF CALIFORNIA
	2010-10-20 04:09:47	19.4	5.8	24.74	-109.19		GULF OF CALIFORNIA
5	2009-07-03 11:00:17	14.4	5.9	25.20	-109.87		GULF OF CALIFORNIA
6	2007-09-01 19:14:26	14.9	6.1	24.78	-109.89		GULF OF CALIFORNIA





Source: IRIS

USGS: Are Earthquakes Really on the Increase?

- In 1931, there were about 350 stations operating in the world
- Today, more than 8,000 stations are in place.. and data now comes in rapidly via electronic mail, internet and satellite
- The NEIC(National Earthquake Information Center) now locates about 20,000 earthquakes each year (or 50 per day).
- According to long-term records (since about 1900), we expect about 17 major earthquakes (7.0 - 7.9) and one great earthquake (8.0 or above) in any given year.

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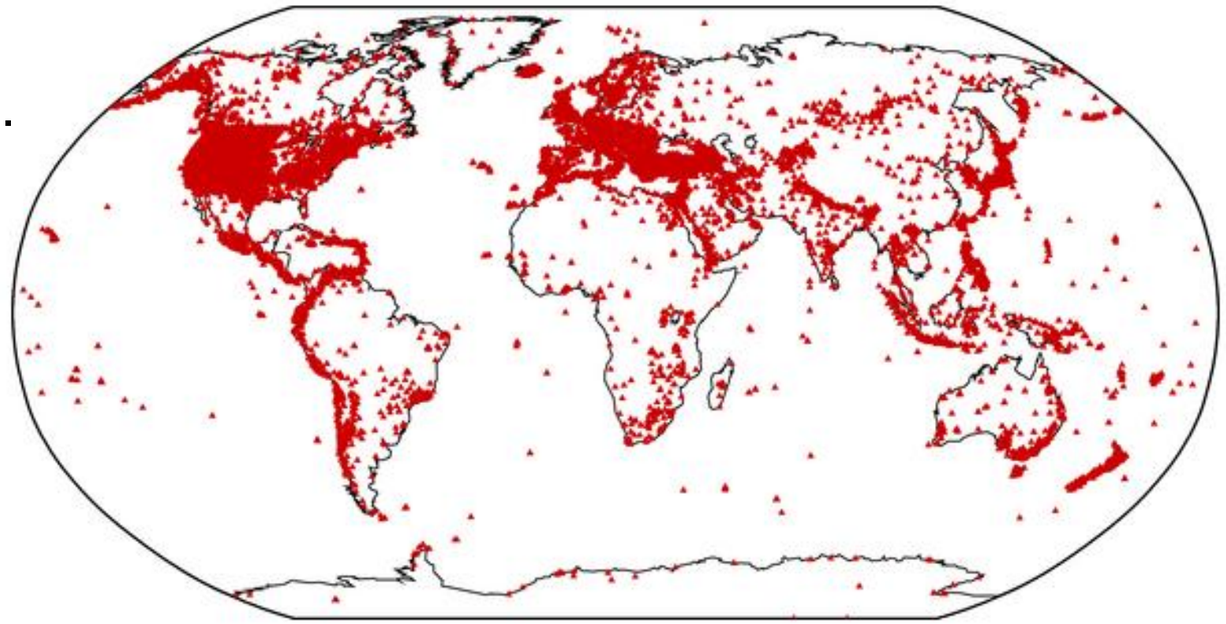
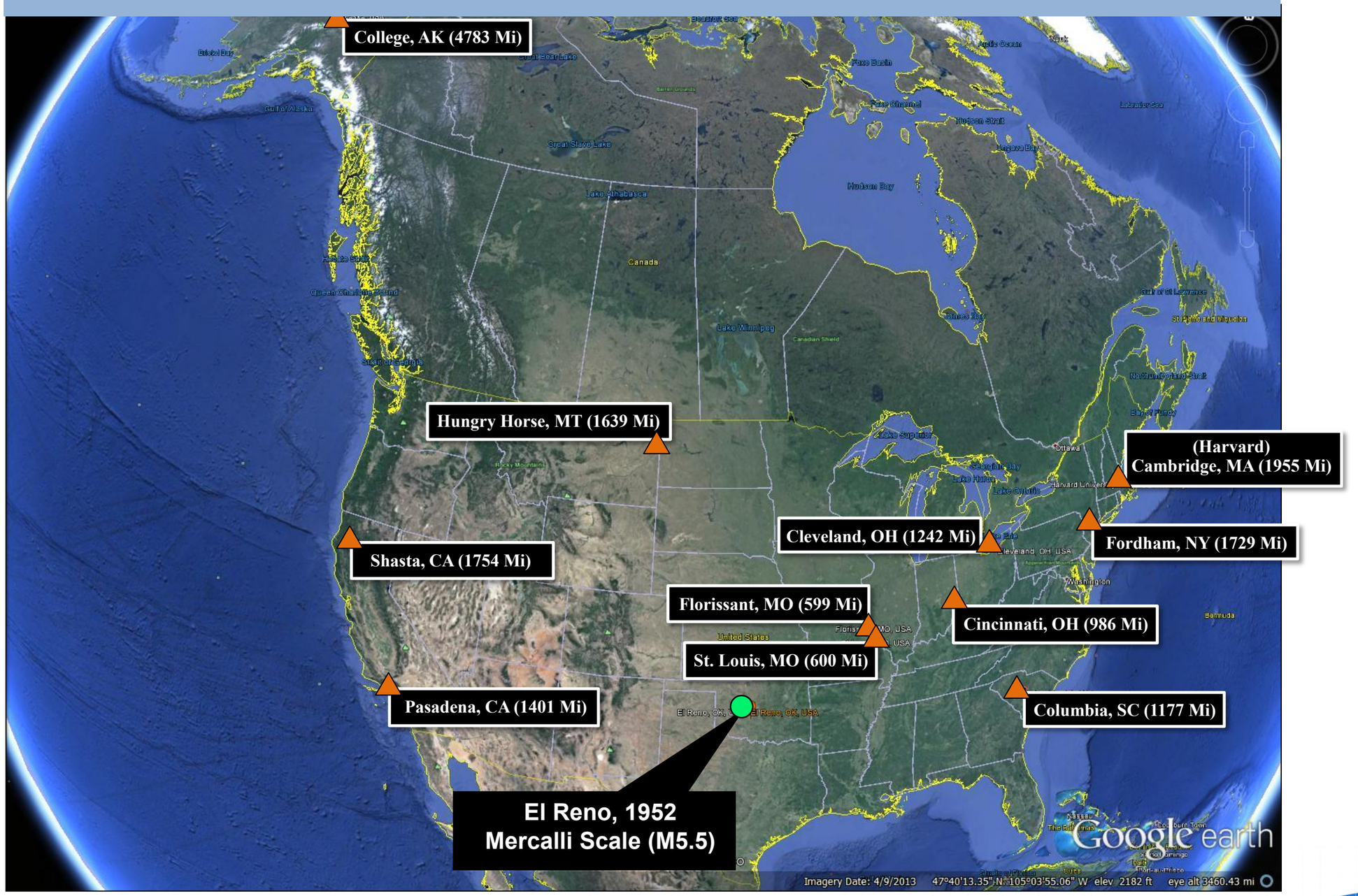


Source: http://earthquake.usgs.gov/learn/topics/increase_in_earthquakes.php

Prior to 1961 there were no seismic stations in Oklahoma
The closest was in St Louis 500 miles from El Reno



*Source: USGS, 2014; Google Earth

**** "Revised Instrumental Hypocenters and Correlation of Earthquake locations and tectonics in the central United States"
By David Gordon
US Geological Survey Professional Paper 1364 (1988)

“ Due to low station density and low instrument magnifications only a very few earthquakes were located instrumentally less than magnitude 4 until the 1960s”

“The deployment of 10 stations starting in 1961 coincided with a dramatic increase in the number of instrumentally located earthquakes”

**

<u>Modern day very different!</u>

Seismometers in the permanent monitor grid in most of the central and eastern continental U.S. are spaced up to 200 miles apart.
With this spacing, the system is capable of measuring events down to approximately M3.0 or M3.5
Some areas this may extend down to a M2.5.
**

* “<u>Revised Instrumental Hypocenters and Correlation of Earthquake locations and tectonics in the central United States”</u>
By David Gordon
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**Quote from USGS website 2014

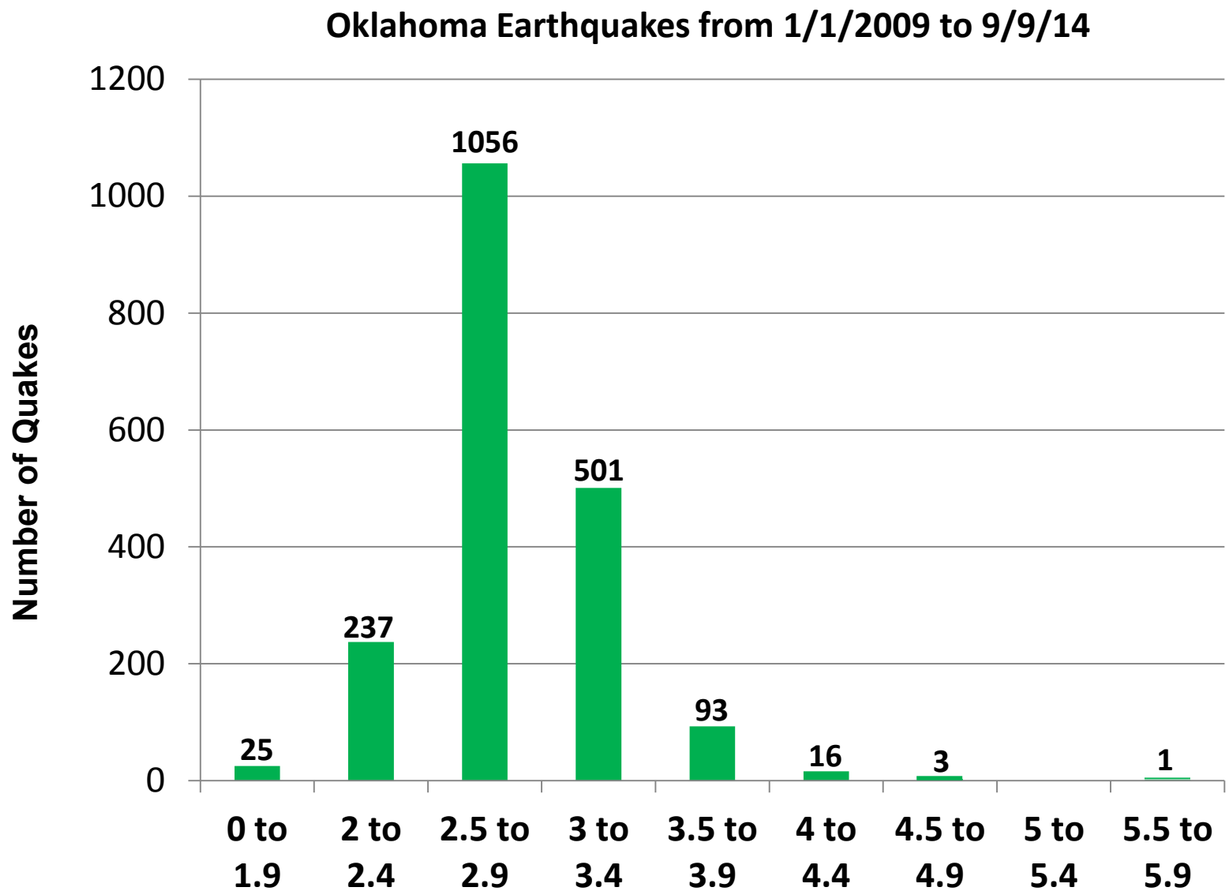
Magnitude	Description	Mercalli intensity	Average earthquake effects	Average frequency of occurrence (estimated)
Less than 2.0	Micro	I	Microearthquakes, not felt, or felt rarely by sensitive people. Recorded by seismographs.[15]	Continual/several million per year
2.0–2.9	Minor	I to II	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9		II to IV	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	IV to VI	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	VI to VIII	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone. Casualties range from none to a few.	1,000 to 1,500 per year
6.0–6.9	Strong	VII to X	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas:	100 to 150 per year
7.0–7.9	Major	VIII or greater[16]	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter. Death toll ranges from none to 250,000.	10 to 20 per year
8.0–8.9	Great		Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions. Death toll ranges from 1,000 to 1 million.	One per year

magnitude 4 is light

slight felt outside

no to minimal damage

some objects may fall off shelves



Source USGS Earthquake database June 25th 2014

World Earthquakes

Magnitude	Average Annually
8 and higher	1
7 - 7.9	15
6 - 6.9	134
5 - 5.9	1319
4 - 4.9	13,000
3 - 3.9	130,000
2 - 2.9	1,300,000

How Much Bigger ... Calculator

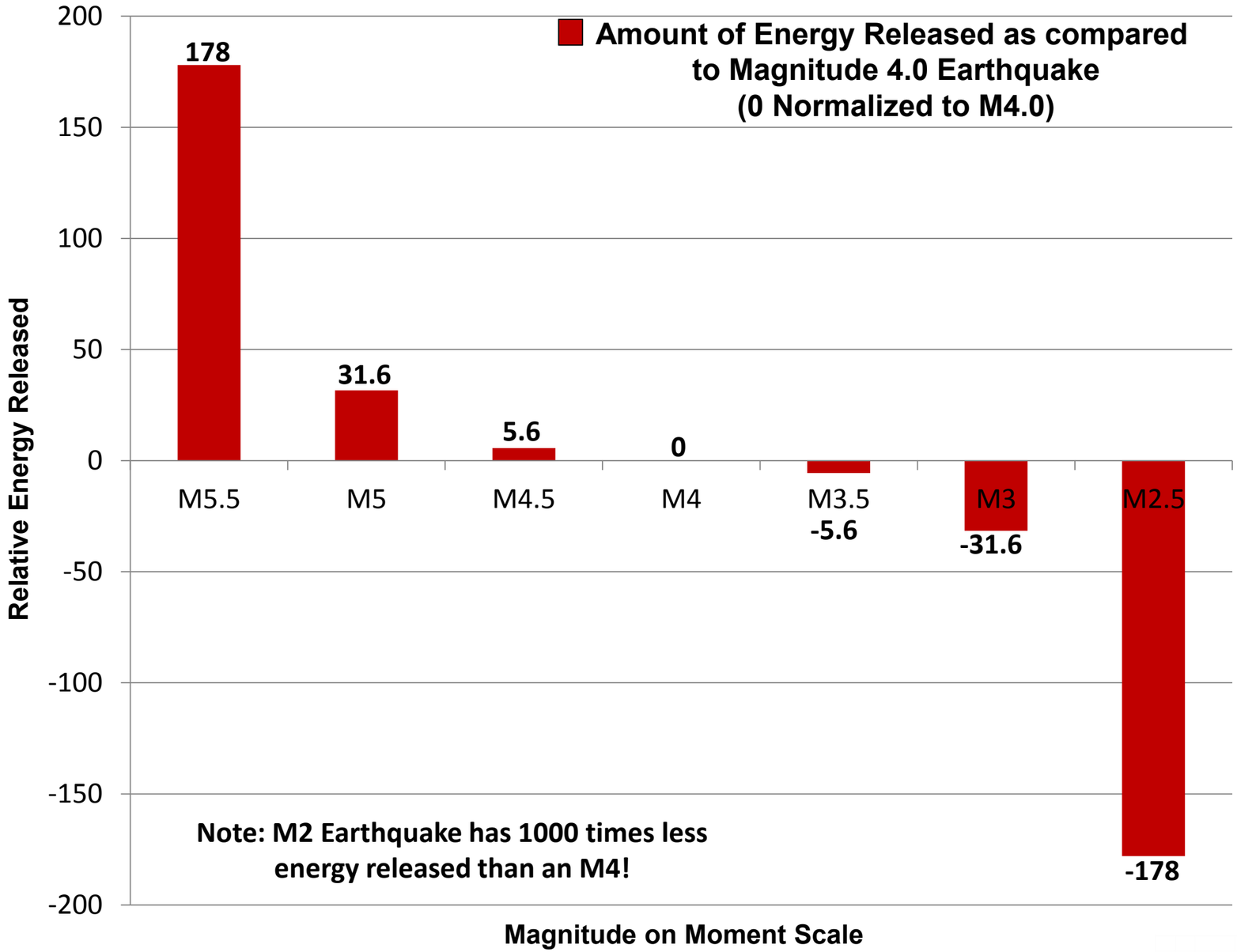
Input Magnitude 1:	Input Magnitude 2:
4	2.5
[Range is -3. to 10.]	[Range is -3. to 10.]

Calculate Reset

Magnitude Difference: 1.5

A magnitude 4 earthquake is 31.622 times **bigger** than a magnitude 2.5 earthquake on a seismogram, but is 177.827 times **stronger** (energy release).

Earthquake Energy

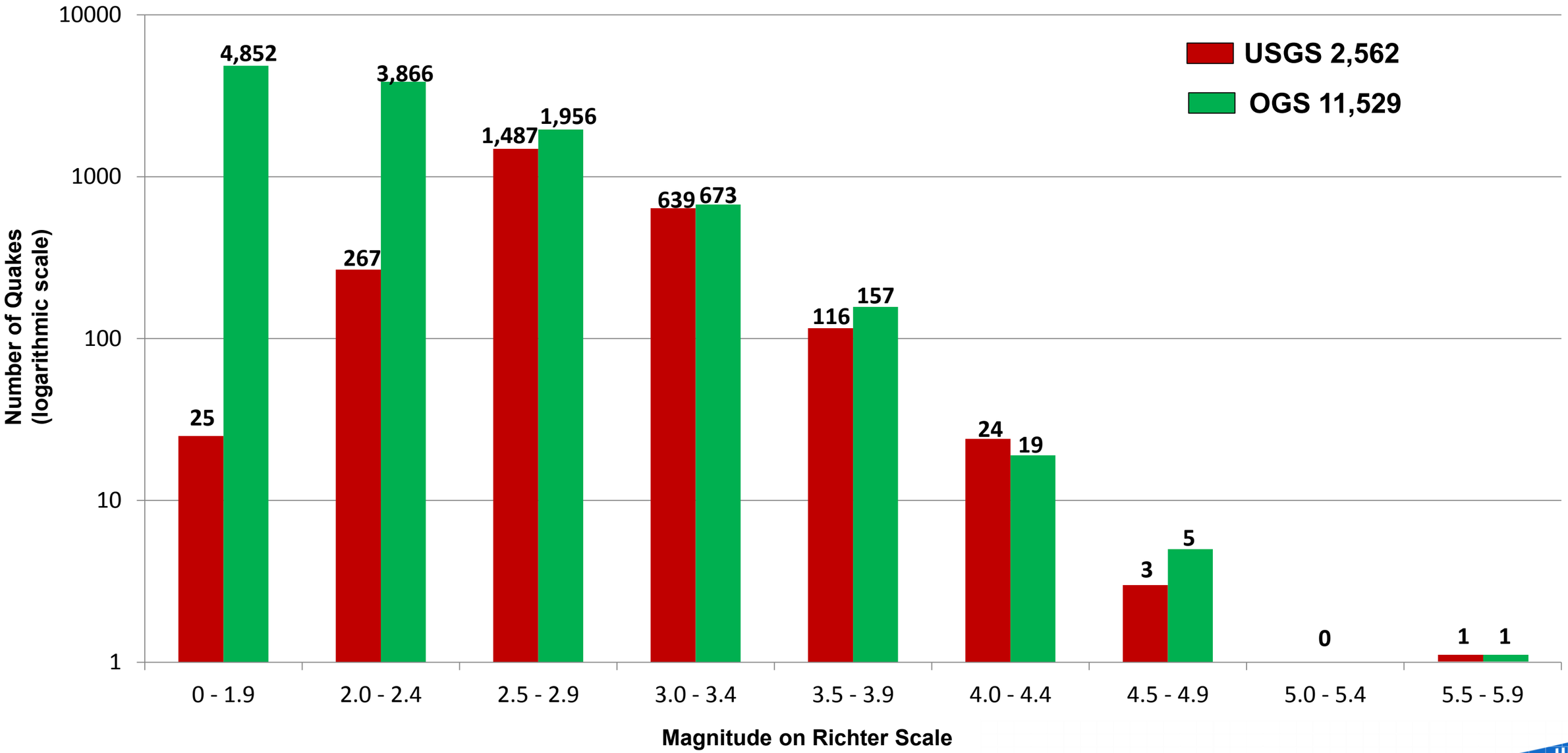


*Sources: USGS, 2014

Magnitude 4 to 4.9 is still considered “light” and “slight felt outside.” Generally causes none to minimal damage; “some objects may fall off shelves.”

