Seismicity Rates in Oklahoma: A Look at the Seismicity Increase of 2014*

Amberlee Darold[1] and Austin Holland[2]

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Abstract

The seismicity rate observed during 2014 in Oklahoma was greater than any previous year. This includes years that had already seen a significant increase in the rate of seismicity. The record number of earthquakes occurred throughout 40 counties in Oklahoma. Of the 5,417 earthquakes reported in 2014, 967 were reported as felt to the Oklahoma Geological Survey (OGS) and/or the U.S. Geological Survey and 585 were of a local magnitude (ML) 3.0 or greater. Seismicity was concentrated in central and north-central Oklahoma with more than 43% of the earthquakes reported by the OGS located within Grant and Logan Counties. For 2014 the OGS catalog is complete to a minimum magnitude of 2.4 ML with several known smaller earthquakes left un-located. Daily seismicity rates through time can be examined to determine when the increase in seismicity rates occurred. These seismicity rates also show that by the end of 2014, the daily rate of magnitude 3.0 or greater earthquakes is roughly equivalent to that of the annual average from 1980 to 2008. The Gutenberg-Richter relationship for the year normalized to a daily rate of earthquakes provides a relationship of a = 3.215 Â±0.241 and b = 1.217 Â±0.022. We will place the seismicity observed within 2014 in the context of past seismicity in Oklahoma and will also examine whether 2015 seismicity is consistent with that observed during 2014.

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Seismicity Rates in Oklahoma: A look at the Seismicity Increase of 2014

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AAPG, OCT 2015

Outline

- Oklahoma Seismicity
- Seismicity: 2014-2015
- Rates, Scaling Laws and Catalog Completeness
- OGS Catalog and Seismic Monitoring
- Potential for Damaging Earthquake in Oklahoma

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Oklahoma Seismicity

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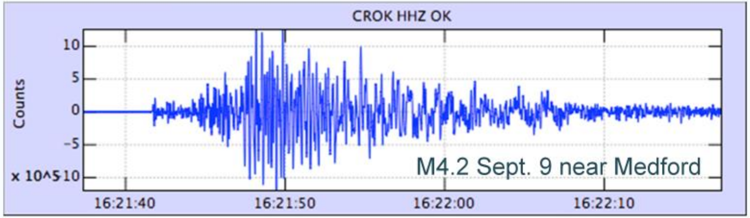
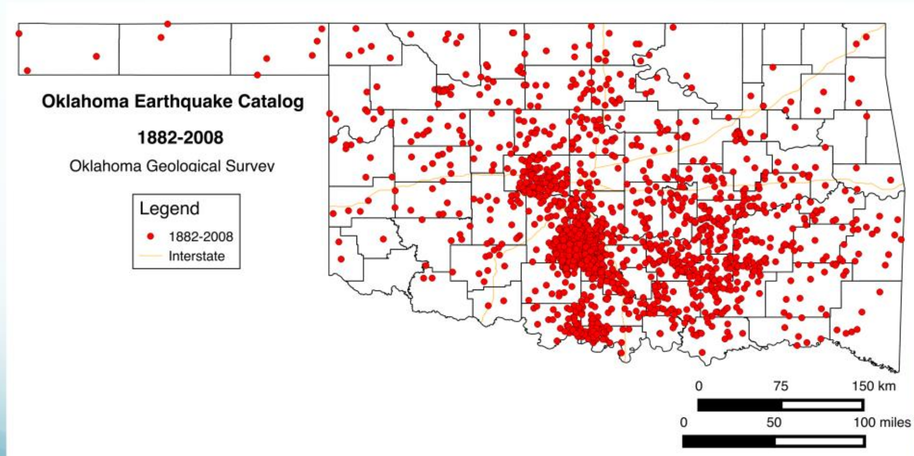


