bilities. This correction lowers the 10-kb velocities by approximately ½%.

The directions of wave propagation were selected according to the symmetry of olivine fabric for each specimen. Dunite A with a strong maximum of olivine *a* axes was treated as uniaxial, and dunite B with strong concentrations of all three olivine axes was considered orthorhombic in symmetry. The relations between wave velocity, the directions of propagation and displacement, and the elastic constants in materials of hexagonal and orthorhombic symmetry [*Love*, 1944; *Hearmon*, 1961] are given in Table 3, along with the dunite velocities.

Discussion

The fabric of dunite A consists of a strong concentration of olivine *a* axes and girdles of olivine *b* and *c* axes (Figure 1). The symmetry axis of this specimen, which is parallel to the olivine *a* axes concentration, is the direction of fast longitudinal wave velocity. This is in agreement with longitudinal wave velocities measured in single crystals of olivine [*Verma*, 1960; *Graham and Barsch*, 1969; *Kumazawa and Anderson*, 1969] which are fast parallel to the olivine *a* axis.

The several cross checks given in Table 3 clearly demonstrate the uniaxial nature of dunite A. Longitudinal wave velocities for propagation directions normal to the strong olivine *a* axes concentration are similar to one another. Transverse wave velocities for propagation parallel to the olivine *a* axes maximum do not vary significantly with displacement direction. For propagation normal to the olivine *a* axis maximum, two transverse waves with different velocities are propagated through the rock. This is illustrated in Figure 2, where in the upper oscilloscope trace the faster transverse wave is received. Rotation of the transducers through steps of 15° decreases the amplitude of the faster wave until only the slower wave is received.

The fabric diagrams of dunite A show weak maximums of olivine *b* and *c* axes in the x_1-x_2 plane. However, the presence of these maximums is not substantiated by the ultrasonic measurements. For example, the weak *b* axes maximums in Figure 1*B* should produce a relatively low longitudinal wave velocity, V_{A13}, which is not observed. This illustrates the advantages of using velocities that provide averages of the degree of orientation for large numbers of crystals over standard optical techniques.

Wave propagation in dunite *B* is similar to wave propagation in orthorhombic crystals. This specimen has strong concentration of all three olivine axes (Figure 1). The fastest longitudinal wave velocity is found for propagation parallel to the olivine *a* axes maximum, whereas propa-

TABLE 4. Elastic Stiffnesses, mb

	Pressure, kb					
	1.0	2.0	4.0	6.0	8.0	10.0
			Dunite A			
c_{11}	2.00	2.02	2.05	2.07	2.08	2.09
c_{33}	2.40	2.43	2.47	2.50	2.52	2.53
c_{44}	0.68	0.69	0.70	0.71	0.71	0.71
c_{12}	0.77	0.79	0.80	0.80	0.81	0.82
c_{13}	0.98	0.98	1.00	1.02	1.02	1.02
			Dunite B			
c_{11}	2.65	2.69	2.74	2.76	2.78	2.80
c_{22}	1.95	1.97	2.00	2.02	2.04	2.05
c_{33}	2.16	2.19	2.23	2.25	2.27	2.29
c_{44}	0.71	0.72	0.74	0.75	0.76	0.76
c_{55}	0.79	0.79	0.80	0.81	0.82	0.82
c_{66}	0.72	0.73	0.75	0.76	0.77	0.78
c_{12}	0.96	0.98	0.98	0.99	1.00	1.02
c_{13}	0.73	0.77	0.79	0.81	0.83	0.85
c_{23}	0.68	0.69	0.70	0.72	0.74	0.76

gation parallel to the *b* axes concentration is characterized by the lowest velocity. This is in agreement with single-crystal measurements of olivine. Two transverse waves with different velocities are propagated parallel to each olivine maximum (Table 3). For this specimen, the tranverse wave velocities are $V_{B2} \simeq V_{B6}$, $V_{B3} \simeq V_{B8}$, and $V_{B5} \simeq V_{B9}$, which confirms the orthorhombic symmetry of the sample.

