Introduction to this special section: Attenuation dispersion

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Extracting quantitative reservoir rock and fluid properties from seismic waves is of paramount importance to improve reservoir productivity and well targeting. There have been significant efforts to extract this information from wave dispersion and attenuation. Dispersion is the variation of velocity with frequency, whereas attenuation is the loss of wave amplitudes with distance. The details in dispersion and attenuation depend on the rock microstructure, larger-scale geology, and fluids. This special section addresses several of these considerations in theory and laboratory settings.

Seismic waves attenuate as a result of geometric spreading and scattering, even in elastic media. Anelasticity, also called intrinsic attenuation, can be viewed as a loss of seismic energy to some other form. Although geometric spreading can easily be accounted for, separating scattering from intrinsic attenuation remains an interesting and challenging problem. In a dissipative earth, attenuation and dispersion are coupled, as described by Kramers-Kronig relations (Bourbié et al., 1987). For scattering attenuation, we have the relationships defined by O'Doherty and Anstey (1971). This means that in principle, independent measurements of attenuation and dispersion can and should be validated.

In exploration geophysics, there are two main reasons to study wave attenuation and dispersion. On one hand, an attenuation model is extracted from field data with the purpose of improving the seismic image. In this case, the physical nature of the attenuation is not the (main) interest. On the other hand, advances in data acquisition and processing (e.g., full-wavefield inversion, high-resolution imaging with streamer technology, and OBS) have opened the door to extracting quantitative fluid and rock properties directly from seismic data. However, the biggest challenge for directly estimating the rock and fluid properties from field seismics is that the aforementioned mechanisms that contribute to wave attenuation are coupled. Robust methods to extract attenuation from seismic data are topics of active research (Dasgupta and Clark, 1998; Toverud and Ursin, 2005; Chapman et al., 2006; Reine et al., 2012).

Separate measurements of wave-induced fluid-flow attenuation and dispersion can be performed in the laboratory and form the largest contribution to this special section. Field and laboratory measurements show that in many instances, wave attenuation depends substantially on frequency. Therefore, laboratory data on wave attenuation and dispersion at seismic frequencies (below 200 Hz) are required to validate theoretical models that ultimately would be used to interpret field seismic observations. However, this is no easy task because low-frequency laboratory experiments are complicated to perform. This special section brings together most of the facilities around the world that are capable of performing such seismic frequency measurements in the laboratory. The following articles introduce their experimental apparatuses and show results in a variety of rocks. It may be of interest to the community and beyond to have these laboratories measure a set of the same rocks to push the quality of all laboratories to an even higher level.

Caspari et al. explain the observed seismic wave attenuation and velocity dispersion in patchy-saturated rocks by wave-induced fluid flow. They show that mesoscale fluid patches in continuous random-media models, based on Biot's theory, can explain wave attenuation at a range of scales: from laboratory data, time-lapse well logs, and numerical seismic simulations. This allows them to estimate the size of the fluid patches that predict their data best.

Mikhaltsevitch et al. measure with a stress-strain apparatus the frequency dependence of Young's modulus and attenuation on high- and low-permeability dry and water-saturated sandstones. They show that sandstone permeability can be responsible for the observed frequency dependence of moduli and attenuation. Their data follow Kramers-Kronig causality principle and have implications on the applicability of Gassmann's fluid-substitution model at seismic frequencies for these samples.

Li et al. compare the effect that cracks have on the shear modulus frequency dependence between megahertz and megahertz by measuring fractured quartzite and synthetic sintered glass-bead samples. Based on their laboratory analysis, they describe the effect that pressures and fluids have on the frequency dispersion of the shear modulus. They argue that in low-permeability rocks, the transition between relaxed and unrelaxed pore-fluid pressures occurs between seismic and ultrasonic frequencies, and thus care should be taken when applying megahertz elastic data to seismic data analysis in such rocks.

Liner proposes to extend layer-induced scattering attenuation to a constant-Q model with a known relationship between attenuation and dispersion. He argues that this may be a way to extend the well-known Backus-averaging effects on velocity to seismic attenuation.

Tisato et al. calibrate Young's modulus and attenuation measurements at seismic frequencies with detailed numerical modeling of Berea Sandstone. Their experimental design is also capable of measuring induced transient pore-fluid pressures inside the rock samples. Mesoscopic-scale fluid-flow numerical models are combined with these data to predict the laboratory-measured wave attenuation as a function of frequency.

Fortin et al. develop an apparatus that measures the bulk modulus of dry and saturated samples at less than a hertz and at 1 MHz. At low frequency, samples behave as though drained and the saturated modulus is estimated with Gassmann's relation. The bulk-modulus dispersion of Fontainebleau Sandstone and a basalt sample are quantified by comparing this estimate to the observations at 1 MHz. An elastic effective-media theory is used to evaluate the crack density and aspect ratio responsible for the observed dispersion in the laboratory measurements.

Batlze et al. present observations of different viscoelastic mechanisms that are responsible for frequency-dependent elastic moduli and attenuation on samples in the laboratory. Dissipation resulting from fluid flow is the primary mechanism in permeable rocks, but movement of bound water in mudstones might be an important mechanism, which so far has not received much attention. Moreover, they show that the dissipation in heavy oils can be caused by the oil itself. TLE

References

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