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Is it possible to infer the frequency-dependent seismic attenuation of fractured materials from high-strain creep tests?

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The seismic and hydraulic characterization of fractured rocks is an important objective for reservoir development in general and the production of geothermal energy in particular. The attenuation of seismic waves in saturated fractured media is governed by local displacements of the fluid relative to the solid induced by the compressions and extensions associated with the passing wavefield. This phenomenon is generally referred to as wave-induced fluid flow (WIFF). Recent evidence suggests that this energy dissipation mechanism is sensitive to the interconnectivity of the fractures, which offers the perspective of linking seismic observations to the hydraulic properties of fractured rocks.

Here, we consider the results of laboratory experiments, which are referred to as creep tests. Such tests consist of applying a constant stress to a water-saturated thermally cracked glass sample and recording the resulting strain response as a function of time. The primary advantages of the considered material are (i) that the fracture network is well documented and (ii) that the homogeneous and non-porous glass matrix limits WIFF to the fracture network. Due to the high stress levels as well as other technical issues, creep tests are not commonly used for laboratory-based measurements of energy dissipation. Therefore, an objective of this study is to explore whether and to what extent such data can be interpreted in terms of the seismic attenuation characteristics of the probed samples, as this might open access to a vast reservoir of corresponding data, notably for cracked materials.

Transforming the observed time-dependent stress-strain relation into the Fourier domain, allows us to infer the corresponding frequency-dependent attenuation characteristics, which we then seek to interpret through numerical simulations based on Biot's quasi-static poroelastic equations. The 2D geometry of the fracture network considered in these simulations is derived from a scanning electron-microscope image of a vertical cut through a cracked cylindrical glass sample. In our model, the fractures are represented as highly permeable and highly compliant features embedded in a much less permeable and much stiffer matrix. The results of these simulations suggest that the considered 2D model is capable of capturing the basic characteristics of the laboratory observations, notably, the overall shape and frequency dependence of the inferred attenuation behavior. This in turn indicates that WIFF between connected fractures is indeed the governing seismic energy dissipation mechanism. However, it is important to note that the predicted magnitude of the attenuation is very sensitive to compressibility and permeability of the fractures, which are not well constrained. Moreover, it must be assumed that some non-linear effects associated with the high strain rates of the considered creep tests are likely to be present, most likely in the form of a frequency-independent contribution to the observed attenuation characteristics.