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Upper-crustal scattering parameters as derived from induced micro-seismicity and acoustic log data

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In deterministic seismology it is assumed, that each inhomogeneity within the traversed medium causes a travel time shift and/or special phase in the observed seismogram. This information may then be used to analyze the properties of the inhomogeneity (e.g. location, size). However, this method is only successful for inhomogeneities larger than the station separation, the Fresnel zone and the wavelength. In the Earth's curst there exist many small-scale heterogeneities. Stochastic models can be used to determine the most important statistical parameters of the small-scale inhomogeneities neglecting their exact locations. In high-frequency seismograms (> 1 Hz) information on heterogeneity and seismic absorption is reflected by wave trains following the direct wave featuring decreasing amplitude with increasing lapse time, know as Coda waves. Since seismic wave propagation through a heterogeneous and absorbing medium is an extremely complex process, it has become common practice to use seismogram envelopes instead of complete waveforms to gain insight in the attenuation properties. Besides the manifestation in high-frequency seismograms information on heterogeneity can be extracted from well-logs. Borehole measurements provide detailed 1D information on the distribution of elastic properties within the upper crust at scales from about one meter to several kilometers. Strong random fluctuations in seismic velocity having short wavelengths superposed on a step-like structure represent here the deterministic and stochastic components of the crustal structure. These observations suggest a description of the crust as a random medium with a broad spectrum of heterogeneity.

In the framework of developing techniques for the estimation of attenuation properties in geothermal reservoirs, as part of the German research program *Geothermal Energy and High-performance Drilling (gebo)*, seismogram envelope inversion and statistical analysis of acoustic logs have been applied to data from the German Continental Deep Drilling (KTB) project. In the present research a passive seismic data set is considered which was acquired during a long-term hydraulic fracturing treatment at the KTB in 2000. Induced seismicity was recorded with a temporal seismic network, consisting of 40 stations, at epicentral distances less than 20 km. Processed seismic events have magnitudes $M_l \leq 1.0$. Acoustic log data comprise the P- and S-wave velocity distribution logged in two boreholes. In the pilot borehole continuous data reach from the surface (28 m) to a depth of approx. 4000 m, while for the main borehole coherent logs are available between 285 m and 7160 m.

Scattering and intrinsic attenuation, derived from micro-seismic events at the KTB, reasonably match regional attenuation models for Southern Germany. In contrast, scattering strength estimated from acoustic log data exceeds the regional attenuation models by one order of magnitude. The scattering coefficient shows weak but almost identical frequency dependence for both types of analysis that is best-described by a power-law form. From the frequency dependence it can be inferred that a von Kármán-type of random medium is a good model for representing the fractured geothermal reservoir at the KTB. The estimated Hurst exponent, related to the scattering coefficient, is also in good agreement with reference values derived for the upper crust.