Imaging Poro-Elastic Effects induced by a Normal Fault Aseismic-to-Seismic Dislocation in Shales

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Understanding fault reactivation as a result of subsurface fluid injection in shales is critical in geologic CO$_2$ sequestration and in assessing the performance of radioactive waste repositories in shale formations. Since 2015, two semi-controlled fault activation projects, called FS and FS-B, have been conducted in a fault zone intersecting a claystone formation at 300 m depth in the Mont Terri Underground Research Laboratory (Switzerland). In 2015, the FS project involved injection into 5 borehole intervals set at different locations within the fault zone. Detailed pressure and strain monitoring showed that injected fluids can only penetrate the fault when it is at or above the Coulomb failure criterion, highlighting complex mixed opening and slipping activation modes. Rupture modes were strongly driven by the structural complexity of the thick fault. An overall normal fault activation was observed. One key parameter affecting the reactivation behavior is the way the fault's initial very low permeability dynamically increases at rupture. Such complexity may also explain a complex interplay between aseismic and seismic activation periods. Intact rock pore pressure variations were observed in a large volume around the rupture patch, producing pore pressure drops of ~4 10$^{-4}$ MPa up to 20 m away from the ruptured fault patch. Fully coupled three-dimensional numerical analyses indicated that the observed pressure signals are in good accordance with a poro-elastic stress transfer triggered by the fault dislocation.

In 2019, the FS-B experiment started in the same fault, this time activating a larger fault zone volume of about 100 m extent near (and partially including) the initial FS testbed. In addition to the monitoring methods employed in the earlier experiment, FS-B features time-lapse geophysical imaging of long-term fluid flow and rupture processes. Five inclined holes were drilled parallel to the Main Fault dip at a distance of about 2-to-5m from the fault core “boundary”, with three boreholes drilled in the hanging wall and two boreholes drilled in the foot wall. An active seismic source-receiver array deployed in these five inclined boreholes allows tracking the variations of p- and s-wave velocities during fault leakage associated with rupture, post-rupture and eventually
self-sealing behavior. The geophysical measurements are complemented by local three-dimensional displacements and pore pressures measurements distributed in three vertical boreholes drilled across the fault zone. DSS, DTS and DAS optical fibers cemented behind casing allow for the distributed strain monitoring in all the boreholes. Twelve acoustic emission sensors are cemented in two boreholes set across the fault zone and close to the injection borehole. Preliminary results from the new FS-B fault activation experiment will be discussed.