OKLAHOMA GEOLOGICAL SURVEY

A State Agency For Research and Public Service

Potential for Induced Seismicity and Current Mitigation Efforts within Oklahoma

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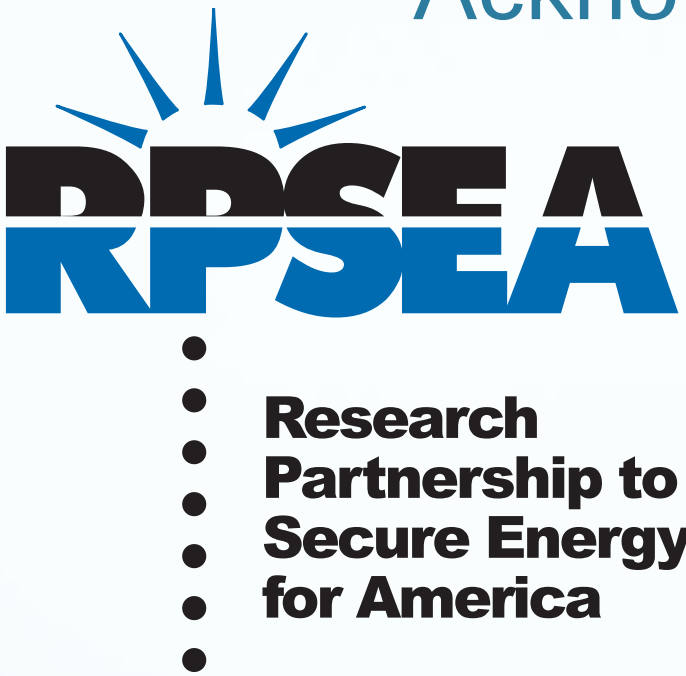
Acknowledgements



Industry contributors to RPSEA and fault database

Oklahoma Independent PetroleumAssociation (OIPA)

USGS – providing many different temporary seismic stations

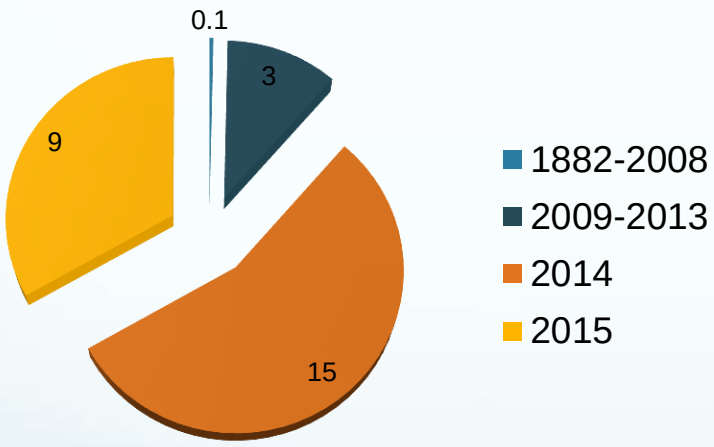
Significant Input from the Oklahoma Corporation Commission

Oklahoma Secretary of Energy and Environment

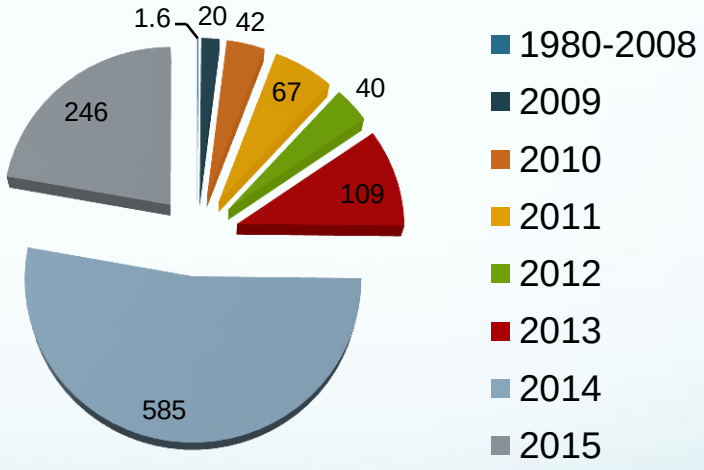
OU Mewbourne College of Earth and Energy