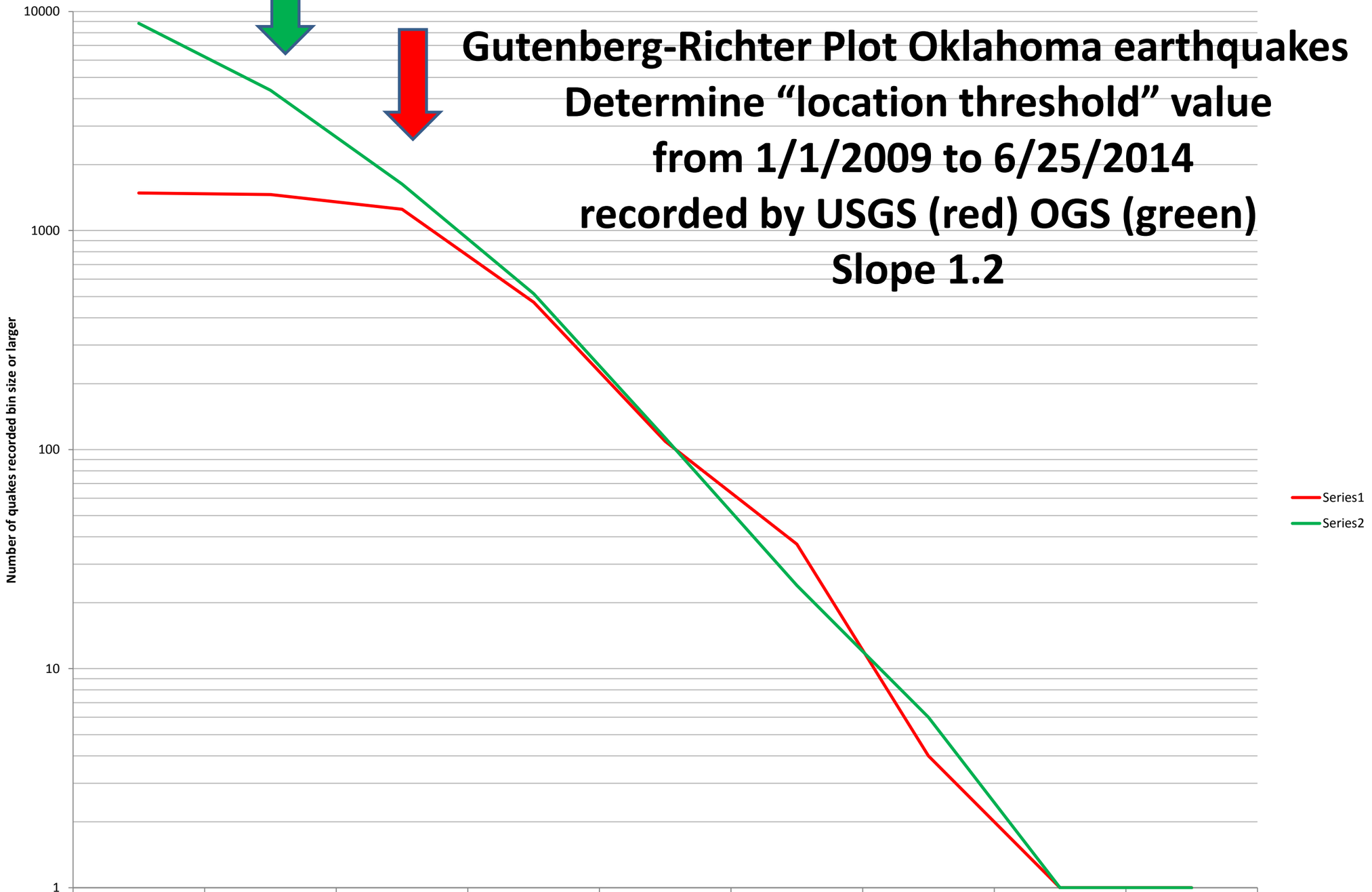
1 , 2 and 3 magnitudes are obviously less significant

Oklahoma Earthquakes from 1/1/2009 to 12/5/2014



*Sources: USGS & OGS, December 2014

Gutenberg-Richter Plot Oklahoma earthquakes
Determine “location threshold” value
from 1/1/2009 to 6/25/2014
recorded by USGS (red) OGS (green)
Slope 1.2

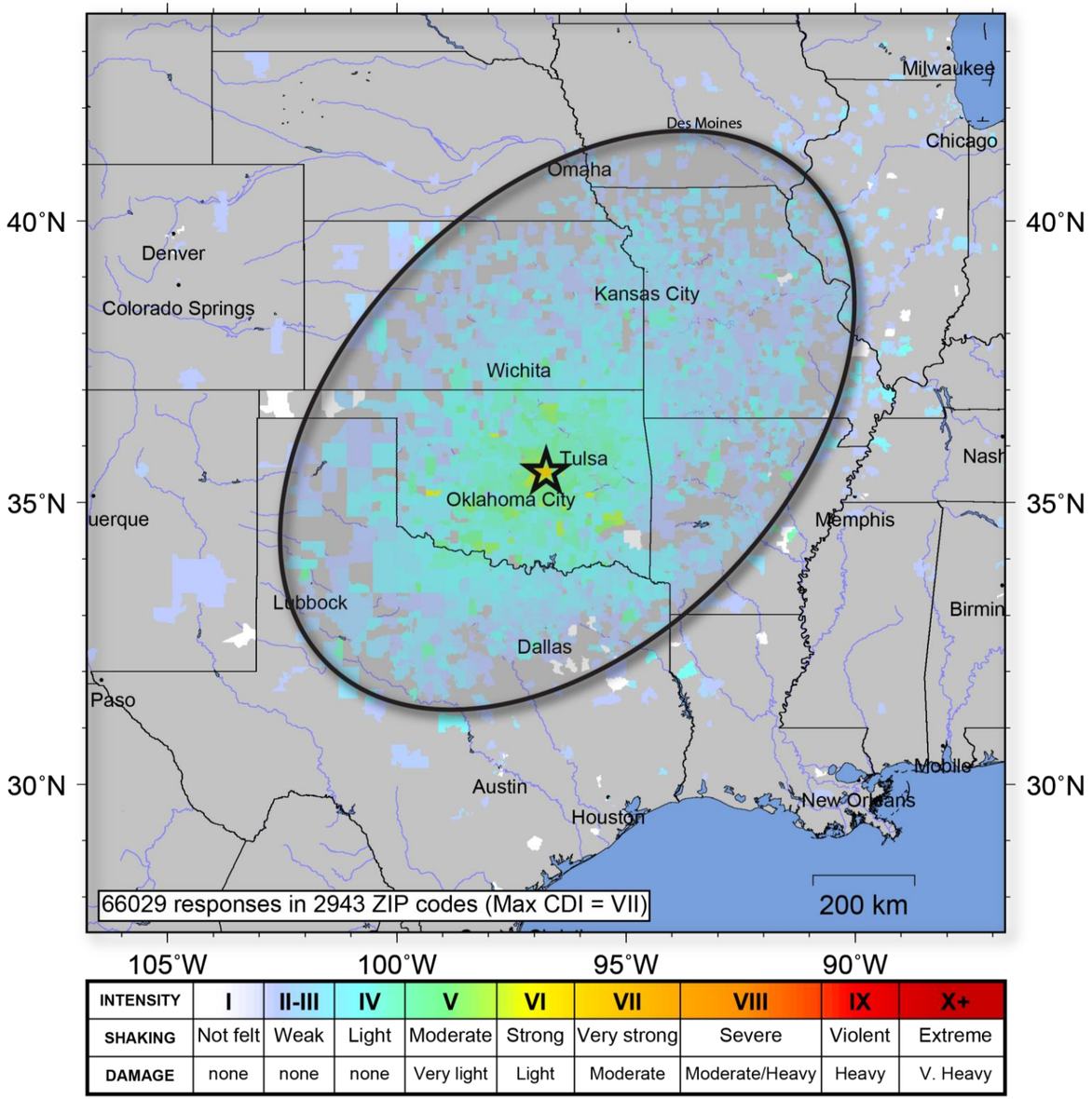


	0 - 1.9	2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9	4.0 - 4.4	4.5 - 4.9	5.0 - 5.4	5.5 - 5.9
Series1	1485	1459	1251	471	109	37	4	1	1
Series2	8831	4372	1629	515	113	24	6	1	1

Richter Magnitude bins

Oklahoma Large Earthquakes: Past and Present

Prague, Oklahoma
5.6 event on November 7th 2011

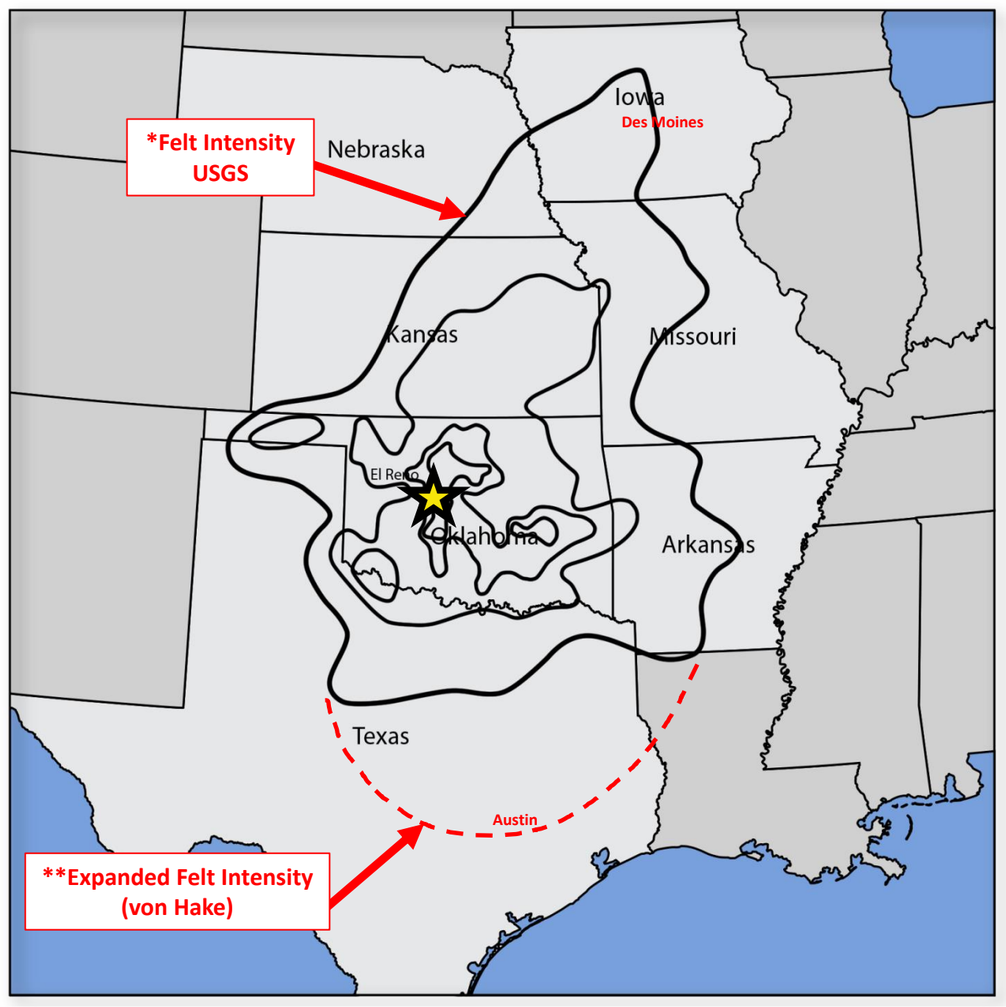


INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Processed: Mon Aug 12 18:22:02 2013

USGS Community Internet Intensity Map
OKLAHOMA
Nov 5 2011 10:53:10 PM local 35.5373N 96.7466W M5.6 Depth: 5 km ID:usb0006klz

El Reno, Oklahoma
5.5 event on April 9th 1952

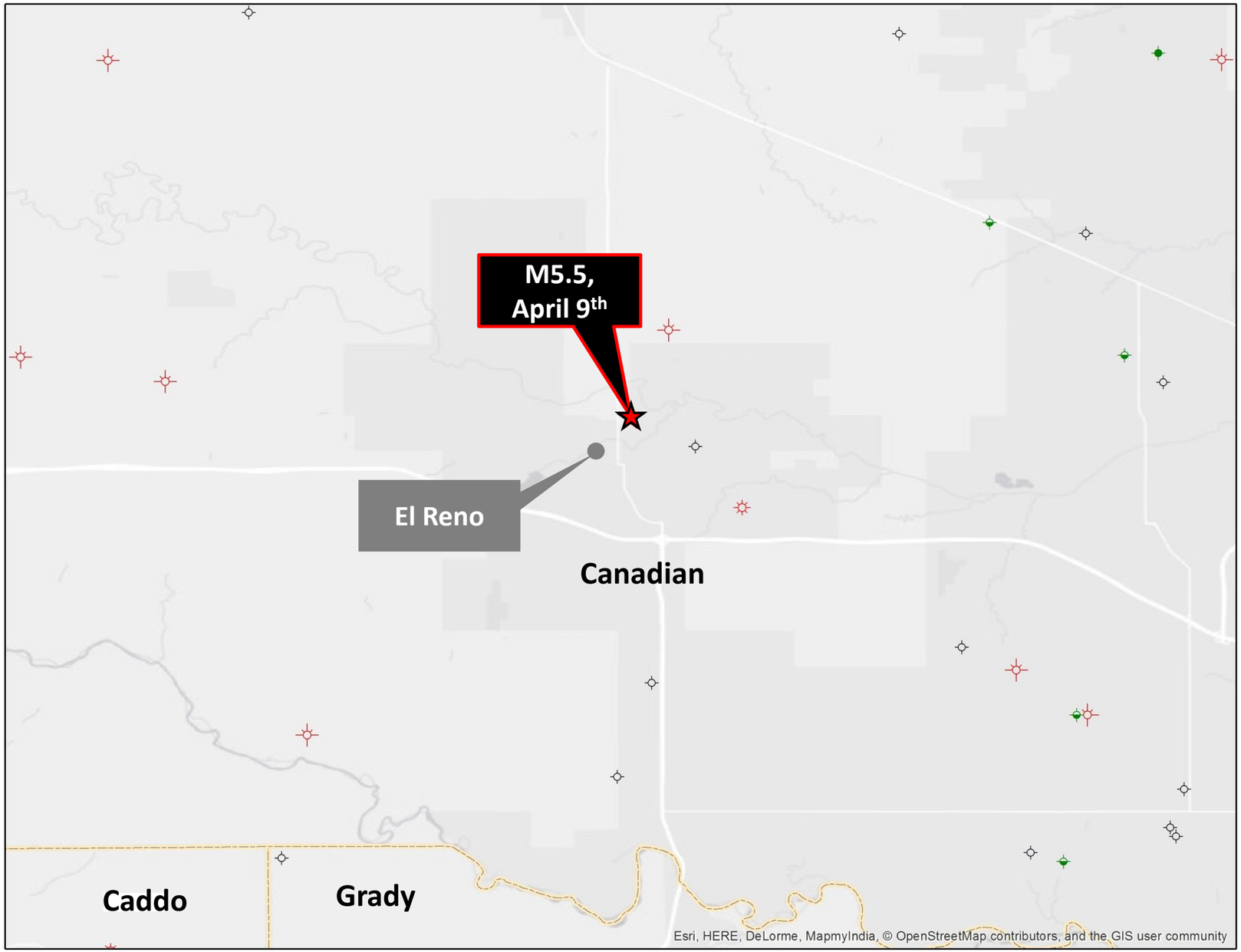


Limited detection by people and damage only and no internet to collect data

*Abridged from Seismicity of the United States, 1568-1989 (Revised), by Carl W. Stover and Jerry L. Coffman, U.S. Geological Survey Professional Paper 1527, United States Government Printing Office, Washington: 1993.

**Graphic representation as per textual information contained in the Earthquake Information Bulletin, Volume 8, Number 2, March - April 1976, by Carl A. von Hake

El Reno Quake – Wells Prior to April 1952



*Sources: USGS, 2014

EL Reno Ok has long history of quakes

- 27 reported “felt” quakes in 1908, 1910, 1918(4),
  1929, 1933, 1952 (16),1953(3)

September 1918

“Objects were thrown from shelves**”**

”It cracked the bank building in Union City”

December 27, 1929

“at least one chimney fell “

“clocks stopped, objects moved, and some reports indicated
the walls and floors seemed to sway.”

“ In several cities, people rushed from their homes in alarm. “

“It sounded as though an automobile had crashed into our house””

“ I thought my furnace has exploded”!

Newspaper reports from El Reno 1952

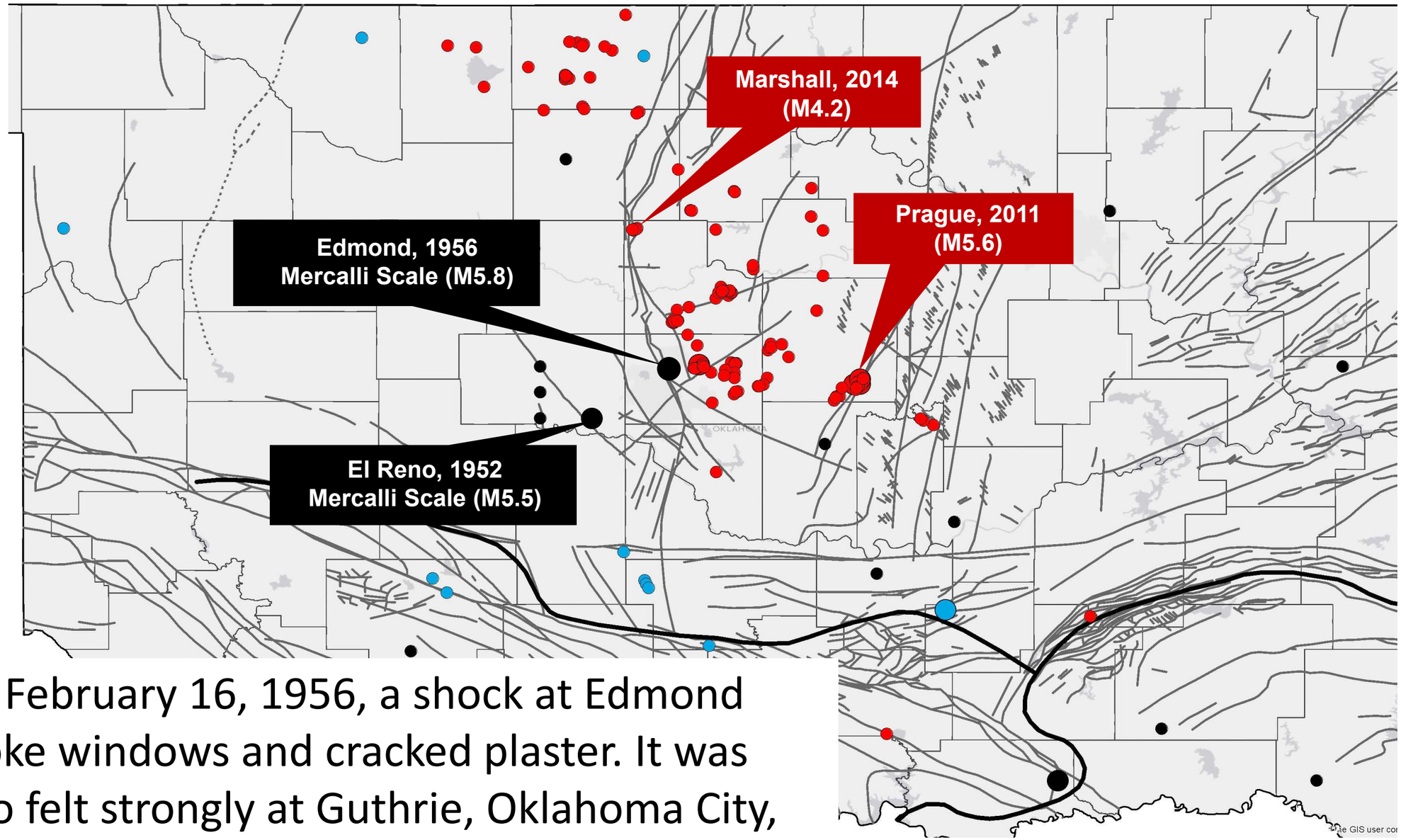
- “Windows and water pipes were broken in many areas”
- “Bomb burst feared”
- “An El Reno infant narrowly escaped death when a brick chimney crashed into the room where he slept”
- “It almost shook me out of bed; it sounded like something blew up in the basement”
- One women reported ”a man is under my bed” she said she “awoke and saw the bed move and wanted police to investigate!"

