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Estimation of fracture compliance based on group delays inferred from full-waveform sonic log data

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Fractures, which are ubiquitous in the Earth's upper crust, have significant impacts on a wide range of human activities, and, hence, their adequate characterization is of wide interest and importance. Seismic methods have significant potential for effectively addressing this objective. When a seismic wave propagates across a fluid-filled fracture, its amplitude is diminished and its travel time is increased. Based on the linear slip theory, the associated amplitude decays and phase delays can be used to estimate the mechanical compliance of fractures. Full-waveform sonic (FWS) log data are particularly well-suited for this purpose. While the amplitudes of FWS data acquired during standard continuous logging runs (tool being moved uphole at a constant logging speed) can be somewhat unstable, the associated first-arrival travel times are generally quite robust. In this work, we exploit the relation between the time delay that seismic waves experience across fractures and relate them to the associated compliances. Specifically, we estimate fracture compliance from the differences in group time delay of the refracted P-wave between fractured and non-fractured sections along a borehole. Numerical simulations indicate that the proposed method provides reliable compliance estimates not only for individual fractures, but also for sets of multiple discrete fractures. This finding is corroborated by applying our approach to FWS log data acquired in the course of standard logging runs in the Bedretto Underground Laboratory (www.bedrettolab.ethz.ch). Our estimates are comparable to previously inferred compliance values in a closely comparable geological environment (Grimsel test site, www.grimsel.com). The latter were inferred under rather ideal conditions, involving the quasi-static acquisition of the FWS data as well as the combination of amplitude and travel time information for their interpretation. An interesting and important open question, which we plan to address in the following, concerns the influence of the heterogeneity of the host rock embedding the fractures on compliance estimation in general and on the proposed method in particular.