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Ellenburger wastewater injection and seismicity in North Texas

Matthew J. Hornbach [a,*], Madeline Jones [a], Monique Scales [a], Heather R. DeShon [a], M. Beatrice Magnani [a], Cliff Frohlich [b], Brian Stump [a], Chris Hayward [a], Mary Layton [a]

[a] Huffington Department of Earth Sciences, Southern Methodist University, Dallas, TX, United States
[b] University of Texas Institute for Geophysics, University of Texas at Austin, Austin, TX, United States

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ABSTRACT

North Texas has experienced a roughly exponential increase in seismicity since 2008. This increase is primarily attributable to wastewater injection into the Ellenburger Formation—a carbonate formation located within and just above seismically active zones. To our knowledge, there has been no previous comprehensive ~10 year analysis comparing regional seismicity with basin-wide injection and injection pressure of wastewater into the Ellenburger, even though monthly injection/pressure records have been made publically available for nearly a decade. Here we compile and evaluate more than 24,000 monthly injection volume and pressure measurements for the Ellenburger formation. We compare Ellenburger injection pressures and volumes to basin-wide injection pressures and volumes, and to earthquake locations and rates. The analysis shows where cumulative injection volumes are highest, where injection pressures and formation pressures are increasing, how injection volumes have changed regionally with time, and how Ellenburger injection volumes and pressures correlate in space and time with recent seismicity in North Texas. Results indicate that between 2005 and 2014 at least 270 million m^3 (~1.7 billion barrels) of wastewater were injected into the Ellenburger formation. If we assume relative homogeneity for the Ellenburger and no significant fluid loss across the 63,000 km^2 basin, this volume of fluid would increase pore fluid pressure within the entire formation by 0.09 MPa (~13 psi). Recent spot measurements of pressure in the Ellenburger confirm that elevated fluid pressures ranging from 1.7 to 4.5 MPa (250–650 psi) above hydrostatic exist in this formation, and this may promote failure on pre-existing faults in the Ellenburger and underlying basement. The analysis demonstrates a clear spatial and temporal correlation between seismic activity and wastewater injection volumes across the basin, with earthquakes generally occurring in the central and eastern half of the basin, where Ellenburger wastewater injection cumulative volumes and estimated pressure increases are highest. The increased seismicity correlates with increased fluid pressure, which is a potential cause for these earthquakes. Based on these results, we hypothesize it is plausible that the cumulative pressure increase across the basin may trigger earthquakes on faults located tens of kilometers or more from injection wells, and this process may have triggered the Irving-Dallas earthquake sequence. We use these results to develop preliminary forecasts for the region concerning where seismicity will likely continue or develop in the future, and assess what additional data are needed to better forecast and constrain seismic hazard.

1. Introduction

The Bend Arch-Fort Worth Basin in North Texas has experienced a rapid increase in the number of earthquakes beginning in 2008 (Fig. 1). This basin includes the largest metropolitan area in the southern United States–the Dallas-Fort Worth Metroplex. Prior to 2008, no confirmed felt earthquakes had occurred in the basin despite more than 160 years of settlement and more than 40 years of seismic monitoring (Frohlich and Davis, 2002; Frohlich et al., 2011, 2016). Since 2008, however, earthquakes in the Fort Worth Basin have generally increased in number, magnitude, and hence moment release, with the basin experiencing its largest (M4.0) earthquake in 2015 (Fig. 2).

There have been numerous investigations concerning the cause of recent earthquakes in North Texas and most conclude that the injection of oil and gas flowback brine water into deep sedimentary formations is probably responsible for reactivating faults and causing seismicity in the basin (Frohlich et al., 2011, 2016, 2012; Justinic et al., 2013; Gono et al., 2015; Hornbach et al., 2015). All

* Corresponding author.
E-mail address: mhornbach@smu.edu (M.J. Hornbach).

