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Poro-elastic analysis of the velocity dispersion and attenuation behavior of broad-band multi-frequency sonic logs

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Modern sonic logging tools designed for environmental and engineering applications allow for measurements of the phase velocity and the attenuation of P-waves at multiple emitter frequencies over a bandwidth covering 5 to 10 octaves. We have explored the possibility of constraining the permeability of saturated alluvial sediments based on the poro-elastic interpretation of the velocity dispersion and frequency-dependent attenuation of such broad-band sonic log data. Theoretical considerations indicate that, for saturated unconsolidated sediments in the silt to sand range and typical emitter frequencies ranging from approximately 1 to 30 kHz, the observable P-wave velocity dispersion is sufficiently pronounced to allow for reliable first-order estimations of the underlying permeability structure based on the theoretical foundation of poro-elastic seismic wave propagation. Theoretical predictions also indicate that the attenuation behavior should show detectable variations over the entire range unconsolidated lithologies. The corresponding predictions have been tested for a borehole penetrating a typical surficial alluvial aquifer. With regard to the P-wave velocity dispersion, our results do indeed indicate that, even without any additional corrections or calibrations, the thus obtained permeability values as well as their variabilities within the pertinent lithological units are remarkably close to those expected based on the corresponding granulometric characteristics. Conversely, the results of our attenuation measurements are more difficult to interpret because (i) the inferred attenuation values are systematically higher than the theoretically predicted ones and because (ii) the form of their dependence on frequency is variable and only partially consistent with theoretical expectations. This is surprising, even enigmatic, since the overall quality of our data is uniformly high to very high and the currently available evidence indicates that the classical theoretical framework of poro-elasticity should be valid in the considered permeability and frequency ranges.