Chapter I

INTRODUCTION

One of the fundamental aspects of elastic wave propagation in all materials, and in rocks in particular, is the absorption and irreversible conversion of wave energy into heat. A large body of experimental knowledge indicates that the distance that a wave propagates in any rock is roughly proportional to the wavelength. Although the fraction of energy dissipated during each cycle is, thus, nearly independent of frequency, the loss in rocks is highly variable from one rock to another and it is also sensitive to changes in the environmental conditions. The specific loss factor, Q, has, for example, been known to change by several orders of magnitude when a nominally dry sample is placed under vacuum.

The ultimate resolution that can be achieved in any seismic experiment is related to the intrinsic attenuation. For a given signal-to-noise ratio, the resolution is basically a function of Q. As an example, it has been suggested that the use of shear waves in reflection seismology might give better resolution than obtained using P-waves, because the lower velocity of S-waves would imply shorter wavelengths. This hope was not realized since the attenuation for shear waves is usually no less than for P-waves, and the usable propagation distance is thus no greater when measured in wavelengths.

In recent years it has been recognized that attenuation and velocity are related in such a way that a full understanding of traveltimes or other observations that have traditionally been used to infer velocities requires a knowledge of the absorption properties. This applies particularly when the mechanical response of the same material is measured at widely separate frequencies or time scales. For example, information about the response of the mantle comes from plate tectonics, postglacial uplift, Chandler wobble, free oscillations and body waves. In order to relate observations in one of those bands to those in another, the effects of anelasticity must be accounted for.

A similar situation exists in exploration seismology where one wants to relate observations from reflection experiment in the range of a few tens of hertz, results from well logs at a few kilohertz and ultrasonic measurements on cores at frequencies around one megahertz.

In order to estimate attenuation from observational data, it is necessary to make some assumptions about the velocity structures. Numerous small-scale inhomogeneities can cause apparent attenuation through scattering and intrabed multiple reflections [Schoenberger and Levin, 1978]. In estimating attenuation and velocity from observations, there is considerable trade-off between absorption and velocity in that a given set of observations may often be satisfied either by a simple attenuation structure and a complex velocity structure, or a more complex attenuation structure and a simpler velocity structure. It follows that in order to obtain optimum estimates of either velocity or attenuation, an estimate of the other is also needed.

In the first chapters of this thesis, the constraints of linearity and causality are applied to obtain fundamental relations between velocities at different frequencies when the specific loss factor, or Q, is either independent of, or slowly varying with, frequency. The implications for transient pulse propagation and reflections are explored in some detail.

Chapter V presents a close look at a particular mechanism for absorption in heterogeneous media, thermal relaxation and phase transitions involving pore fluids. This is a well-known mechanism for absorption in solids; however, our results indicate that the presence of fluids will greatly increase the effect of this loss mechanism. A review of other mechanisms is given by Mavko et al. [1979].

In Chapter VI, numerical techniques for the computation of wave propagation in inhomogeneous media are developed which include the effects of absorption. The approach chosen for this turns out to be advantageous for wavefield extrapolation in heterogeneous media even when the effects of absorption are not included, and has been extensively used to migrate reflection data collected by the Consortium for Continental Reflection Profiling (COCORP) [Lynn et al. 1979; Lynn, 1979].

In the final chapter methods are developed to determine details of the spatial variations of wave-propagation parameters above a strong reflecting horizon from multichannel seismic reflection data. The theory is equally applicable to attenuation and velocity. Application of these inversion methods to data from a producing gas field shows a detailed pattern of amplitude and velocity variations which correlate with each other and with reflections observed on common-offset seismic sections.

Not only is it desirable from a theoretical viewpoint to consider velocity and attenuation together, but it also turns out that some of the methods that work best for modeling or inversion of attenuation also give very good results when applied to velocity data.