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# A numerical study of the mechanism of injection-induced and triggered seismicity at the Pohang Enhanced Geothermal Systems project, South Korea

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Hydraulic stimulation for the creation of an Enhanced Geothermal System (EGS) reservoir could potentially reactivate a nearby fault and result in man-made earthquakes. In November 15, 2017, an $M_w$ 5.5 earthquake, the second largest after the initiation of the South Korean national instrumental monitoring system, occurred near an EGS project in Pohang, South Korea. The earthquake occurred on a previously unmapped fault, that is here denoted the $M_w$ 5.5 Fault. A number of previous studies to model the hydraulic stimulation in the Pohang EGS project have been carried out to identify the mechanism of seismic events. Those previous studies focused on coupled hydro-mechanical processes without the consideration of pre-existing fractures and thermal effects. This study presents an investigation of the mechanisms of induced and triggered seismicity in the Pohang EGS project through three-dimensional coupled thermo-hydro-mechanical numerical simulations. Fractures intersecting the open-hole sections of two deep boreholes, PX-1 and PX-2, clearly indicated by field observations are modeled along with the $M_w$ 5.5 Fault. Models of stress-dependent permeability models are calibrated based on the numerical reproduction of the pressure-time evolution during the field hydraulic stimulations. The Coulomb failure stress change at the $M_w$ 5.5 Fault is calculated to quantify the impact of five hydraulic stimulations. In the case of PX-2 stimulations, the pore pressure buildup results in a volumetric expansion of the reservoir and thereby the perturbation of stresses is transferred to the $M_w$ 5.5 Fault. The volumetric contraction of the reservoir by the temperature reduction could slightly perturb the stress distribution at the $M_w$ 5.5 Fault. In the case of PX-1 stimulations, shear slip of the PX-1 fracture is explicitly modeled. The modeling shows that transfer of the shear stress drop by the shear slip stabilizes the $M_w$ 5.5 Fault, which is consistent with the field observation that the seismicity was not induced at the $M_w$ 5.5 Fault by the PX-1 stimulations. The cooling-induced thermal stress additionally reduces the effective normal stress of PX-1 fracture. Thus, some additional shear slip of the PX-1 fracture is induced by the thermal effect. However, the modeling shows that for both PX-1 and PX-2 stimulations, thermally-induced stress perturbations are very small compared to pressure-induced stress perturbations.