Oklahoma Geological Survey
Richard D. Andrews
Interim Director and State Geologist
Dr. Austin Holland, State Seismologist

Statement on Oklahoma Seismicity
April 21, 2015

Based on observed seismicity rates and geographical trends following major oil and gas plays with large amounts of produced water, the rates and trends in seismicity are very unlikely to represent a naturally occurring process. Historically, the Oklahoma Geological Survey (OGS) recorded on average about 1 ½, magnitude three or greater (M3+) earthquakes each year, within Oklahoma. During 2013, the OGS observed on average about 2, M3+ earthquakes each week on average, and this rate continued to increase during 2014. Currently, the OGS is reporting on average about 2 ½, M3+ earthquakes each day. The OGS considers it very likely that the majority of recent earthquakes, particularly those in central and north-central Oklahoma, are triggered by the injection of produced water in disposal wells.

The primary suspected source of triggered seismicity is not from hydraulic fracturing, but from the injection/disposal of water associated with oil and gas production. Produced water is naturally occurring water within the Earth that is often high in salinity and co-exists with oil and gas in the subsurface. As the oil and gas is extracted/produced, so is the water. This water is then separated from the oil and gas and re-injected into disposal wells, often at greater depth from which it was produced. However, it is often stated that disposed water is wastewater from hydraulic fracturing. While there are large amounts of wastewater generated from hydraulic fracturing, this volume represents a small percentage of the total volume of wastewater injected in disposal wells in Oklahoma.

The observed seismicity of greatest concentration, namely in central and north-central Oklahoma, can be observed to follow the oil and gas plays characterized by large amounts of produced water. Seismicity rates are observed to increase after a time-delay as injection volumes increase within these plays. In central and north-central Oklahoma, this time-delay can be weeks to a year or more.

The OGS can document the following geological and geophysical characteristics related to the recent earthquake activity within Oklahoma.

- The seismicity rate in 2013 was 70 times greater than the background seismicity rate observed in Oklahoma prior to 2008. While unlikely, this rate could have been potentially explained by natural variations in earthquake rates from naturally occurring swarms. The seismicity rate is now about 600 times greater than the background seismicity rate, and is very unlikely the result of a natural process.
- 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. However, it is recognized that naturally occurring earthquake swarms do occur and have occurred within the region.

- These earthquakes swarms are occurring over a large area, about 15% of the area of Oklahoma, that has experienced significant increase in wastewater disposal volumes over the last several years.
- The earthquakes are primarily occurring on faults that are optimally and sub-optimally oriented within Oklahoma's tectonic stress regime.
- Both triggered and naturally occurring earthquakes release accumulated tectonic stress on these faults.
- Most of the earthquakes in Oklahoma are occurring within crystalline basement, deeper than most oil and gas operations. However, reactivation of deeper basement faults from water injection/disposal at shallower depths is often observed in cases of triggered seismicity.
- The majority of wastewater disposal is targeted for injection in the Arbuckle formations, which closely overlie the crystalline basement.
- As a result of high bulk permeability within sections of the Arbuckle, pressure from water injection/disposal may be transmitted several miles from an injection site.
- The high density of injection wells in central and north-central Oklahoma combined with the high permeabilites within the Arbuckle makes identifying relationships between specific wells and seismic activity difficult.

The OGS endeavors to accurately document seismicity within Oklahoma, and is increasing its capability to improve earthquake monitoring and data products. This includes the addition of staff, as well as updating and adding seismic equipment to improve seismic monitoring coverage throughout the state. In addition, the OGS is compiling a database of known fault locations within Oklahoma from published scientific literature and voluntarily fault data contributions from the Oklahoma Independent Petroleum Association (OIPA). The OGS also participates in projects with the United States Geological Survey (USGS) and other researchers worldwide in the ongoing investigation of Oklahoma seismicity.

The OGS also works closely with the Oklahoma Corporation Commission (OCC) to provide information on Oklahoma seismicity and research publications on triggered and induced seismicity. The OGS collaborates with the Interstate Oil and Gas Compact Commission and Ground Water Protection Council States First Initiative Workgroup on Induced Seismicity in multi-state efforts to better understand the problem and develop a regulatory framework.

The OGS continues to make its data and data products publicly available in a timely manner, and to contribute to research and the public discussion of earthquakes in Oklahoma. As communicated in the joint USGS/OGS statement dated May 2, 2014, the earthquake hazard in Oklahoma has increased due to the increased rate of seismicity. It is important for Oklahomans to learn what to do during a significant earthquake, and be prepared. The OGS and the Oklahoma Office Emergency Management provide such information on their respective websites.