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Hydraulic and Acoustic Properties of Alpine Fault DFDP1a Core

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The permeability structure of fault zones and surrounding wall rock is an important control on the hydrologic behavior of fault zones and on poro-elastic deformation processes that affect fault mechanics. Several recent fault zone drilling projects have aimed to sample and conduct in situ measurements across active, major plate boundary faults in order to better understand fault mechanics, hydrogeology, and earthquake processes. The Deep Fault Drilling Project (DFDP) aims to sample the active Alpine Fault (AF), on the South Island of New Zealand. The early phase of this project included 2 boreholes that penetrated the active AF at depths of ∼100 m and ∼150 m (DFDP-1A and 1B), and provided a suite of core samples transecting the fault from hanging wall mylonite, across cataclastically deformed fault rocks, and into Quaternary footwall gravels. Here, we report on laboratory experiments designed to measure permeability and ultrasonic velocities of core samples of fault and wall rock over a range of effective stresses.

We performed steady-state, constant head permeability tests in a standard triaxial vessel under isotropic stress conditions, with effective confining stress ranging from 2.5 MPa to 63.5 MPa. In tandem with the permeability measurements, we conducted ultrasonic wavespeed measurements to determine P- and S- wavespeeds from time-of-flight. Most of our tests were performed on subsamples of DFDP 1A core, 25 mm in diameter and with lengths ranging from 17-36 mm. Additional tests were performed on samples of fault gouge from the nearby DFDP 1B hole, and on fault gouge obtained from a nearby trench excavation. Subsamples from the core were taken in a core parallel orientation, at an orientation of ∼45 degrees to the Alpine Fault.

We find that the permeability for wall rock mylonite and cataclasite samples decreases from 9.8 x 10^{-15} m^2 to 2.5 x 10^{-18} m^2 and 1.0 x 10^{-15} m^2 to 1.4 x 10^{-19} m^2, respectively, with effective stress from 2.5 - 63.5 MPa. We also observe that permeability of cataclasites decreases with proximity to the active fault core, over all of the effective stresses we explored. Fault gouge permeability decreases from 5.8 x 10^{-19} m^2 to 4.4 x 10^{-20} m^2 over this range of effective stress. Our results are consistent with values inferred from downhole tests and qualitative observations during drilling which suggest in situ permeabilities of 10^{-14} m^2, 10^{-16} - 10^{-17} m^2, and 10^{-19} m^2 for the mylonites, cataclasites, and fault core, respectively. Together, these data suggest that the fault core should act as a barrier to fluid flow, whereas the surrounding damaged rock is highly permeable. The fault gouge permeability is sufficiently low to facilitate transient pore pressure effects during rapid slip, potentially including thermal pressurization and dilatancy hardening.

The P-wave velocity of our samples increases systematically with effective stress. P-wave velocities for wall rock mylonite and cataclasites increase from 3.3 km/s to 4.6 km/s and 2.7 km/s to 4.8 km/s, respectively, with effective stress from 2.5 to 63.5 MPa. P-wave velocity of fault gouge increases from 2.8 km/s to 4.4 km/s over this range of stresses. The clay-rich and poorly lithified samples from within and near the active fault, including hanging wall cataclasite, fault gouge, and footwall gravel, along with the heavily fractured hanging wall mylonite, all exhibit lower P-wave velocities than more competent and lithified cataclasite samples farther from the active AF. Our results are consistent with borehole logging data that show an increase in P-wave velocity from the mylonite into the competent cataclasites, and a decrease in P-wave velocity through the clay-rich cataclasite and into the fault zone.