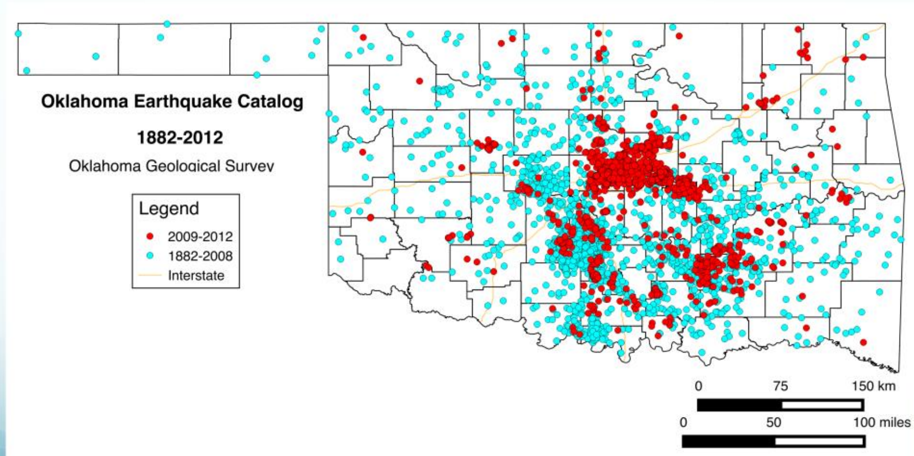
OGS Seismic Monitoring Program

- The OGS seismic monitoring program was established to document and compile earthquake occurrences, examine these occurrences, and through extensive research, gain a better understanding of earthquake processes as well as assess hazard throughout the state of Oklahoma.
- 1961 - The first seismograph in Oklahoma
- 1977 - A statewide network was operational
- 2010 - A complete overhaul and the beginning of what is now the Oklahoma Seismic Network

Oklahoma Seismicity



Oklahoma Seismicity



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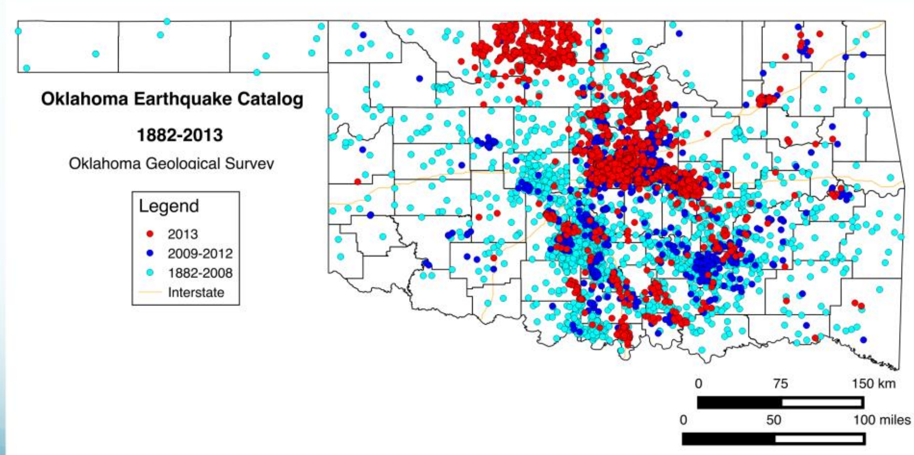
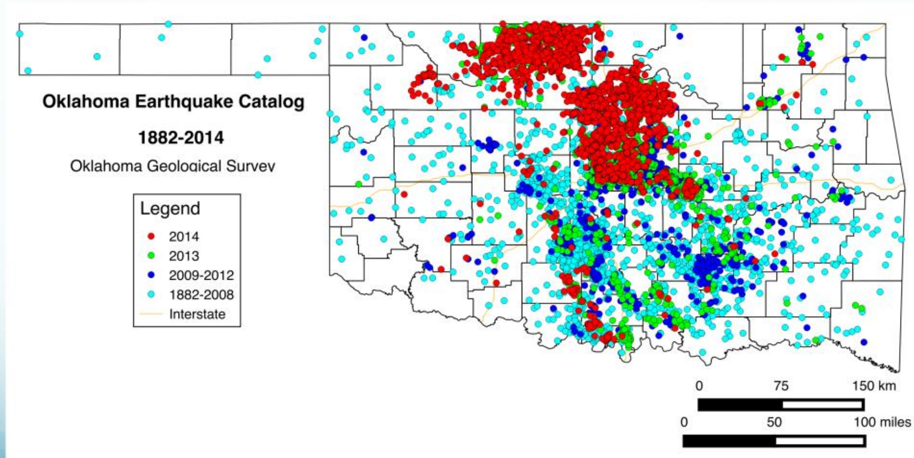
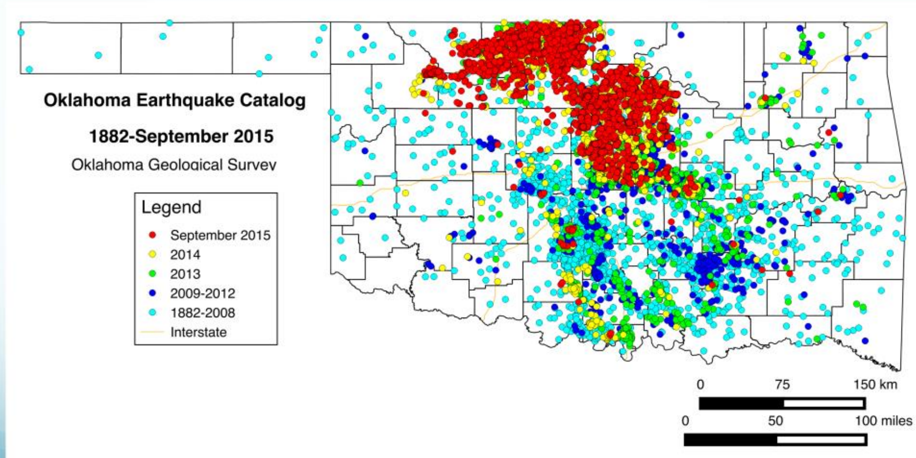


