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## Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 $M_w$ 5.7 earthquake sequence Expand

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### Abstract

Significant earthquakes are increasingly occurring within the continental interior of the United States, including five of moment magnitude ( $M_w$ )  $\geq 5.0$  in 2011 alone. Concurrently, the volume of fluid injected into the subsurface related to the production of unconventional resources continues to rise. Here we identify the largest earthquake potentially related to injection, an  $M_w$  5.7 earthquake in November 2011 in Oklahoma. The earthquake was felt in at least 17 states and caused damage in the epicentral region. It occurred in a sequence, with 2 earthquakes of  $M_w$  5.0 and a prolific sequence of aftershocks. We use the aftershocks to illuminate the faults that ruptured in the sequence, and show that the tip of the initial rupture plane is within  $\sim 200$  m of active injection wells and within  $\sim 1$  km of the surface; 30% of early aftershocks occur within the sedimentary section. Subsurface data indicate that fluid was injected into effectively sealed compartments, and we interpret that a net fluid volume increase after 18 yr of injection lowered effective stress on reservoir-bounding faults. Significantly, this case indicates that decades-long lags between the commencement of fluid injection and the onset of induced earthquakes are possible, and modifies our common criteria for fluid-induced events. The progressive rupture of three fault planes in this sequence suggests that stress changes from the initial rupture triggered the successive earthquakes, including one larger than the first.

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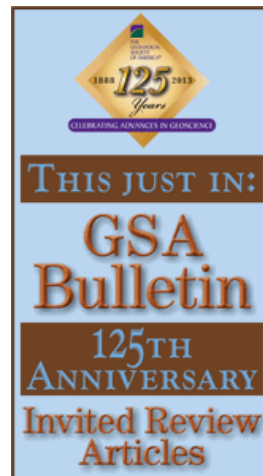
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