Oklahoma's Increase in Earthquakes Earthquake rates per year

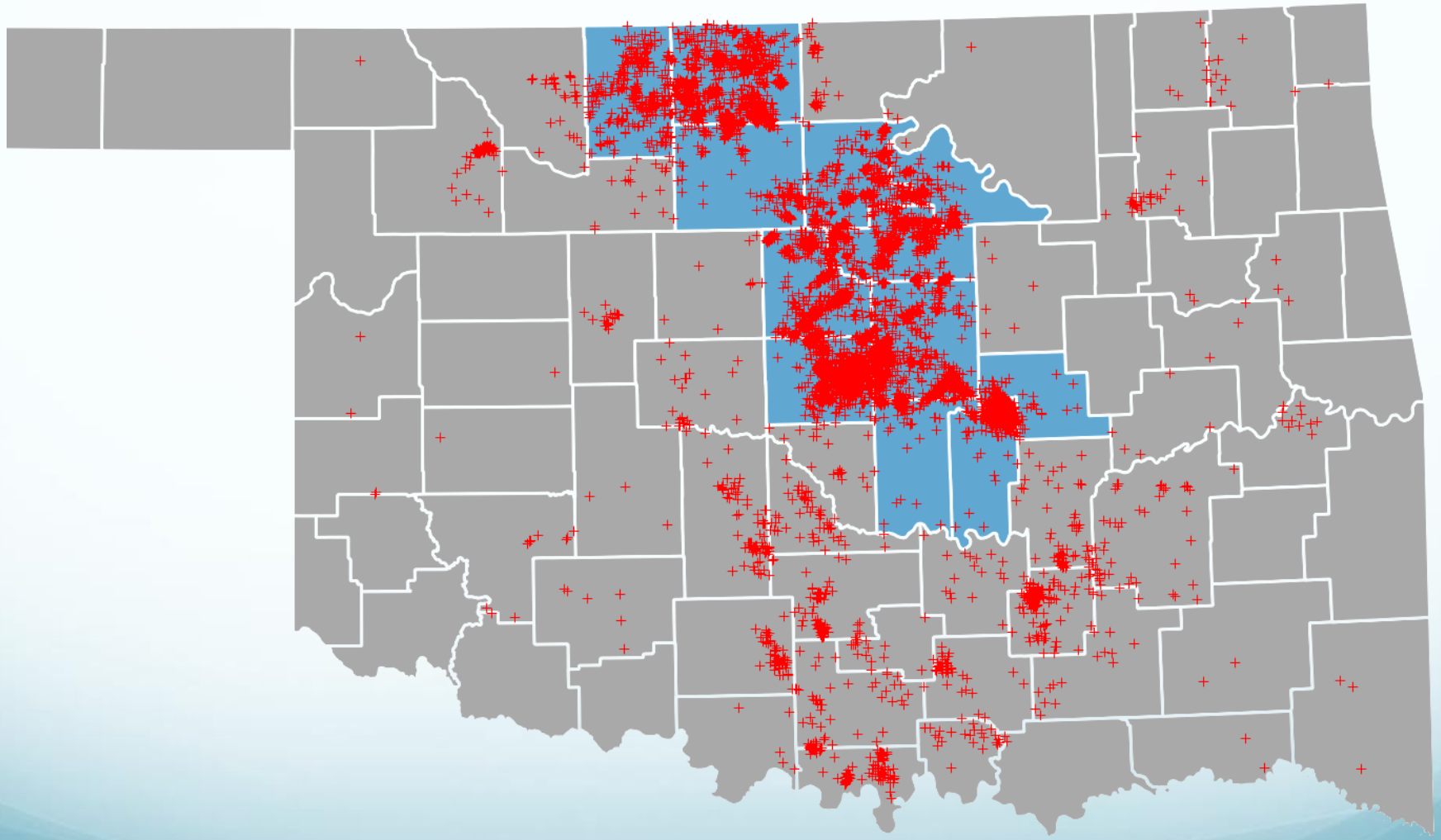
Magnitude 4 or Greater Earthquakes



Magnitude 3 or Greater Earthquakes

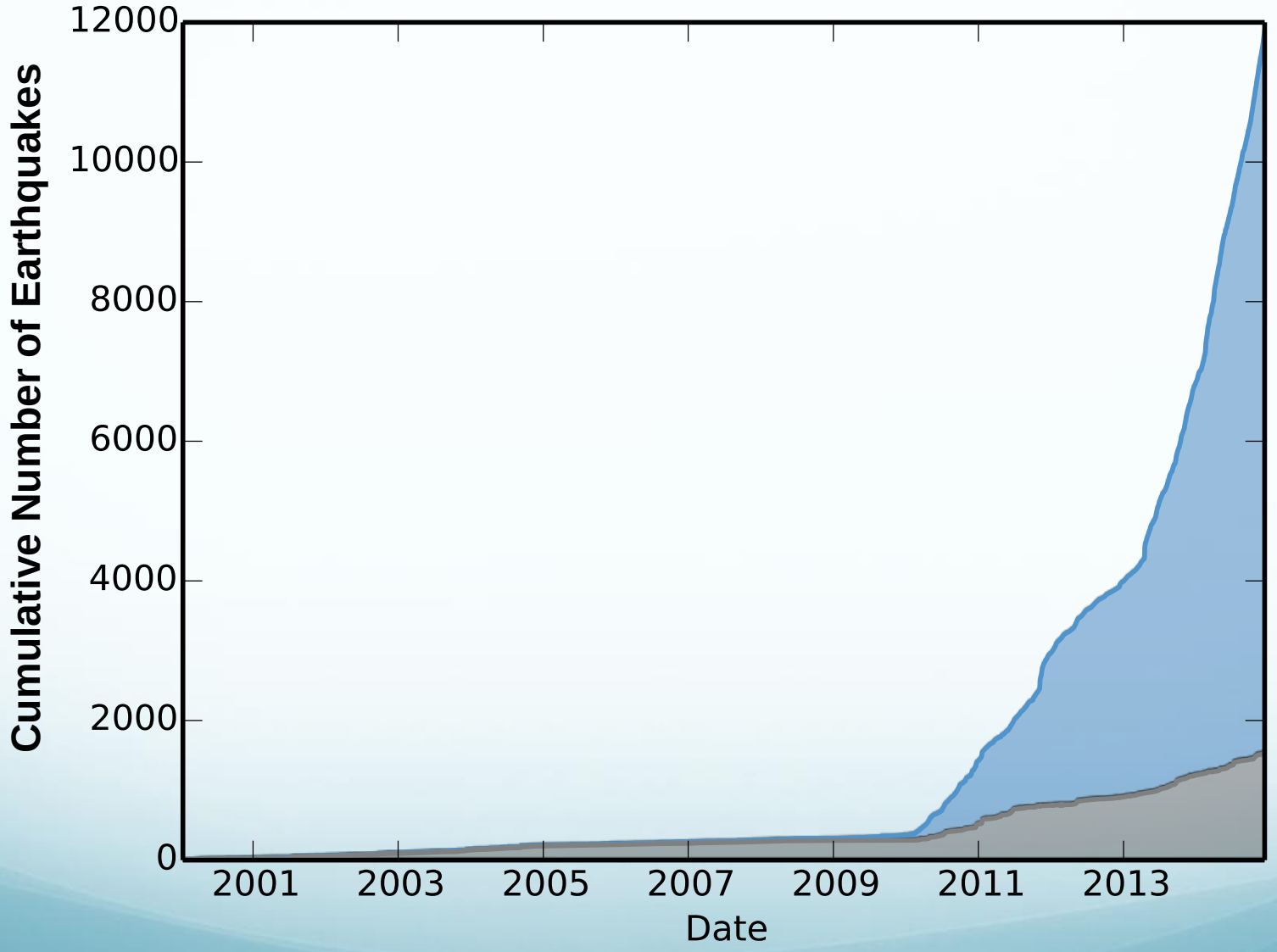