Oklahoma Seismicity

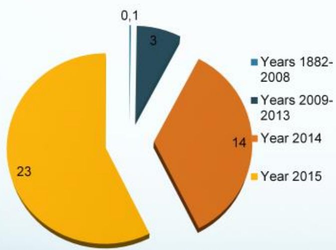


Oklahoma Seismicity

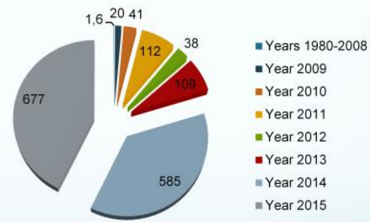


Oklahoma's Increase in Earthquakes
Number Earthquakes per Year

Magnitude 4 or Greater Earthquakes/Year



Magnitude 3 or Greater Earthquakes/Year



Updated 09-28-2015

Seismicity: 2014-2015

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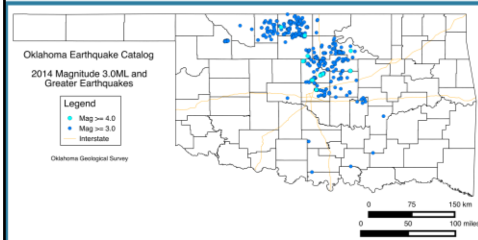
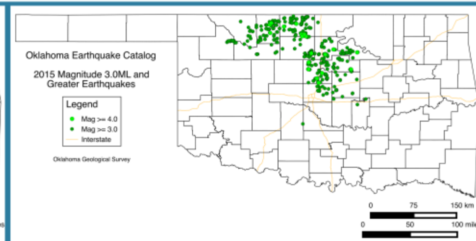
2014 Compared to 2015

