OGS POSITION STATEMENT-OKLAHOMA EARTHQUAKE ACTIVITY
February 17, 2014

There has been a significant increase in seismic activity (earthquakes) in Oklahoma since 2009. And although the majority of these earthquakes are not strong enough to be felt, the Oklahoma Geological Survey (OGS) recognizes that the increase in "felt" seismic activity is of interest to the citizens of the state. This statement communicates what, in the opinion of the OGS, the data currently tells us and outlines our plans for monitoring future activity and conducting research to better understand Oklahoma seismicity.

What does the current data tell us?

- Oklahoma has long been recognized as having significant earthquake activity, and the OGS began earthquake monitoring 40 years ago with its first seismic station that is still in operation near Leonard, OK. Also during the 30-year period prior to 2009 when the OGS expanded its monitoring to a network of stations, there was an average of about 50 locatable earthquakes each year, with only a few strong enough to be felt.
- Since 2009, the earthquake activity in Oklahoma has been approximately 40 times higher than in the previous 30 years.
- Based on reported "felt" earthquakes prior to the establishment of the OGS network, this recent level of seismicity is significantly greater than the past 100 years. However, even a 100-year timeframe is not statistically representative in geological terms for a plate interior.
- While more than 90% of these earthquakes are too small to be felt, they are recorded by the OGS network.
- The majority of the historical and more recent earthquakes are located on or near the Nemaha Ridge, the Ouachita-Arbuckle-Wichita Mountain front, and other major geological paleo-structures. Over geological time, these structures have been a source of significant tectonic and seismic activity.
- Oklahoma has always been more seismically active than much of the mid-western United States, possibly due to these major structures.
- Consistent with the observations above, the implied fault movements (focal mechanisms) for the majority of the earthquakes appear to be consistent with regional (natural) stresses in Oklahoma.

Regarding the possible relationship between recent earthquake activity and oil and gas activities, we make the following observations:

- It has long been recognized by scientists that both fluid injection and withdrawal in the subsurface can trigger earthquakes by altering conditions on naturally occurring faults that are near failure.
- Fluid injection associated with oil and gas activities has occurred for a long-time in Oklahoma. These activities include enhanced oil recovery, hydraulic fracturing, and waste water disposal. Hydraulic fracturing has occurred in

Oklahoma since 1948 and more than 100,000 wells have been hydraulically fractured.

- There are currently approximately 4,000 active saltwater disposal wells in Oklahoma and about 30,000 nationally. Recognized occurrences of triggered seismicity related to saltwater disposal wells are rare. The National Research Council estimates about one in 4,000 on average nationwide (NRC Study, Table 3.4).
- About 80% of the State is within 15 kilometers (9 miles) of an Underground Injection Control (UIC) Class II water disposal or enhanced oil recovery injection well. For this reason, identifying possible induced or triggered seismicity requires more scientific evidence than simply identifying spatial correlations. It is also important to note that about 99% of the earthquakes that have occurred in Oklahoma over the past few years also lie within 9 miles of a UIC Class II well.
- While the number of salt-water disposal wells has continued to increase within Oklahoma over the past few years, examination of available data showing increases in injection volumes by region within Oklahoma do not show correlation to changes in seismicity rates within the region. A possible exception to this observation is north-central Oklahoma.
- Most of the earthquakes are located deeper in crystaline basement and not in the shallower, sedimentary section where salt-water disposal is taking place. This does not rule out the possibility that oil and gas activity can trigger deeper earthquakes or that small, shallower earthquakes can act as a "trigger" for larger, deeper earthquakes, but there is currently little if any direct evidence for this in Oklahoma.
- The majority of water disposal wells operate at very low pressure, but a significant portion of the injection is also near basement that may be highly fractured and thus capable of allowing water to circulate to greater than normal depths.
- The energy released by earthquakes is thousands of times greater than the energy that may have been added by water disposal, which demonstrates that the earthquakes themselves are, ultimately, the result of the release of natural stresses. In the case of the 2011 "Prague Earthquake Sequence", the energy released by the earthquakes was approximately 100,000 times greater than the potential energy added by water injection/disposal in that area since 1998.
- A statistical analysis conducted by the OGS during the period January 1, 2010 – June 1, 2012 showed that for about 2% of the wells that were hydraulically fractured during this period, there may be a correlation in time and space between earthquakes and wells that are within 8 kilometers (5 miles) of each other. Statistical work shows that although some of these earthquakes may be a coincidence, it is unlikely that all possible cases identified are a coincidence.
- The best, documented case of induced seismicity within Oklahoma is from Garvin County. There are other potential induced seismicity cases, such as

