Potential Link Between 2020 Mentone, West Texas M5 Earthquake and Nearby Wastewater Injection: Implications for Aquifer Mechanical Properties

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Abstract The M5 Mentone earthquake that occurred on March 26, 2020, was the largest event recorded over the last 2 decades in West Texas within the Delaware Basin, a U.S. major petroleum-producing area. Also, numerous hydrofracturing and wastewater disposal wells are spread across this region. Within a 30 km distance to mainshock, eight class-II injection wells for industrial wastewater disposal target the deep porous Ellenburger aquifer at an average rate of 1.36 × 10^6 barrel (BBL) per month during 2012–2020. Poroelastic models of fluid diffusion show these nearby injectors collectively imparted up to 80.5 kPa of Coulomb stress at the mainshock location, capable of triggering this M5 event. Assuming the Mentone event occurs when pore-pressure increase is maximum, the time delay between peak injection and the M5 occurrence corresponds with an optimal permeability of 6.76 × 10^-14 m² for the Ellenburger aquifer layer, in agreement with independent estimates.

Plain Language Summary On March 26, 2020, a M5 earthquake took place near the town Mentone in West Texas, located within one of the largest petroleum-producing areas in the United States. This area also contains injection sites designated for disposing of wastewater coproduced from unconventional hydrocarbon production processes. Our study found that this earthquake could be triggered by fluid diffusion from the nearby disposal wells. Seismicity’s timing and location are consistent with injection occurring in an immediately permeable aquifer and are indicators for individual wells’ operation. These provide essential information to help industrial practitioners and regulatory agencies to assess the associated seismic hazard, implement mitigation measures, and draft policies or guidelines for disposal well management.

1. Introduction

Residual brine coproduced from water-bearing oil reservoirs and hydraulic fracturing is injected into and stored in deep porous aquifers that are often hydraulically connected to the crystalline basement (Chang & Segall, 2016; Hornbach et al., 2015; Walsh & Zoback, 2015). The relationship between fluid injection and the slip potential on nearby faults can be evaluated by modeling the stress field change due to fluid diffusion (Segall & Lu, 2015; H. Wang, 2000; R. Wang & Kluempel, 2003; Zhai et al., 2019). This mechanism is suggested as the primary driver of the current elevated seismicity rate adjacent to some of the disposal sites across the central and eastern United States (Ellsworth, 2013; Frohlich et al., 2020; Langenbruch et al., 2018; Rubinstein & Mahani, 2015; Walsh & Zoback, 2015). Additionally, the injection-induced seismic hazard could be associated with the aseismic fault slips causing seismicity at farther distances than that fluid diffusion can reach (Bourouis & Bernard, 2007; Cornet et al., 1997; Duboeuf et al., 2017; Guglielmi et al., 2015; Sumy et al., 2014). Poor knowledge of local hydrogeology is the main source of uncertainties when investigating the link between injection operation and follow-up seismicity. Such information is critical for modeling the fluid-rock coupling and is available only at sparsely distributed drilled holes (Walsh & Zoback, 2015). Knowledge of injection history (cause) and associated seismicity (effect) enables us to estimate the hydrological properties of the injection medium (e.g., Shirzaei et al., 2019; Tung & Masterlark, 2018; Tung et al., 2018; Zhai et al., 2019).

On March 26, 2020, an M5 earthquake hit the town of Mentone in West Texas (henceforth called Mentone earthquake), located within one of the largest hydrocarbon production areas in the United States.
This earthquake is the largest event recorded within the Delaware Basin since the 1995 M5.7 Alpine earthquake (Frohlich, 2012; Savvaidis et al., 2019; Trabant et al., 2012). There are eight deep disposal wells located within 30 km northwest of the epicenter, injecting fluid at an average rate of $5 \times 10^5$ BBL/month following 2012 (RRC, 2020) (Figure 1 and Table S1). Here, we investigate the possible link between the injection operation and the Mentone earthquake by simulating the pore fluid pressure change and poroelastic stresses for 2012–2021. The time delay between the commencement of injection operation and the Mentone earthquake’s occurrence is used to constrain the Ellenburger injection layer’s bulk permeability.

