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Basement Fault Reactivation by Fluid Injection into Sedimentary Reservoirs

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Many suspected injection-induced earthquakes occur in crystalline basement rather than in the overlying sedimentary injection reservoir. To address why earthquakes nucleate in the basement rather than the injection layer we investigate the relationship between pore pressure diffusion, rock matrix deformation, and induced fault reactivation through 3D fully coupled poroelastic finite element models. These models simulate the temporal and spatial perturbation of pore pressure and solid stresses within a basement fault that extends into overlying sedimentary layers and that is conductive for flow along the fault but a barrier for flow across. We compare the effects of direct pore pressure communication and indirect poroelastic stress transfer from the injection reservoir to the fault on increasing the Coulomb failure stress that could reactivate the basement fault for normal, reverse, and strike-slip faulting stress regimes. Our numerical results demonstrate that volumetric expansion of the reservoir causes a bending of the fault near the injector and induces shear tractions along the downdip direction of the fault in the basement. These induced shear tractions act to increase the Coulomb failure stress for a normal faulting stress regime, and decrease the Coulomb failure stress for a reverse faulting regime. For a strike-slip faulting stress regime, the induced shear tractions increase the Coulomb failure stress both in the reservoir and basement. The induced normal traction on the fault reduces the Coulomb failure stress in all three tectonic regimes, but is larger in the reservoir than in the basement due to the more pronounced poroelastic effect in the reservoir. As a result, strike-slip stress regimes favor fault reactivation in the basement. Whereas the magnitude of the direct pore pressure increase exceeds the magnitude of induced poroelastic stress change, the poroelastic stress change increases the Coulomb failure stress in the basement fault for the normal and strike-slip faulting stress regime, but decreases the Coulomb failure stress for the reverse faulting stress regime. Because the pore pressure effect, without consideration of poroelastic stress changes, would always result in fault reactivation in the injection layer, we demonstrate that fault reactivation along basement faults is governed by the coupled effects of pore pressure change and resulting poroelastic stress perturbation.