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SEISMIC ATTENUATION IN POROUS ROCKS: MECHANISMS AND MODELS

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Understanding and modelling of attenuation and dispersion of elastic waves in fluid-saturated rocks is important for a range of geophysical technologies that utilise seismic, acoustic or ultrasonic waveforms and amplitudes. In particular, lateral variations of the attenuation in the overburden can distort seismic amplitudes from deeper targets, leading to errors in earth characterisation. Conversely, seismic attenuation is controlled by subsurface properties and thus has a potential to be used as an attribute for subsurface characterisation.

A major cause of elastic wave attenuation is viscous dissipation due to the flow of the pore fluid induced by the passing wave. Wave-induced fluid flow (WIFF) occurs as the passing wave creates local pressure gradients within the fluid phase and the resulting fluid flow causes internal friction until the pore pressure is equilibrated. The fluid flow can take place on various length scales. Wavelength-scale fluid pressure relaxation between peaks and troughs of a passing wave is known as global or macroscopic flow as described by Biot's theory of poroelasticity. WIFF caused by spatial variations of matrix or fluid properties on a scale much smaller than the wavelength but much larger than individual pore size is known as mesoscopic flow. Most common manifestations of the mesoscopic attenuation is WIFF between pores and fractures, or between patches of rock saturated with different fluids. Pore-scale WIFF, known as local or squirt flow occurs between more compliant voids (cracks, grain-to-grain contacts) and relatively stiff pores. When the rock is compressed, much greater pressure builds up in compliant than stiff pores, resulting in the fluid pressure gradient, fluid flow and dissipation. A similar mechanism causes very substantial seismic attenuation in rocks saturated with viscoelastic substances such as heavy oil or bitumen.

Despite major advances in theoretical modelling and laboratory measurements of attenuation, connecting these models to seismic observations remains a challenge. To address this challenge we develop an early-arrival waveform inversion (WI) approach to estimation of scattering and intrinsic P-wave dissipation factors Q_P^{-1} from zero-offset downhole seismic measurements. The inversion is based on the full-wave simulation over a thin-layered viscoacoustic model constrained by sonic and density logs. High-resolution logs provide information on the finely-layered structure of the subsurface, and hence, allow one to model explicitly spectra fluctuations and phase distortions associated with the interference and multiple scattering in the layered subsurface. Depending on the scale of logs supplied into the inversion, it can recover either intrinsic Q_{int}^{-1} or total Q_{eff}^{-1}. In turn, scattering attenuation can Q_{scat}^{-1} be deduced from the inverted effective and intrinsic dissipation factors. The inversion modelling is based on the plane wave propagation over complex reflectivity matrices and is limited to the assumption of the horizontally layered subsurface. We also assume that the absorption and its associated dispersion can be described through a constant Q-model for the band-limited VSP experiment (5-200 Hz). The full-wave synthetic tests and two field VSP case-studies show that the proposed WI can separate scattering versus intrinsic attenuation and estimate Q^(-1) in a robust manner even in small depth windows (~ 200 m).