Love County, but scientific evidence for a direct, causal relationship has not yet been clearly defined in these other cases.

- The "Jones Earthquake Swarm" appears, in part, to have shown some activity that statistically deviates from the regional stresses and other general observations of seismicity in Oklahoma. Models have been proposed in an attempt to explain the Jones Swarm by researchers. At this time a direct link to oil and gas activity and this unusual earthquake sequence cannot be established.
- Models describing possible causal relationships should be validated with definitive data and conclusions from these models should be tested. Ultimately, this is how we gain the knowledge needed to understand seismic risk, whether natural or induced.

What are the plans for future study/research by the Oklahoma Geological Survey to better understand Oklahoma seismicity?

- The Oklahoma Geological Survey, in cooperation with faculty in the Mewbourne College of Earth and Energy at the University of Oklahoma, industry, the Oklahoma Cooperation Commission, and the Office of the Oklahoma Secretary of Energy and Environment, recently received notification that a research grant from the Research Partnership to Secure Energy for America (RPSEA) was approved. The title of the grant is "4D Integrated Study Using Geology, Geophysics, Reservoir Modeling and Rock Mechanics to Develop Assessment Models for Potential Induced Seismicity Risk". RPSEA is administered through the U.S. Department of Energy and final approval for this funding is pending.
- The RPSEA Grant will provide resources for increased monitoring of seismic activity (additional monitoring stations). This will result in increased detection of smaller (not felt) events, improved public access to seismic (earthquake) data, and faster and more accurate location of earthquakes.
- Additionally, the RPSEA grant provides for basic research to better understand the geological, geophysical and engineering aspects of induced seismicity.
- The OGS is participating in the United State Geological Survey (USGS) Powell Center Workgroup on Induced Seismicity.
- The OGS is working with industry (through the Oklahoma Independent Petroleum Association), the Oklahoma Corporation Commission, the Office of the Oklahoma Secretary of Energy and Environment and researchers at the University of Oklahoma to improve our understanding of subjects such as the distribution of geologic faults and seismic velocity of the subsurface (to improve calculating locations and other key parameters of earthquakes).
- In support of this work, the OGS is increasing its resources in the area of earthquake seismology. This will provide additional capability to not only improve our monitoring and reporting of earthquakes, which is the primary responsibility of the OGS, but to perform studies on selected and more

"localized" earthquakes series to better understand these within the context of Oklahoma seismicity. Such studies could include:

- Continued analysis of the 2011 Prague earthquakes sequence
- Continued analysis of the Jones sequence
- Arcadia Lake sequence - 2013
- Wellston/Luther sequence – 2013
- Love County sequence - 2013
- Other specific studies as appropriate

Summary of Current Oklahoma Seismicity

The OGS has not ruled out that some earthquakes may have a relationship to oil and gas activities such as water disposal/injection, and examining these issues remains a major focus of ongoing research. The majority of earthquakes in Oklahoma are not strong enough to be felt and it is important to note that an apparent spatial correlation does not necessarily imply a causal relationship. Additionally, fluid disposal alone is not adding enough energy into the system to materially change the natural stresses. Overall, the majority, but not all, of the recent earthquakes appear to be the result of natural stresses, since they are consistent with the regional Oklahoma natural stress field.

The OGS is increasing its resources in the area of earthquake seismology. This will provide additional capability to not only improve our monitoring and reporting of earthquakes, which is the primary responsibility of the OGS, but also to better understand key geophysical, geological and engineering concepts within the context of Oklahoma seismicity, and communicate these findings to the citizens of the state.