2014
584

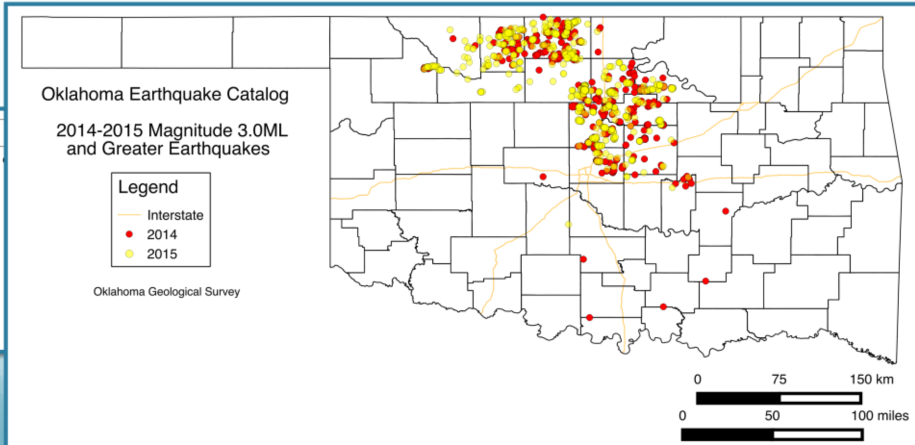
2015
684





2014 Compared to 2015

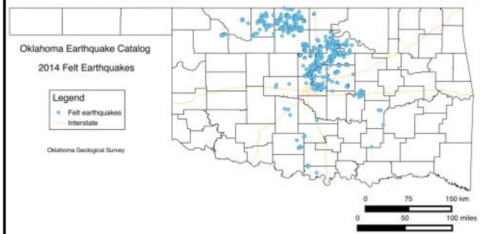
2014	2015
584	**684**

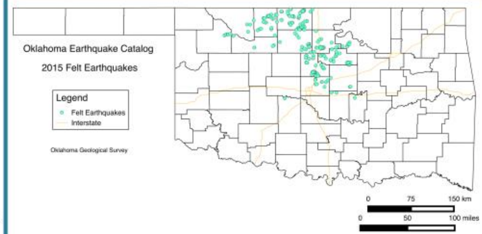


Earthquakes Reported Felt

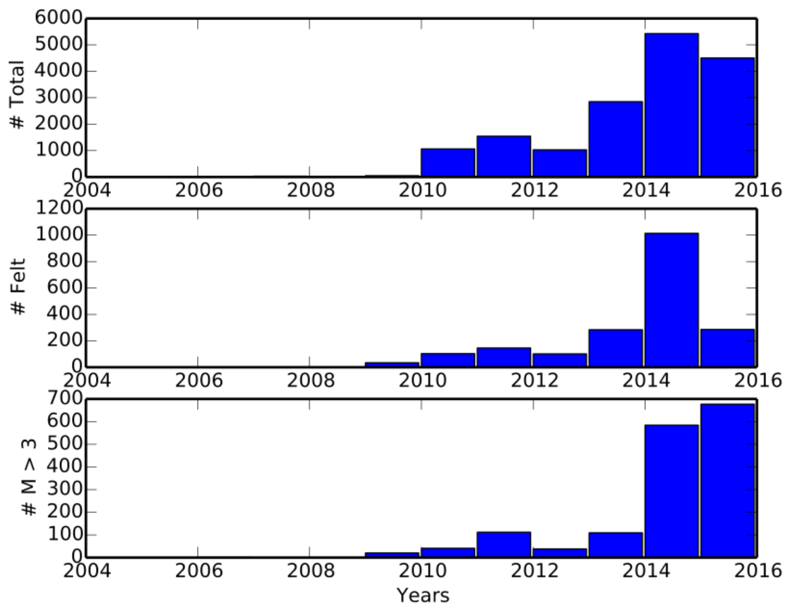
2014 Felt
1013

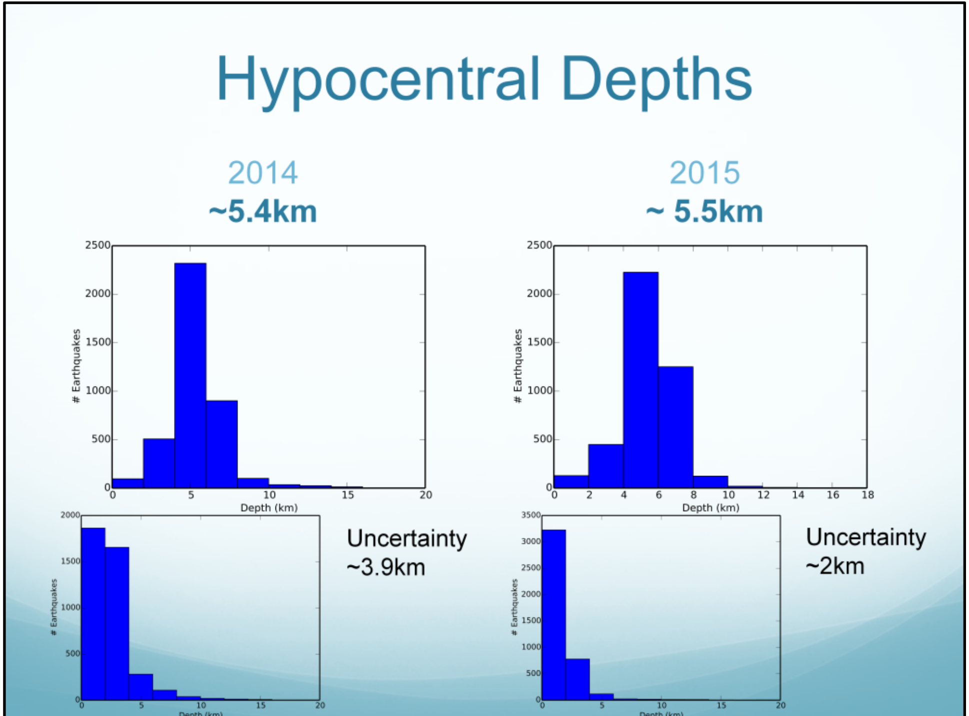
2015 Felt
290





Earthquakes Reported Felt

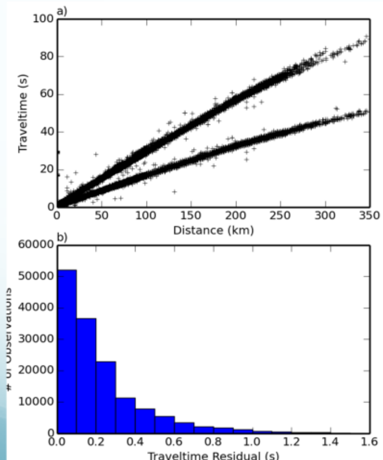




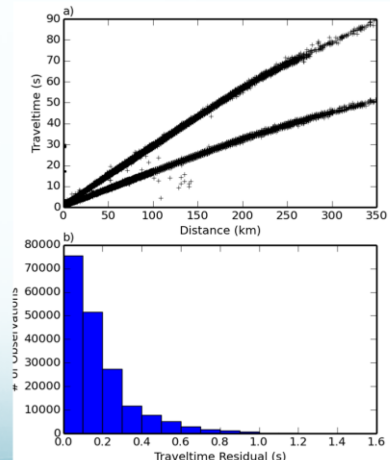
Presenter's notes:
~18,000ft
~12,800ft
~6,500ft

