High susceptibility to remote triggering of seismicity in the Raton Basin from 2016-2018

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Coal-bed methane production in the Raton Basin is accompanied by deeper re-injection of produced wastewater. Seismicity in the Precambrian basement beneath the basin rose sharply in concert with increased production and wastewater injection since 2000. This region, split almost equally between southern Colorado and northern New Mexico at the eastern edge of the Rocky Mountain front, is historically seismically active, has high heat flow, and has a complex history of faulting and magmatism. Thus, the rise in seismicity likely results from interactions between natural tectonic and hydrothermal systems and anthropogenic wastewater injection. Remote triggering of seismicity by the dynamic stress from passing seismic waves created by distant earthquakes has been widely used to identify areas where high pore fluid pressure places faults very close to their thresholds for shear failure. A prior study using Transportable Array data from ~2007-2009 and one adopted TA station at the eastern edge of the Raton basin since 2009 noted the occurrence of Raton seismicity triggered by distant earthquakes (van der Elst et al., 2013). We use ~2 years of data from a new local 8-station network, including stations close to injection wells, to investigate remote triggering in the Raton basin from 2016-2018. We find that the Raton Basin is highly susceptible to dynamic triggering for the majority of Mw>7 earthquakes (~13 of 21) during our study period from 2016–2018. Interestingly, we find that some local earthquakes are triggered by body waves in addition to surface waves. Triggering in response to smaller body-wave stresses demonstrates the region's high susceptibility considering that observations of remote triggering are more commonly linked to surface waves of Mw>8 events. Ongoing research includes development of more thorough catalogs of triggered and non-triggered seismicity and analysis of how susceptibility varies with teleseismic wave polarization. The former will more accurately identify areas of high pore pressure and how they evolve through time, and the latter may provide further insight regarding the type and orientation of basement faults that host triggered events.

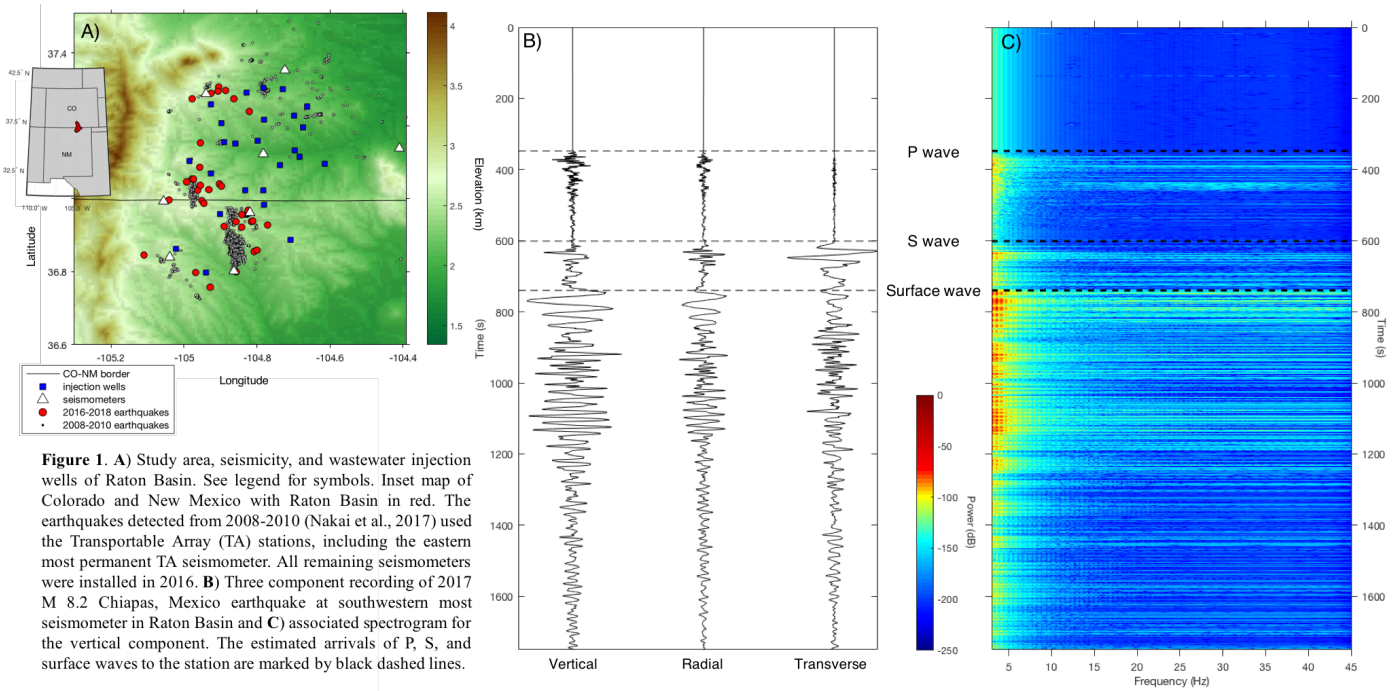

Figure 1. **A**) Study area, seismicity, and wastewater injection wells of Raton Basin. See legend for symbols. Inset map of Colorado and New Mexico with Raton Basin in red. The earthquakes detected from 2008-2010 (Nakai et al., 2017) used the Transportable Array (TA) stations, including the eastern most permanent TA seismometer. All remaining seismometers were installed in 2016. **B**) Three component recording of 2017 M 8.2 Chiapas, Mexico earthquake at southwestern most seismometer in Raton Basin and **C**) associated spectrogram for the vertical component. The estimated arrivals of P, S, and surface waves to the station are marked by black dashed lines.

1. van der Elst, N. J., Savage, H. M., Keranen,K. M., & Abers, G. A. (2013). Enhanced remote earthquake triggering at fluid-injection sites in the midwestern United States. *Science*, 341, 164–167. doi:10.1126/science.1238948
2. Nakai, J.S., Sheehan, A. F., & Bilek, S. L. (2017). Seismicity of the Rocky Mountains and Rio Grande Rift from the EarthScope Transportable Array and CREST temporary seismic networks, 2008-2010. *JGR: Solid Earth*, 122, 2173-2192.