El Reno 1952/1953 continued

- “buildings swayed for 23 minutes ”
- “ Oklahoma City’s Lynn Groom was knocked down while trying to get out of bathtub and required stitches.”
- “Mrs. Deshaw was cut and bruised by falling plaster in her home. ”
- “ Dr. Hamm was dumped out of his chair in Norman by the shocks.”
- “Oklahoma City Policeman said the quake nearly shook the phone right out of his hand.”
- “A two foot neon sign was jarred loose and fell to the pavement.“

Oklahoma Fault Map

First recorded quake in the state was in Dec 2nd 1897 in Grant County



Edmond population
1960 = 8,577
2012 = 85,885

1900-1960
- 3.5 – 4.49
- 4.5 – 5.8

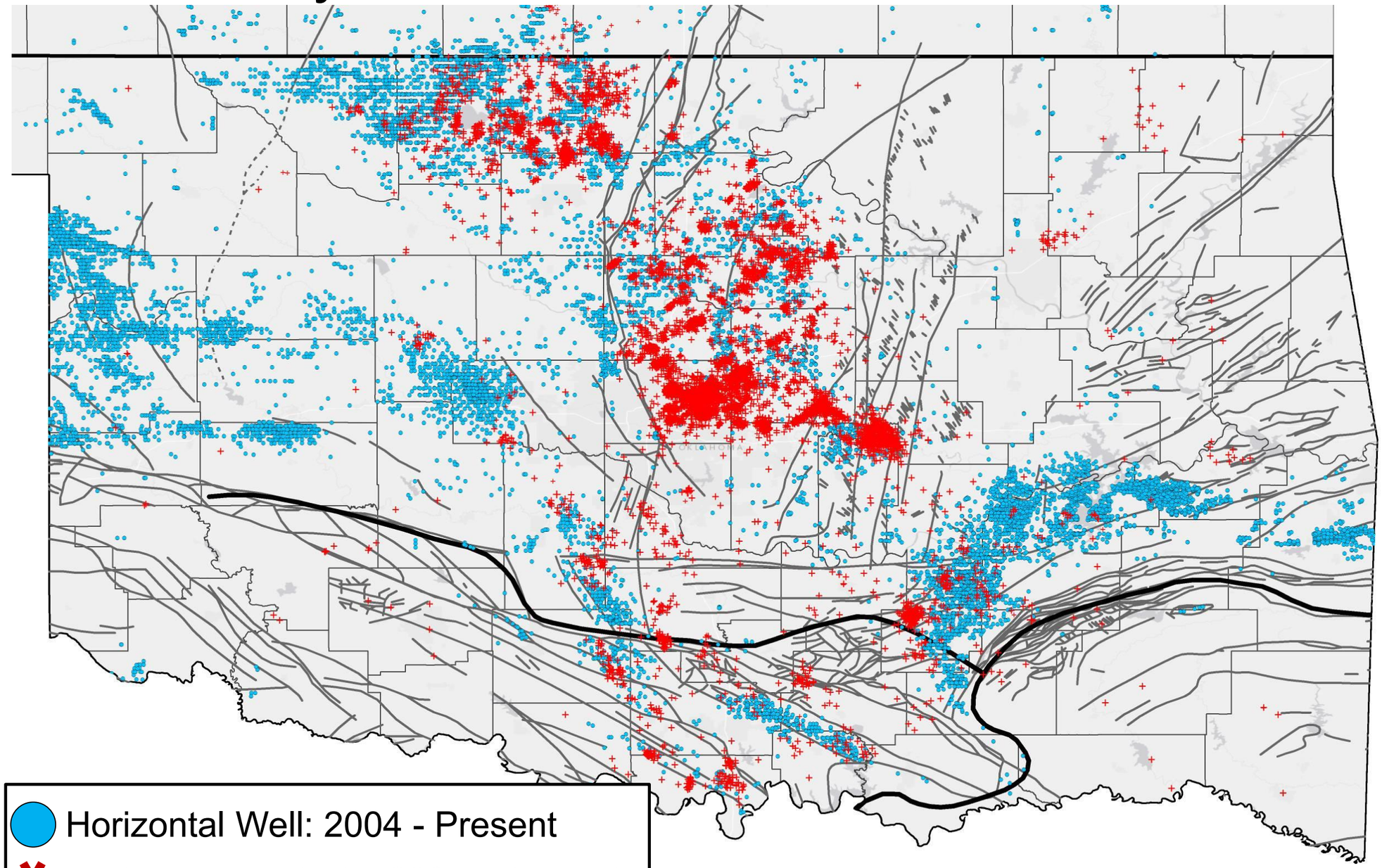
1961-2003
- 3.5 – 4.49
- 4.5 – 5.8

2004-2014
- 3.5 – 4.49
- 4.5 – 5.8

On February 16, 1956, a shock at Edmond broke windows and cracked plaster. It was also felt strongly at Guthrie, Oklahoma City, and Pawnee

**Source: OGS, USGS September 2014; Abridged from Earthquake Information Bulletin, Volume 8, Number 2, March - April 1976, by Carl A. von Hake*

Earthquakes not in same areas as Horizontal Oil and Gas activity!



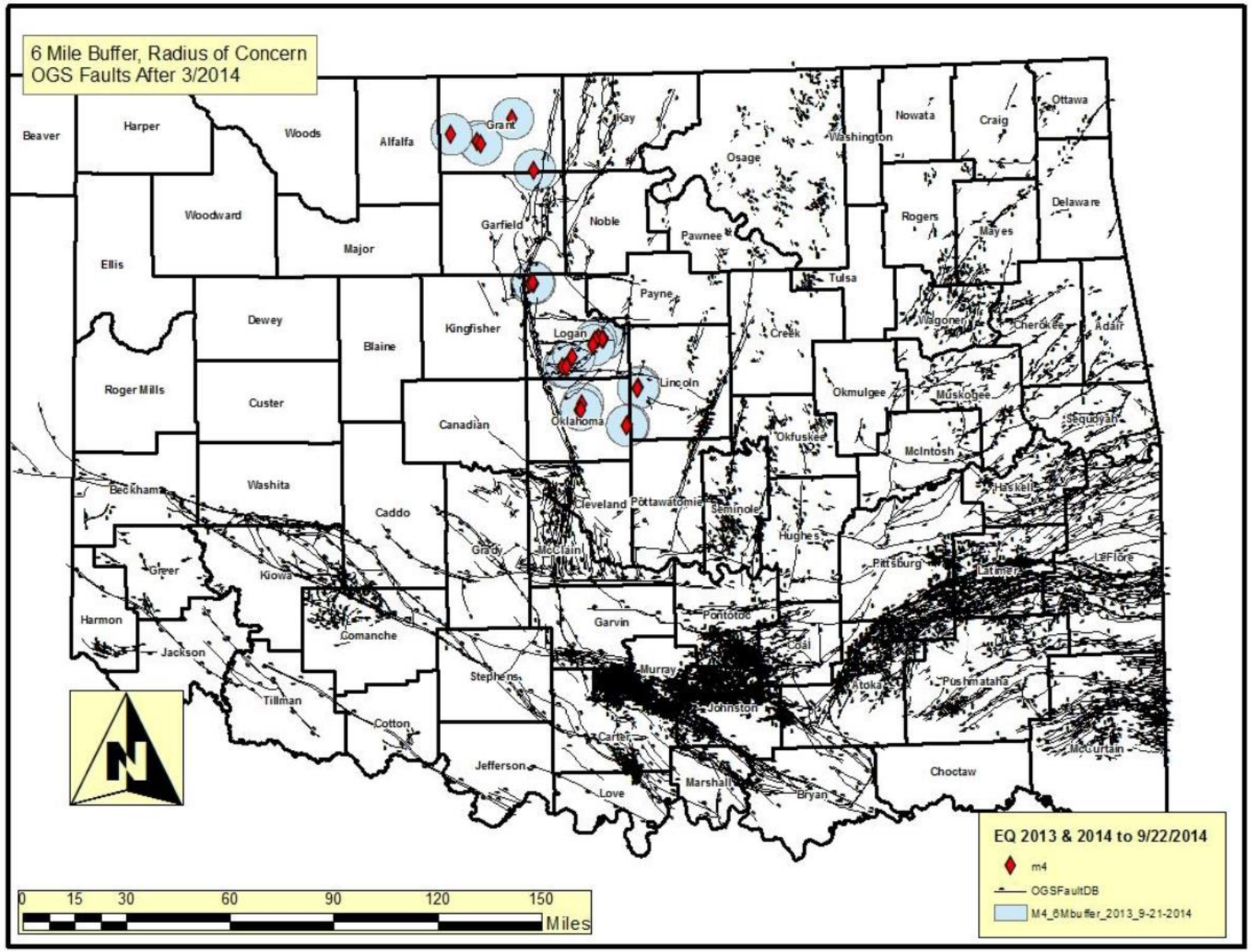
"These earthquakes had absolutely nothing to do with hydraulic fracturing, we can say that with confidence."

Austin Holland,
Oklahoma Geological Survey research seismologist

Source:
Shaking up state
By Bailey Elise McBride
Associated Press, May 2014

***Source: September 2014 OGS, DI Desktop, & GDS*

- Tim Baker Manager of Pollution Abatement at the Oklahoma Corporation Commissions Oil and Gas Division Presented at IOGCC Conference in Columbus Ohio November 2014



"10 Km diameter circles drawn around all magnitude 4 seismic events in Oklahoma"

" There are no high volume injection wells within these circles "

Jan 1st 2009 to June 9th 2013 quakes in OK	June 9th 2013 to August 9th 2014 quakes in OK	August 9th 2014 to December 9th 2014 quakes in OK
initial 3 ½ years	13 to 4 months ago	Last 4 months

Quakes in Oklahoma are moving north!

**Source: USGS, December 2014*

Velocity Model

An initial 1D velocity model (figure 2) was developed by digitizing and averaging compressional sonic logs for the 22 closest wells to the Wilzetta Fault to constrain the shallowest ~2km of the crust (figure). Deeper velocities were constrained by analyzing surface wave dispersion curves (Robert Herman, personal communication, 2012).

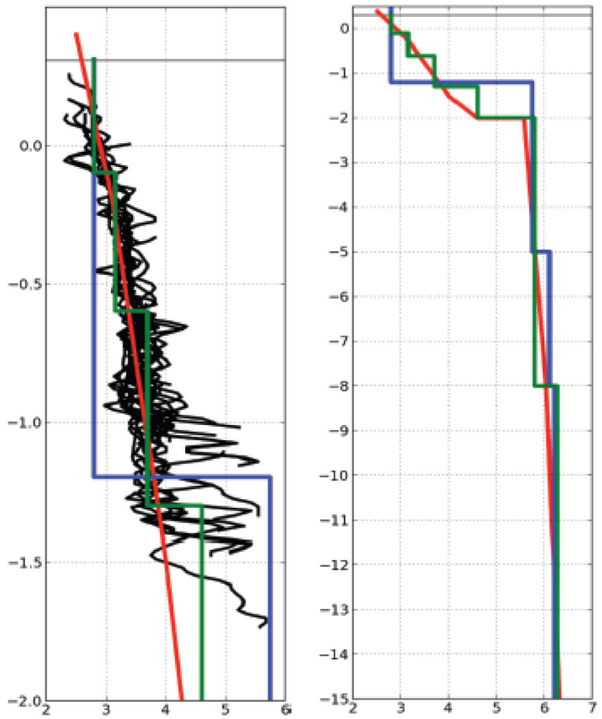
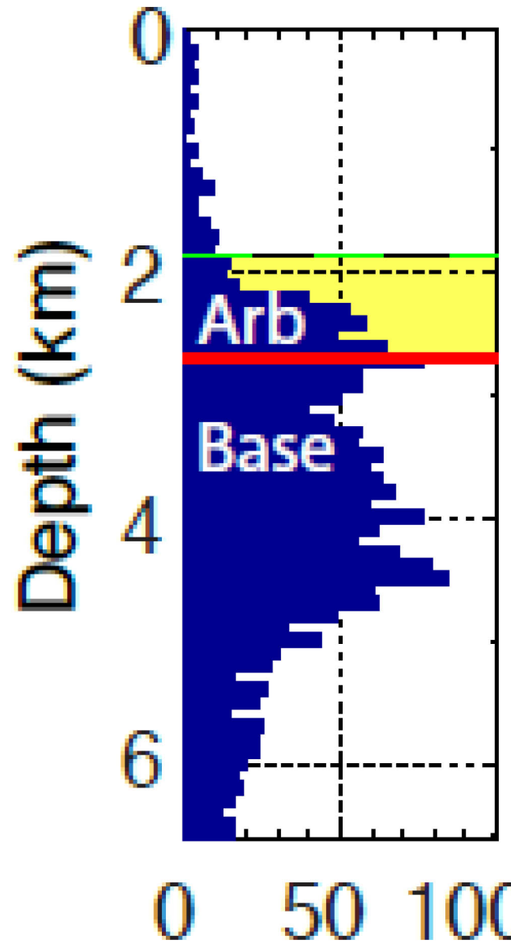


Figure 2: Left: Velocity models and sonic logs from the Wilzetta Fault area down to 2km deep, the top of crystalline basement (Luza and Lawson, 1981).

Right: Velocity models down to 15 km.

Blue: final 1D model used in Keranen et al (2013).
Red: gradient-based starting model used in this study (input for NonLinLoc).
Green: discrete-layer starting model used in this study (input for HypoDD2.1b and FMTomo).
Black: Smoothed sonic logs.
Grey: Average station elevation.



From Keranen et al. 2014
Claims that
"over 20% of the quakes are in the sedimentary column"

From Toth, Chen, Holland 2014
" in the 100 quakes near the Prague event only approximately 7.5% were in the sedimentary column less than 2 KM"

The locations here are significantly deeper than those reported in Keranen et al. (2013)

MEWBOURNE COLLEGE OF EARTH & ENERGY
The University of Oklahoma

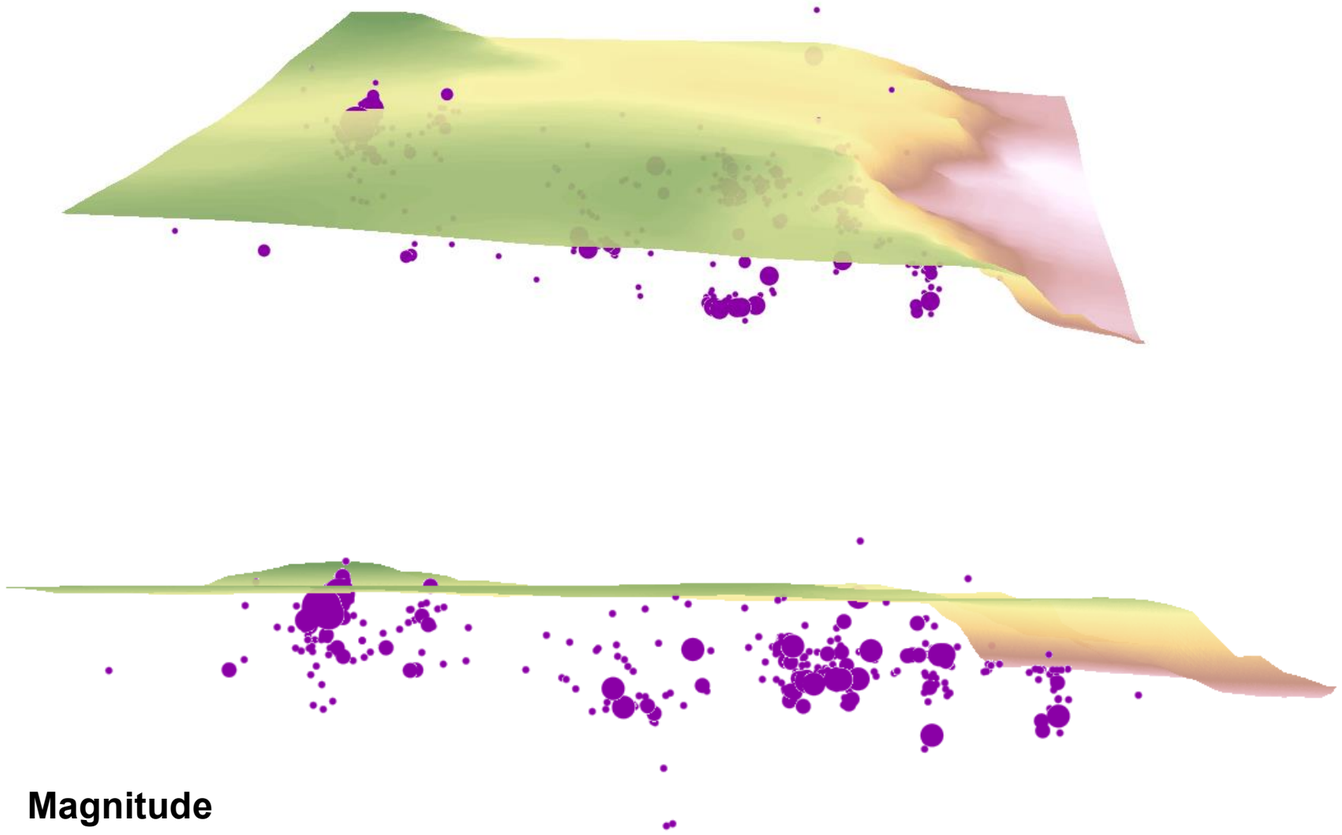
Separation of the Earthquake Tomography Inverse Problem to Refine Hypocenter Locations and Tomographic Models: A Case Study from Central Oklahoma

2014

Toth, C.R.[1], Chen, C.[1], Holland, A.A.[2]
[1] University of Oklahoma, Norman; [2] Oklahoma Geological Survey