Phase Travel-Times

2014



2015



Presenter's notes: 1D regional velocity model does reasonably well shown from travel-time curves and residuals. 2014-1015 shows that analysis has become more consistent.

Rates, Scaling Laws and Catalog Completeness

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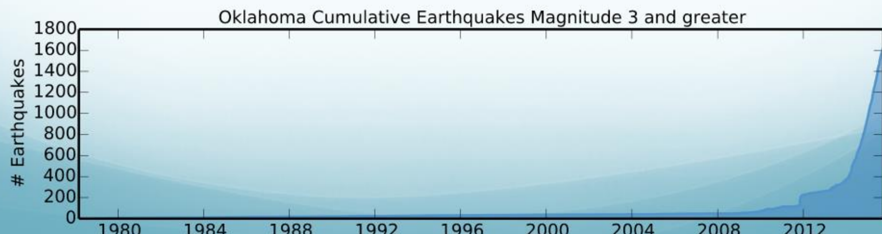
Seismicity Rate

The number of earthquakes in a specified interval of space-time-magnitude, normalized by the length of the time interval.

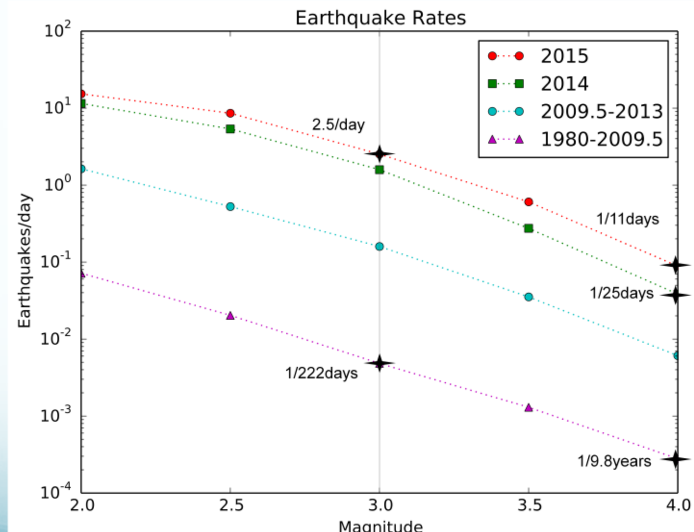
- Oklahoma has a low background rate
  - ~1.6 earthquakes of M3 or greater/year, derived from historical seismicity recorded 1980-2008.
- Understanding seismicity rate changes is fundamental in seismology
  - especially for prediction and forecasting purposes
- Statistically significant or not…
  - Rate increase for OK is obvious and significant



Presenter’s notes: Jump in cumulative rate due to November 2011 Prague sequence.

Contemporary Earthquake Rates Have Far Surpassed Background Rates

- M 4+ is currently ~1 every ten days.
- M 3+ is currently over two a day.
- At this rate the OGS is unable to locate all felt earthquakes in Oklahoma (~M 1.8+)



Declustered rate with the GR fit

Presenter's notes:
- Declustered rate

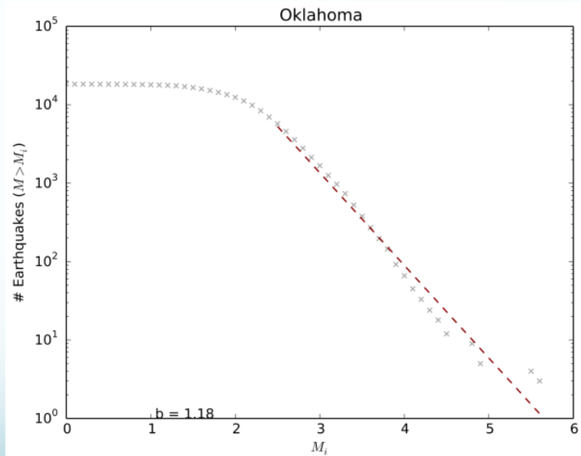
- - Gutenberg Richter fit

GR-Scaling Law

$\log_{10} N(x) = a - bx$

The relationship between earthquake magnitude and frequency

- The Gutenberg Richter b-value: It is the slope of line segment, starts at the Mc and ends at the largest magnitude value in the catalog. Empirically, the value has been found to be ~1, simply stating that for every 1 M3.0 you can expect 10 M2.0.