Oklahoma Earthquakes 2009-2014

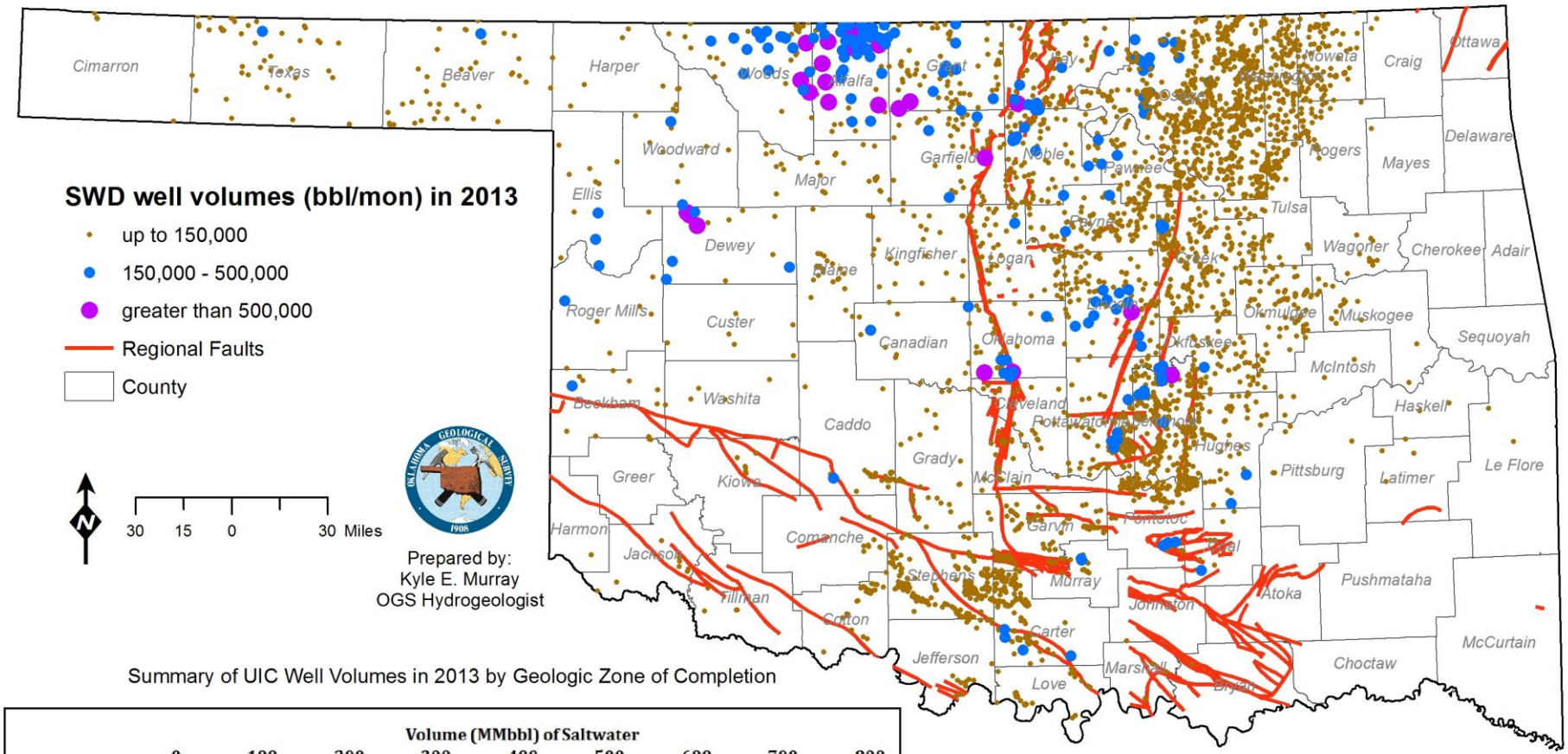


Area of greatest increase is about 15% of Oklahoma.
Captures areas of significant waste-water disposal wells