2. Data and Methods

2.1. Local Hydrogeology of Southwestern Delaware Basin

The M5 Mentone earthquake took place in the central Delaware Basin, a subbasin of the larger Permian Basin in West Texas and southeast New Mexico (Figure 1(a)) (USGS, 2020). In this region, the majority of the recent seismicity is linked to wastewater disposal (Deng et al., 2020; Frohlich et al., 2020; Skoumal et al., 2020; Zheng et al., 2019) and hydraulic fracturing (Lei et al., 2019; Savvaidis et al., 2020). The Delaware Basin comprises a thick layer (up to 4 km) of early Permian shale deposits (e.g., Bone Spring formation and Wolfcamp formation) overlain by the midlate Permian sediments (e.g., Delaware Mountain Group) (Matchus & Jones, 1984) (https://www.beg.utexas.edu/resprog/permianbasin/gis.htm). The shale formations typically exhibit a low permeability and seat on a carbonate layer belongs to the Ordovician Ellenburger Group (Hennings et al., 2019). Beneath the shale layer, the porous Ellenburger layer serves as a wastewater disposal reservoir, facilitating fluid diffusion and reducing the pore-pressure buildup during wastewater disposal (Hornbach et al., 2016; Ruppel et al., 2005; H. Wang, 2000) (Table S1).

2.2. Seismicity and Injection Before the Mentone Earthquake

The M5 Mentone earthquake sequence occurred on a normal fault dipping $\sim 37^\circ$ to the south with an average strike of $\sim 82^\circ$ (Skoumal et al., 2020). It was preceded by a swarm of 71 events within 5 km whose moment magnitudes range between 0.6 and 3.8 (enclosed by the red box in Figure 1 and Table S1). The M5 hypocenter is also located at a depth of 9.5 $\pm$ 3.3 km (USGS, 2020) or 6.2 $\pm$ 1.9 km (TexNet) within the basement. According to the Texas Railroad Commission (RRC) database, there are eight deep injection wells within 30 km of the Mentone epicenter (Figure 1). We have obtained the associated locations, depths, and pressurized injection volumes of these deep injection wells. The average injection depth is 4.8 km, and the combined peak injection rate is $\sim 5 \times 10^5$ BBL/month, which was recorded between late-2018 and early-2019, roughly 10 times the injection rate at the beginning of 2012 (Figures 1(b) and 2). Two active hydrofracking wells were located near the epicenter, whose activity halted weeks before the Mentone event (see Section 4.2 for more discussion).

2.3. Coupled Poroelastic and Seismicity Rate Modeling

The evolution of pore pressure and poroelastic stresses induced by fluid injections is simulated using a one-way-coupled numerical code developed by R. Wang and Kümpel (2003) (see supplementary information...
Figure 2. Spatiotemporal propagation of changes in (a, e, i, m, q, u, and y) pore-pressure change component, \( \mu \Delta P \), (b, f, j, n, r, v, and z) projected poroelastic stress change component, \( \Delta \tau + \mu \Delta \sigma \), of \( \Delta \text{CFS} \), (c, g, k, o, s, w, and a1) Coulomb failure stress, \( \Delta \text{CFS} = (\Delta \tau + \mu \Delta \sigma) + \mu \Delta P \), and (d, h, i, p, t, x, and b1) seismicity rate induced by the distant injectors (red inverted triangles filled with color scaled by the respective monthly injection rate) between 2012 and 2020, assuming \( D_{\text{Ellenburger}} = 1 \text{ m}^2 \text{ s}^{-1} \) (cf., Barbour et al., 2017). The \( \Delta \text{CFS} \) is averaged over the receiver fault orientations of \( O_1 = [\text{Strike}_1, \text{Dip}_1, \text{Rake}_1] = [285^\circ, 56^\circ, -77^\circ] \) and \( O_2 = [82^\circ, 37^\circ, -109^\circ] \) (USGS, 2020). The seismicity is shown as gray dots, while the red star denotes the M5 event.
for more details). A simplified five-layer Earth model is developed to describe the medium’s hydrogeological properties (Table S2) (cf., Deng et al., 2020; Zhai & Shirzaei, 2018). Pore pressure is calculated at the bottom of the injection layer, following earlier studies (Zhai & Shirzaei, 2018; Zhai et al., 2019, 2020). We applied a directed Monte Carlo search method to estimate the Ellenburger layer’s permeability given the Mentone earthquake’s delayed occurrence (see supplementary information for more details). Changes in Coulomb Failure stress, ΔCFS, quantify how changing stress and pore pressure brings faults closer to failure (King et al., 1994; Stein, 1999):

\[
\Delta \text{CFS} = \Delta \tau + \mu (\Delta \sigma + \Delta P) = \left( \Delta \tau + \mu \Delta \sigma + \mu \Delta P \right)
\]

(1)

where \( \Delta \tau \) is the shear-stress change parallel to the receiver fault strike/rake, \( \Delta \sigma \) is the normal-stress change perpendicular to the fault surface, \( \Delta P \) is the pore-pressure change, and \( \mu = 0.6 \) is the frictional coefficient.

