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Scattering attenuation in fracture systems: the critical opalescence of solids

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The phenomenon of critical opalescence occurs in a phase transition at the critical point. At this point the density contrast and the meniscus between liquid and vapour vanishes, and the two phases coexist as population of dispersed droplets and bubbles whose correlation length approaches the wavelength of light. The mixture is optically translucent (or 'opalescent') due to the multiple scattering that results. We examine an analogy to this phenomenon in the scattering of seismic waves, using a 2D numerical model for wave propagation in fractured media. Synthetic fractures are grown using a deterministic-stochastic multi-scale cellular automaton model which provides a set of synthetic data at various fracture densities and correlation lengths. This fracture population is then gridded to represent 'broken' or 'intact' cells, and each broken element is assigned a normal and tangential stiffness according to a local equivalent medium theory. A finite difference code is then used to model wave propagation through the medium. At low crack densities the macroscopic properties can be approximated by a macrosopic anisotropic equivalent medium theory with easily recognisable P and S-wave fronts. At critical crack densities, where the crack density is high and the correlation length is effectively infinite, the medium almost completely destroys the coherent P and S wave phases through multiply scattering, with a significant attenuation and an associated increase in the coda. This phenomenon is similar to critical opalescence of light, with the additional complication of including longitudinal waves and mode conversions. Above the critical point, deformation occurs as a single mega-fault, and the coherent part of the wavefield is recovered, with identifiable transmitted and reflected phases. Such modelling may be used in principle to infer fracture densities and correlation lengths from field data, and in principle to detect fluid pressure

changes in fracture populations using time-lapse seismic data.