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Deep-Injection and Closely Monitored Induced Seismicity at Paradox Valley, Colorado

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Abstract

The U.S. Bureau of Reclamation's Paradox Valley Unit (PVU) extracts aquifer brine from nine shallow wells along the Dolores River, Paradox Valley, in southwestern Colorado and, after treating, high pressure injects the brine 4.3–4.8 km below the surface. PVU injects at rates between ~800 and ~1300 L/min. Since 1991, PVU has emplaced over 4×10^6 m^3 of fluid and induced more than 4000 surface-recorded seismic events. The events are recorded on the local 15-station Paradox Valley Seismic Network. The induced seismicity at Paradox separates into two distinct source zones: a principle zone (>95% of the events) asymmetrically surrounding the injection well to a maximum radial distance of ~3 km, and a secondary, ellipsoidal zone, ~2.5 km long and centered ~8 km northwest of the injection well. The expansion of these zones has stabilized since mid-1999, about three years after the onset of continuous injection. Within the principal zone, hypocenters align in distinct linear patterns, showing at-depth stratigraphy and the local Wray Mesa fracture and fault system. The primary faults of the Wray Mesa system are aseismic, striking subparallel to the inferred maximum principal stress direction, with one or more faults, probably, acting as fluid conduits to the secondary seismic zone. Individual seismic events, in both zones, do not discernibly correlate with short-term injection parameters; however, a 0.5 km^2 region immediately northwest of the injection well responds to long-term, large-scale changes in injection rate and the surpassing of a threshold injection pressure. Focal mechanisms of the induced events are consistent with simple double-couple, strike-slip moments and subhorizontal extension to the northeast. In addition, the fault planes are consistent with principal stress directions determined from borehole breakouts. More than 99.9% of the PVU seismicity is below human detection (~M 2.5). However, approximately 15 events have been felt locally, with the largest being a magnitude M 4.3. Because of the M 4.3 and two earlier-felt M ~3.5 events and injection economics, PVU changed injection strategies three times since 1996. These changes reduced seismicity from ~1100 events/year to as low as ~60 events/year.

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