The velocities for most of the cross checks of the two dunites agree remarkably with single-crystal elastic theory. However, the two dunites do not behave as perfect single crystals. This is not surprising, since several different cores from each dunite were used for the measurements in Table 3. As is shown by their densities (Table 3), the cores differ slightly from one another in accessory mineral content. In addition, olivine orientation most likely varies slightly from core to core.

By using the velocities in Table 3 and mean values of the cross checks, the elastic stiffnesses have been calculated for the two dunites. These are given in Table 4 for several pressures. The mean atomic weights and the Voigt and Reuss averages for isotropic aggregates are given at several pressures for both dunites in Table 5. The formulas and significance of these two averaging techniques have been discussed in many papers [e.g., *Hearmon,* 1961; *Birch,* 1961; *Christensen,* 1965] and will not be repeated here. Using the standard equation for accidental errors in compound quantities [*Topping,* 1966], the VRH averages of the bulk and shear moduli are accurate to 6% and 2%, respectively.

The physical properties for isotropic aggregates of the two dunites are compared in Table 5 with the elastic properties measured for a single crystal of olivine ($Fo_{93}Fa_7$) by *Kumazawa and Anderson* [1969]. The differences in the properties of the dunites and the olivine single crystal are due to many factors that complicate the elasticity of rocks. Both rock samples contain accessory minerals which undoubtedly influence their elastic properties. In addition, the olivine in the dunites is slightly more iron-rich than the single-crystal olivine studied by Kumazawa and Anderson.

Dunite A contains more than 10% serpentine, which has been shown by *Christensen* [1966*b*] to have a significant effect on the elastic properties of dunites and peridotites. The relatively high Poisson's ratio and the lower velocities for dunite A (Table 3) are a consequence of this partial serpentinization. Partial serpentinization also appears to influence the pressure derivatives of the velocities of dunite. *Birch* [1961] has shown that the closure of grain boundary cracks is responsible for the sharp rise in velocity with increasing pressure below 2 kb. Above a few kilobars, the change in velocity with increasing pressure was interpreted as an intrinsic property related to the elasticity of the constituent minerals. The pressure derivatives of the longitudinal wave velocity for dunite B above 2 kb are somewhat higher than the pressure derivatives for single-crystal olivine, whereas the pressure derivatives for the transverse wave velocities are close to single-crystal measurements. This suggests that above 2 kb grain boundary cracks are still influencing the longitudinal velocities but have little effect on the transverse wave velocities. The pressure derivatives for dunite A, on the other hand, are in closer agreement with the olivine single crystal measurements. Serpentinization in dunite A is common along grain boundaries and has most likely eliminated the effect of grain boundary cracks on velocities above a few kilobars.

The elastic properties of rocks are usually described in terms of the theory of isotropic elasticity. In calculating the elastic constants of rocks, it is common to use mean velocities for three propagation directions [e.g., *Birch,* 1961; *Christensen,* 1966*a, b*]. Since the calculations usually involve squared velocities, the resulting accuracies in the elastic constants are considerably less than the accuracies of the velocities. In highly anisotropic rocks such as dunite, mean velocities for measurements in only three orthogonal directions produce additional uncertainties in calculated isotropic constants. Examination of Tables 3 and 5 suggests, however, that simple mean velocities from measurements in three mutually perpendicular directions give values close to true isotropic elastic properties in highly anisotropic rocks. The mean longitudinal velocity at 10 kb from the velocities V_{A1}, V_{A4}, and V_{A7} is 8.24 km/sec, compared to a VRH value of 8.29 km/sec. For dunite B, mean longitudinal-wave velocity at 10 kb determined from the orthogonal set V_{B1}, V_{B4}, and V_{B7} is 8.42 km/sec. This agrees well with the VRH value of 8.45 km/sec.