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A novel method for analyzing seismic energy loss associated with wave-induced fluid flow

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Whenever a seismic wave propagates through a fluid saturated porous rock that contains heterogeneities in the mesoscopic scale, that is, heterogeneities larger than the typical pore size but smaller than the predominant wavelengths, local gradients in the pore-fluid pressure arise. These pressure gradients, which are due to the uneven response of the heterogeneities to the stress applied by the passing seismic wavefield, induce viscous fluid flow and energy dissipation. Consequently, seismic waves tend to be strongly attenuated and dispersed in this kind of media. This attenuation mechanism scales with the compressibility contrast between heterogeneities and the background. Correspondingly, environments characterized by patchy saturation as well as fractured media represent two prominent scenarios where seismic attenuation due to wave-induced fluid flow is expected to be the predominant energy dissipation mechanism. Numerical oscillatory compressibility and shear tests based on the quasistatic poroelasticity equations provide an effective means to compute equivalent viscoelastic moduli for representative rock samples of the heterogeneous media under study. Approaches of this type rely on the existence of a dynamic-equivalent medium, that is, the heterogeneous porous rock is represented by an equivalent homogeneous viscoelastic solid that exhibits an overall response similar to that of the original heterogeneous porous sample. This methodology allows for extracting the equivalent seismic attenuation and phase velocity of the sample, but fails to provide any information with regard to the underlying physical processes.

In this work, we present a novel approach based on the quantification of the energy loss taking place in the interior of the considered heterogeneous rock sample. To this end, we first determine the spatial distribution of the energy dissipation in response to the applied oscillatory stresses. Next, we quantify the total dissipated energy as well as the peak strain energy stored during one harmonic oscillation cycle. We then use these two quantities to compute seismic attenuation as a function of frequency based on the classical definition of the quality factor. We perform an exhaustive numerical analysis considering a wide variety of 1D and 2D structures. This permits us to verify that thus inferred attenuation curves are in very good agreement with those obtained with the “conventional” dynamic-equivalent method. Moreover, the proposed methodology allows for identifying and exploring the regions within the considered samples where energy dissipation occurs in response to the prevailing types of mesoscopic heterogeneities. This, in turn, has the potential of fundamentally improving our understanding of the physical processes governing seismic energy dissipation in response to wave-induced fluid flow.