Injection-Induced Earthquakes

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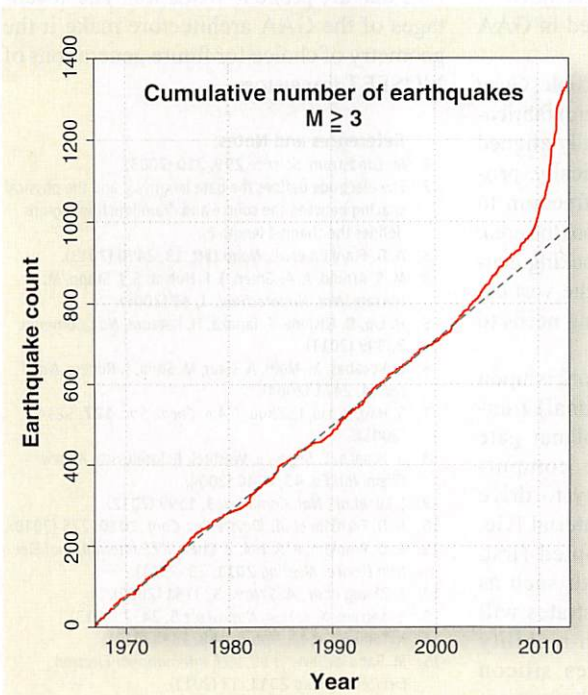
http://dx.doi.org/10.1126/science.1225942

Cite this article as W. L. Ellsworth, *Science* **341**, 1225942 (2013). DOI: 10.1126/science.1225942

Background: Human-induced earthquakes have become an important topic of political and scientific discussion, owing to the concern that these events may be responsible for widespread damage and an overall increase in seismicity. It has long been known that impoundment of reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface, and injection of fluids into underground formations are capable of inducing earthquakes. In particular, earthquakes caused by injection have become a focal point, as new drilling and well-completion technologies enable the extraction of oil and gas from previously unproductive formations.

Advances: Microearthquakes (that is, those with magnitudes below 2) are routinely produced as part of the hydraulic fracturing (or "fracking") process used to stimulate the production of oil, but the process as currently practiced appears to pose a low risk of inducing destructive earthquakes. More than 100,000 wells have been subjected to fracking in recent years, and the largest induced earthquake was magnitude 3.6, which is too small to pose a serious risk. Yet, wastewater disposal by injection into deep wells poses a higher risk, because this practice can induce larger earthquakes. For example, several of the largest earthquakes in the U.S. midcontinent in 2011 and 2012 may have been triggered by nearby disposal wells. The largest of these was a magnitude 5.6 event in central Oklahoma that destroyed 14 homes and injured two people. The mechanism responsible for inducing these events appears to be the well-understood process of weakening a preexisting fault by elevating the fluid pressure. However, only a small fraction of the more than 30,000 wastewater disposal wells appears to be problematic—typically those that dispose of very large volumes of water and/or communicate pressure perturbations directly into basement faults.

Outlook: Injection-induced earthquakes, such as those that struck in 2011, clearly contribute to the seismic hazard. Quantifying their contribution presents difficult challenges that will require new research into the physics of induced earthquakes and the potential for inducing large-magnitude events. The petroleum industry needs clear requirements for operation, regulators must have a solid scientific basis for those requirements, and the public needs assurance that the regulations are sufficient and are being followed. The current regulatory frameworks for wastewater disposal wells were designed to protect potable water sources from contamination and do not address seismic safety. One consequence is that both the quantity and timeliness of information on injection volumes and pressures reported to regulatory agencies are far from ideal for managing earthquake risk from injection activities. In addition, seismic monitoring capabilities in many of the areas in which wastewater injection activities have increased are not capable of detecting small earthquake activity that may presage larger seismic events.



Earthquakes with magnitude (M) ≥ 3 in the U.S. midcontinent, 1967–2012. After decades of a steady earthquake rate (average of 21 events/year), activity increased starting in 2001 and peaked at 188 earthquakes in 2011. Human-induced earthquakes are suspected to be partially responsible for the increase.

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ARTICLE OUTLINE

ADDITIONAL RESOURCES

The following resources provide an introduction to earthquake hazards and risk, the science of induced earthquakes, and strategies for managing the risk.

C. Nicholson, R. L. Wesson, "Earthquake hazard associated with deep well injection: A report to the U.S. Environmental Protection Agency," *U.S. Geol. Surv. Bull. 1951* (1990); http://pubs.usgs.gov/bul/1951/report.pdf.

Committee on Induced Seismicity Potential in Energy Technologies, *Induced Seismicity Potential in Energy Technologies* (National Research Council, Washington, DC, 2012); http://dels.nas.edu/Report/Induced-Seismicity-Potential-Energy-Technologies/13355.

S. Horton, Disposal of hydrofracking waste fluid by injection into subsurface aquifers triggers earthquake swarm in central Arkansas with potential for damaging earthquake. *Seismol. Res. Lett.* **83**, 250–260 (2012). doi:10.1785/gssrl.83.2.250

Tutorial material on probabilistic seismic hazard analysis (PSHA): www.opensha.org/sites/opensha.org/files/PSHA_Primer_v2_0.pdf

M. D. Zoback, Managing the seismic risk posed by wastewater disposal. *Earth Magazine* **57**, 38–43 (2012).