OKLAHOMA GEOLOGICAL SURVEY 1908

Central Oklahoma Quake events 3 or greater from OGS database 2009 to July 2014

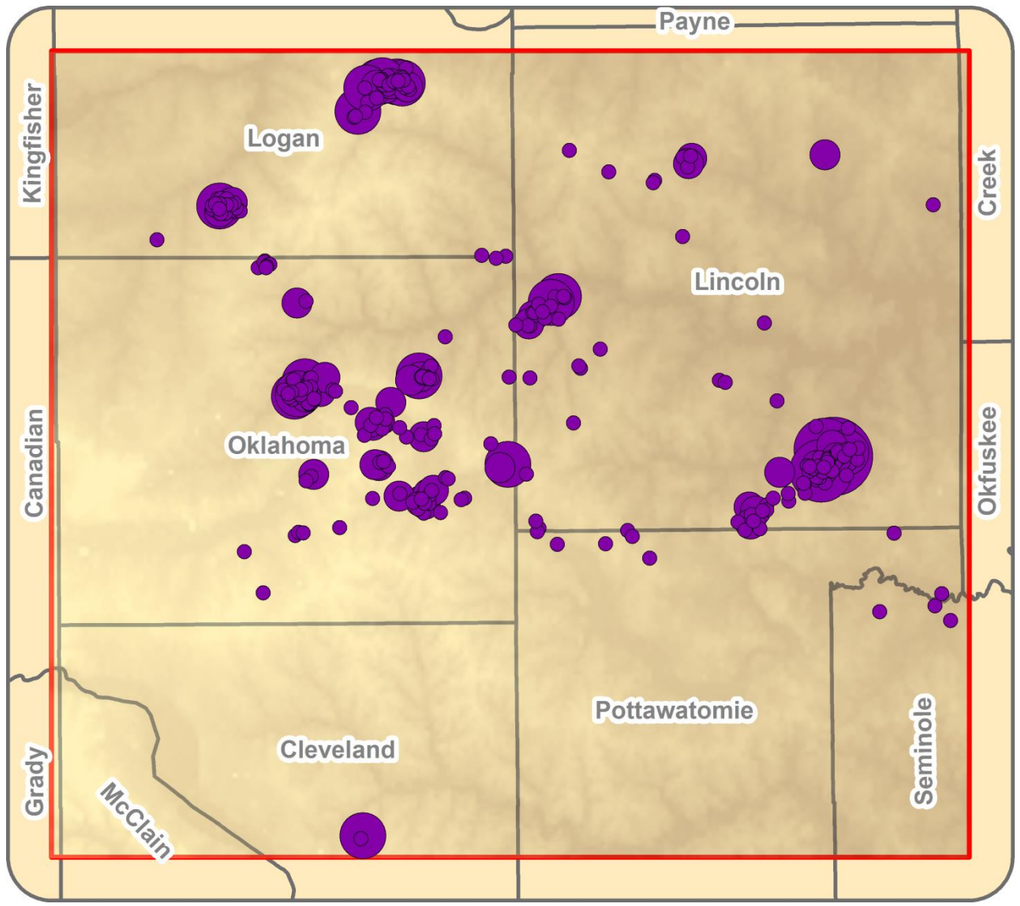


Magnitude

- 3.00 - 3.50
- 3.51 - 4.00
- 4.01 - 4.50
- 4.51 - 5.00
- 5.01 - 5.60

View looking southeast
Datum = ground level

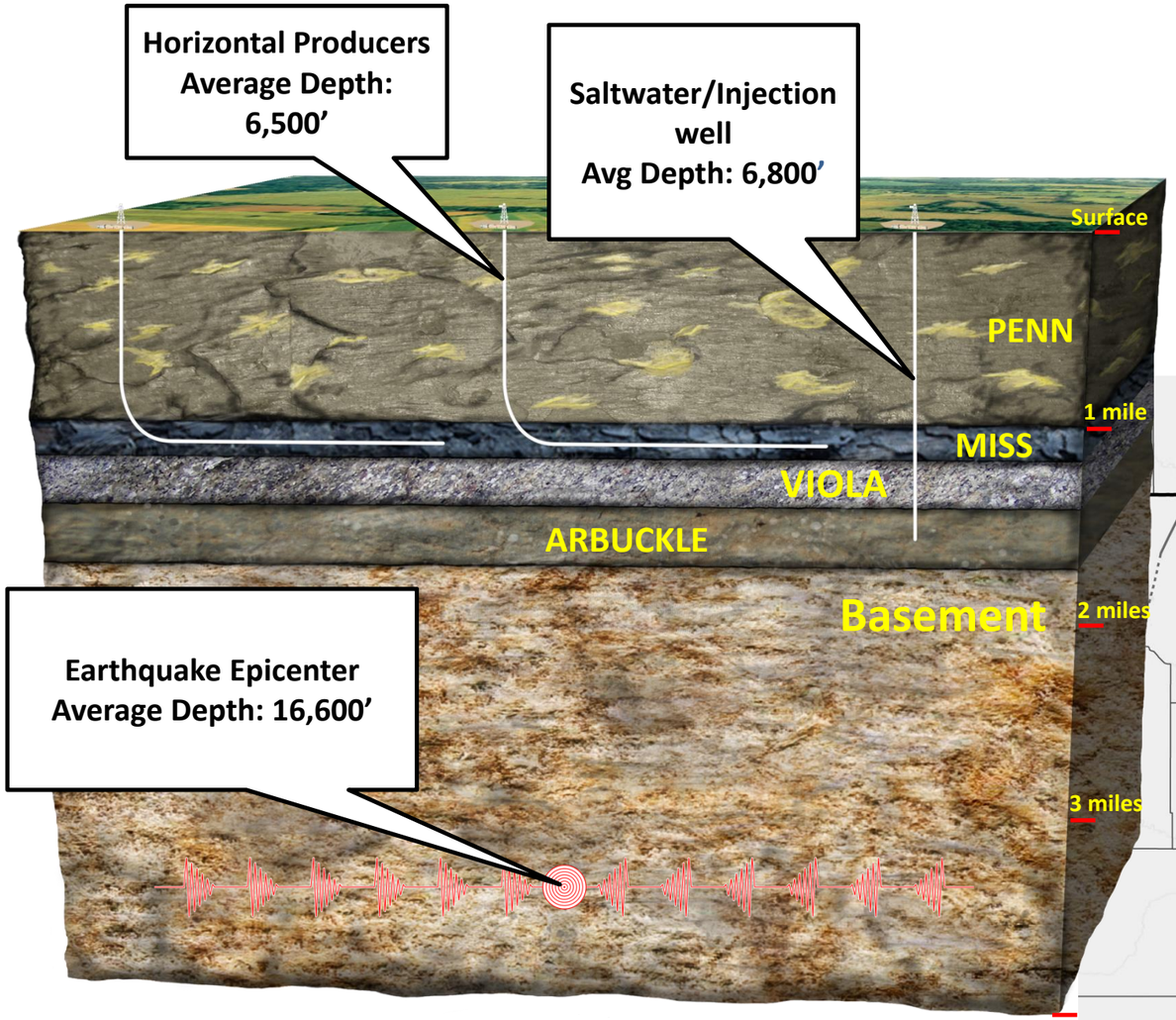
Quakes 3D plotted as compared to depth to magnetic basement by Earthfield Technology Project Elephant Merge
****data accuracy +/-10% of total depth**
2x vertical exaggeration



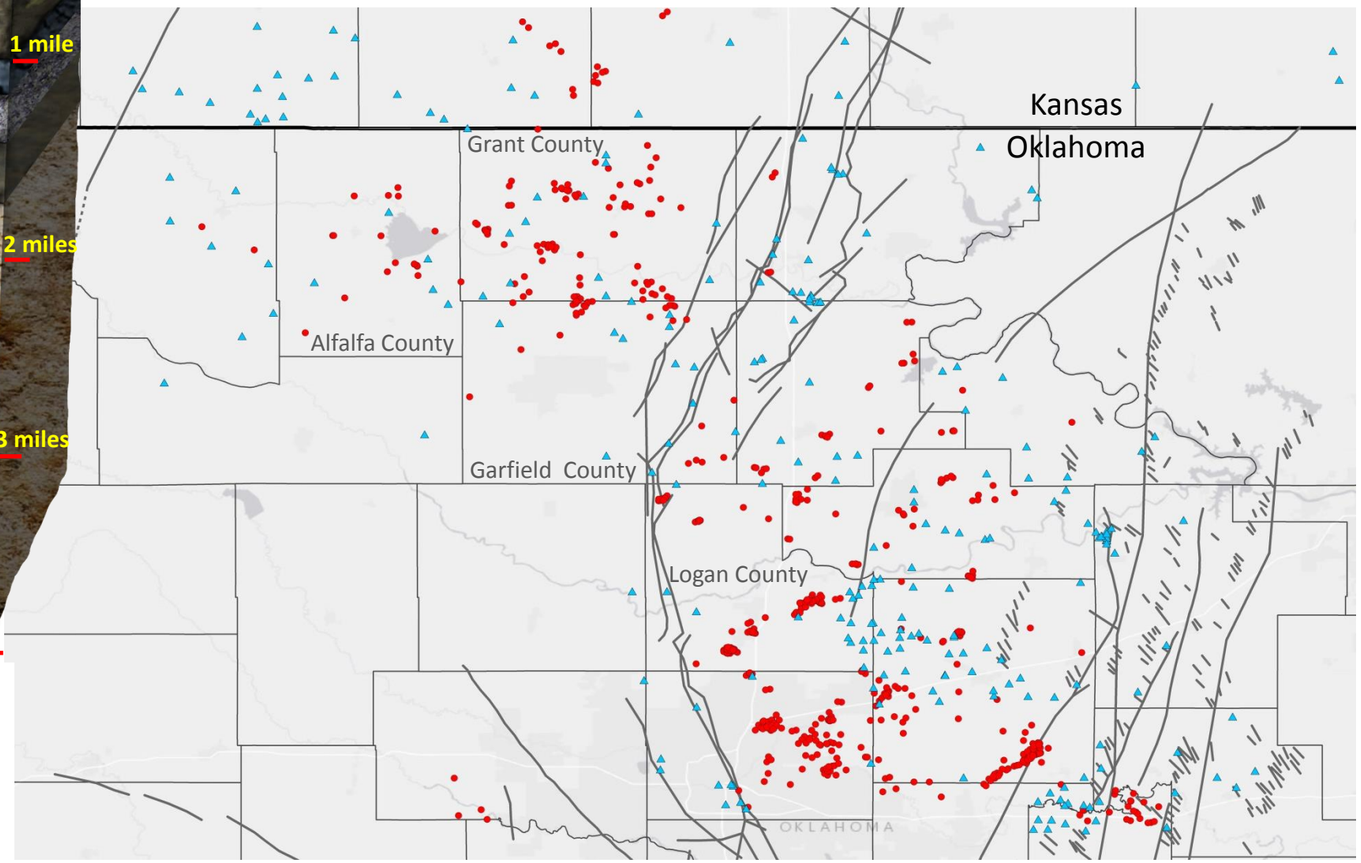
Median depth of quakes in Northern Oklahoma and Logan County

- Choctaw 6.8 KM 4.2 Miles 22,176 feet
- Arcadia 5.6 KM 3.5 Miles 18,480 feet
- Waterloo 5.0 KM 3.1 Miles 16,380 feet
- Liberty 5.0 KM 3.1 Miles 16,380 feet
- Langston 5.0 Km 3.1 Miles 16,380 feet
- Marshall 4.6 KM 2.85 Miles 15,048 feet
- **Average 17,477feet**
- Source OGS OF1 2014 Town hall Meeting Edmond

North-Central Oklahoma: an “in-depth” look



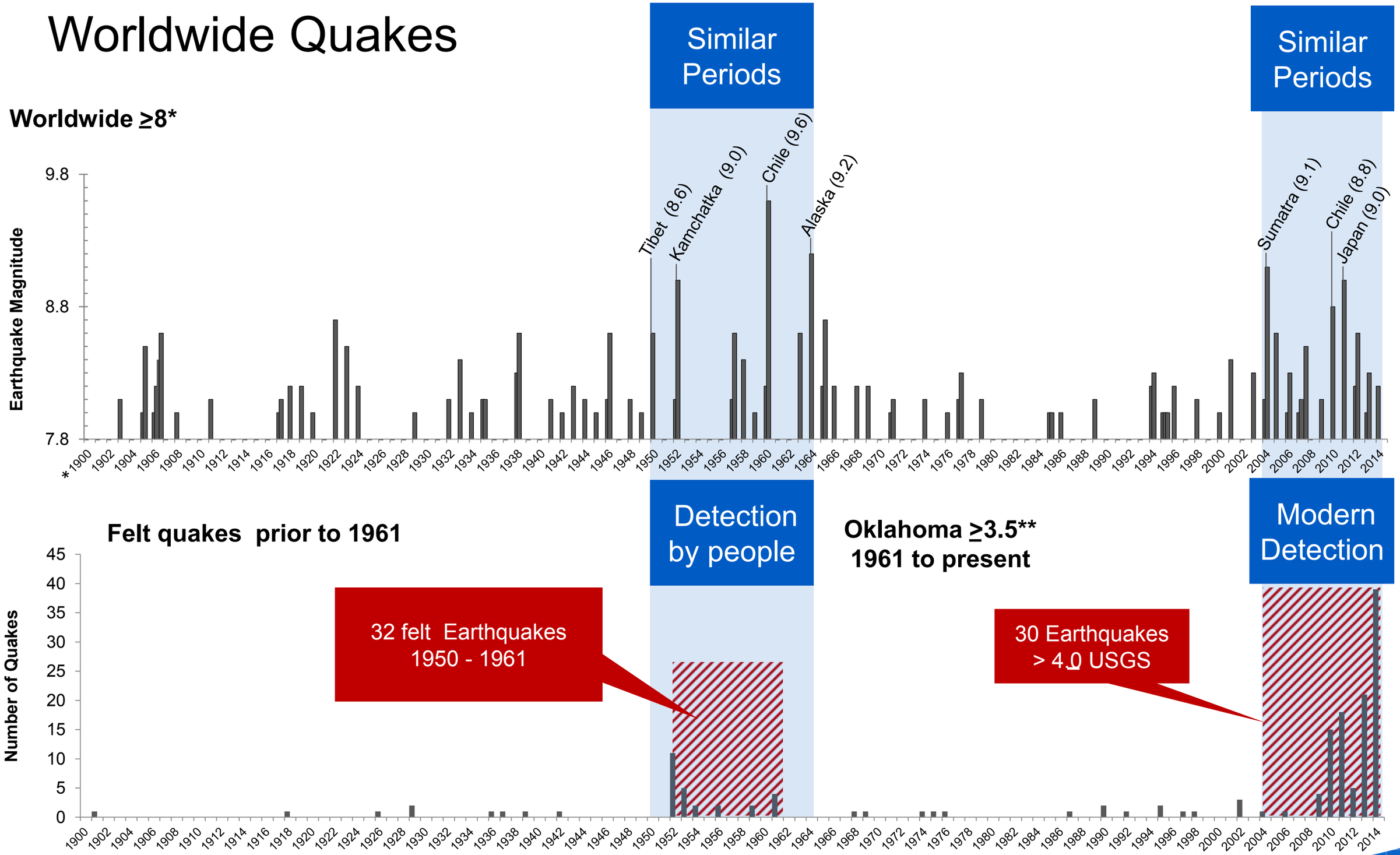
Since 2008, the average Earthquake epicenter depth was approximately **10,000’** deeper than the average depth of disposal/injector wells in this area!



Quakes occurring in granitic basement along faults previously unidentified because they are old faults not found in the overlying sedimentary sections!

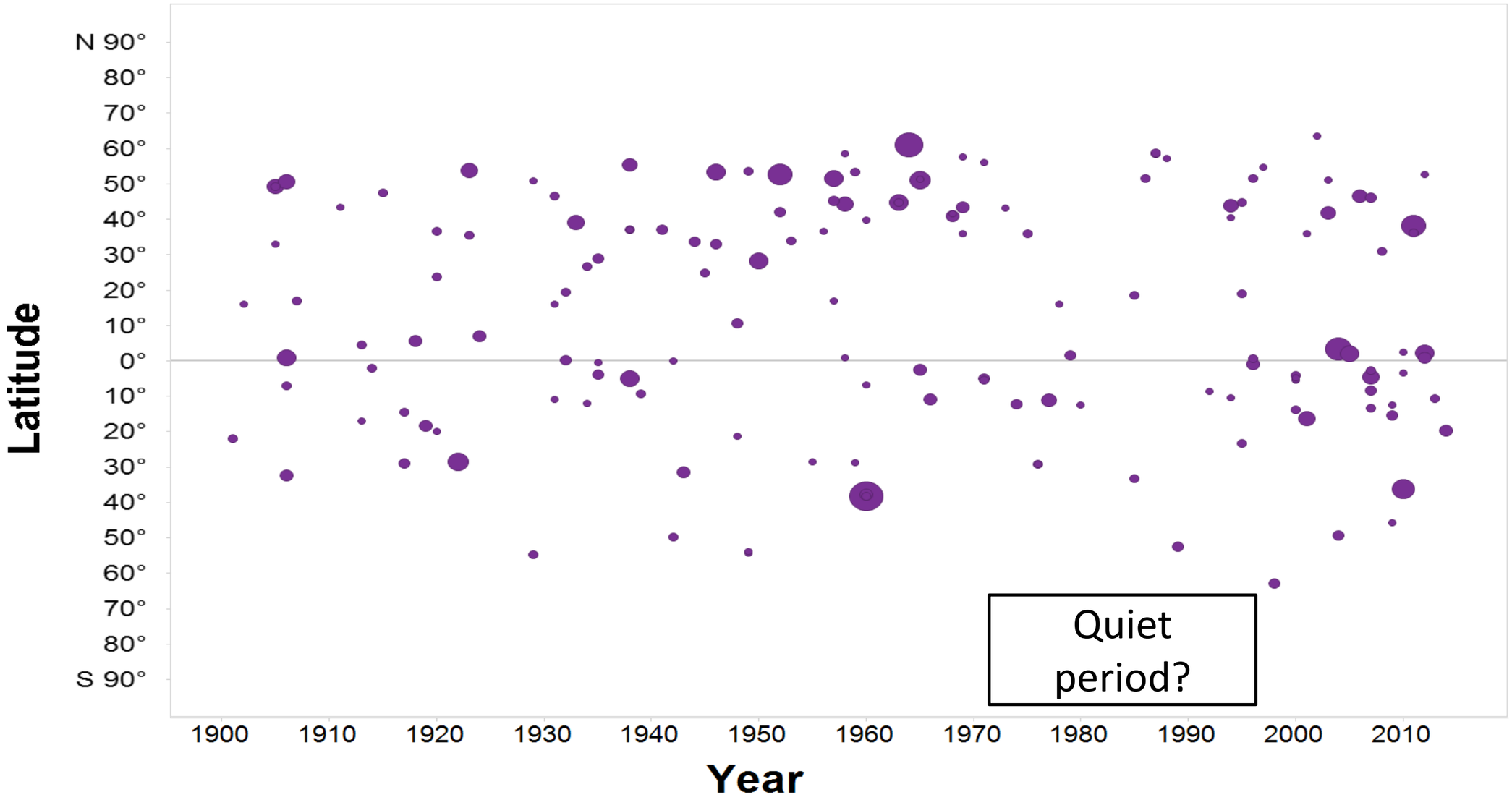
*Sources: USGS & Drilling Info, September 2014

Worldwide Quakes



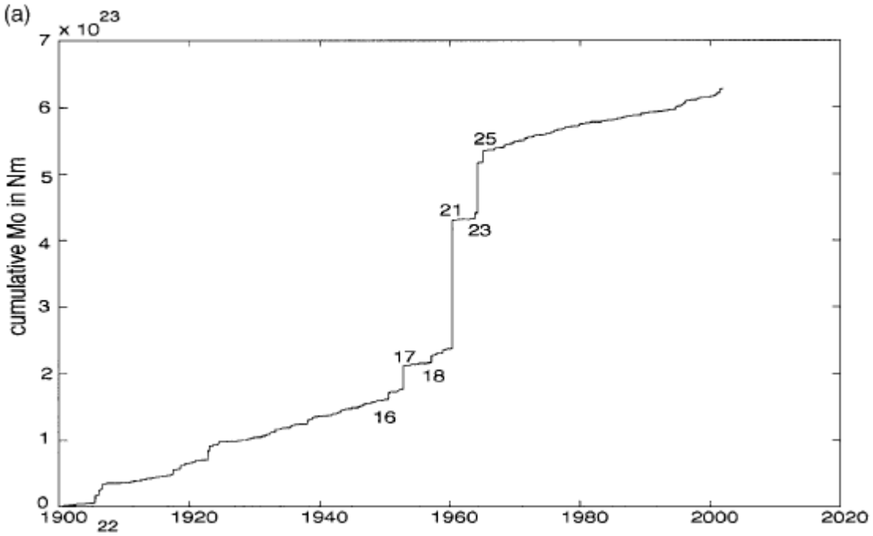
Sources: USGS, 2014
***Source: OGS, 2014*

Space-Time Distribution of Large, Shallow Earthquakes (Magnitude > 7.8 and Depth < 50 km)



Note Added to Proof

In the present article, we discussed the subsequent surge in moment release from 2000 to 2001 in both the Pacific and anti-Pacific hemispheres and the significance of occurrence in June 2001 of the **M** 8.4 Peru event, and we suggested that a new global cycle may have begun. On 26 December 2004, a mega-quake (our term for an earthquake of **M** ≥9) occurred off the coast of Sumatra. The recent occurrences of this mega-quake and the adjacent (to the southeast) rupture of a **M** 8.7 Sumatra event of 28 March 2005, confirm that we have entered a new period of high moment release and probable temporal clustering of mega-quakes.