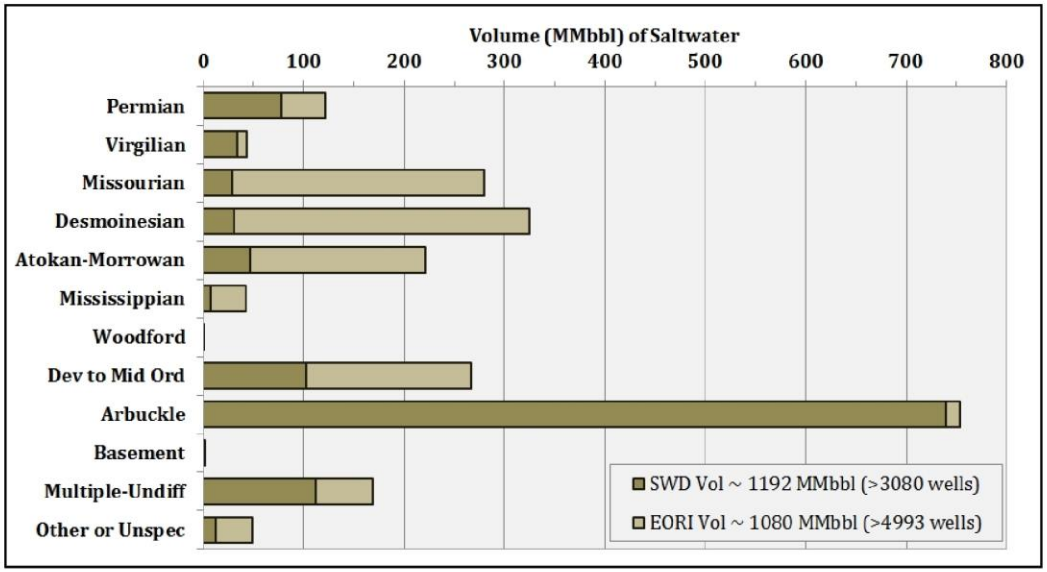
Cumulative Seismicity in Oklahoma



Oklahoma Geol. Survey www.okgeosurvey1.gov/pages/earthquakes/catalogs.php



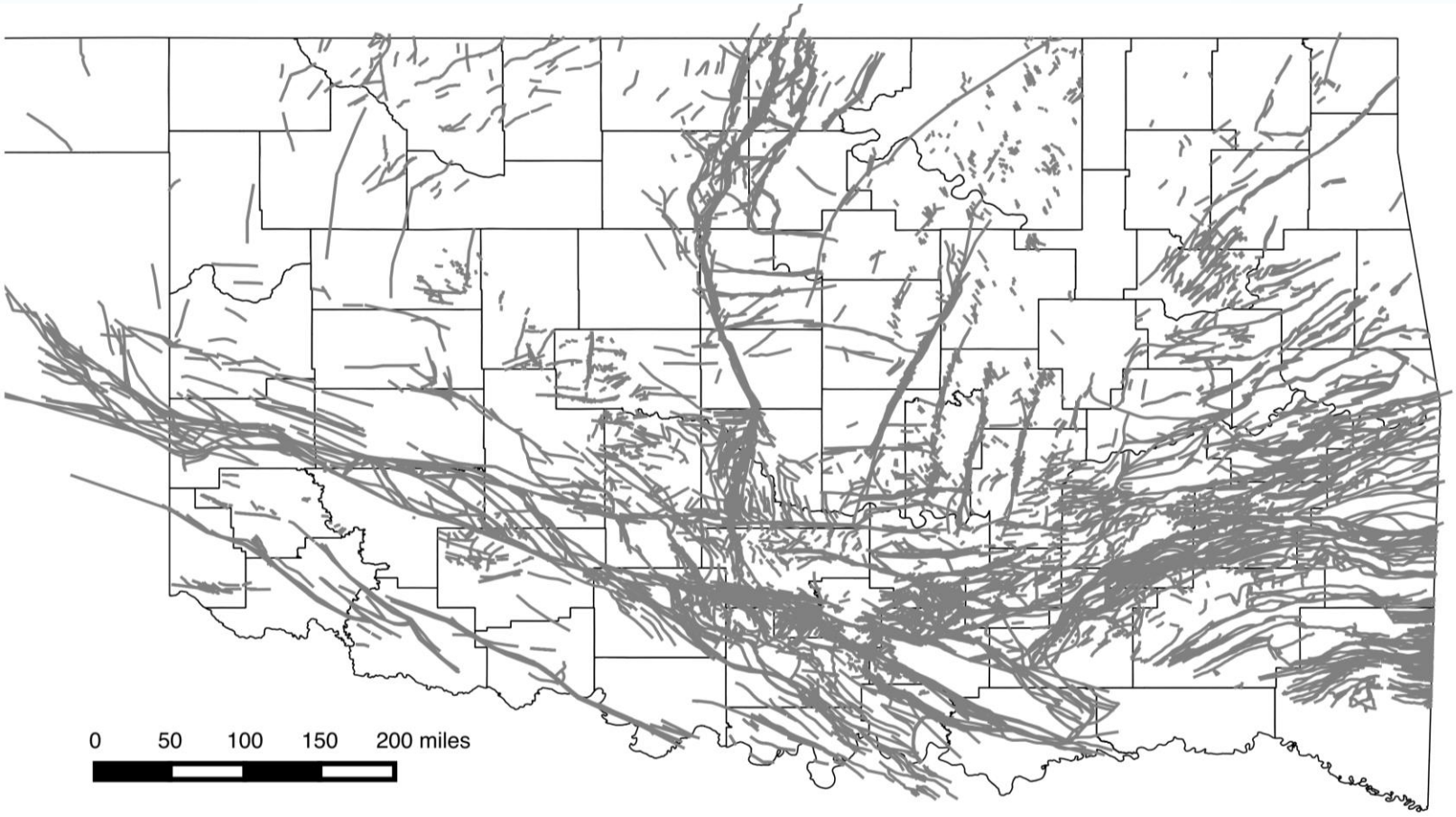
Summary of UIC Well Volumes in 2013 by Geologic Zone of Completion



