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Scaling of postinjection-induced seismicity: An approach to assess hydraulic fracturing related processes

Lisa Johann, Carsten Dinske, and Serge Shapiro
Freie Universität Berlin, FR Geophysik, Berlin, Germany (lisajohann@zedat.fu-berlin.de)

Fluid injections into unconventional reservoirs have become a standard for the enhancement of fluid-mobility parameters. Microseismic activity during and after the injection can be frequently directly associated with subsurface fluid injections. Previous studies demonstrate that postinjection-induced seismicity has two important characteristics: On the one hand, the triggering front, which corresponds to early and distant events and envelops farthest induced events. On the other hand, the back front, which describes the lower boundary of the seismic cloud and envelops the aseismic domain evolving around the source after the injection stop.

A lot of research has been conducted in recent years to understand seismicity-related processes. For this work, we follow the assumption that the diffusion of pore-fluid pressure is the dominant triggering mechanism. Based on Terzaghi's concept of an effective normal stress, the injection of fluids leads to increasing pressures which in turn reduce the effective normal stress and lead to sliding along pre-existing critically stressed and favourably oriented fractures and cracks. However, in many situations, spatio-temporal signatures of induced events are captured by a rather non-linear process of pore-fluid pressure diffusion, where the hydraulic diffusivity becomes pressure-dependent. This is for example the case during hydraulic fracturing where hydraulic transport properties are significantly enhanced.

For a better understanding of processes related to postinjection-induced seismicity, we analytically describe the temporal behaviour of triggering and back fronts. We introduce a scaling law which shows that postinjection-induced events are sensitive to the degree of non-linearity and to the Euclidean dimension of the seismic cloud (see Johann et al., 2016, JGR).
To validate the theory, we implement comprehensive modelling of non-linear pore-fluid pressure diffusion in 3D. We solve numerically for the non-linear equation of diffusion with a power-law dependent hydraulic diffusivity on pressure and generate catalogues of synthetic seismicity. We study spatio-temporal features of the seismic clouds and compare the results to theoretical values predicted by the novel scaling law. Subsequently, we apply the scaling relation to real hydraulic fracturing and Enhanced Geothermal System data.

Our results show that the derived scaling relations well describe synthetic and real data. Thus, the methodology can be used to obtain hydraulic reservoir properties and can contribute significantly to a general understanding of injection related processes as well as to hazard assessment.