The evolution of relative seismicity rate, \( R_{\text{seismicity}} \), is thus modeled as a function of background stressing rate and ΔCFS (Dieterich, 1994; Segall & Lu, 2015):

\[
\frac{dR_{\text{seismicity}}}{dt} = \frac{R_{\text{seismicity}}}{\tau_0} \left( \frac{\Delta \text{CFS}}{\tau_0} - R_{\text{seismicity}} \right)
\]

(2)

where \( \tau_0 \) is the background stressing rate, which is assumed to be \( 10^{-5} \) MPa/year (Calais et al., 2006), \( A = 0.003 \) is a constitutive parameter in the rate-and-state friction law (Segall & Lu, 2015), and \( \bar{\sigma} \) is the background effective normal stress. Based on a normal faulting regime and depth-dependent vertical tectonic stress, the estimated normal stress associated with the M5 event focal mechanism is around 40 MPa at the seismogenic depth (Fan et al., 2016; Lund Snee & Dvory, 2020) (see supplementary information for more details).

3. Results

Using poroelastic models and injection records obtained from the RRC, we simulate the stress impacted by each injection well to the Mentone earthquake fault. Pore pressure and poroelastic stresses are calculated at the bottom of Ellenburger, and we assume that the basement and Ellenburger group are hydraulically connected. Snapshots of the injection rate, \( \Delta P \), ΔCFS, and seismicity rate (\( R_{\text{seismicity}} \)) are shown in Figure 2, assuming a reference reservoir diffusivity \( (D_{\text{Ellenburger}}) \) of 1 m² s⁻¹ (cf., Barbour et al., 2017). The magnitude of \( \mu \Delta P \), the pore-pressure component of ΔCFS (Equation 1), is roughly an order of magnitude larger than and opposite in sign to that of the poroelastic stress component, \( \Delta \tau + \mu \Delta \sigma \) (Equation 3). Thus, the pattern and amplitude of ΔCFS are mainly controlled by pore-pressure change (Figures 2, 3(a), and S1). We investigate the stress field’s temporal evolution (Figure 2) due to injection at wells that have become active since 2012, approximately one new well per year (Figures 1(b) and 2 and Table S1). As the fluid diffuses within the permeable Ellenburger layer (Figures 2(c), 2(g), 2(k), 2(o), 2(s), 2(w), and 2(a1)), the potential of induced seismicity northwest of the M5 epicenter increases due to the elevation of the positive ΔCFS. See the supplementary Movie S1 for the graphical animation of ΔCFS evolution and Figure S1 for models of different reservoir permeability.

In 2012, pore pressure was high in the vicinity to well 1 launched early that year (Figure 2(a)). In the following, the pressure front of 100 kPa propagated radially and merged with that originated from well 2 that became active in late-2013 to the north, resulting in a broader zone of positive \( \Delta P \) (Figure 2(e)) and ΔCFS (Figure 2(g)). In mid-2015, the zone of positive pore pressure expanded southward to join that of well 3 that is only \( \sim 19 \) km away from the M5 epicenter and injected at a rate of \( 5.24 \times 10^5 \) BBL/month (Figures 2(i) and 2(k)). The M5 fault has not received a significant ΔCFS, although a combined volume of \( 2 \times 10^8 \) BBL has been injected since 2012 (Figures 1(b), 2, and 3(a)). Well 5 (\( \sim 12 \) km away) from the M5 epicenter with an injection rate of \( 8.73 \times 10^5 \) BBL/month appeared to play a pivotal role in the M5 event’s occurrence. In 2018, well 6, 7, and 8 began their operation (Figure 2(q)), amounting the local injection rate to a maximum of \( 5.3 \times 10^6 \) BBL/month in 2019 and resulting in ΔCFS increase at a rate of \( \sim 40 \) kPa/year (Figures 1(b),
In early 2020, positive $\Delta P$ and $\Delta CFS$ appeared to affect the majority of the study region (Figures 2(y), 2(a1), and 3(c)), and at the same time, the tip of $\Delta P = 100$ kPa and $\Delta CFS = 50$ kPa reached the location of M5 event and most (>97%) swarms (Figures 2(y), 2(a1), and 3(c)), bringing the local faults closer to rupture (Figures 2(y), 2(a1), and 3(c)).