Cumulative moment release, 1900–2001, for **M** ≥7 earthquakes. (a Global-moment release.

Evidence for a Global Seismic-Moment Release Sequence
by Charles G. Bufe and David M. Perkins
Bulletin of the Seismological Society of America, Vol. 95, No. 3, pp. 833–843, June 2005, v

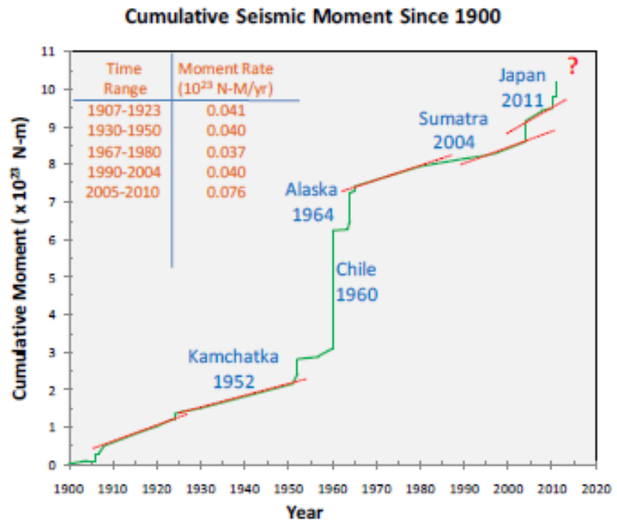


Figure 4: Global Seismic Moment Release 1900 - 2010 From M≥7.0 Earthquakes[18]

The time period 1950 through 1965, where the graph is mostly vertical, shows the huge increase in seismic moment release worldwide due to the clustering of great and giant earthquakes.
Note the generally uniform slope of the curve before and after the outbreak of great earthquakes. This figure was updated to include the Tokohu-oki, Japan earthquake of 2011.

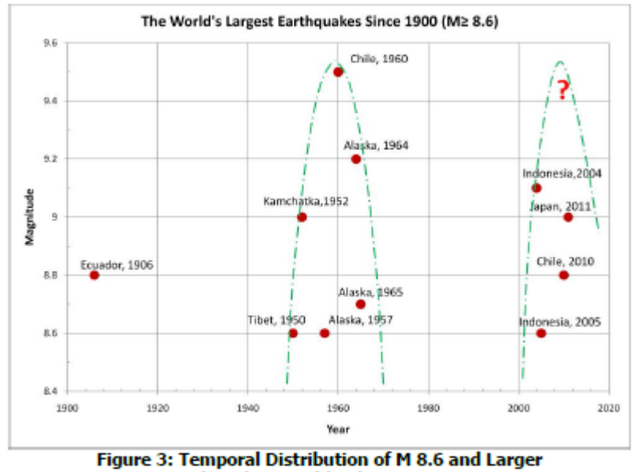


Figure 3: Temporal Distribution of M 8.6 and Larger Earthquakes Worldwide Since 1900

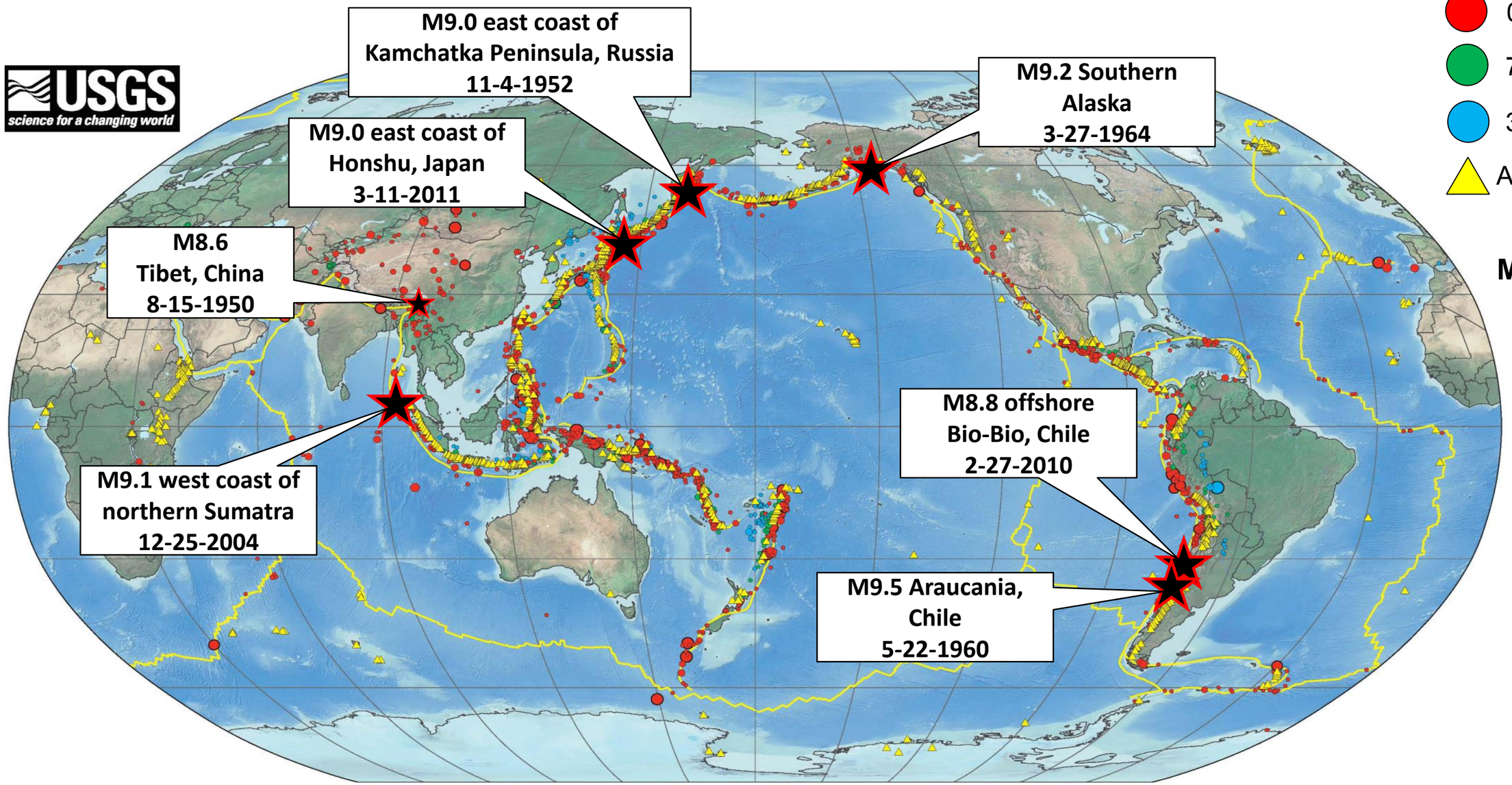
Conclusions

The statistics of great and giant earthquake occurrences indicate that the historical temporal clustering of these earthquakes on a global scale cannot be attributed to chance. It appears that the giant 2004 Andaman-Nicobar (Sumatra) earthquake began a new cycle of global great earthquake activity. If the current cycle follows the one that occurred in the 1950 - 1965 timeframe, we may be only about half way through the cycle, and the largest earthquake in the current cluster may not have yet occurred. Physical processes that might be responsible for the observed global earthquake clustering are not known, but appear not to be related to shallow co-seismic effects of elastic Earth properties which dominate deterministic models of near-field and far-field stress changes. Rather, global effects of great and giant earthquakes more likely are transmitted large distances over relatively short time intervals through post-seismic relaxations and strain transfer mechanisms in the deep ductile layers of the Earth.

SPATIAL AND TEMPORAL EARTHQUAKE CLUSTERING: PART 1 **GLOBAL EARTHQUAKE CLUSTERING**
Paul C. Thenhaus, Dr. Kenneth W. Campbell
and Dr. Mahmoud M. Khater
October 14, 2011

EQECAT
AN ABS GROUP COMPANY

Worldwide Earthquakes Larger than M8.8



Depth of focus

- 0-69 km
- 70-299 km
- 300-700 km
- Active volcanoes

Magnitude Size

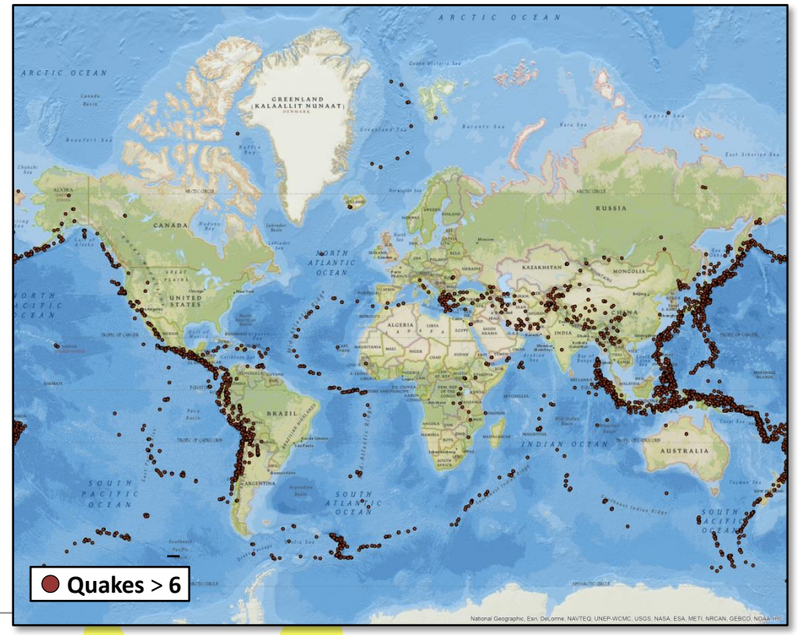
- 4 - 5.9
- 6 - 6.4
- 6.5 - 6.9
- 7 - 7.4
- 7.5
- 7.6
- 7.7
- 7.8
- 7.9
- 8.0
- 8.1
- 8.2

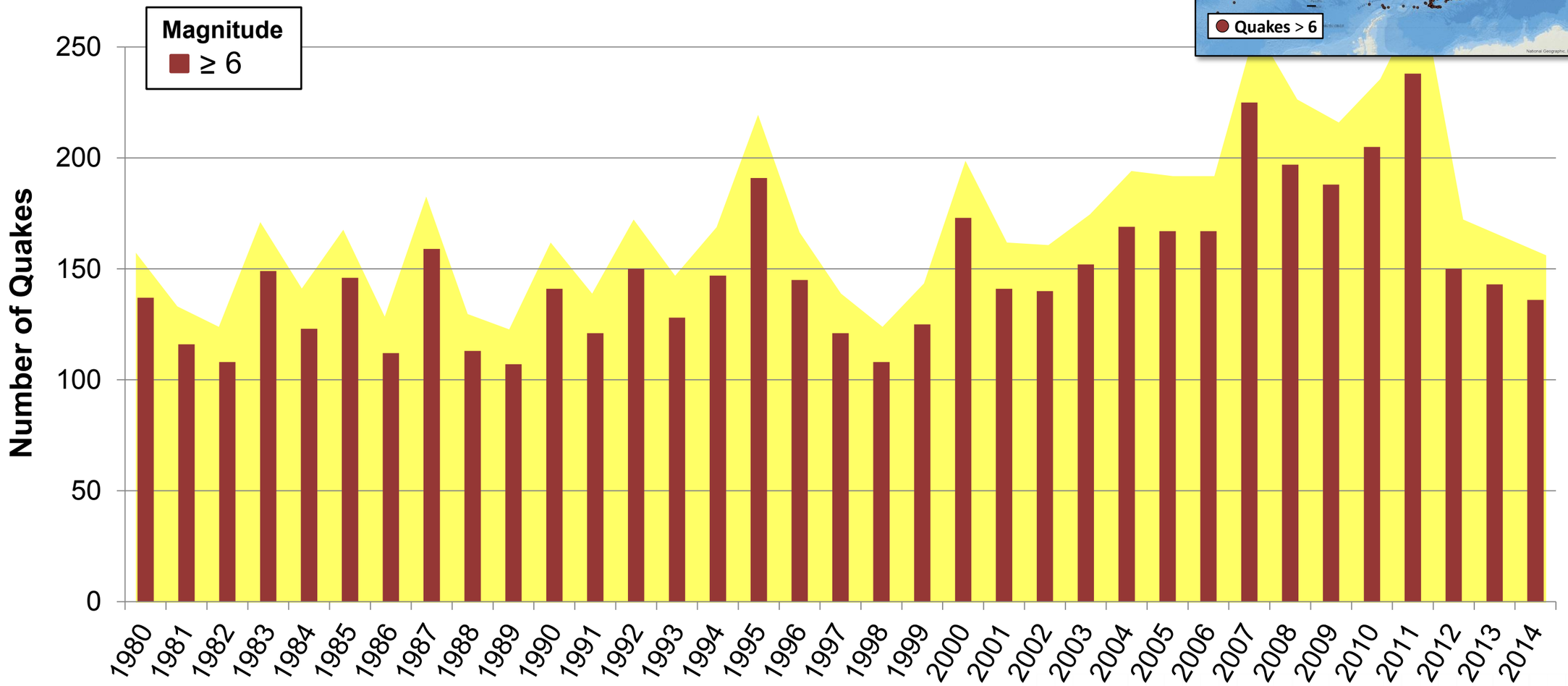
**Sources: USGS, 2014*

Summary of Large World Quakes

- Since 1900 there have been 6 Earthquakes magnitude 8.8 or greater.
- 3 happened after 2004
- 3 happened between 1952 and 1964
- The 9.1 Indonesian event in 2004 sped up the rotation of the earth by 3 microseconds (Nature, Dec 30 2004).
- The 2011 magnitude 9 event offshore Japan shifted the planet on its axis by nearly 4 inches and shortened the day by 1.8 milliseconds(NASA Earth 3/14/2011)
- Both Earthquakes resulted in widespread Tsunami damage.