Cumulative b-value 1.18, Mc 2.5

Presenter's notes: N=# earthquakes>=x

B-value Changes

$(\log_{10} N(x) = a - bx)$

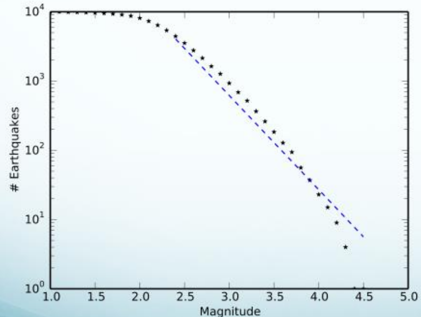
2014

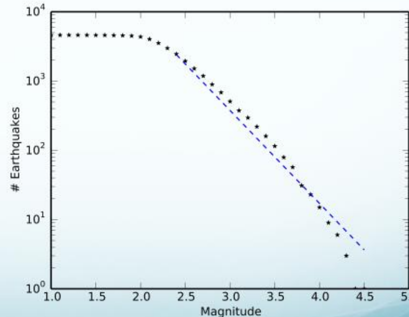
a = 6.872084 +/- 0.302781
b = 1.360281 +/- 0.008237

2015

a = 6.601840 +/- 0.241594
b = 1.342258 +/- 0.011049

a and b are constants for a fixed data set.





High b-value – Oklahoma has a high portion of small earthquakes to large ones

Variations of b-value

- Variations from a b-value of 1?
  - Data may have an incorrect magnitude of completeness (Mc).
  - Magnitudes may be incorrectly calculated.
  - Dataset too is small, statistics of small numbers.
  - Mainshock and aftershocks may have not fully released the accumulated strain for low b values.
  - Characteristics of swarm behavior?

The majority of earthquakes in central and north-central Oklahoma occur as earthquake swarms and not in the typical foreshock-mainshock-aftershock sequences that are characteristic of naturally occurring earthquake sequences throughout the world in a variety of tectonic settings.

Magnitude of Completeness

- Magnitude of completeness (Mc):

  the smallest value of magnitude at which the catalog is thought to have included all seismic events.

- Why is an accurate determination of the Mc important?
  - The Gutenberg-Richter b-value is very sensitive to the determined or assumed Mc
  - Analyzing changes in seismic rates require an accurate determination of the Mc. Forecasting and seismic hazard assessment depend upon knowledge of the Mc.
  - A value too high discards valuable data and a value too low leads to a biased analysis by using incomplete data.
  - OGS Mc has changed significantly through time.
    - Prior to 2013, Mc ~2.0
    - 2014 Mc ~2.5

Man-made changes to seismicity rate

- Detection changes
  - Seismic network changes
    - Installation and or closure of stations
      - Increased or decreased detection of smaller events
  - Aftershock sequences
  - Can be avoided using magnitude cutoff
- Reporting changes
  - Changes in personnel, workload and operating hours
  - Can be avoided using magnitude cutoff
- Magnitude shifts
  - Systematic changes M_L-M_W
  - Change in seismic network
    - Variation in equipment response and distribution

Seismic networks and their associated catalogs inherently contain man-made changes it is important to recognize and minimize these effects.

Catalog Incompleteness:

- Why can't we record and locate every earthquake?
  - Aftershocks may be hidden in the coda of larger events either other aftershocks or the mainshock
  - Events may be too small to be detected at enough stations and, therefore, cannot be located
  - Seismic stations may not be physically capable of recording events of a very small size and/or the amplitude of such events may be below the noise level of a station
  - Manual review of automatic location
  - Limited seismic station coverage
  - Limited staff to keep up with the number of events being recorded per day

