Geophysical Research Abstracts
Vol. 14, EGU2012-1889-1, 2012
EGU General Assembly 2012

Joint inversion of surface wave and body wave data for the characterisation of a fault system in New Zealand

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A seismic reflection dataset was acquired by the Applied and Environmental Geophysics group at ETH Zurich to characterise a site across the Alpine Fault near the village of Inchbonnie on the South Island of New Zealand. The Alpine Fault is a transpressional strike slip fault and is the largest of several New Zealand faults that occur at the boundary of the Australian and the Pacific tectonic plates. The site is just north of the intersection between the Alpine Fault and the Hope Fault and features a fault step-over zone. It is further characterised by glacial, glaciolacustrine, lacustrine and fluvial sediments (mostly gravels), transported and distributed by the Taramakau River. The dataset consists of five high resolution seismic reflection lines that cross the fault zone. The lengths of the seismic lines range from 383 m to 1198 m. The data were initially processed to image seismic reflection sections and the P-wave first arrivals were picked. A significant amount of surface wave energy however was present in the records as well, such that dispersion curves could be extracted along the seismic lines using a moving Gaussian window and picked energy maxima in the f-k domain. Surface-wave dispersion curves and P-wave first arrivals were then jointly inverted to provide a comprehensive P- and S-wave velocity model of the site.

The joint inversion algorithm is a damped weighted least-squares algorithm based on a local 1D forward model for the surface wave dispersion curves and a 2D forward model for the P-wave first arrivals. The local 1D models for surface waves are linked to each other through spatial regularisation. Further constraints can be added to comply with a priori information and physical links between model parameters (VP and VS). The final outcome is a 2D internally consistent VP and VS model. The inversion scheme works very well for weakly laterally varying media, but in the case of abrupt lateral variations the spatial regularisation should be manually set to avoid over-smoothing of the final 2D models. Hence, before inverting the data, the seismic gathers were analysed by applying several algorithms aimed at detecting phase and energy variations of Rayleigh wave propagation along the line. Sharp variations were indeed identified. They correspond to the faults outlined on the seismic reflection sections. This preliminary information was used to set the spatial regularisation and finally the data were inverted.

The final models allowed the site to be characterised down to a depth of 30-40m. The final seismic velocity models feature two different depositional environments on either side of the main Alpine fault and provided a Poisson's ratio distribution consistent with hydrogeological information about the site.