Raton Basin induced seismicity from 2016–2019 reveals short length-scale faults

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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, 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 over the past two decades likely results from interactions between natural tectonic and hydrothermal systems and anthropogenic wastewater injection. The last three years of seismicity (2016–2019) are investigated using two arrays within the basin, 1) an ongoing 8 broadband station deployment with an average distance of ~30 km between stations and 2) a 1 month 96 node deployment in Summer 2018 with <3 km spacing between stations. Previous long-term seismic studies of the last two decades using significantly less dense arrays (>70 km station spacing) resulted in three dominant earthquake clusters extending in length ~10–25 km and trending N-S with magnitudes ranging $5.3 \geq M > 2$. The locations of our three-year earthquake catalog of >5000 earthquakes with M<4.3 dominantly fall within two of the three regions of previously noted seismicity. After relative relocation using hierarchical clustering, we find more distinct linear features that suggest the two largest ~N-S trending clusters of seismicity are composed of multiple shorter faults, some of which exhibit strikes that are rotated with respect to the ~N-S orientation of the composite cluster. Very little seismicity (<0.2%) is observed in the third cluster which produced the largest recent earthquake (M 5.3 in 2011). The majority of earthquakes occur within basement rock with depths between 2–6 km below sea level. Full moment tensor inversions for earthquakes M>2.5 reflect mostly NE-SW to NW-SE striking, normal faulting in the Raton Basin which is consistent with regional E-W extension and stress orientation.

Figure: Earthquake location maps. Triangles are broadband seismometers. Blue squares are wastewater injection wells. Red dots are earthquakes. A) Black dashed boxes denote the three seismically active regions from previous studies. B) The background color denotes the number of earthquakes (10^x) in each 0.25 km^2 area.