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On the nature of induced seismicity: control from pore pressure distribution

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An increase in pore pressure along crustal fault is known to contribute to earthquake nucleation. From a theoretical point of view, faults are expected to reactivate when the effective friction coefficient, which increases with increasing fluid pressure, achieves the static friction of the fault. However, while the static reactivation of the fault is well established, the influence of the state of stress and of the pore pressure level on the nature of the induced seismicity remains poorly constrained.

Here, we conducted laboratory injection experiments on saw-cut sample of andesite coming from geothermal reservoirs. Fluids were injected directly along the fault through a borehole located at a fault edge, and fluid pressure was continuously measured during injection at the two edges of the fault. In addition to regular mechanical measurements and acoustic emissions monitoring, we used eight strain gages located at different along the fault to monitor the onset of fault reactivation and the propagation of dynamic instabilities.

Injections were conducted at three different effective confining pressure (30 60 and 95 MPa with an initial pore pressure of 10 MPa), and along fault loaded at 90 percent of the peak shear stress. Independently of the confining pressure, each injection experiments was associated to dynamic instabilities, episodic slow slip and stable slip events. Dynamic instabilities rupturing the entire fault occur when only a small portion of the fault is affected by the fluid pressure perturbation. In these conditions, a slip front propagates far behind the fluid pressure front. When the slip front outgrows the fault, dynamic instability occurs, inducing fault dilatancy and shear-induced fluid flow. Increasing cumulative slip leads to the progressive homogenization of the fluid pressure along the fault. This homogenization promotes the transition from dynamic instabilities to episodic slow slip events, and to stable reactivation when the fluid pressure is completely homogeneous. Our experimental results are supported by numerical modelling coupling Dieterich-Ruina rate-and-state friction law and poroelastic interaction. The distribution of the fluid pressure at the onset of the instability, and its degree of heterogeneity, could control the nature of the seismicity.