Murray 2014, OGS OF1-2014

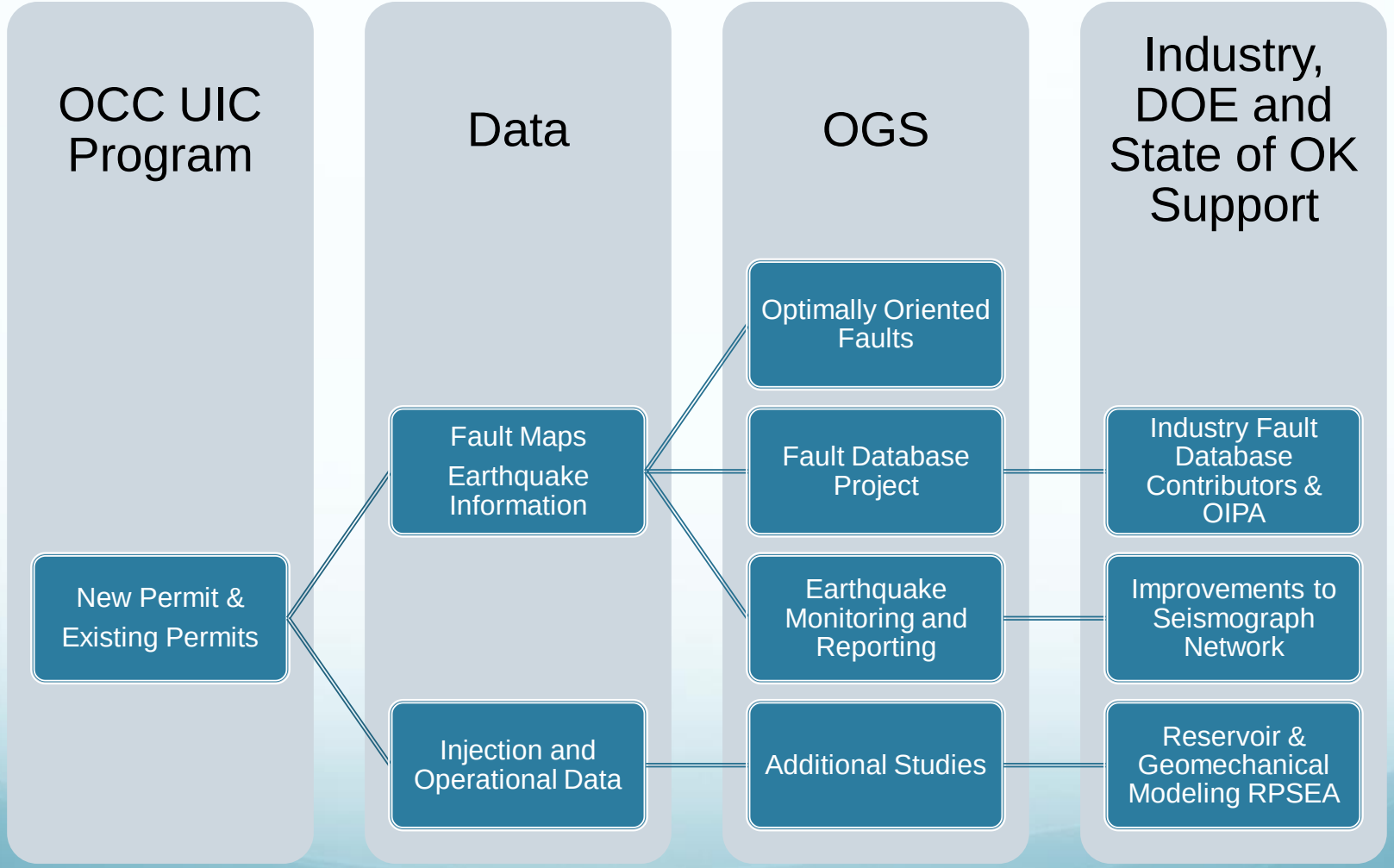
Index Location Map for Oklahoma

Mapped Faults in Oklahoma



Faults are compiled from industry contributions and published literature

Interagency Cooperation



Oklahoma Corporation Commission UIC Program

- The Underground Injection Control (UIC) program was created in 1974 by the Safe Drinking Water Act.
  - All wastes injected underground are required to comply.
- Oil Gas Conservation Division (OGCD) received primacy to run the UIC program for oil and gas activities in 1981.
  - Class II wells under the UIC definition
- Class II wells are classified in two types
  - 2D wells are Disposal Wells (SWD)
  - 2R wells are Enhance Recovery Wells (EOR).
    - EOR wells re-inject produced water back into the same producing formation to help extract the remaining oil.
  - In Oklahoma there are 4,626 SWD Wells and 7,037 EOR Wells

Provided by the OCC

OCC UIC Program

- 2D or Disposal wells take waste-water and inject it into the subsurface

  This water is not generally what we think of as water

  - High salinity >> sea water
  - Other hydro-carbon and chemical constituents

  This waste-water comes from two primary sources

  - Naturally occurring water that is removed with oil and gas ("Produced" Water)
  - Hydraulic fracturing ("Flowback" Water) - relatively small amount of total volume