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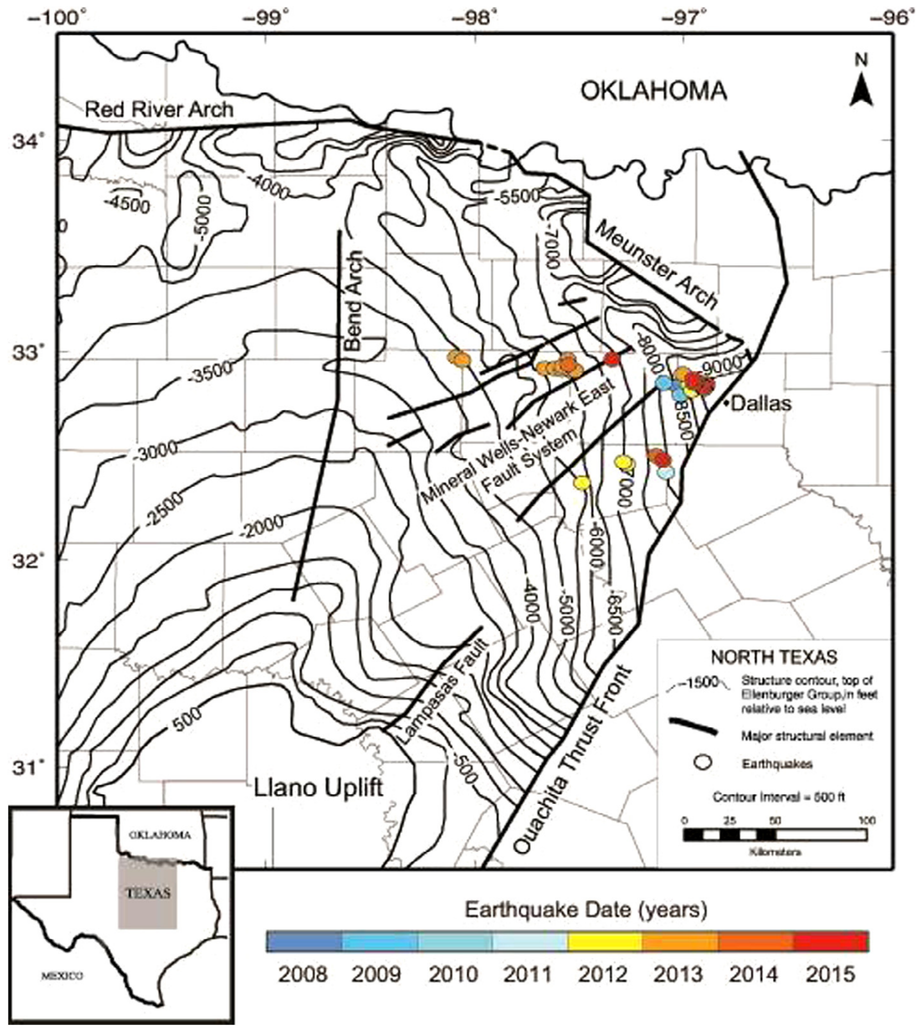

Fig. 1. Map of the Bend-Arch Fort Worth Basin showing earthquake epicenters reported in the USGS ANSS Catalog (location uncertainty of ∼10 km). Contours indicate the top of the Ellenburger formation based on Pollastro et al. (2007). The basin depocenter is below the cities of Irving and Dallas in western Dallas County, where a significant increase in seismicity occurred in the past 3 years.

of these investigations focus on discreet relationships between regional wastewater injection sites and earthquakes. An important unanswered question is why some high volume injection sites induce earthquakes while others do not. Fully addressing the induced seismicity hazard requires understanding not only subsurface pressure changes but also the local stress regime. Although the stress regime in the Fort Worth Basin is only marginally constrained, published earthquake focal mechanism across the basin (e.g. Justinic et al., 2013; Hornbach et al., 2015) suggest the maximum principal stress direction extends in a northeast to southwest direction consistent with regional stress studies (e.g. Zoback and Zoback, 1980).

Two of the investigations assessing the cause of earthquakes in the Fort Worth basin (Gono et al., 2015; Hornbach et al., 2015) modelled subsurface permeability, pressure, and structure to estimate pore fluid pressure changes over time. Although both studies concluded regional seismicity is most likely induced by wastewater injection, a limitation of these modeling studies is their inability to fully account for subsurface complexity, and thus to constrain completely how pressures and volumes of injected wastewater influence subsurface stress. Specifically, significant uncertainties concerning fault locations, fault orientations, fault permeability, fluid flow paths, and regional stress regimes often limit the applicability of such modeling investigations. Limitations of these studies, combined with a decade of pressure and injection data made available by the Texas Railroad Commission, motivate us to explore alternative methods for forecasting where future seismicity might occur as wastewater injection continues in the basin.

In the present investigation we apply an alternative statistical approach that avoids the uncertainties associated with detailed 3D fluid flow modeling; we make straightforward statistical comparisons between wastewater injection practices, subsurface pressures, and regional seismicity. Statistical methods comparing seismicity and injection have found a correlative relationship in other large basins, especially in Oklahoma (e.g. Walsh and Zoback, 2015; Weingarten et al., 2015). In the Fort Worth Basin, Frohlich (2012) compared wastewater injection locations with regional seismicity during the two years when the US Earthscope Transportable Array was deployed across the area. Additionally, for 13 of the 28 counties located in the Fort Worth Basin, Gono et al. (2015) produced a nearly basin-scale fluid model noting the relationship between modeled subsurface pressure in the Ellenburger and regional seismicity. While both of these investigations found a spatial association between wastewater injection, subsurface injection pressure, and regional seismicity, neither evaluated the complete publically available pressure/volume data for all wastewater injection wells in the Ellenburger for the entire ∼ 10 year period when seismicity has increased significantly (Fig. 2).