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Estimating attenuation and fracture compliance from full-waveform sonic data

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The attenuation and phase velocity of seismic waves contain valuable information on the mechanical and hydraulic properties of the probed medium. In the particular case of fractured rocks, the amplitudes of propagating seismic waves decay due to various mechanisms, such as geometrical spreading, intrinsic background attenuation, wave-induced fluid flow (WIFF) between fractures and the embedding background, and transmission losses across fractures whose aperture is comparable to the prevailing wavelengths. In this work, we aim at characterizing the mechanical properties of fractures from the P-wave velocity changes and transmission losses inferred from full-waveform sonic (FWS) log data. Our methodology is validated using synthetic FWS logs and then applied to observed data. The latter were acquired in a borehole penetrating multiple fractures and shear zones embedded in a granodioritic rock mass. In order to extract the transmission losses from attenuation estimates, we first remove the contributions associated with other amplitude loss mechanisms. The amplitude decay associated with geometrical spreading is estimated by performing numerical simulations of sonic wave propagation that reproduce the borehole environment and validated by inferring the corresponding correction directly from the FWS data through the use of multiple source-receiver offsets configurations. After correcting for geometrical spreading, the intrinsic background attenuation is estimated from the measurements acquired in the intact zones, which are identified using sonic velocity profiles as well as televiewer images. We found that the estimated background attenuation values are very high (Q=12-14), which, however, is in agreement with previously reported estimates at this site. Lastly, the variations with respect to the background reference attenuation can be attributed to transmission losses and/or mesoscopic WIFF. We use pertinent theoretical models of mesoscopic WIFF to demonstrate that this contribution to the total compressional wave attenuation is likely to be largely negligible due to the very low permeability of the background rock and, hence, the remaining attenuation can be mainly attributed to transmission losses. Once we obtain the attenuation associated to a certain fracture of interest, we can readily compute the transmission coefficient, which, using linear slip theory, can then be directly related to the mechanical compliance of the fracture. The results indicate that the estimated mechanical compliance values range from 3x10-11 m/Pa to 2x10-9 m/Pa with the highest values being associated with zones with partially and/or fully open fractures.