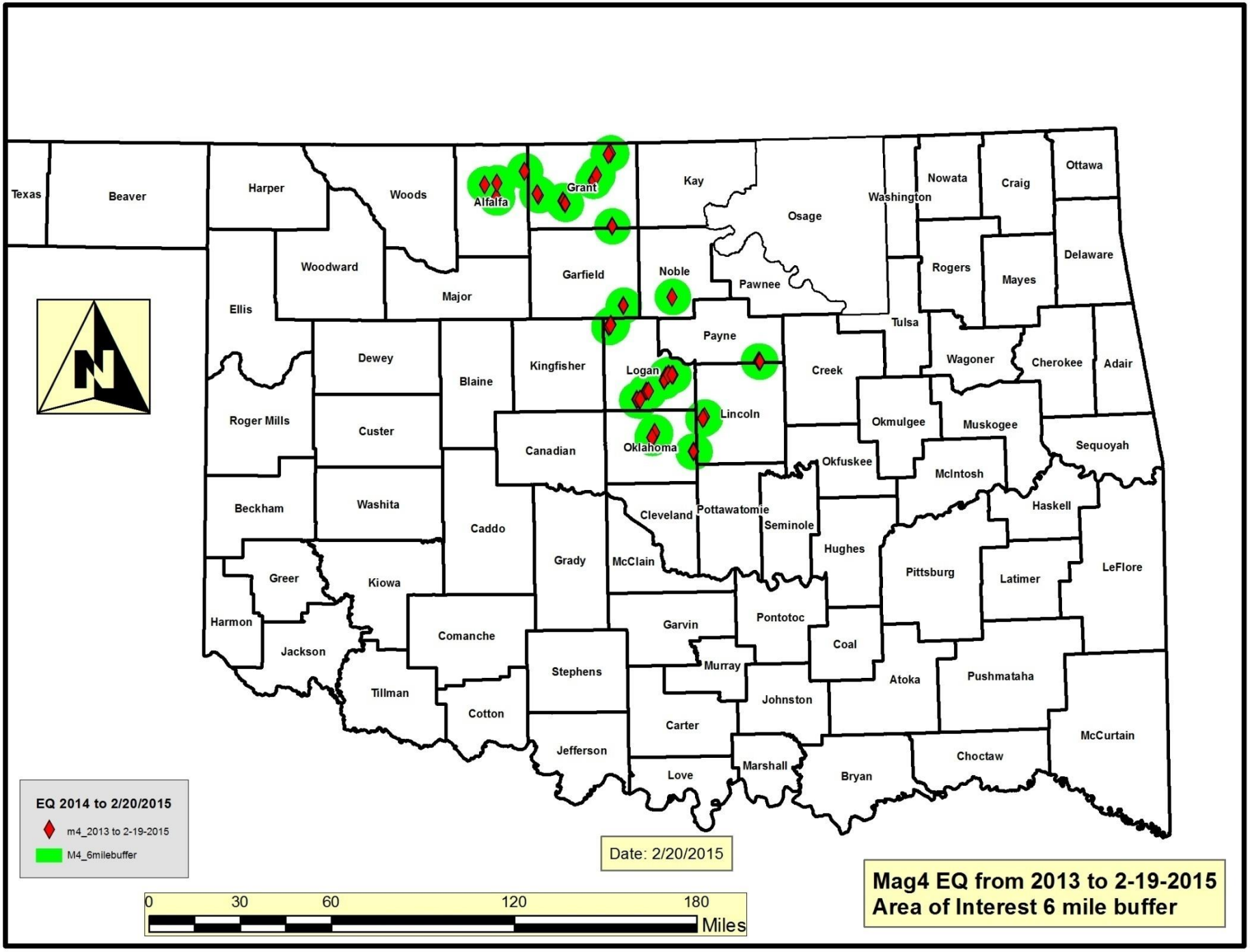
- Of the 4,626 disposal wells, there are 969 wells that are authorized for disposal into the Arbuckle formation.

Provided by the OCC

OCC Traffic Light Protocol (Modified Permits)

1. Check location of proposed well with permitting map
2. If well location is within 3 miles of optimally oriented fault, within 6 miles of a seismic cluster, or within an area of interest ask operator for a technical meeting
3. Ask operator to demonstrate level of risk of induced seismicity (technical data)
4. Require application to go to hearing
5. Staff will take neutral position

Provided by the OCC


Texas
Beaver
Harper
Woods
Alfalfa
Grant
Kay
Osage
Washington
Nowata
Craig
Ottawa
Woodward
Garfield
Noble
Pawnee
Rogers
Mayes
Delaware
Ellis
Major
Payne
Tulsa
Dewey
Blaine
Kingfisher
Logan
Creek
Wagoner
Cherokee
Adair
Roger Mills
Custer
Canadian
Oklahoma
Lincoln
Okmulgee
Muskogee
Sequoyah
Okfuskee
McIntosh
Beckham
Washita
Caddo
Cleveland
Pottawatomie
Seminole
Haskell
Hughes
Grady
McClain
Pittsburg
Latimer
LeFlore
Greer
Kiowa
Harmon
Jackson
Comanche
Garvin
Pontotoc
Coal
Tillman
Stephens
Murray
Atoka
Pushmataha
Cotton
Carter
Johnston
McCurtain
Jefferson
Love
Marshall
Bryan
Choctaw
EQ 2014 to 2/20/2015
m4_2013 to 2-19-2015
M4_6milebuffer
Date: 2/20/2015
0
30
60
120
180
Miles
Mag4 EQ from 2013 to 2-19-2015
Area of Interest 6 mile buffer

Evolution of Area Of Interest

- Area Of Interest (AOI) includes seismic cluster.