Presenter's notes: Not enough station coverage throughout the state

OGS Catalog and Seismic Monitoring

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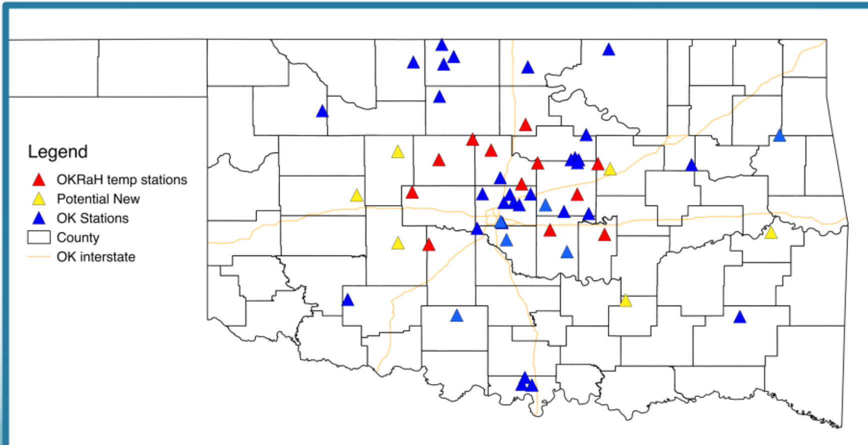
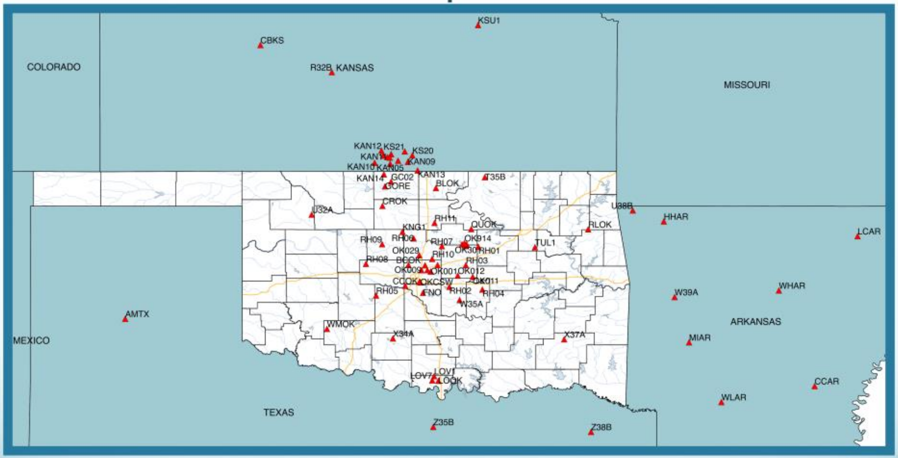
OGS Catalog

- Require phase arrivals from at least four seismic stations
- Must be located in Oklahoma
- M_L routinely calculated for all events
- M_W calculated for all events M_L 3.8 and greater
- Preliminary and subject to change with further analysis
- Currently working to keep catalog at a Mc of M2.5

The OGS network of seismic stations began operating in 1977, greatly expanded in 2010 and continues today.



Stations Used by OGS to Locate Oklahoma Earthquakes



The time, locations, and magnitude of an earthquake are determined from the data recorded by seismograph stations

Presenter's notes: Currently showing 71 stations

Potential for Damaging Earthquake in Oklahoma

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USGS science for a changing world

Record Number of Oklahoma Tremors Raises Possibility of Damaging Earthquakes

Updated USGS-Oklahoma Geological Survey Joint Statement on Oklahoma Earthquakes

Originally Released: 10/22/2013 1:07:59 PM; **Updated May 2, 2014**

The rate of earthquakes in Oklahoma has increased remarkably since October 2013–by about 50 percent – significantly increasing the chance for a damaging magnitude 5.5 or greater quake in central Oklahoma.

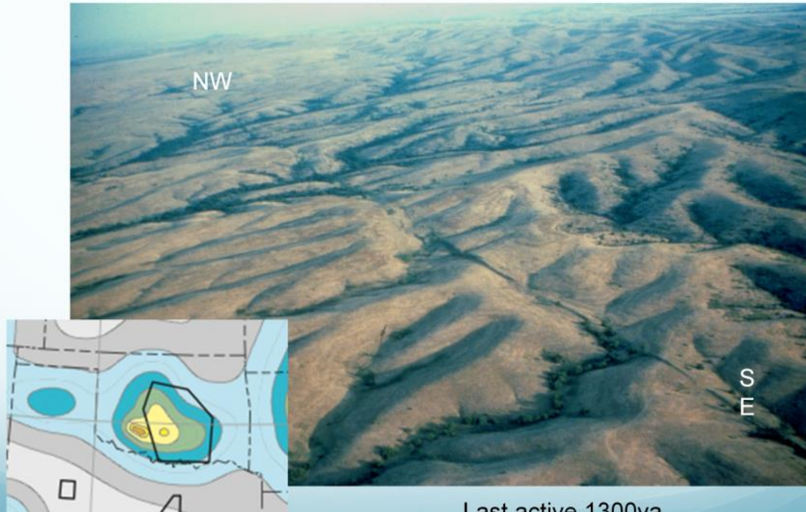
Simply, the number of M4+ Oklahoma has experienced, we could expect a M5+

