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volume change, apart from an elastic effect which can be represented by an isotropic moment tensor, has a direct gravitational effect on the excitation. This effect is due to a balanced force field consisting of a point force at the source and a continuous distribution of volume forces throughout the earth. The latter distribution, if not taken into account, may give rise to artificial phases in the frequency spectrum of the normal modes.

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Vlaar, N.J.: On the excitation of the earth's seismic normal modes. Pure and Appl. Geophys. **114**, 863–875, 1976

Seismic Velocities and Density of an Attenuating Earth

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The dispersion that accompanies attenuation has been taken into account in many recent body wave studies. In free oscillation and surface wave investigations, however, the effect has been assumed to be of second order and, hence, has been ignored. Liu, Anderson, and Kanamori (1976) have recently re-examined this effect and have shown it to be first order across the seismic band. In order to compare data from different frequency bands, then, a frequency-dependent correction must be applied to the observed phase velocities. The corrected data will then be representative of the elastic properties of the earth at the selected reference frequency. In the case of the free oscillations and long-period surface waves corrected to body wave frequencies (about one cycle/s), this correction factor is of the order of 1%, many times larger than the uncertainty of the raw data.

As a first step in determining the appropriate attenuation corrections, a satisfactory Q model must be developed. We have used free oscillation, surface wave, and body wave observations to obtain a new average Q structure for the earth, designated model SL1. This model includes a low Q zone at both the top and the bottom of the mantle. In these regions, seismic velocities will be frequency dependent. This Q model has been used to correct the observed eigenperiods of the spheroidal and toroidal modes to a reference period of 1 s. The corrected data set was then inverted to obtain the radial variation of density and seismic velocities within the earth. The largest changes from previous gross earth models, obtained through inversion of uncorrected data, occur in the upper mantle and at the very base of the lower mantle. In the upper 700 km of the earth, the inferred compressional and shear velocities increase by about 2% over previous results. The resulting body wave travel-times no longer show the large discrepancies with times predicted by body wave studies. In particular, the shear wave travel-times show only a 1.0 s baseline shift relative to the Jeffreys-Bullen values as compared to the 6–10 s shift of past models. Deep continental-oceanic mantle differences are no longer required to explain this feature.

The fact that seismic velocities depend significantly on frequency considerably complicates efforts to determine the structure and composition of the mantle. A detailed knowledge of the frequency dependence of Q from ultrasonic frequencies to normal mode frequencies as well as the distribution of attenuation with depth is necessary before seismic data can be interpreted with confidence. The development of a Standard Earth is substantially hindered as well. If the Standard Earth is a valid concept, then a standard Q model and reference frequency must also be developed. Work in this area is only just barely beginning. Further, elastic properties at tidal and Chandler periods differ from those at seismic periods and this also restricts the application of a Standard Earth Model.

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A First-Motion Alternative to Geometrical Ray Theory

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In recent years, the direct measurements of the seismic ray parameter and comparisons with synthetic seismograms have improved the interpretations of seismic data. This is particularly true of structure near interfaces in both the crust and deep interior of the earth. Until very recently, however, the computation of synthetic seismograms was too expensive and complicated for routine use. In addition several approximations were necessary in the theory. In this paper the approximations used in generalized ray theory are investigated in more detail and a new approximation is derived.

The generalized ray method is extended to vertically inhomogeneous media without approximation by homogeneous layers (Chapman, 1976a). The response is obtained as an infinite series of depth integrals rather than a summation of many rays. It is shown that this series converges rapidly to geometrical ray theory when the latter is valid. However, it is still expensive to compute the multiple integrals and a simple approximation exists for the infinite series. This we call the *first-motion approximation.*

The first-motion approximation is equivalent to geometrical ray theory but remains valid at caustics and shadows. The same approximation can be derived from generalized ray theory, the WKBJ approximation (Chapman, 1976b) or an intuitive physical argument (disk ray theory). The approximation is sufficiently simple that computations can be performed on a routine basis from the travel-time curve. Comparisons of synthetic seismograms using the first-motion approximation and other methods have been made. The method is sufficiently simple that it can be extended to cases where the WKBJ approximation is invalid, to laterally inhomogeneous and attenuating models and to the inverse problem.

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