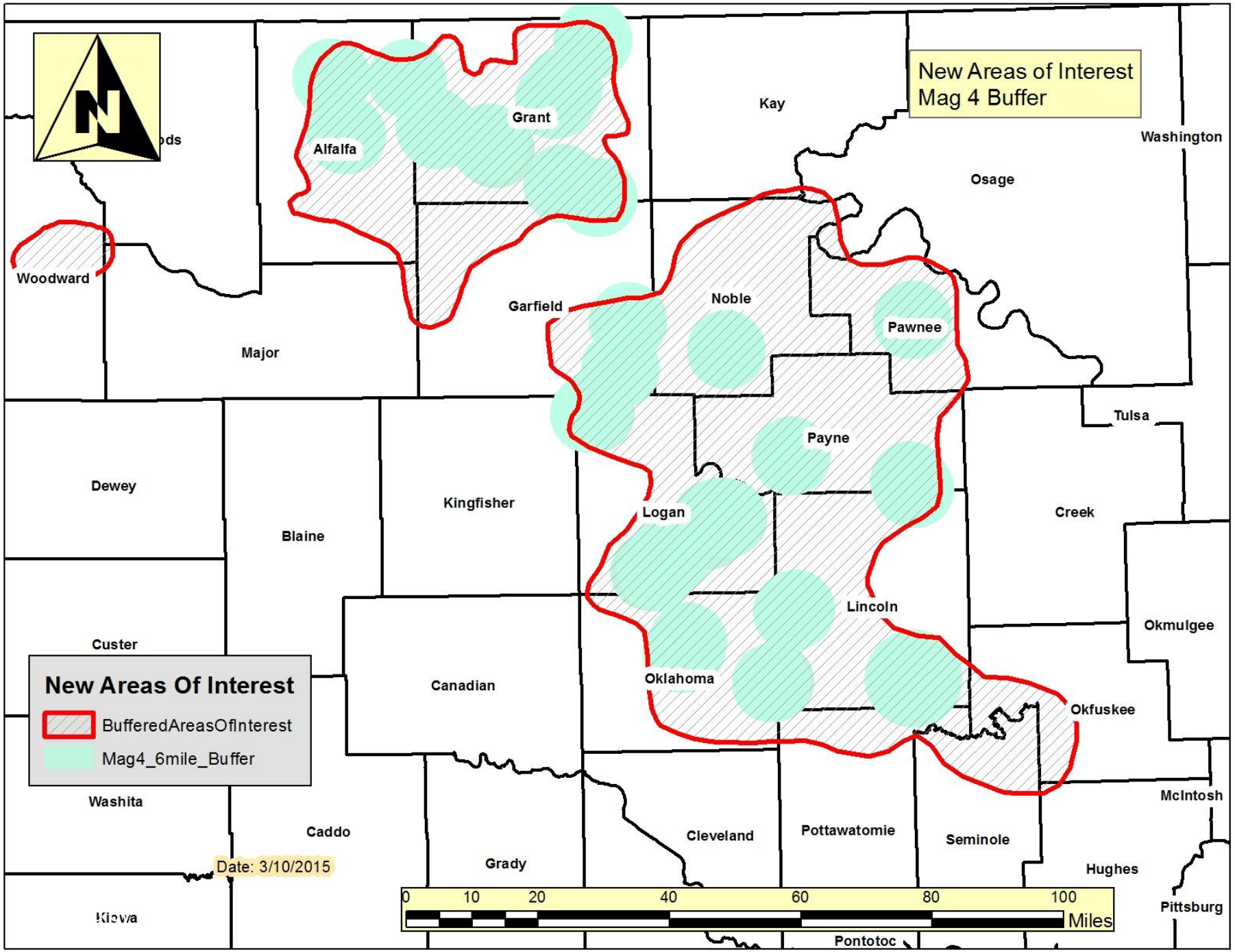
  1. Cluster is defined as an area consisting of