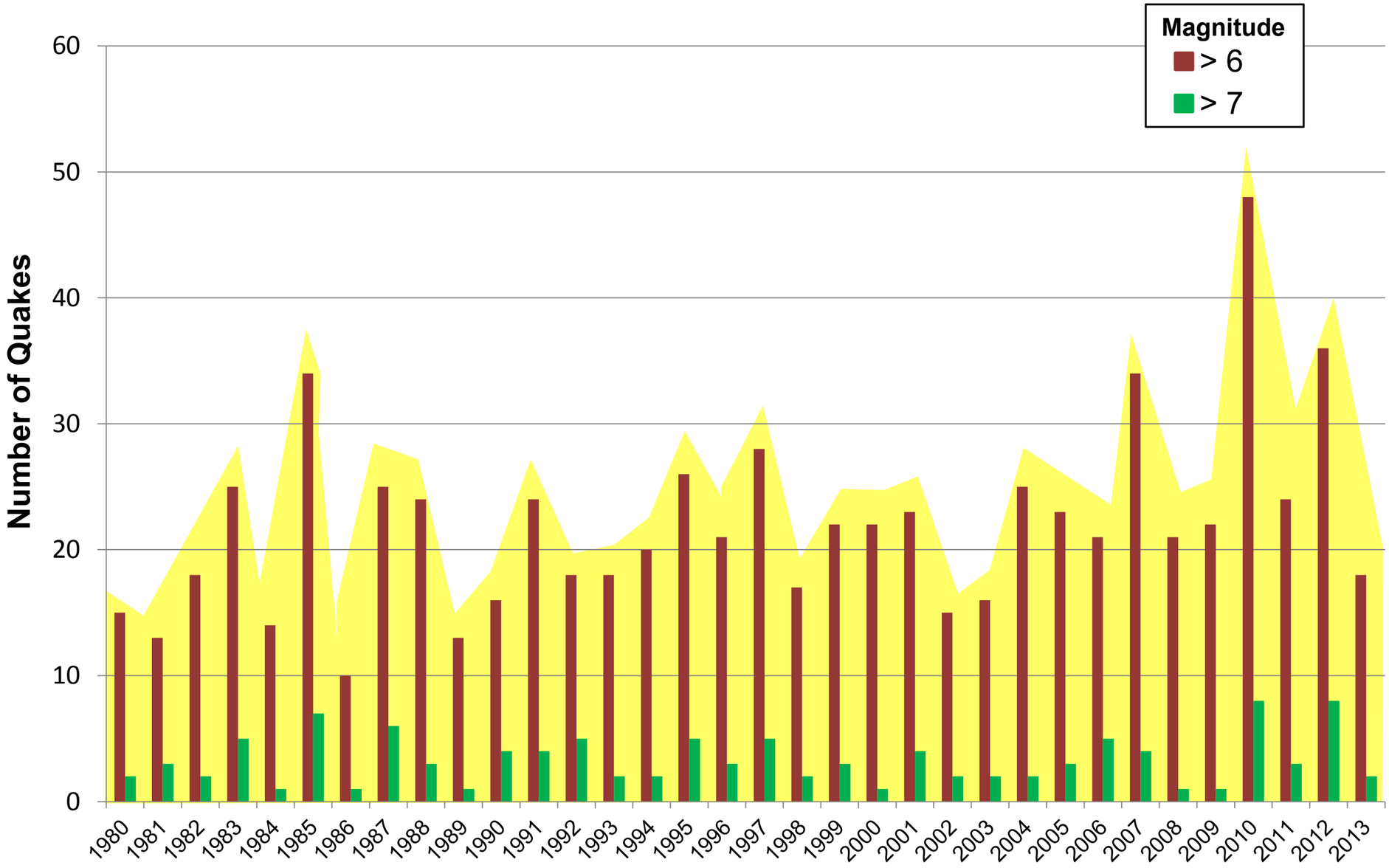
World Earthquakes 1980 – June 2014





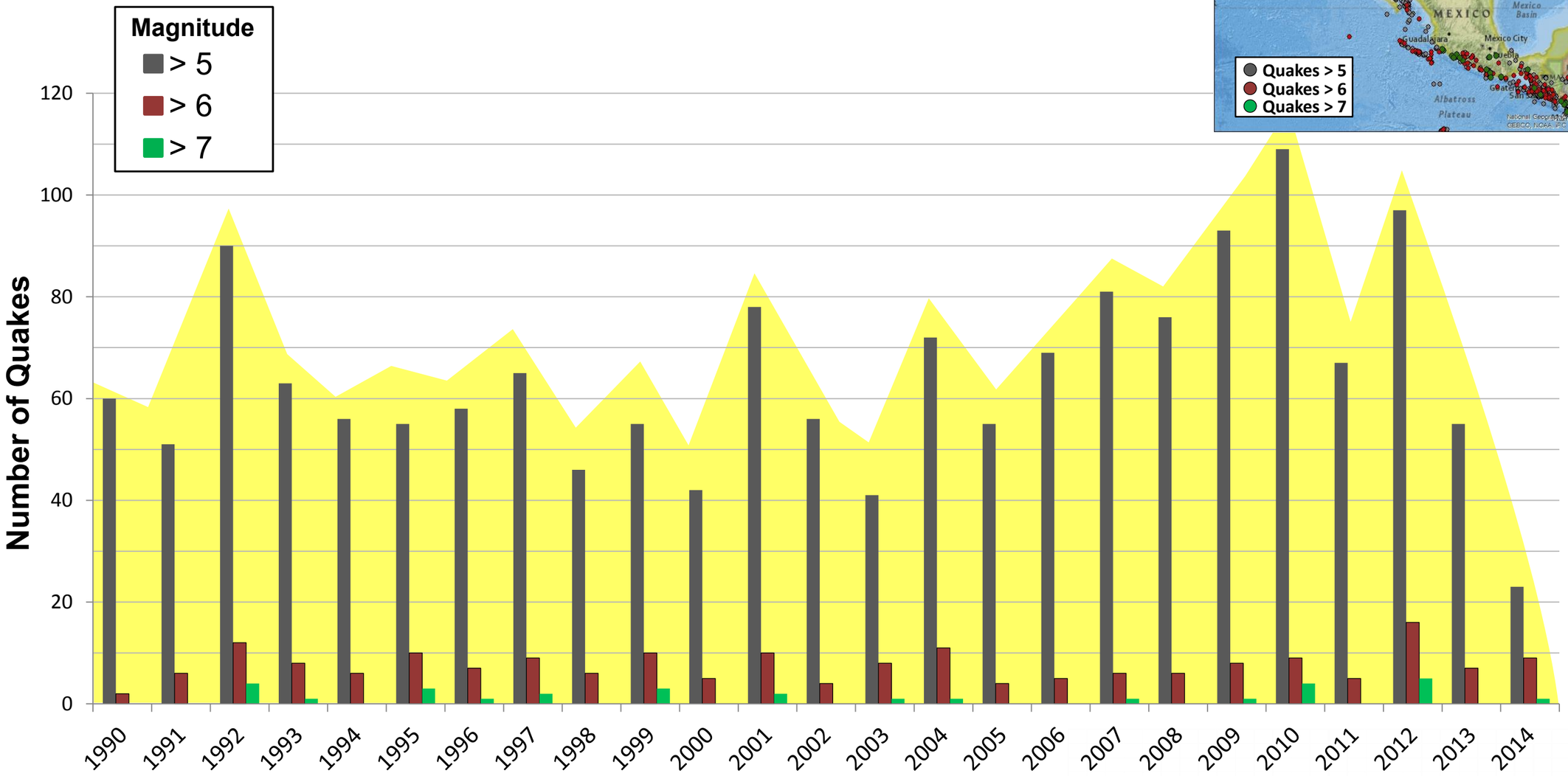
**Source: USGS, October 2014*

North, South, & Central America's Earthquakes 1980 to 2013



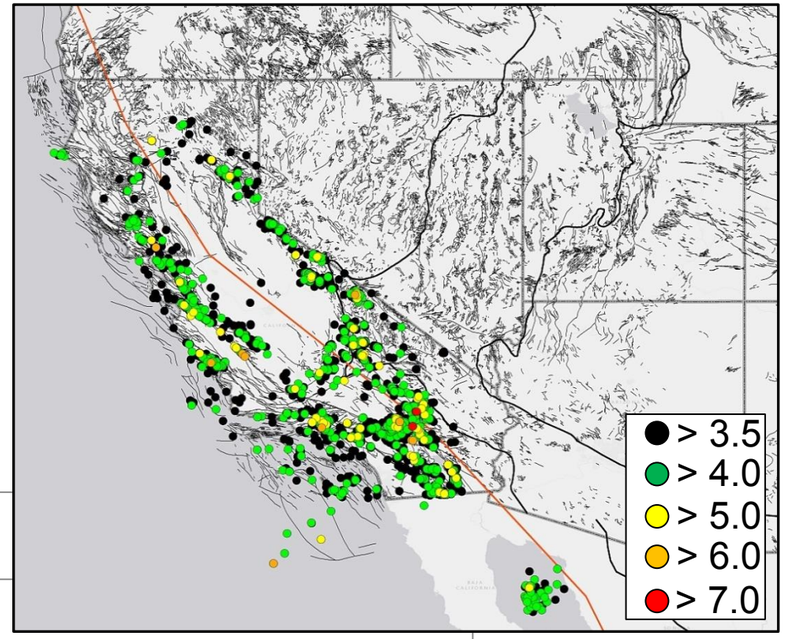
*Source: USGS, 2014

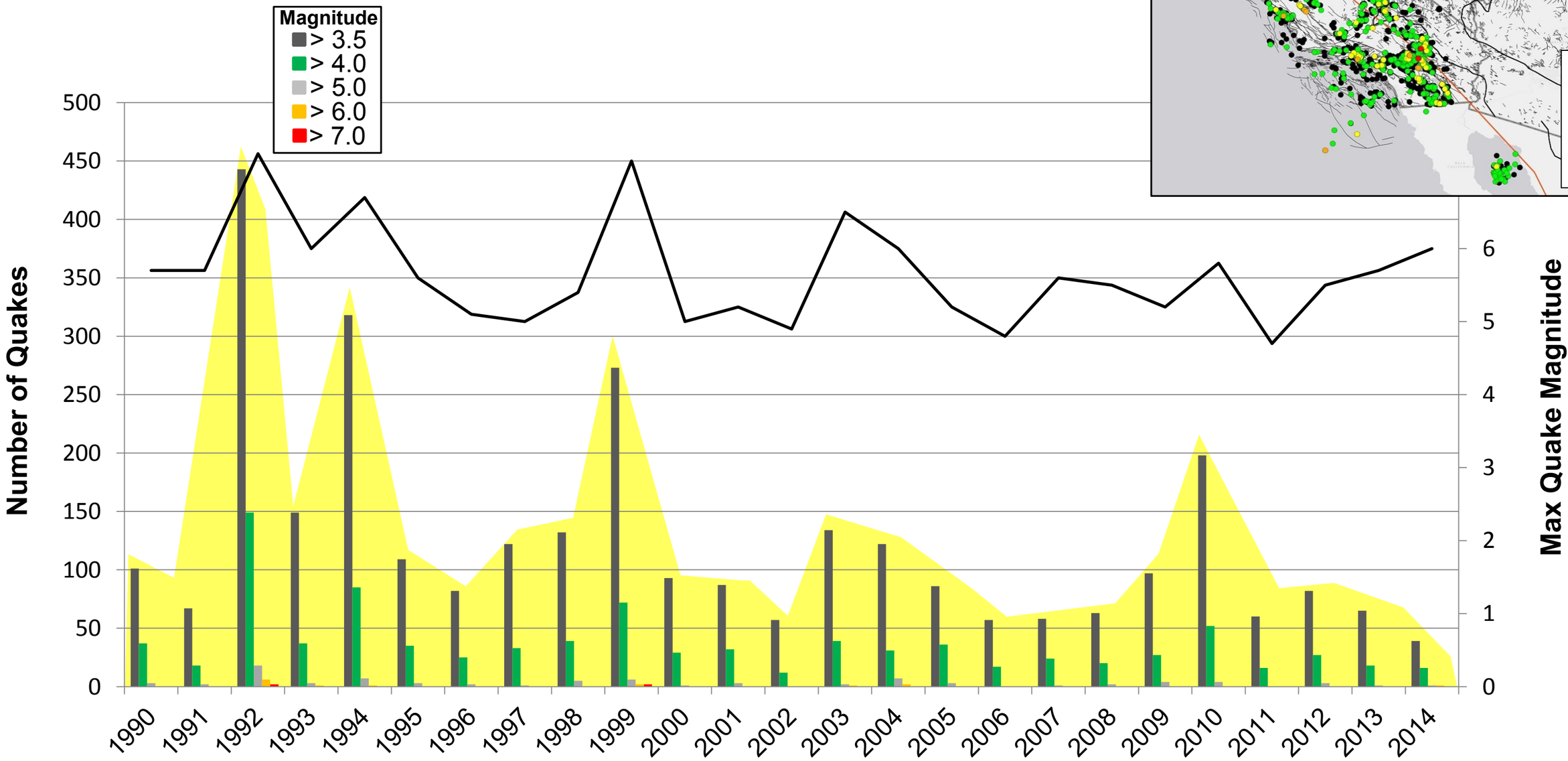
North & Central America Earthquakes
1980 – June 2014



