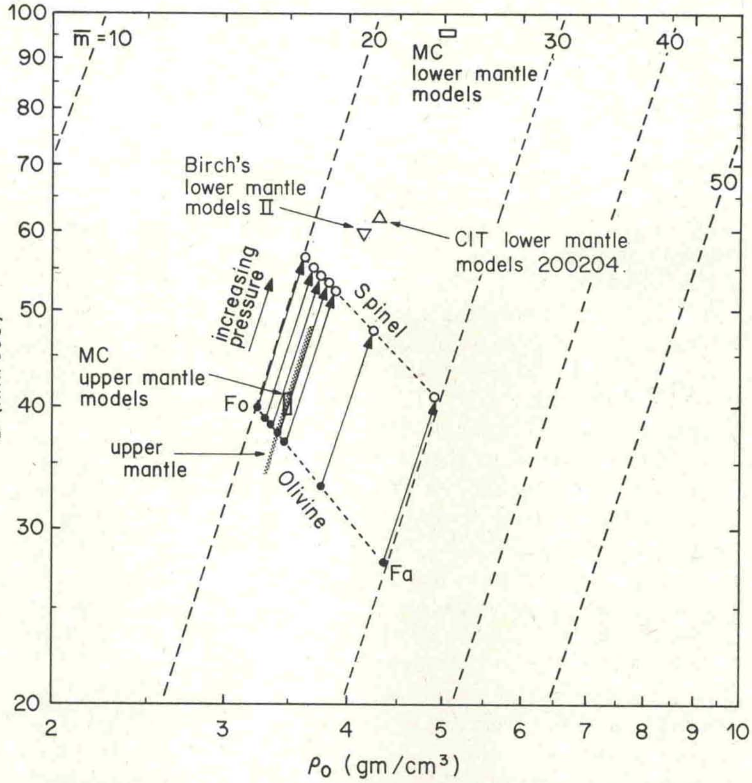

Fig. 2. The seismic parameter–density relation for olivine with different Fe/Mg ratios. The contours are derived from D. Anderson's Φ law. The closed circles show experimental quantities; the open circles show hypothetical data points. Various models of the upper and lower mantles are indicated in the figure. The range of Monte Carlo (MC) successful models is shown by rectangles.

point meets at the intercept of the two lines drawn from the density and the mean atomic weight surprisingly well.[2] If we were to assume that the olivines of other compositions behave similarly, a series of lines parallel to a specific mean atomic weight characterized by the Fe/Mg ratio in the olivine composition can be drawn. Knowing the end-point density of the spinel of the given composition, then one is able to estimate velocity in that spinel phase. In this manner, both the compressional- and the shear-wave velocities in the spinel phase were found; they are plotted in Figure 1 for the compressional-wave velocity as an example. These hypothetical data points are identified in the figure with open circles.

The geophysical significance of these estimated data points, though they are subjected to confirmation, should not be underestimated. As noted by *D. L. Anderson* [1967*a*], recent progress in seismological advances (surface waves, free oscillations, large seismic arrays studies, etc.) make it possible to refine the standard velocity-depth profiles of Bullen, Gutenberg, Jeffreys, and Lehmann. One of the more significant contributions is a refinement of the velocity-depth profiles in Bullen's *C*- region ranging from about 400 km down to 1000 km in depth. Surface wave studies by *D. L. Anderson and Toksöz* [1963] demonstrated, for example, that this region consists of a series of relatively thin

[2] Both D. L. Anderson and O. L. Anderson, during their respective presentations at the Birch symposium in April 1970, made similar observations. On the basis of data presented by *Mizutani et al.* [1970], the same observation was also noted by *Liebermann* [1970] in a paper that has just appeared in this journal. The writer expresses his thanks to R. C. Liebermann for sending a copy of his paper along with a review as a referee for the present report.

(about 50 km thick) regions of a rapid increase in velocity. *D. L. Anderson* [1967*a*] further noted that the most notable of these discontinuities occur at depths near 400 and 600 km. Most of the discontinuities can be attributed to solid-solid phase changes that have been directly observed in the laboratory or inferred from studies of the behavior of analog compounds or shock-wave studies [see, for a recent review, *Ahrens et al.*, 1969]. From the laboratory measurements, it has been inferred that near 400 km olivine collapses to the spinel or 'pseudospinel' phase with 8% (for Fe_2SiO_4) to 10% (for Mg_2SiO_4) increase in density.