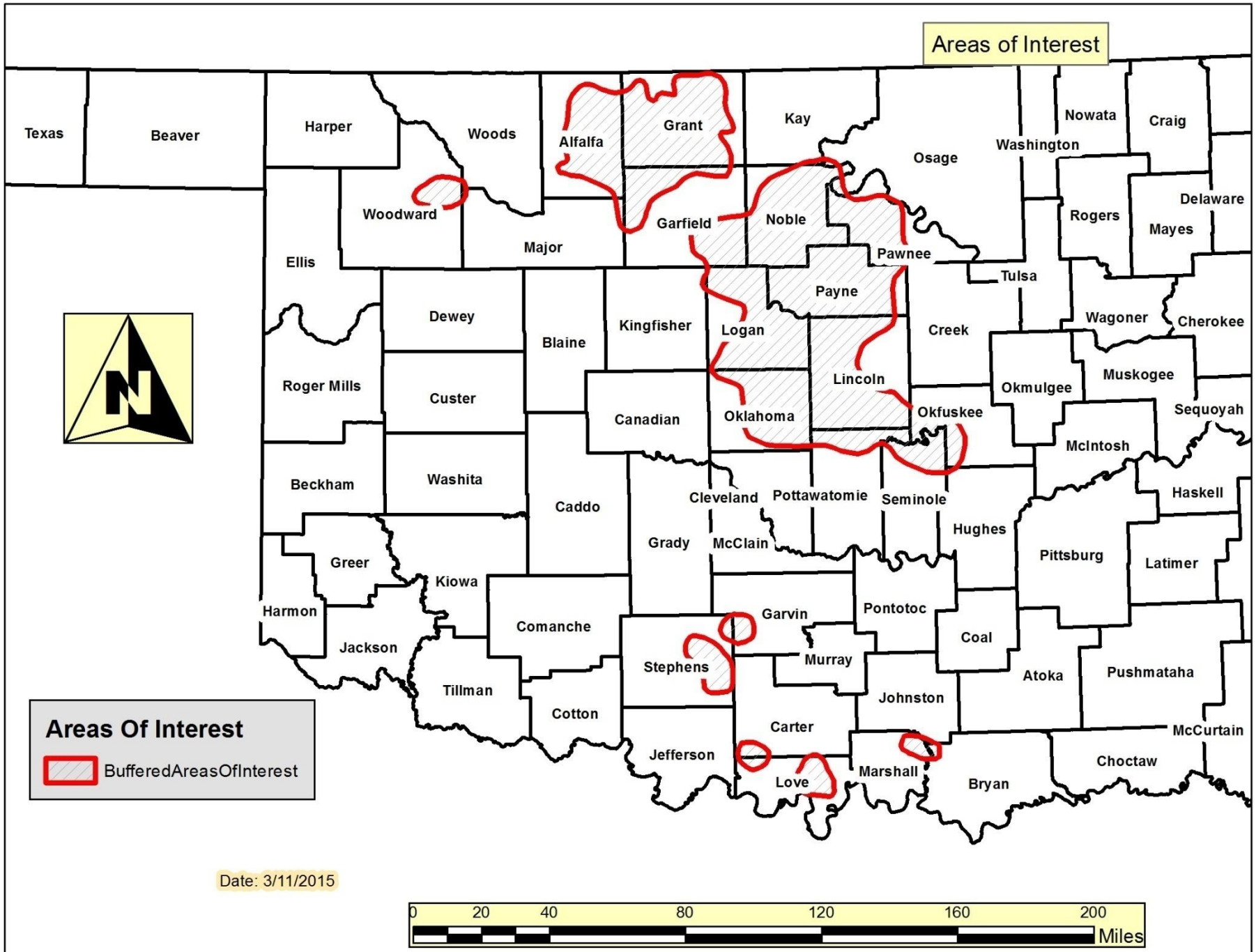
     at least two events with epicenters

     within 0.25 miles of each other, with at least

     one event with a magnitude 3.0 or greater

  2. AOI is a 10 km (6 mi) buffer from the cluster's center


New Areas of Interest
Mag 4 Buffer
Grant
Alfalfa
Kay
Washington
Osage
Woodward
Garfield
Noble
Pawnee
Major
Tulsa
Payne
Dewey
Kingfisher
Logan
Creek
Blaine
Lincoln
Okmulgee
Custer
Canadian
Oklahoma
Okfuskee
New Areas Of Interest
BufferedAreasOfInterest
Mag4_6mile_Buffer
McIntosh
Washita
Caddo
Cleveland
Pottawatomie
Seminole
Grady
Hughes
Date: 3/10/2015
0 10 20 40 60 80 100
Miles
Kiowa
Pittsburg
Pontotoc


Areas of Interest
Texas
Beaver
Harper
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Grant
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Nowata
Craig
Osage
Washington
Woodward
Garfield
Noble
Rogers
Delaware
Mayes
Major
Pawnee
Ellis
Tulsa
Payne
Dewey
Blaine
Kingfisher
Logan
Creek
Wagoner
Cherokee
Roger Mills
Custer
Lincoln
Okmulgee
Muskogee
Canadian
Oklahoma
Okfuskee
Sequoyah
McIntosh
Beckham
Washita
Caddo
Cleveland
Pottawatomie
Seminole
Haskell
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Jackson
Stephens
Murray
Atoka
Pushmataha
Tillman
Johnston
Cotton
Carter
McCurtain
Jefferson
Marshall
Choctaw
Love
Bryan
Areas Of Interest
BufferedAreasOfInterest
Date: 3/11/2015
0
20
40
80
120
160
200
Miles

OGCD Area Of Interest Arbuckle 2D Actions

- All Arbuckle Disposal Wells must provide the following:
  1. Operators must provide information to the OGCD that the Arbuckle disposal wells within the area of interest are not in contact or communication with the crystalline basement rock.
  2. Wells found not to be in contact or in communication with the crystalline basement will be allowed to resume normal operations.
  3. Wells found to be in contact or in communication with the crystalline basement must plug back.

- Directive sent out March 18th , operators have 7 days to begin reporting. Operators will have until April 18th to provide their information to the OGCD.

- Operators who do not provide this information or do not have an approved plugging schedule will be required to reduce their disposal volumes by 50% until they satisfy the directive.

Summary

- The rate of seismicity has increased dramatically and so has the seismic hazard
  - Earthquake preparedness is being communicated to the public
- Continue to provide data products to stakeholders and identifying new data sources
- Multi-agency cooperation and data exchange and sharing are critical in addressing issues with informed science
- Developing a greater understanding of physical processes in Oklahoma will help to inform future mitigation strategies