**Figure 3.** (a) Temporal evolution of Coulomb failure stress, $\Delta CFS_{M5}$, pore pressure, $\Delta P_{M5}$, poroelastic shear stress, $\Delta \tau_{M5}$, and normal stress $\Delta \sigma_{M5}$ at the M5 epicenter assuming aquifer diffusivity, $D_{Ellenburger} = 1 \text{ m}^2 \text{ s}^{-1}$ and frictional coefficient, $\mu = 0.6$. Positive $\Delta CFS_{M5}$ indicates the M5 fault was unclamped by injections, while the gray-shaded zone of $\Delta CFS < 0$ represents fault stabilization. (b) Contribution of $\Delta CFS_{M5}$ by each well at the M5 location. Wells 5 and 3 being the two closest wells to the M5 epicenter exert the largest impact comprising respectively 45% (45 kPa) and 18% (23 kPa) of $\Delta CFS_{M5,incidence}$. (c) Temporal evolution of $\Delta CFS$ experienced by the M5 event (red line) and near-field seismicity (black lines) whose occurrence is denoted by the orange dot and red dots, respectively. All near-field swarms and the M5 event happened with $\Delta CFS_{incidence} > 10$ kPa. (d) $\Delta CFS_{incidence}$ evolution is compared for the scenarios of $D_{Ellenburger} = 0.24, 0.5, 1, 2, \text{ and } 2.5 \text{ m}^2 \text{ s}^{-1}$ and the preferred value is 1. (e) Positive relation between the mean/maximum injection rate and $\Delta CFS_{M5,incidence}$ received from each well (with exponential fit). (f) Linear regression between $\Delta CFS_{M5,incidence}$ gained from each well and its distance from the epicenter. The $\Delta CFS$ is averaged over the receiver fault orientations of O1 and O2 (USGS, 2020) (also see Figure 2).
nearby 71 swarms is, on average, 86 kPa (Figure 3(c)). Some of the swarms could be related to the postseismic effect of the Mentone mainshock. However, we focus on studying the potential link between the nearby injection and the mainshock. The detailed investigation of individual aftershocks and their relationship with the mainshock is beyond this study's scope and the subject of future work.

Next, the seismicity rate, \( R_{\text{seismicity}} \) was estimated using the \( \Delta CFS \) time series (see supplementary information for details), showing a spatiotemporal pattern similar to \( \Delta CFS \) (Figure 2). We obtain a seismicity rate \( \sim 3 \) times higher than the background rate during the Mentone event (Figure 2(b1)).

4. Discussions and Conclusion

4.1. Critical Stress Change

To investigate the stress criterion needed for triggering the Mentone event, we invoked the Coulomb failure criterion, in which fault shear strength (\( \tau_s \)) is related to effective normal stress (\( \sigma_n' \), rocks cohesion (\( \tau_0 \)), and the coefficient of friction (\( \mu \)) through

\[
\tau_s = \tau_0 + \mu \sigma_n'
\]

where \( \sigma_n' \) is related to principal stress (\( \sigma \)) and pore fluid pressure (\( P \)) via

\[
\sigma_n' = \sigma - P
\]

The failure may occur when shear stress exceeds the \( \tau_s \) for a given \( \sigma_n' \). Shear stress can alter due to nonzero differential stress changes caused by the imparted poroelastic stress. Also, \( \sigma_n' \) depends on the magnitude of the stresses and the orientation of the fault concerning the tectonic stress field. The principal stresses' magnitude can reduce due to increased pore fluid pressure (Equation 4). Although we suggested that pore-pressure change due to injection might have triggered the Mentone earthquake, we note that establishing a threshold for pressure change to trigger an earthquake is not trivial (e.g., Talwani & Acree, 1985). Following earlier studies (e.g., Townend & Zoback, 2000), we assumed that faults are critically stressed if they have not ruptured recently. Therefore, a small perturbation of the stress field due to fluid diffusion can likely trigger earthquakes. Some examples include seasonal modulation of the seismicity due to hydrological unloading (Carlson et al., 2020; Christiansen et al., 2007; Johnson et al., 2017), triggering earthquakes due to tides (Tanaka et al., 2002; Wilcock, 2001) and induced seismicity due to pore-pressure change by seasonal snowmelt (Montgomery-Brown et al., 2019; Saar & Manga, 2003). Several studies suggested that a pore-pressure increase of 0.01–0.1 MPa can trigger seismicity (Harris, 1998; Roeloffs, 1996; Stein et al., 1992, 1994).

