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Theoretical estimates of magnitudes of earthquakes induced by pore-pressure perturbations with large aspect ratios

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Being able to reliably and accurately estimate the possible maximum magnitude of fluid-injection-induced earthquakes is of critical importance to quantify the associated seismic hazard and to define operational constraints for geo-reservoirs. In previous studies, we developed theoretical estimates of the magnitude of fluid-injection-induced earthquakes based fracture mechanics, assuming circular pressure perturbations. However, natural reservoirs are typically much wider than thicker. Therefore, here we discuss the application of our model to horizontally elongated pressurized regions with realistic aspect ratios.

Assuming circular pressure perturbations, we derived a physical model estimating how large a rupture will grow on a given fault and for a given pore-pressure perturbation. We used two approaches. The first, semi-analytical approach is based on pore pressure evolution obtained by solving the diffusion equation for a cylindrical reservoir with no-flow boundaries. The second approach is an approximation to the first one, based on a point-load approximation of the pres-sure perturbation on the fault, allowing derivation of a complete analytical formula relating the magnitude of the largest arrested rupture, $M_{max-arr}$, to injection and slip-weakening friction parameters. We found that the $M_{max-arr}$ scales with cumulative injected fluid volume as a power law with exponent of 3/2. In contrast, the M_{max} relation by McGarr (2014) is a linear scaling (exponent of 1). While for the dataset used by McGarr (2014) the difference between our and McGarr's models is relatively small, inclusion of datasets with broad range of injected fluid volumes (from 10-10m3 to 1010m3) suggests better agreement with our model. However, inclusion of extended pressure perturbations into our two models, while maintaining the (semi-)analytical character, is not viable. Therefore, we perform numerical dynamic-rupture simulations to investigate rupture nucleation and arrest for pressure perturbation with large aspect ratios. We then interpret our findings and discuss implications for the two previously derived (semi-)analytical models. In particular, we find that our circular perturbation equations are also an adequate predictor of the final size under elongated perturbations for a wide range of aspect ratios and background stress values.