ATTENUATION OF SEISMIC WAVES IN ROCKS AND APPLICATIONS IN ENERGY EXPLORATION

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ABSTRACT

One of the least understood aspects of seismic wave propagation in the earth is the absorption or dissipation of wave energy into heat. This study presents results relating to four aspects of this problem.

The first is the development of a mathematical description for the general elastic response and wave propagation in materials where the specific loss or Q factor is exactly independent of frequency. From the fundamental constraints of linearity and causality, relations for the frequency-dependence of velocity and for the evolution of transient pulses are developed. The case where Q varies slowly with frequency is also treated, as well as the effects of Q on reflection coefficients at interfaces between two different materials.

Next we take a close look at one particular mechanism for the dissipation of energy, thermal relaxation. This mechanism, which affects compressional waves more than shear waves, is highly sensitive to the state and the nature of the pore fluids. When the pore fluid is water, a rapid increase of attenuation with temperature is expected, up to the boiling point. When the pore space contains mixtures of gas and liquid phases, the attenuation is sensitive to pore pressure and gas saturation in a manner that complements the dependence of velocity on these variables. Especially large losses are expected when small amounts of gas are introduced into an otherwise liquid-saturated rock. Solubility of the gas in the liquid and phase transitions leads to an even greater absorption.

The third section deals with wave propagation in media where attenuation and velocity are spatially heterogeneous. Finite-difference solutions to the wave equation, similar to those used in the oil-exploration industry in the migration of seismic reflection data, are developed to include the effects of absorption, as well as arbitrary spatial heterogeneities. This makes it possible to model the seismic response for geologically realistic situations.

Finally, methods are developed to extract information about spatial variations of attenuation and velocities from seismic reflection data. The approach used is similar to that used in medical tomography. The application of the inversions to amplitude and traveltime data from unstacked common-

midpoint reflection data, yields detailed pictures of the subsurface. The interpreted attenuation and velocity anomalies show correlations with diffractions observed on the common-offset reflection sections.

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