The fault nodal planes of the Mentone earthquake (Figure 1) are aligned well with the orientation of \( S_{\text{shmax}} \) (Lund Snee & Dvory, 2020; Lund Snee & Zoback, 2016, 2018, 2020), which indicates that the normal fault of the mainshock is near-optimally oriented concerning the stress field. A first-order calculation using the Mohr-circle suggests that a 10° deviation of the fault strike from the optimal orientation requires an extra 0.9 MPa/km stress change to initiate the failure.

4.2. Possible Impact of Hydrofracking and Other Triggering Mechanisms

Apart from deep wastewater injection, hydrofracking is also suggested to be a driver of seismicity within the Delaware Basin (Savvaidis et al., 2020; Schultz et al., 2020; Skoumal et al., 2020). According to the FracFocus database, two nearby hydrofracking wells were active during some of these swarm occurrences, while no fracking activity was documented at the time of the M5 Mentone earthquake. These sites are respectively located 2.4 and 2.9 km away from the epicenter averagely at a true vertical depth (TVD) of \( \sim 3.3 \) km (Figure 1). This TVD depth represents the distance from the surface to the deepest point of penetration. However, their operations respectively ended 48 and 102 days before the M5 event though HF-induced aseismic slip might be able to trigger swarms over a long period of months (e.g., Eyre et al., 2020).
Furthermore, hydrofracking operations often occur within the shallow shale layer. Thus, without a preexisting pathway, such as faults conduits, hydrofracking fluid’s vertical diffusion to the deep basement is not feasible. The presence of fault conduits in this area is yet to be confirmed in independent studies. In short, we cannot rule out the possibility of triggering the Mentone event by hydrofracking operations. However, we argue that this effect is of second-order importance compared with that of deep-seated wastewater injection. More work is needed to investigate the possible link between the nearby hydrofracking and the Mentone event, which requires additional data and new models beyond this study’s scope.

The other triggering mechanisms include injected fluid reaching the Mentone hypocentral area from a different direction, such as the southeast, through unmapped faults. As suggested in the literature (e.g., Bhattacharya & Viesca, 2019; Eyre et al., 2019; Guglielmi et al., 2015), injection-induced aseismic fault slip can also trigger earthquakes at farther distances and explain the delay between peak injection and seismicity, which are subjects of future studies. It is also worthy of future investigation if the preceding swarm could cause the Mentone earthquake in late 2019.

### 4.3. Individual Wells Contribution to Potentially Triggering Mentone Event

Coulomb stress changes imparted to the M5 fault (Figure 3(e)) is directly related to the rate of fluid injection, as suggested in earlier studies (Alghannam & Juanes, 2020; Peterie et al., 2018; Walsh & Zoback, 2015; Weingarten et al., 2015; Zhai et al., 2020). The injected volume at the two closest wells, namely, well 3 (UIC#111641, 19 km away) and well 5 (UIC#114451, 12 km away), can alone trigger the M5 event (Figure 3(b)) as they respectively contributed 18.3 kPa (23%) and 45.0 kPa (45%) to ΔCFS₅₅_incidence (Figure 3(b)), a stress change that is shown adequate to trigger seismic events elsewhere (Keranen et al., 2014; King et al., 1994; Stein, 1999). Also, injection at any two of wells 1 (UIC#103236, 26 km away), 2 (UIC#108115, 30 km away), and 6 (UIC#114946, 18 km away) could elevate ΔCFS₅₅_incidence above 10 kPa (Figure 3(b)). Furthermore, the ΔCFS₅₅_incidence exerted by each well correlates ($R^2 = 0.91$) with the inverse square of its distance from the M5 epicenter. Thus, closer wells play a more critical role in triggering the Mentone event (Figure 3(f)), as suggested in earlier studies (Peterie et al., 2018; Walsh & Zoback, 2015; Yeck et al., 2016; Zhai et al., 2020). For instance, substituting the injection rate of well 6 (17.7 km from epicenter) with that of well 5 (12 km from epicenter) reduces the imparted ΔCFS₅₅_incidence from 45 kPa to less than 10 kPa (Figures 3(b) and 3(f)). This implies that a ∼50% increase in the well-fault distance can result in a ∼80% drop in received ΔCFS (Figures 3(b) and 3(f)). This first-order knowledge is useful when planning injection within the vicinity of an active fault. For instance, the M5 fault is influenced by a ΔCFS₅₅_incidence < 10 kPa when the injectors are located at >25 km distance (i.e., injection occurs only at well 1, 2, 4, and 7) (Figures 3(b) and 3(f)). This information can be used to regulate and plan injection operations to minimize the likelihood of triggering major earthquakes (e.g., Delgado et al., 2001; Marufuzzaman et al., 2015).

