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Development of an experimental approach to explore in situ fracture hydromechanics with ground surface tiltmeters and periodic fluid pressure perturbations

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Fractured bedrock reservoirs are of socio-economical importance, as they may be used for storage or retrieval of fluids and energy. The characterization of such systems remains challenging, especially at scales where transport processes are critically controlled by the structure and properties of fracture networks. In particular, the hydromechanical behavior of fractures needs to be understood as it has implications on flow and fluid storage. It also governs stability issues, that is to say medium failure and associated seismicity. Laboratory, numerical or field experiments have brought considerable insights to this topic. Nevertheless, in situ hydromechanical experiments are less commonplace, mainly because of technical, instrumental or cost limitations. Here, we present the early stage development and validation of a novel approach aiming at capturing the integrated hydromechanical behavior of natural fractures. It consists in combining the use of surface tiltmeters to monitor the deformation associated with the periodic pressurization of fractures at depth in crystalline rocks. Periodic injection and withdrawal advantageously avoids mobilizing or extracting significant amounts of fluid and may be applied to natural media where high fluid pressures cannot be tolerated or achieved. In addition, the perturbation's oscillatory nature is intended to: 1) facilitate the recognition of its signature in tilt measurements; 2) explore various volumes of rock around the inlet and thereby assess scale effects typical of fractured systems. By stacking tilt signals, which is a broadly used data processing method in seismology, we managed to detect small tilt amplitudes associated to pressure-derived fracture deformation. Therewith, we distinguish differences in mechanical properties between the 3 tested fractures but we show that tilt amplitudes are weakly dependent on pressure penetration depth. Using an elastic model, we obtain fracture stiffness estimates that are consistent with published laboratory and field data. Our results should encourage further improvement of the method.