- An increase like this has not been observed in modern seismology in an intra-plate setting.
- The chances of a large damaging earthquake in Oklahoma are small but not zero

	Magnitude (m)					
Duration	**3.0**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**
4 Year	1.0000	1.0000	1.0000	0.9239	0.4151	0.1057
1 Year	1.0000	1.0000	0.9690	0.4883	0.1213	0.0246
6 months	1.0000	1.0000	0.9083	0.3873	0.0955	0.0204
30 days	1.0000	0.7814	0.2496	0.0528	0.0102	0.0019
10 days	1.0000	0.5433	0.1505	0.0334	0.0070	0.0015

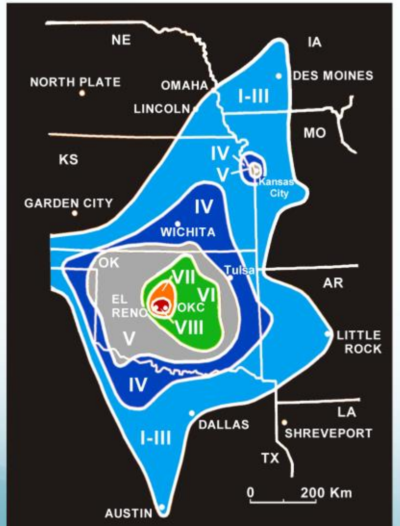
Presenter's notes: Increased Seismic Hazard

Meers Fault



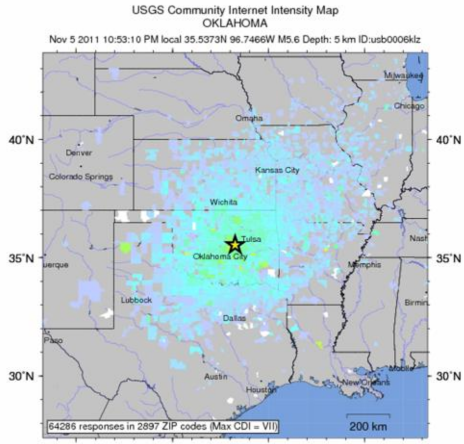
Last active 1300ya,
Estimated at a M 7.0 event

April 1952, El Reno Earthquake 5.5M



Crack in OKC State Building

November 2011, Prague Earthquake 5.6M

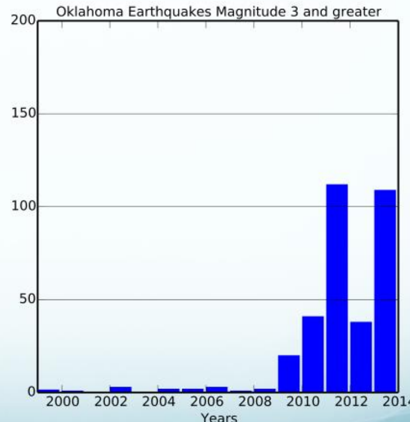


INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

St. Gregory's University in Shawnee

In Summary

- By 2013 the seismicity rate was 70X the background rate
- 2014 the seismicity rate was 400X the back ground rate
- Currently in 2015 the seismicity rate is 600X the back ground rate
  - We are locating 2.5 magnitude 3.0 or greater earthquakes per day.



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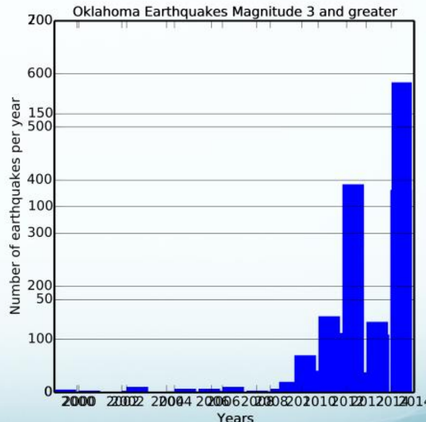

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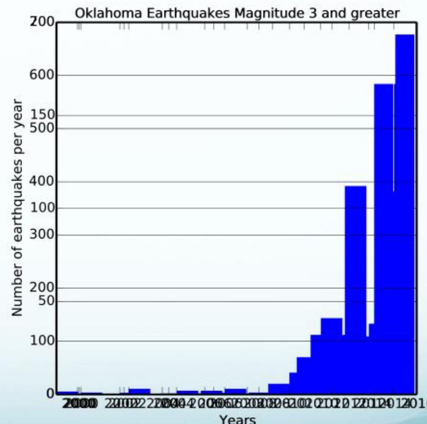

Questions or Comments?

http://www.ogs.ou.edu

http://www.okgeosurvey1.gov

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Oklahoma Geological Survey - Earthquake Notices