However, accurate assessments of the regional earthquake hazard associated with injection operation require detailed knowledge of data/model uncertainties (Savvidis et al., 2019; R. Wang & Kümpel, 2003), other lesser-known physical processes associated with fluid diffusion (Galis et al., 2017; Pollyea et al., 2019; Segall & Lu, 2015; Yeo et al., 2020), subsurface geology (Matchus & Jones, 1984), and fault’s state of stress (Lockner & Beeler, 2002). Noting that a large portion of induced earthquakes occurred on unmapped faults (Goebel & Shirzaei, 2021; Lund Sneé & Zoback, 2018; Walsh & Zoback, 2016), special attention have to be paid when expanding the implications of this investigation to other study areas of a different geological/hydrological environment.

### 4.4. Implications for Aquifer Hydrological Properties

Delayed induced seismicity and fault destabilization are observed in Texas, Oklahoma, and Kansas (e.g., Deng et al., 2020; Langenbruch & Zoback, 2016; Zhai et al., 2019), which are associated with the distance between injection and seismicity and rock permeability (e.g., Barbour et al., 2017; Keranen et al., 2013; Walsh & Zoback, 2015). Assuming that the Mentone event occurred at the peak of the ΔP₅₅ due to wastewater injection, the observed seismic location and timing could be used to constrain the aquifer’s hydrological...
properties, such as permeability. This parameter determines the rate and amplitude of pore-pressure evolution, which in turn controls the seismicity rate changes derived from physics-based induced earthquake models (Chang & Segall, 2016; Langenbruch et al., 2018; H. Wang, 2000; R. Wang & Küumpel, 2003; Zhai et al., 2019). Here, we used the delay between the occurrence of the M5 Mentone earthquake and peak ΔP$_{M5}$ to search for the most favorable permeability (see supplementary information for details of the search algorithm). An aquifer permeability of $k_{Ellenburger} = 10^{-13.17}$ ± 0.4 m$^2$ allows the M5 event to occur when the largest ΔP$_{incidence}$ of 166 kPa (or ΔCFS$_{M5-ve}$ of 87 kPa) (Figure 4(b)) is imparted to the area of Mentone event in early 2020. This is consistent with the permeability range of 10$^{-13.7}$ to 10$^{-13}$ m$^2$ suggested from prior studies (Domenico & Schwartz, 1998; Hornbach et al., 2016; RRC, 2020) (Figure 4(a)).

To test the sensitivity of optimized $k^*$ to the M5 location accuracy, we repeated our search, but this time considered an average horizontal location error of ~2 km for the relocated M5 event (e.g., Savvaidis et al., 2019). The optimum $k^*$ is defined so that the associated pore-pressure change is maximum within a square box of 4 km x 4 km centered at the Mentone earthquake epicenter. We find that a $k^*$ between 10$^{-13.04}$ and 10$^{-13.17}$ m$^2$ fulfills this criterion, which is in the same range as our initial estimation.

**Data Availability Statement**

The Railroad Commission of Texas provides the injection data at [http://gis.rrc.texas.gov/GISViewer/](http://gis.rrc.texas.gov/GISViewer/) (last access in 2020 November). The FORTRAN code implementing R. Wang and Küumpel (2003) approach is available at [https://www.gfz-potsdam.de/en/section/physics-of-earthquakes-and-volcanoes/infrastructure/tool-development-lab/](https://www.gfz-potsdam.de/en/section/physics-of-earthquakes-and-volcanoes/infrastructure/tool-development-lab/) (last access in 2020 November). Information on the hydrofracking wells is
available at the FracFocus database (http://fracfocusdata.org/digitaldownload/FracFocusCSV.zip, last access in 2020 November).

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