*Source: USGS, June 2014

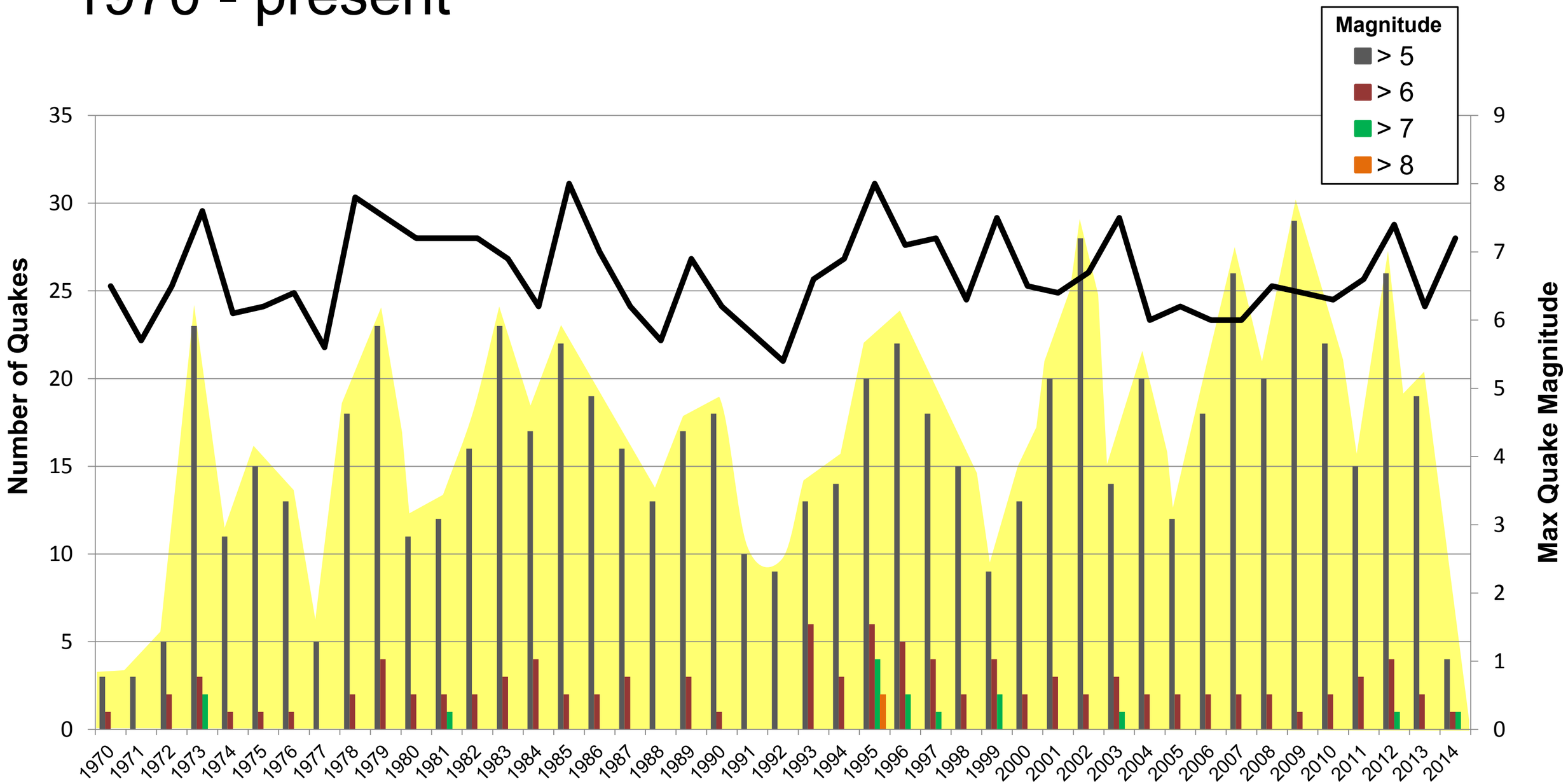
California
1990 - Present





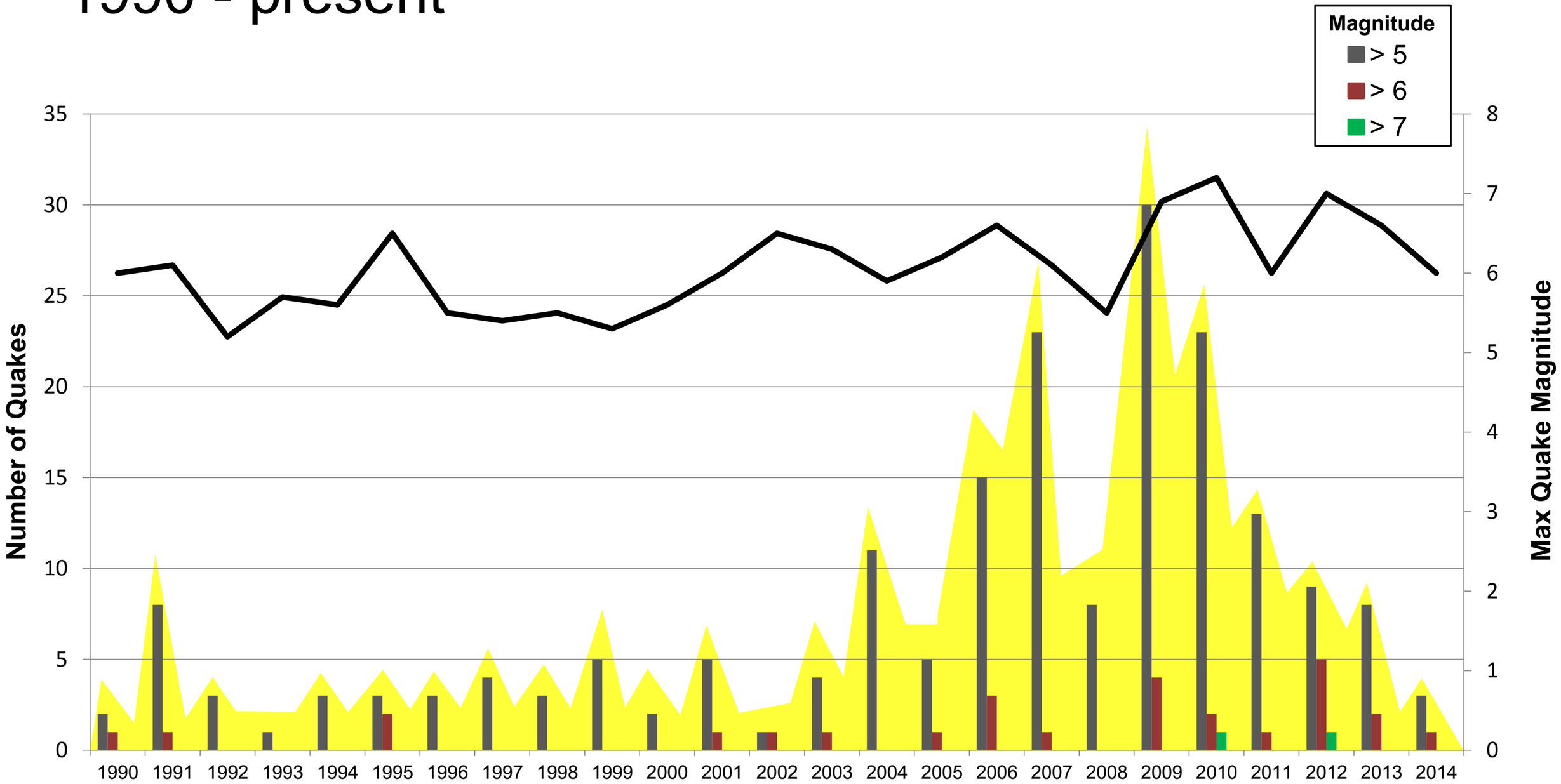
**Source: USGS, November 2014*

Subduction Area of Southern Mexico
1970 - present



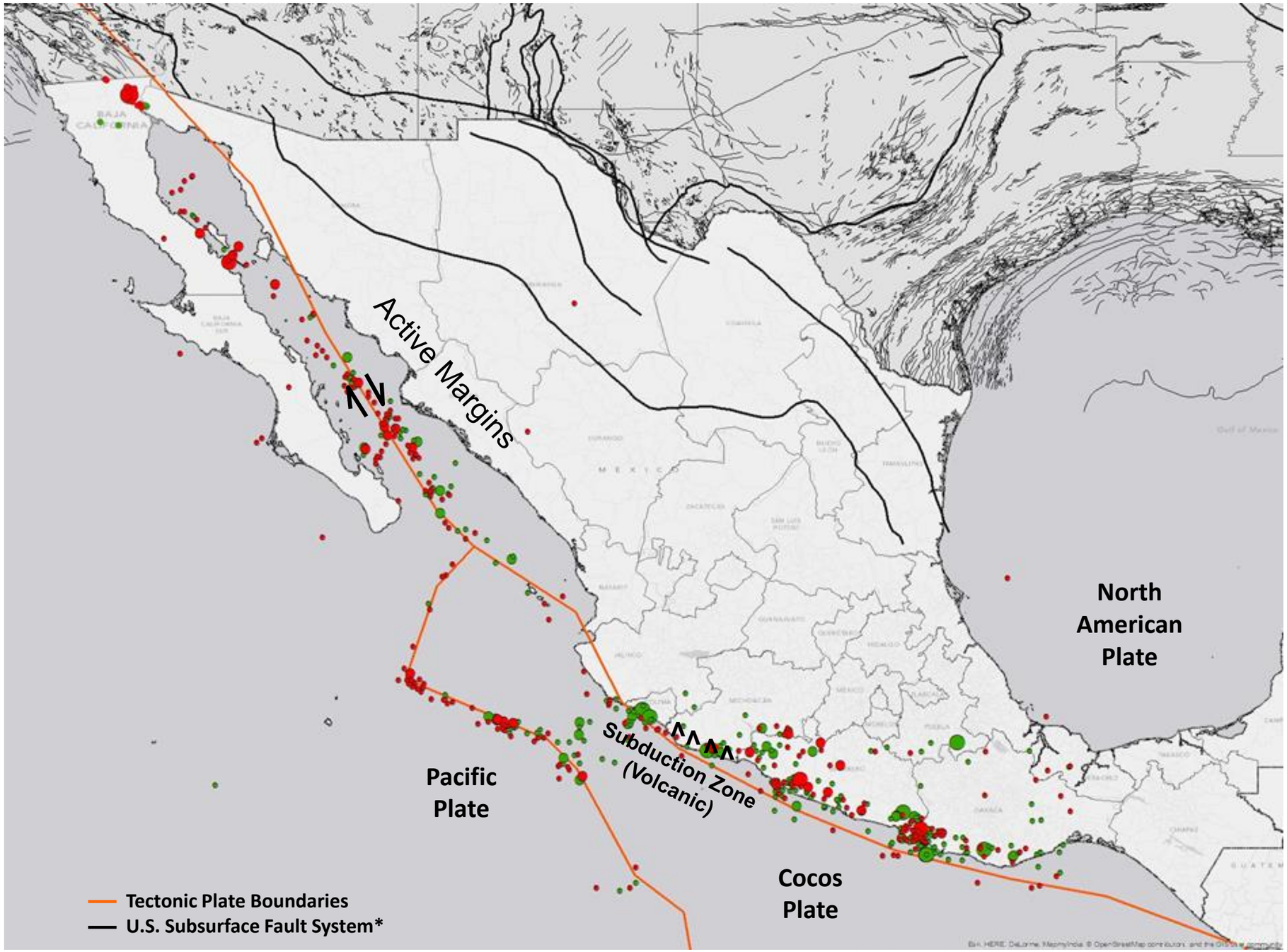
**Source: USGS, June 2014*

Gulf of California
1990 - present



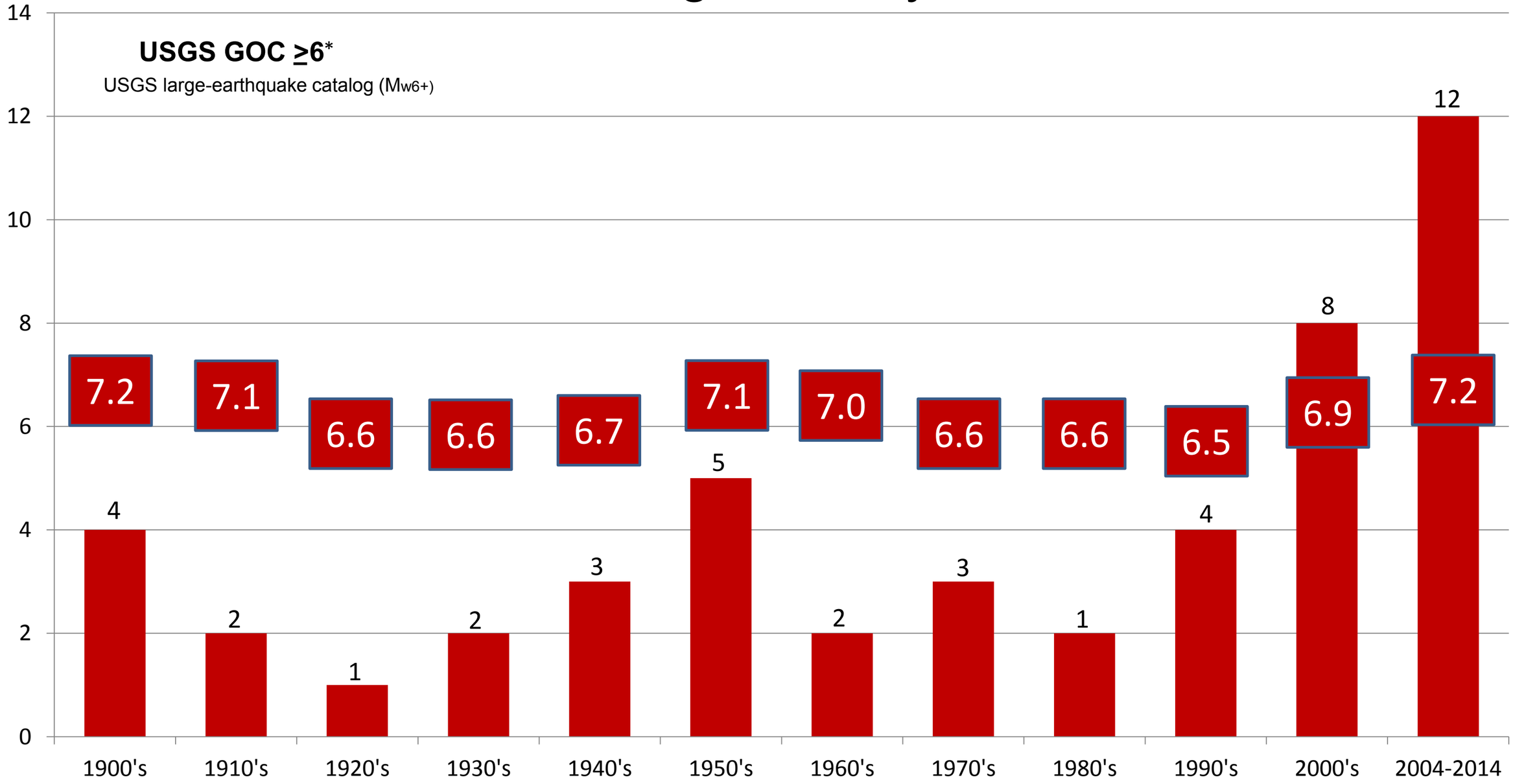
**Source: USGS, November 2014*

Gulf of California (GOC) & South Mexico Subduction Area



*Source: USGS, November2014

Gulf of California: Quake History count and Maximum Magnitude by decade



Sources: USGS, 2014; Latitude 22.0 to 32.6*N, Longitude -105.2* to -117.3*W

More evidence of seismicity in the 50s!

“Shake Rattle and Roll “

Bill Haley and the Comets 1954

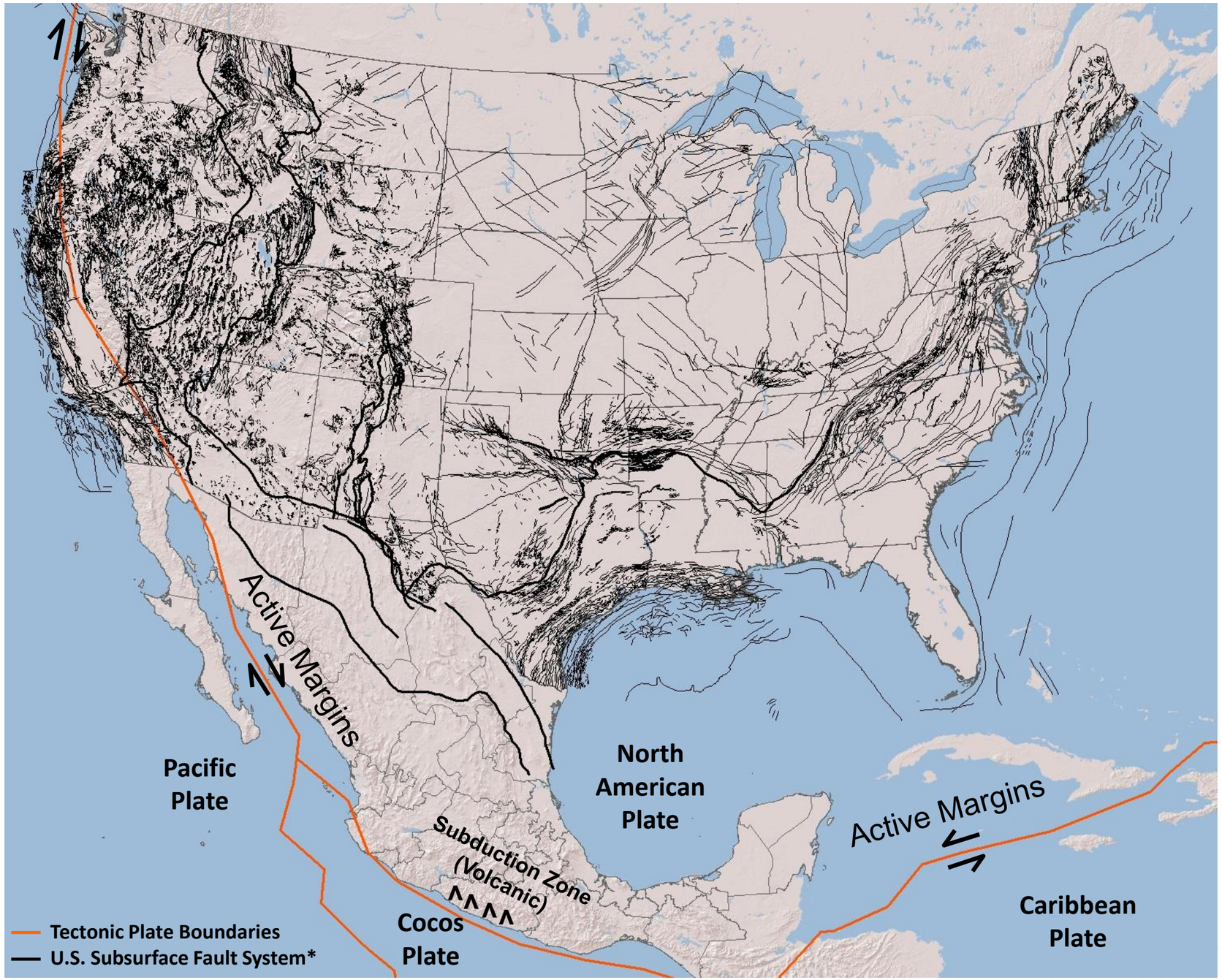
“All Shook Up”

Elvis Presley 1957

“Whole Lotta’ Shakin’ Going On”

Jerry Lee Lewis 1957

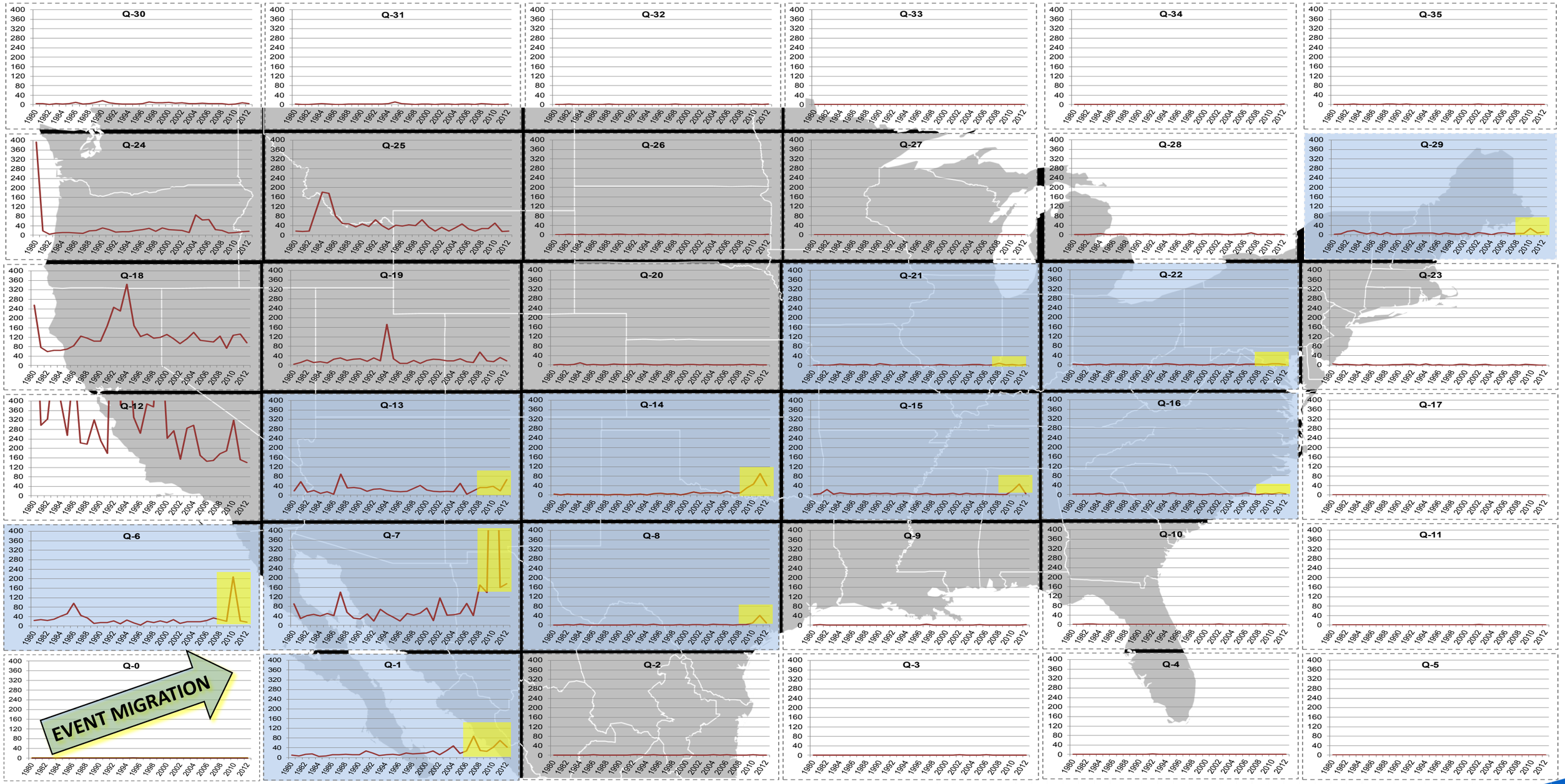
The Rest of the Story!



*Source: Geologic Data Systems

North America Map by Lat/Long Quadrant

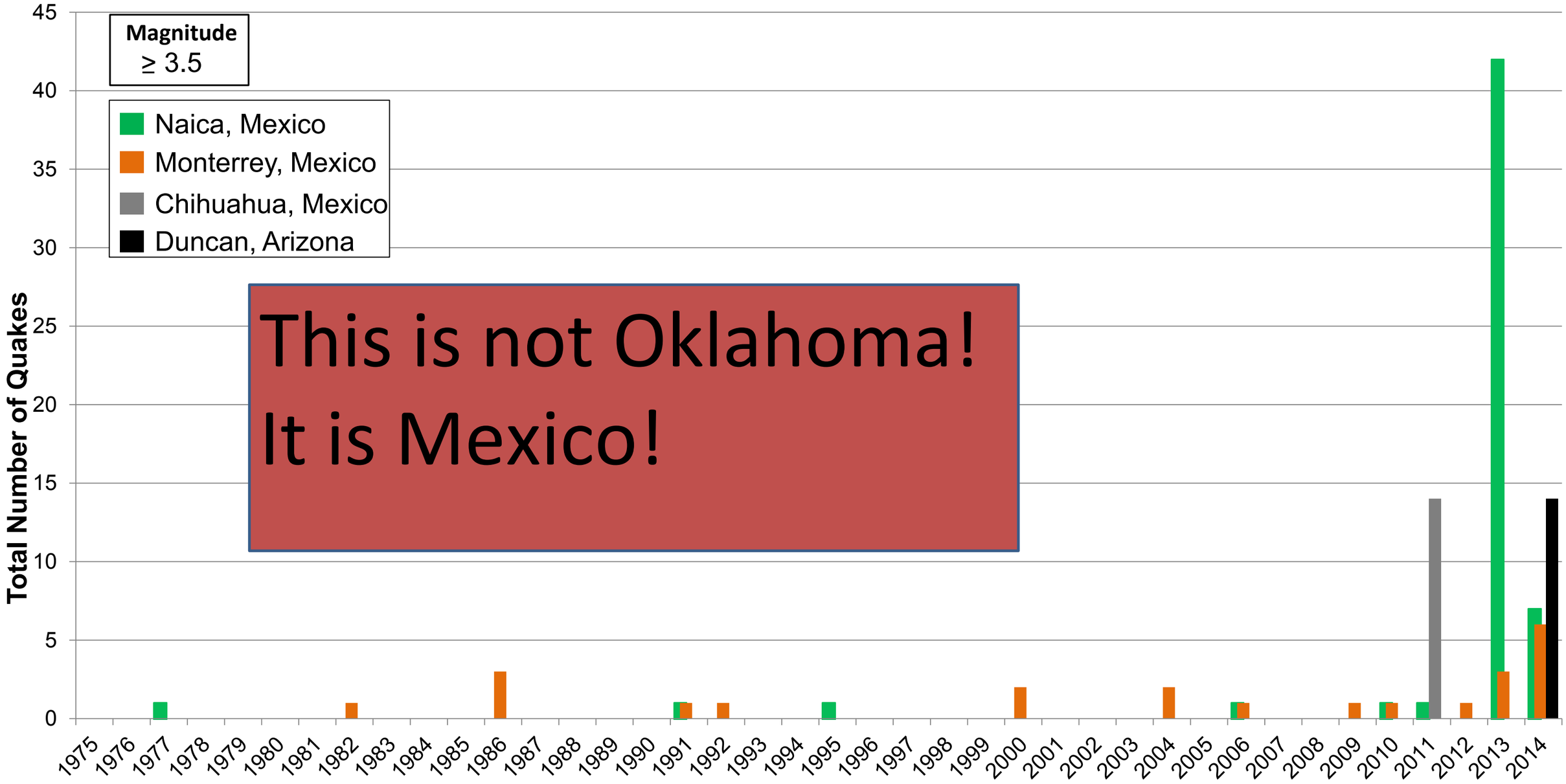
Magnitude ≥3
(Scale 400 on Y axis)



*Source: USGS, 2014

Data trend from 1980 - 2013

Mexico Interior Historical Earthquake Count

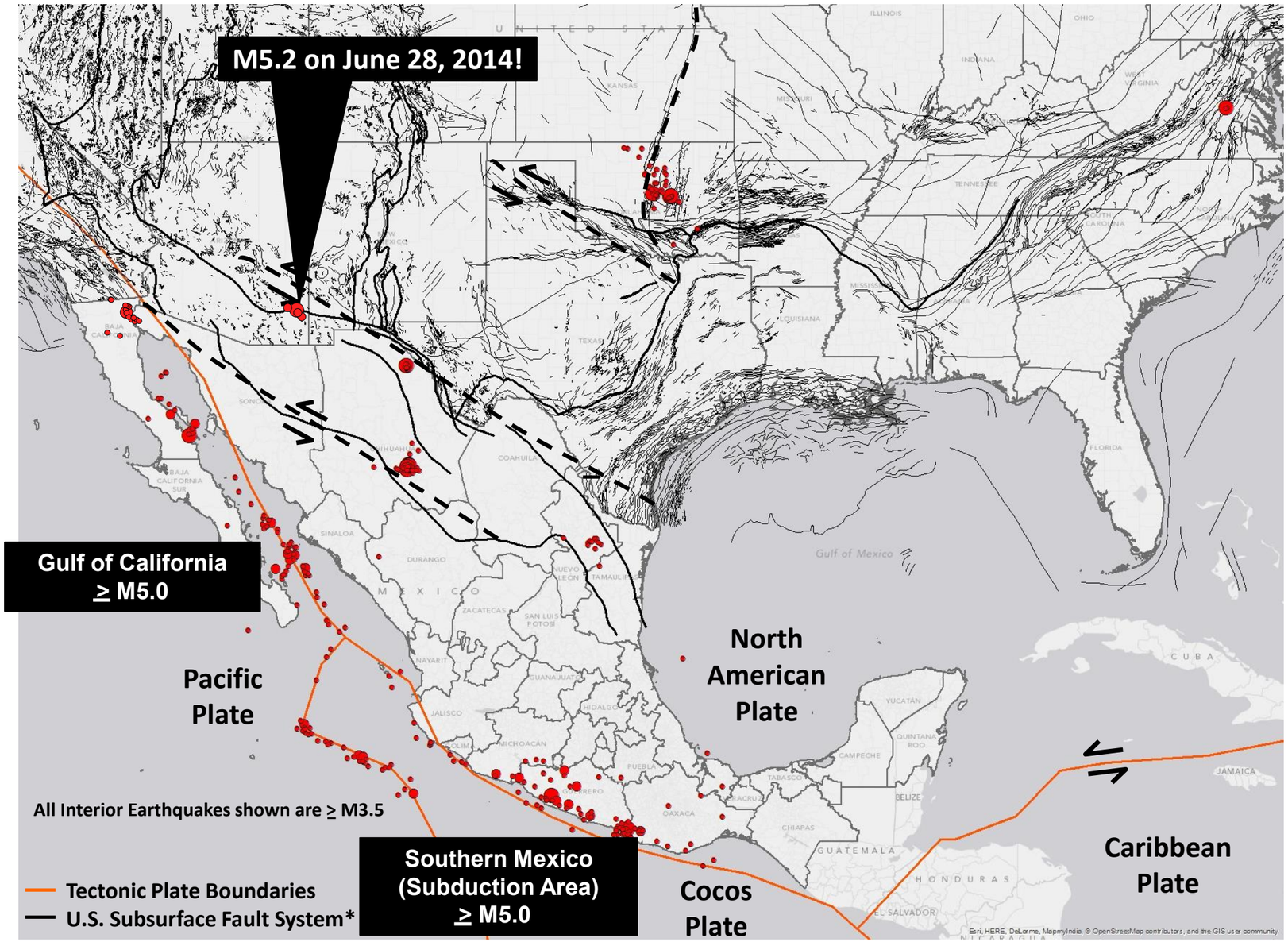


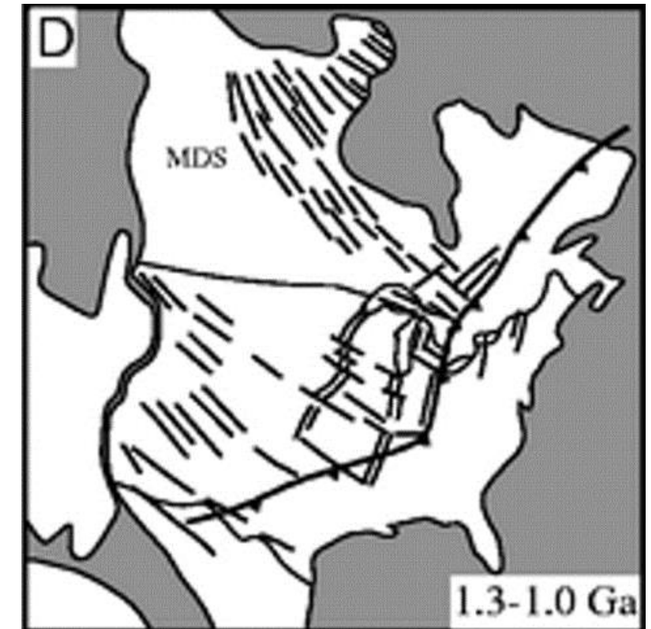
This is not Oklahoma!

