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Induced seismicity after borehole fluid injections

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We present a model for the temporal distribution of microseismic events induced by borehole fluid injections into reservoirs. We put the focus on seismicity induced after the stop of fluid injections. Here, our main concern is the identification of parameters controlling the decay rate of seismicity after injection stops. The particular importance of a theoretical model for the occurrence of seismicity after stop of injection is underlined by observations after stimulations of geothermal reservoirs at different locations. These stimulations have shown that the post injection phase contains a high seismic risk, which is up to now uncontrollable, because the processes leading to the occurrence of post injection events are not well understood. Based on the assumption that pore pressure diffusion is the governing mechanism leading to the triggering of seismic events, we develop a method to calculate the seismicity rate during and after fluid injections. We show that the obtained solution after injection is very similar to the frequency scaling law of aftershocks, namely the Omori law. We propose a modified Omori law, which describes how post injection seismicity depends on parameters of injection source and reservoir rock and the strength of a pre-existing fracture system in the reservoir. We analyze two end members of fracture strength, representing stable and unstable pre-existing fracture systems. Our results shows, that the decay rate of post injection seismicity is highly dependent on the strength of the fracture system. Furthermore, we show that the existence of an unstable fracture system in a reservoir results in a critical trend of seismic activity, which explains the occurrence of events with the largest magnitude close after the stop of injection. This result coincides with observations made after the stimulation of Enhanced Geothermal Systems (EGS). We verify our theoretical model by an application to synthetic data sets resulting from finite element modeling and real data collected in case studies performed at Fenton Hill and Soultz-sous-Foret.