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Injection-Induced Seismic Slip: Theoretical Insights and Proposed Experiment in a Mine

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Abstract: Fluid injection into the crust - the process essential to the stimulation of production from gas and oil reservoirs, geothermal energy extraction, and geological sequestration of CO_2 - is known to induce small and sometimes large earthquakes. Locally elevated pore fluid pressure due to the injection tends to reduce the crust strength and can lead to reactivation of slip on pre-existing fractures or faults if the static Coulomb failure condition is met locally. As the pressurized region spreads due to pore fluid diffusion, slip can accumulate quasi-statically (at the pace of the pore fluid diffusion), or dynamically. The important questions are (1) what are the conditions leading to escalation of slip, and nucleation of dynamic rupture propagation; and (2) what is the run-out distance of the dynamic rupture before it is arrested, or, in other words, what separates micro-seismic events from earthquakes? These questions are addressed theoretically in a model of slip on a single fault subjected to uniform prestress and locally peaked, diffusively spreading pore pressure field. Nucleation of dynamic propagation comes about naturally in this model when the fault frictional strength decreases from its peak (static) value with slip, while arrest of dynamic propagation and ensuing slow growth of the slipping patch is imminent if the residual fault strength at ambient conditions exceeds the prestress (an "aseismic" fault). Interestingly, the largest dynamic run-out distance and dynamically accumulated slip on aseismic faults occur under conditions of marginal-pressurization, defined by the minimum value of the fluid overpressure that is still sufficient to activate fault slip. Such injection conditions are, therefore, the most vulnerable ones to activation of dynamic weakening mechanisms (e.g., thermal pressurization) capable of sustaining the earthquake slip and generating larger earthquakes, which is not inconsistent with some observations that largest injection-induced seismic events can occur well after the end of fluid injection (e.g., Denver earthquakes). When the assumption of uniform prestress is relaxed, small prestress heterogeneity generates recurrent dynamic slip as the pressurized region spreads along the fault, reminiscent of progression of microseismicity observed in in-situ injection experiments. In the second part of this talk, a controllable earthquake rupture experiment proposed at the former Homestake Mine (South Dakota) will be discussed. Recently discovered fault, which is present on multiple levels of the mine, represents a unique opportunity to study dynamic slip nucleation and arrest in situ by subjecting the fault to a controlled fluid injection and thermally changing background stresses at scales of 10-100 meters.

References:

Garagash, D. I., and Germanovich, L. Nucleation and arrest of dynamic slip on a pressurized fault. Submitted to Proceedings of the Royal Society, London, A, February 2012.

Germanovich, L.N., Murdoch, L.C., Garagash, D.I., Reches, Z., Martel, S.J., Gwaba, D., Elsworth, D., and Onstott, T.C. Earthquake rupture experiment on the Homestake fault. Proceedings of 2011 NSF Engineering Research and Innovation Conference, Atlanta, Georgia, January 4-7, 2011.