Poroelastic effects of the damaged zone on seismic fracture reflectivity

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The presence of fractures has a predominant influence on the hydraulic and mechanical behavior of rocks. These effects are particularly pronounced and relevant for otherwise largely impermeable and stiff formations. There is widespread evidence pointing to the ubiquitous presence of damaged zones surrounding fractures and faults. The enhanced permeability associated with these zones can promote fluid pressure diffusion in the vicinity of fractures when seismic waves travel through the corresponding subsurface volume. This process, together with the inherent mechanical weakness of damaged zones, is expected to affect the seismic reflectivity of fractures and faults. We investigate these effects based on Biot's theory of poroelasticity. To this end, we consider a 1D layered representation of the fracture and the associated damaged zone in conjunction with embedding elastic and impermeable half-spaces. We compare a fully elastic fracture-background reference model with a model consisting of a poroelastic fracture and damaged zone enclosed within an elastic background. For these two models, we compute the normal incidence seismic P-wave reflectivities at the background-fracture and at background-damaged zone interfaces, respectively. We also include a model that represents the fracture-damaged zone poroelastic system as an equivalent viscoelastic layer. We aim to test the validity of this representation since it would imply that a similar correspondence is possible to establish when more realistic descriptions of the damaged zone are considered. For this additional model, the viscoelastic layer is characterized by its frequency-dependent P-wave modulus, estimated by applying White's classical upscaling procedure for 1D poroelastic media composed of alternating layers. We test the validity of the elastic-viscoelastic model by comparing its reflectivity against the corresponding results from the elastic-poroelastic model. In doing so, we find that the simplified elastic-viscoelastic model faithfully reproduces the reflectivity of its elastic-poroelastic counterpart up to a threshold frequency, at which resonances produced within the viscoelastic layer become dominant. Overall, our results show that, in the seismic frequency range, there is a substantial increase in seismic fracture reflectivity resulting from the combined effects of fluid pressure diffusion and mechanical weakening associated with the surrounding damaged zone. This, in turn, indicates that the seismic reflectivity of a fracture may indeed be dominated by the thickness and physical properties of its surrounding damaged zone rather than by the properties of the fracture sensu stricto.