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I. APPLICATION OF NORMAL MODE THEORY TO SEISMIC SOURCE AND STRUCTURE PROBLEMS

II. SEISMIC INVESTIGATIONS OF UPPER MANTLE LATERAL HETEROGENEITY

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Abstract

In Part I, the theory of the normal modes of the Earth is investigated and used to build synthetic seismograms in order to solve source and structural problems. After a study of the physical properties of spheroidal modes leading to a rational classification, two specific problems are addressed: the observability of deep isotropic seismic sources and the investigation of the physical properties of the Earth in the neighborhood of the Core-Mantle boundary, using SH waves diffracted at the core's surface.

In Chapter 1, it is shown that five different families of spheroidal modes can be isolated on the basis of their physical properties, including group velocities, attenuation and excitation functions. Except for a few hybrid modes, these families are arranged in "pseudo-overtone" branches, along which physical properties vary smoothly. The simplified model of a spherical, non-gravitating Earth is used to give a theoretical description of the properties of modes with low angular orders. Their group velocity is shown to be consistent with the physical concept of dispersion along a pseudo-overtone branch, thereby justifying the use of asymptotic expansions along them in generating synthetic seismograms. An interpretation of the existence of the various families in terms of an increase in mode-coupling with angular order is presented. A formal classification of the spheroidal modes into the five families is made, and a new nomenclature reflecting the physical properties of the modes is proposed.

In Chapter 2, the relative excitation of body and surface waves

by isotropic and deviatoric sources is studied as a function of depth and frequency. Since the fundamental Rayleigh wave excitation dies off faster as a function of frequency and depth for isotropic than for deviatoric sources, an ultra-long period record at Pasadena of the Colombian deep shock of 1970 (for which a compressional precursor was proposed), is studied and compared to synthetic seismograms calculated for several source models. The best agreement is obtained for a pure double-couple source. Linear combinations of synthetics for deviatoric and isotropic sources are tested for a wide range of relative amplitudes, showing the data to be little sensitive to the presence of a reasonably large isotropic component.

In Chapter 3, profiles of seismic shear waves diffracted around the core (Sd) for three deep events recorded at stations across North America and the Atlantic Ocean are used to determine the properties of the lower mantle in the vicinity of the core-mantle boundary. The S wave velocity above the surface of the core is found to be 7.22 ± 0.1 km/s, in agreement with gross Earth models, but higher than previously reported values from direct measurements of Sd. No evidence for a low-velocity zone in the lower mantle is found. Synthetic seismograms for Sd are easily generated through normal mode summation. A comparison of the present data with a synthetic profile for Earth model 1066A gives excellent agreement at periods greater than 45 seconds. Synthetics for other models confirm the absence of a strong low-velocity zone at the base of the mantle, and are used to strongly constrain any possible rigidity of the uppermost layers of the core.

In Part II, data sets of seismic body and surface waves are used in a search for possible deep lateral heterogeneities in the mantle. In both cases, it is found that seismic data do not require structural differences between oceans and continents to extend deeper than 250 km. In general, differences between oceans and continents are found to be on the same order of magnitude as the intrinsic lateral heterogeneity in the oceanic plate brought about by the aging of the oceanic lithosphere. A consistent similarity is inferred between stable shields and the oldest parts of the oceans.

In Chapter 1, an analysis of records of multiply reflected ScS phases from ten deep focus earthquakes yields near-vertical one-way travel-time residuals ranging from -3.5 to +5.0 seconds. Continental and oceanic residuals overlap, and both indicate large lateral variations. Similar values are found for the older oceanic basins (Western Pacific, Brazil Basin) and continental shields. Most, if not all, of the variations can be attributed to differences in the lithosphere and asthenosphere, down to a depth of 200 km, and the present results are in good agreement with local models derived by independent means. Oceanic islands are found to be anomalous with respect to the neighboring ocean floor, the mantle beneath Hawaii, Iceland and Trindade (South Atlantic) being exceptionally slow.

In Chapter 2, Rayleigh wave phase velocities at very long periods (185 to 290 seconds) are investigated and regionalized, taking into account the lateral heterogeneities in the oceanic plates revealed by earlier studies at shorter periods. The two-station method is applied to a few 'pure-age' oceanic paths, and is shown to

be compatible with an average gross Earth model below depths of 180 km. Under this assumed oceanic model, regionalized for age above 180 km, continental velocities are derived from a set of experimental great-circle values, both new or taken from previously published studies. The results basically agree with the earlier studies by Kanamori or Dziewonski, and it is suggested that the assumption of a uniform oceanic model may have been responsible for some scatter in Kanamori's solution. The results of the present inversion are successfully checked against a set of values derived by the two-station method from a pure continental, tectonic, path. A recent event in Indonesia is then used as a further independent check, in what is believed to be the first experimental determination of Rayleigh wave phase velocities over a pure shield path at very long periods. The shield velocities fall within the range of variation of their oceanic counterparts with the age of the plate, in agreement with the results of Chapter 1. This makes velocities derived theoretically from models involving deep continent vs. ocean lateral heterogeneities inconsistent with the present set of experimental data. Finally, it is shown that Dziewonski's model S2 reconciles all experimental seismic data relative to shields without being significantly different from oceanic models below 240 km.