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Evolution of the structural, geochemical and mechanical properties of the Alpine Fault zone from the Deep Fault Drilling Project (DFDP): current achievements and future goals

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Major plate boundaries, such as the Alpine Fault zone (AFZ), have fundamental influences on the crust's mechanical and transport properties. These faults can generate large earthquakes and represent major geohazards. In-situ observations and sampling of active fault zones at depth are possible only through drilling, and are imperative to develop predictive models of fault zone behaviour.

The Deep Fault Drilling Project (DFDP), led by New Zealand scientists with international collaborators, aims to drill and recover core, wireline log, and instrument boreholes of progressively greater depths into the AFZ. The main scientific goal is to understand the mechanics and structural evolution of major faults and the conditions under which large earthquakes occur. The DFDP exploits the rapid regional slip rates of the AFZ, its elevated geothermal gradient, extensively described surface geology, seismic observations, and the fact that the AFZ is in the late stages of its seismic cycle.

Phase 1 of the DFDP successfully drilled two shallow boreholes, DFDP-1A to 101 m and DFDP-1B to 151 m, at Gaunt Creek. Hanging-wall and foot-wall cataclasites were sampled with high recovery, and the Principal Slip Zone (PSZ) of the AFZ was intercepted at 90 m and 128 m. Following geophysical wireline logs that measured density, spontaneous potential, resistivity and neutron porosity, borehole DFDP-1B was instrumented with seismometers, piezometers, and temperature probes.

Hanging-wall cataclasites are altered, cemented rocks with low permeability values of 10^{-16} – 10^{-18} m^2. Resistivity decreases with depth from 275 Ωm to 125 Ωm, while spontaneous potential and neutron porosity increase from 200 mV to 230 mV and from 1% to 15% respectively. Porosity values are interpreted to represent water bound to clays and not water in pore spaces. Individual geophysical logs show little difference between the foot-wall and hanging-wall cataclasites. However a diagram of resistivity versus spontaneous potential identifies unequivocally each of the foot-wall cataclasites, the PSZ, the hanging-wall cataclasites and the mylonites. The PSZ has the lowest resistivity ($<$80 Ωm) and the highest apparent porosity (up to 24%).

An equilibrium geothermal gradient of $\sim$63°C/km was measured suggesting that the brittle-plastic transition is 5-6 km deep. Fluid pressures (P_f) drop significantly across the PSZ, which may be acting as a seal between the hanging-wall, recharged from higher topographic relief, and the foot-wall.

A preliminary fault zone model may be proposed. At shallow depths the PSZ is a narrow planar feature consisting of ultrafine-grained clay gouge with low permeability. The PSZ is surrounded by an asymmetric damage zone hundreds of meters thick, where permeability has been reduced by clay alteration and carbonate cementation in the hanging-wall. During an earthquake, fracturing of the hanging-wall and foot-wall will cause dilatancy and draw in fluids, most likely from along the fault zone. The post-seismic response may involve movement of pressurized, hot fluids through the hanging-wall, causing the alteration and cementation currently observed. The time-dependent response to earthquakes of the hydrologic system of the AFZ may control earthquake recurrence.

Experimental, microstructural and geochemical analyses of core samples from DFDP-1A and B are currently being undertaken.