The seismic parameter–density–mean atomic weight relation for olivine is shown in Figure 2. The contours of the mean atomic weights drawn in the figure are derived from Anderson's Φ law [*D. L. Anderson*, 1967*b*]. (See also *D. L. Anderson* [1969] for a modification). Figure 2 shows the effect of the Mg-Fe substitution in the olivine solid-solution system. Clearly shown here is that the iron substitution in the olivine lattice is very sensitive to the seismic parameter. The seismic parameters inferred from the estimated velocities of spinels are entered also in Figure 2 and identified with open circles. The widely inferred models of the upper and lower mantles [*Birch*, 1961*b*, 1964; *Clark and Ringwood*, 1964; *Anderson*, 1967*b*; *D. L. Anderson and Smith*, 1968] are indicated in the figure. The range of Monte Carlo successful models for the upper and lower mantles given by *Press* [1968*a*, *b*] is also shown by rectangles in the figure. It is seen that the present data on the seismic parameters obtained for olivine with about 83% Fo agree very well with Press's upper-mantle models.

Although olivine may be the most abundant mineral in the upper mantle, a more realistic discussion of the petrology of the mantle from the elasticity studies must include information on the elastic properties of pyroxene and garnet and their variations with pressure and temperature for these minerals. In a subsequent series of communications, we shall report these data; only then will a discussion of the elasticity and composition of the mantle be attempted.

Acknowledgments. I wish to thank W. F. Brace for reading the manuscript and for valuable suggestions. I am grateful to members of the MIT Department of Earth and Planetary Sciences for giving me the opportunity to discuss early stages of this work at a seminar.

This research was supported by National Science Foundation grant GA-11091.

References

Adams, L. H., The compressibility of fayalite, and the velocity of elastic waves in peridotite with different iron-magnesium ratio, *Beitr. Z. Geophys.*, *31*, 315–321, 1931.

Ahrens, T. J., D. L. Anderson, and A. E. Ringwood, Equations of state and crystal structures of high-pressure phases of shocked silicates and oxides, *Rev. Geophys.*, *7*, 667–707, 1969.

Akimoto, S., and H. Fujisawa, Olivine-spinel solid solution equilibria in the system $MgSiO_4$–Fe_2SiO_4, *J. Geophys. Res.*, *73*, 1467–1479, 1968.

Anderson, D. L., Phase changes in the upper mantle, *Science*, *157*, 1165–1173, 1967*a*.

Anderson, D. L., A seismic equation of state, *Geophys. J.*, *13*, 9–30, 1967*b*.

Anderson, D. L., Bulk modulus systematics, *J. Geophys. Res.*, *74*, 3857–3864, 1969.

Anderson, D. L., and O. L. Anderson, The bulk modulus–volume relationship for oxides, *J. Geophys. Res.*, *75*, 3494–3500, 1970.

Anderson, D. L., and M. Smith, Mathematical and physical inversion of gross earth geophysical data (abstract), *Trans. AGU*, *49*, 283, 1968.

Anderson, D. L., and M. N. Toksöz, Surface waves on a spherical earth, 1, Upper mantle structure from love waves, *J. Geophys. Res.*, *68*, 3483–3500, 1963.

Anderson, O. L., and J. E. Nafe, The bulk modulus–volume relationship for oxide compounds and related geophysical problems, *J. Geophys. Res.* *70*, 3951–3963, 1965.

Birch, F., The velocity of compressional waves in rocks to 10 kb, 1, *J. Geophys. Res.*, 65, 1083–1102, 1960.

Birch, F., The velocity of compressional waves in rocks to 10 kb, 2, *J. Geophys. Res.*, *66*, 2199–2224, 1961*a*.

Birch, F., Composition of the earth's mantle, *Geophys. J.*, *4*, 295–311, 1961*b*.

Birch, F., Investigations of the earth's crust in IUGG *Monograph 22*, edited by M. Båth, p. 24, International Union of Geodesy and Geophysics, Paris, 1962.

Birch, F., Density and composition of mantle and core, *J. Geophys. Res.*, *69*, 4377–4388, 1964.

Birch, F., Density and composition of the upper mantle: First approximation as an olivine layer, in *The Earth's Crust and Upper Mantle*, *Geophys. Monogr. 13*, edited by P. J. Hart, AGU, Washington, D. C., 1969.

Brace, W. F., C. H. Scholz, and P. N. LaMori, Isothermal compressibility of kyanite, andalusite, and sillimanite from synthetic agregates, *J. Geophys. Res.*, *74*, 2089–2098, 1969.

Christensen, N. I., Elasticity of ultrabasic rocks, *J. Geophys. Res.*, *71*, 5921–5931, 1966.

Christensen, N. I., Chemical changes associated