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Assessing the P-wave attenuation and phase velocity characteristics of fractured media based on creep and relaxation tests

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Fractures are present in most geological formations and they tend to dominate not only their mechanical but also, and in particular, their hydraulic properties. For these reasons, the detection and characterization of fractures are of great interest in several fields of Earth sciences. Seismic attenuation has been recognized as a key attribute for this purpose, as both laboratory and field experiments indicate that the presence of fractures typically produces significant energy dissipation and that this attribute tends to increase with increasing fracture density. This energy loss is generally considered to be primarily due to wave-induced pressure diffusion between the fractures and the embedding porous matrix. That is, due to the strong compressibility contrast between these two domains, the propagation of seismic waves can generate a strong fluid pressure gradient and associated pressure diffusion, which leads to fluid flow and in turn results in frictional energy dissipation.

Numerical simulations based on Biot's poroelastic wave equations are computationally very expensive. Alternative approaches consist in performing numerical relaxation or creep tests on representative elementary volumes (REV) of the considered medium. These tests are typically based on Biot's consolidation equations. Assuming that the heterogeneous poroelastic medium can be replaced by an effective, homogeneous viscoelastic solid, these numerical creep and relaxation tests allow for computing the equivalent seismic P-wave attenuation and phase velocity.

From a practical point of view, an REV is typically characterized by the smallest volume for which rock physical properties are statistically stationary and representative of the probed medium in its entirety. A more general definition in the context of wavefield attributes is to consider an REV as the smallest volume over which the P-wave attenuation and phase velocity dispersion are independent of the applied boundary conditions. That is, the corresponding results obtained from creep and relaxation tests must be equivalent. For most analyses of media characterized by patchy saturation or double-porosity-type structures these two definitions are equivalent. It is, however, not clear whether this equivalence remains true in the presence of strong material contrasts as those prevailing in fractured rocks.

In this work, we explore this question for periodically fractured media. To this end, we build a medium composed of infinite replicas of a unit volume containing one fracture. This unit volume coincides with the smallest possible volume that is statistically representative of the whole. Then, we perform several creep and relaxation tests on samples composed of an increasing number of these unit volumes. We find that the wave field signatures determined from relaxation tests are independent from the number of unit volumes. Conversely, the P-wave attenuation and phase velocity characteristics inferred from creep tests are different and vary with the number of unit volumes considered. Quite interestingly, the creep test results converge with those of the relaxation tests as the number of unit volumes increases. These findings are expected to have direct implications for corresponding laboratory measurements as well as for our understanding of seismic wave propagation in fractured media.