How wide spread is induced seismicity in the USA and Canada?

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Summary

There have been various high-profile publications on changed seismicity rates in North America in the last 5-8 years due to human activities; in particular Oklahoma features quite distinctively in these publications (Ellsworth, 2013; Keranen et al., 2014; McGarr et al., 2015; Walsh and Zoback, 2015). The seismicity rates per square km in Oklahoma surpass now those in California. Increased seismicity rates in Oklahoma are attributed to increased waste-water disposal. The seismicity rate in Oklahoma in the last 5-8 years is correlated to increased large-scale hydrocarbon production (Figure 1).

The possibility of systematic correlations between increased hydrocarbon production and felt seismicity rates is a pertinent question since the USA became the world's largest hydrocarbon producer in 2013, surpassing both Saudi Arabia's oil production and Russia's dry gas production. For instance, US production of petroleum and other liquid hydrocarbons increased 69% between 2006 and 2014, even exceeding the peak in production of the mid 80s. Increased hydrocarbon production also leads to increased water production which in turn must be disposed of; this is generally done underground. Large-scale increases in hydrocarbon production are thus accompanied by large-scale increases in fluid injection which may cause increased seismicity rates due to increased in situ pore pressure, facilitating slip on critically stressed faults.

Contrary to Oklahoma, analysis of oil and gas production versus seismicity rates in 6 other States in the USA and 3 provinces in Canada finds no State/Province-wide correlation between increased seismicity and hydrocarbon production, despite 8-16 fold increases in production in some States, including North Dakota (Bakken formation) and Pennsylvania, West Virginia (Marcellus shale). However, in various areas, seismicity rates have increased locally.

Within Canada, we consider the provinces of Alberta (renewed oil production from existing conventional plays and new tight plays such as the Montney and Duvernay shales), British Columbia (increased hydrocarbon production from tight Horn River and Montney shales) and Saskatchewan (tight oil from Bakken shale), and within the USA, Pennsylvania, West Virginia, Ohio (tight gas from Marcellus shale), Oklahoma (Woodford shale, Hunton and Mississippi Lime dewatering plays), North Dakota (tight oil from Bakken shale), and on-shore Texas (tight oil from Eagle Ford shale, tight gas from Barnett and Haynesville-Bossier shales). All examined States and Provinces are major producers. Data analyses span 3-5 decades depending on data availability.

A comparison with seismic hazard maps for Canada and the USA shows that several factors must play an important role in determining the likelihood of anthropogenic activities influencing earthquake rates, including the near-surface tectonic background rate, the existence of critically stressed and favorably oriented faults within the region, which must be hydraulically connected to injection wells, and the orientation and absolute magnitudes of the in situ stress field, combined with the injection volumes and implemented depletion strategies.

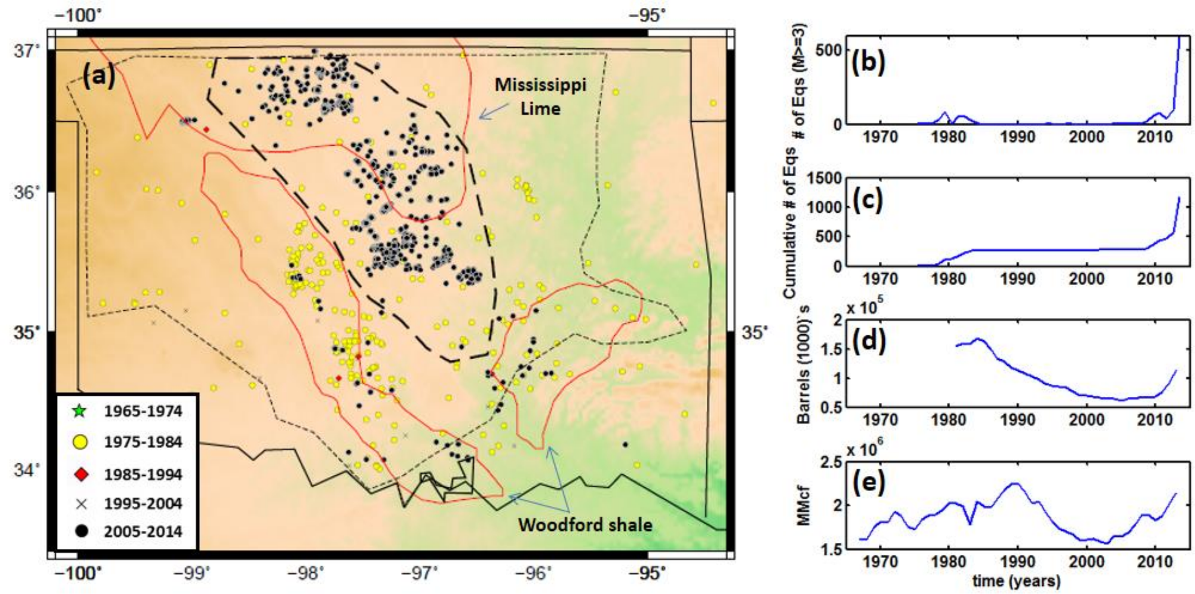

Figure 1. Oklahoma, USA: (A) Seismicity in Oklahoma state during 1965-2014. 1164 events (M>3) occurred within the coordinates: 103.11^{o}-94.41^{o}W, 33.47^{o}-37.08^{o}N. Solid line shapes: Outlines of Woodford shale and Mississippi Lime plays. Thin dashed line: region containing salt-water disposal wells (Walsh and Zoback, 2015). Thick dashed line: region with high density of disposal wells (Walsh and Zoback, 2015). The Hunton play is located just south of the Mississippi Lime within the bold dashed contour. (B) Annual seismicity rates. (C) Cumulative seismicity over time. (D) Oklahoma annual production of crude oil in thousands of barrels. (E) Oklahoma annual natural gas gross withdrawals in million cubic feet (MMcf).

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