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3D seismic imaging of the Alpine Fault and the glacial valley at Whataroa, New Zealand

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The Alpine Fault at the West Coast of the South Island (New Zealand) is a major plate boundary that is expected to rupture in the next 50 years, likely as a magnitude 8 earthquake. The Deep Fault Drilling Project (DFDP) aimed to deliver insight into the geological structure of this fault zone and its evolution by drilling and sampling the Alpine Fault at depth. Here we present results from a seismic survey around the DFDP-2 drill site in the Whataroa Valley where the drillhole almost reached the fault plane. This unique 3D seismic survey includes several 2D lines and a 3D array at the surface as well as borehole recordings. Within the borehole, the unique option to compare two measurement systems is used: conventional three-component borehole geophones and a fibre optic cable (heterodyne Distributed Vibration Sensing system (hDVS)). Both systems show coherent signals but only the hDVS system allowed a recording along the complete length of the borehole.

Despite the challenging conditions for seismic imaging within a glacial valley filled with sediments and steeply dipping valley flanks, several structures related to the valley itself as well as the tectonic fault system are imaged. The pre-processing of the seismic data also includes wavefield separation for the zero-offset borehole data. Seismic images are obtained by prestack depth migration approaches.

Within the glacial valley, particularly steep valley flanks are imaged directly and correlate well with results from the P-wave velocity model obtained by first arrival travel-time tomography. Additionally, a glacially over-deepened trough with nearly horizontally layered sediments is identified about 0.5 km south of the DFDP-2B borehole.

With regard to the expected Alpine fault zone, a set of several reflectors dipping 40-56° to the southeast are identified in a ~600 m wide zone between depths of 0.2 and 1.2 km that is interpreted to be the minimum extent of the damage zone. Different approaches image one distinct reflector dipping at 40°, which is interpreted to be the main Alpine Fault reflector. This reflector is only ~100 m ahead from the lower end of the borehole. At shallower depths (z<0.5 km), additional reflectors are identified as fault segments and generally have steeper dips up to 56°. About 1 km south of the drill site, a major fault is identified at a depth of 0.1-0.5 km that might be caused by the regional tectonics interacting with local valley structures. A good correlation is observed among the separate seismic data sets and with geological results such as the borehole stratigraphy and the expected surface trace of the fault.

In conclusion, several structural details of the fault zone and its environment are seismically imaged and show the complexity of the Alpine Fault at the Whataroa Valley. Thus, a detailed seismic characterization clarifies the subsurface structures, which is crucial to understand the transpressive fault's tectonic processes.