It is Mexico!

*Source: USGS, December 2014

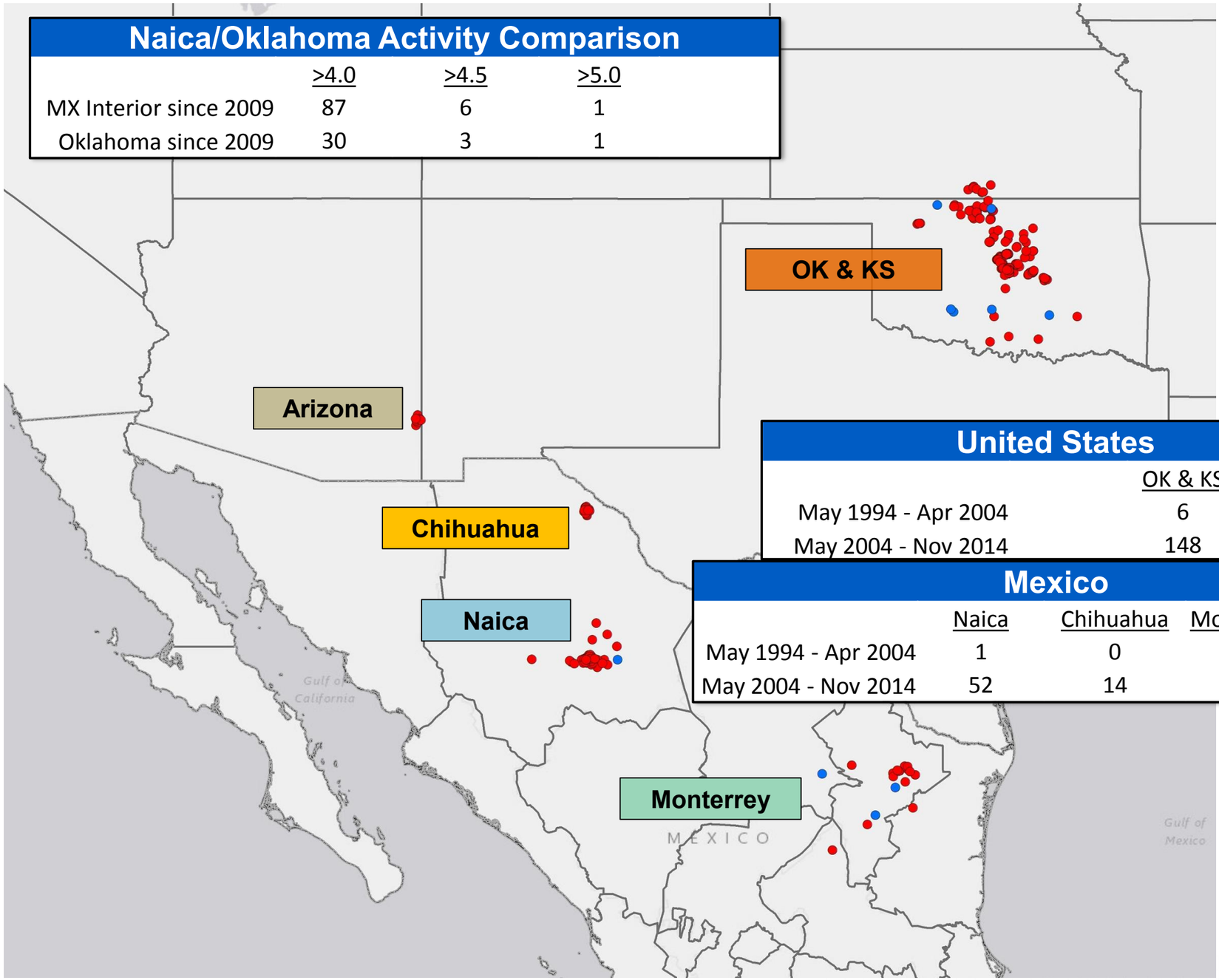
North America Key Earthquake Activity





**Source: Geologic Data Systems, USGS July 2014*

Intra-plate Earthquake Activity on the Rise



Naica/Oklahoma Activity Comparison

	>4.0	>4.5	>5.0
MX Interior since 2009	87	6	1
Oklahoma since 2009	30	3	1

United States (M ≥3.5)

	OK & KS	AZ
May 1994 - Apr 2004	6	0
May 2004 - Nov 2014	148	13

Mexico (M ≥3.5)

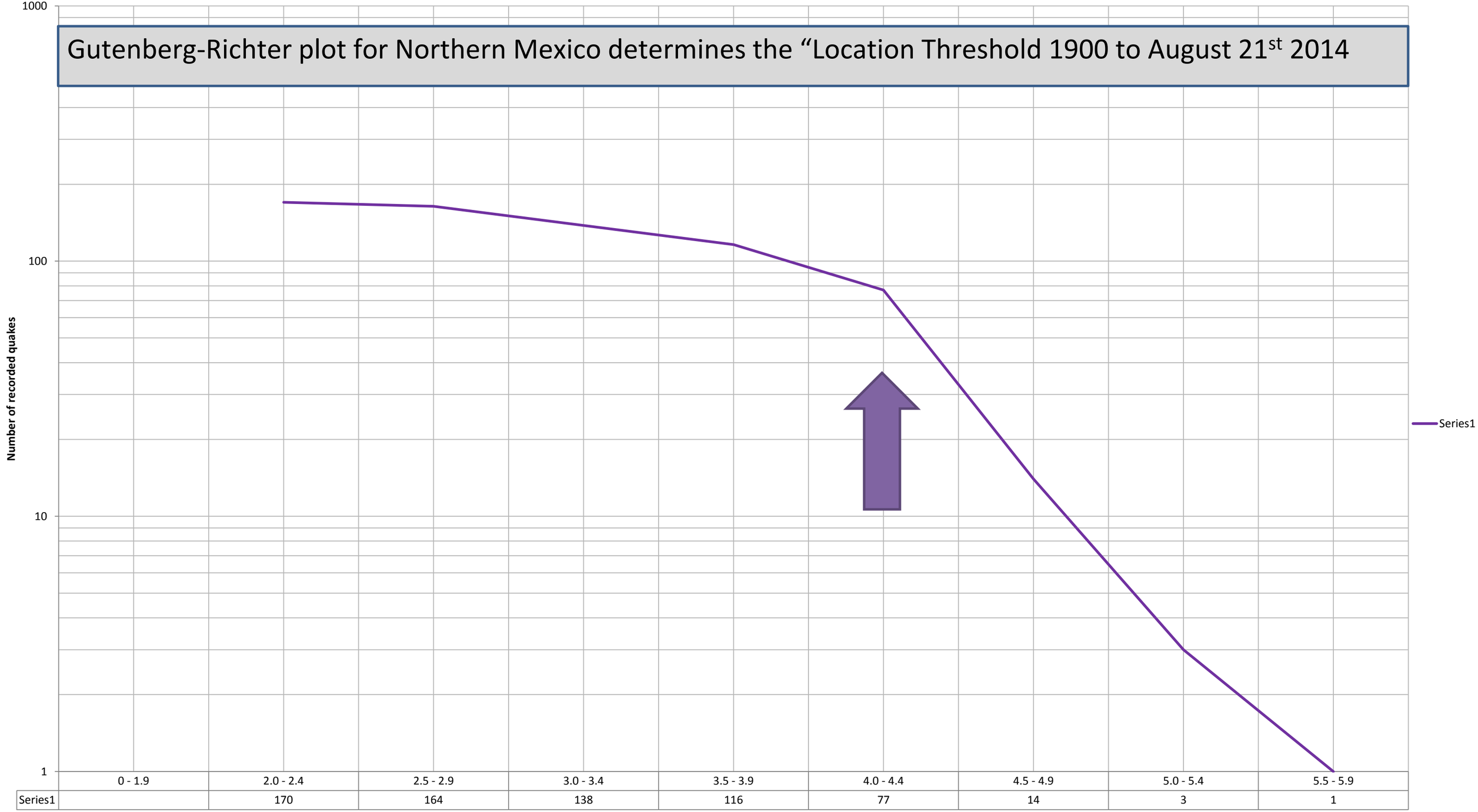
	Naica	Chihuahua	Monterrey	Total
May 1994 - Apr 2004	1	0	3	**4**
May 2004 - Nov 2014	52	14	15	**81**

May 1994 – Apr 2004

May 2004 – Nov 2014

**Source: USGS, Nov 2014*

Gutenberg-Richter plot for Northern Mexico determines the “Location Threshold 1900 to August 21st 2014



	0 - 1.9	2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9	4.0 - 4.4	4.5 - 4.9	5.0 - 5.4	5.5 - 5.9
Series1		170	164	138	116	77	14	3	1

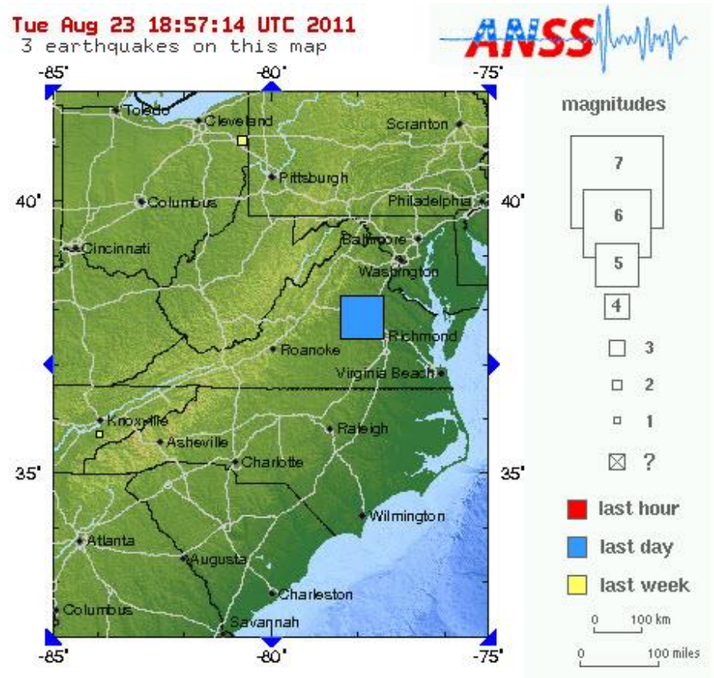
Earthquake Magnitude in bins
(25 to 31 North,-99 to -109 west)

Gutenberg-Richter plot for Northern Mexico
slope -1.25 1900 to Aug 21,2014

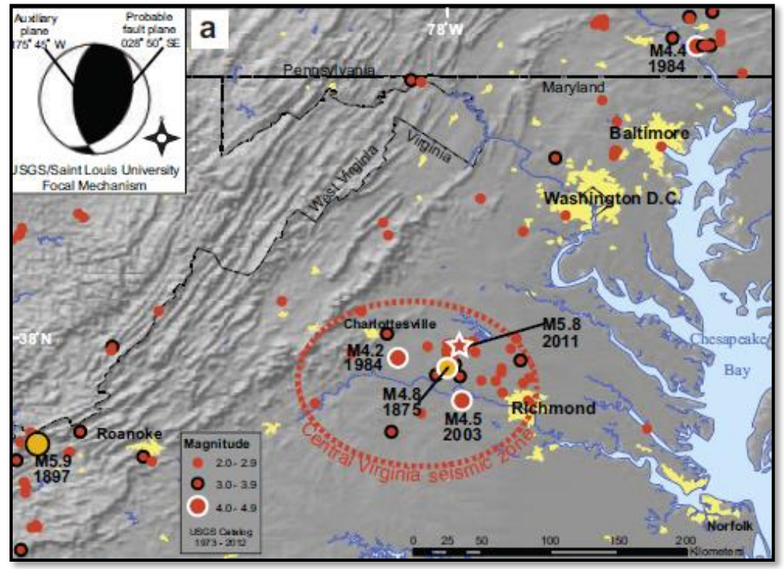
Virginia Quake
August 23rd, 2011

5.8 Richter

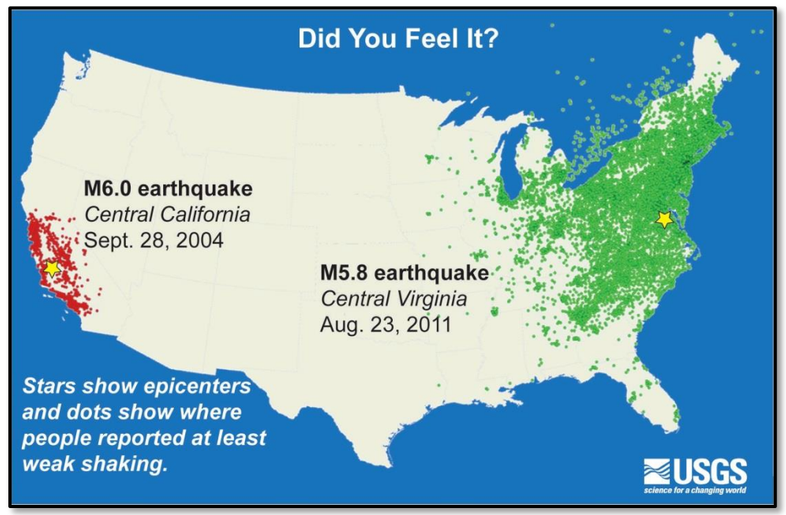
"This may be the largest earthquake to strike the central and eastern United States since the M=5.8 earthquake near Cornwall and Massena, N.Y., in 1944"



Source: VOLUME 93 NUMBER 33 , 14 AUGUST 2012, PAGES 317–324, EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION



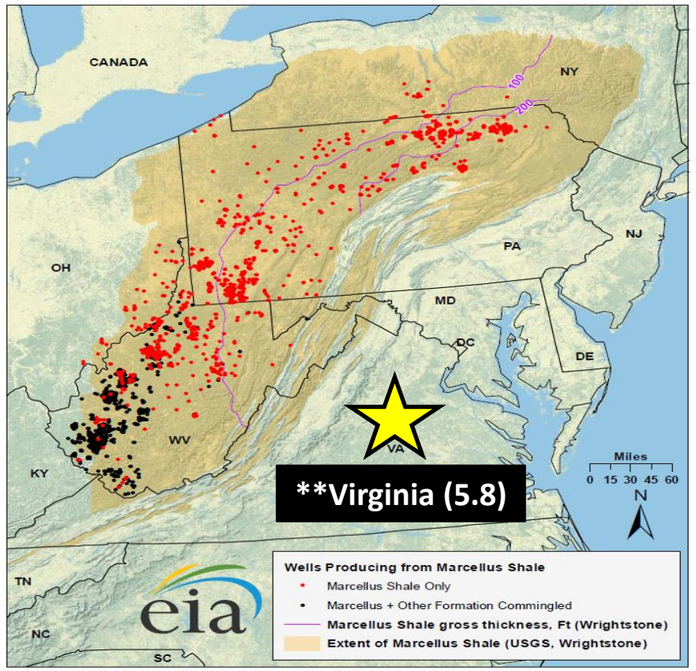
The M = 5.8 earthquake in Central Virginia seismic zone has a moment tensor solution http://earthquake.usgs.gov indicating reverse motion on an east-southeast-dipping plane consistent with aftershocks.



U.S. Geological Survey "Did You Feel It?" data from the M = 5.8 Virginia earthquake (green) and from one of similar magnitude and depth in California (red) illustrate how earthquakes are felt over much larger areas in the eastern United States than those west of the Rocky Mountains.

Photo by J. Scott Applewhite, Associated Press

Damage to buildings such as the Washington Monument in Washington, D.C., 135 kilometers northeast of the central Virginia epicenter.



Source: US Energy Information Administration based on data from WVGES, PA DCNR, OH DGS, NY DEC, VA DMME, USGS, Wrightstone (2009). Only wells completed after 1-1-2003 are shown. Updated June 1, 2011

Be careful of false information on the Internet

Don’t Get “Buffaloed!”*

The animals are supposedly evacuating themselves in anticipation of an eruption at the Yellowstone National Park, which sits on a huge volcanic system.

Curiosity was further fueled by the recent magnitude 4.8 earthquake last month, the largest at the park in 30 years.

But the warning turned out to be a hoax!

Yellowstone released the explanation that it’s not unusual for wildlife to leave the park during the winter to seek food.

The Bison featured in the video are actually running into the park—
that is, “towards” the volcano.

**As per Urban dictionary definition*

Summary

- Oklahoma seismic activity uptick in last 5 years is not unprecedented; what is unprecedented is our ability to measure them

- During the 50s and early 60s a similar active earthquake period occurred in Oklahoma but “under-reported” as compared to today

- Both earthquake prone periods in Oklahoma history were each coincident with 50% of the largest Worldwide quakes over 8.8 Richter Scale during 1900-2014

- Oklahoma activity is likely related to these large quakes despite being away from actual plate boundaries (normally “protected areas”)

- Earthquake locations in Oklahoma are inversely related (statistically) to horizontal drilling, fracking and/or salt water disposal

- Synchronous earthquake activity /swarms have occurred in Virginia, South Carolina, Arizona, NW Alaska and neighboring Mexico where no oil and gas activity is present

QUESTIONS or COMMENTS