TABLE 1. Composition and Measured Properties of Various Olivine Samples (at 296°K and 1 bar)

Sample Composition, mole %	Sample Density, g/cm³	Porosity, %	v_p, km/sec	V_s, km/sec	k_1	k_2
100 Fo	3.164	1.65	8.459 (±0.5)*	4.938 (±0.4)*	0.9655	1.1923
95 Fo/5 Fa	3.176	2.98	8.287 (±0.6)	4.823 (±0.4)	0.9619	1.2148
90 Fo/10Fa	3.270	1.90	8.226 (±0.4)	4.769 (±0.4)	0.9583	1.2381
85 Fo/15Fa	3.386	2.83	8.088 (±0.6)	4.676 (±0.4)	0.9556	1.2560
80 Fo/20Fa	3.365	2.19	8.017 (±0.5)	4.615 (±0.4)	0.9529	1.2744
50 Fo/50Fa	3.732	1.80	7.454 (±0.5)	4.178 (±0.4)	0.9362	1.3947
100 Fa	4.287	2.41	6.502 (±0.5)	3.421 (±0.4)	0.9011	1.7031

* Uncertainties in per cent.

prisms having two opposing faces that are parallel to each other. The density of each specimen was determined by measuring weight in air and in Nujol, a mineral oil (Plough, Inc.), whose specific gravity at 22°C is 0.8815 g/cm³. The sizes of all specimens are in the neighborhood of 1 cm³, large enough to make acoustic measurements on them in all the three mutually perpendicular directions.

Table 1 lists the composition and density of each specimen. The porosity in the specimen was calculated from the X-ray density [see *Yoder et al.*, 1957; *Akimoto et al.*, 1968] of the corresponding chemical composition of olivine.

1.2. Experimental Method

Experimental method used here was identical to our earlier work on quartz and rutile [*Chung and Simmons*, 1969]. Reviewing in brief, the measurements of sound velocities were made with the pulse-echo-overlap method. X-cut and AC-cut quartz transducers with resonance frequencies of 20 MHz were used for generation of *P* and *S* waves, respectively. The material used for acoustic bonding between specimen and transducer was a 50% (by volume) mixture of phthalic anhydride and glycerine. The pressure system used here was a simple piston-cylinder setup of standard design [see *Brace et al.*, 1969]; the sample was not jacketed. The pressure medium was reagent-grade petroleum ether. The pressure was read directly from a precalibrated 7500-bar Heise gauge. The readability of this gauge is better than 0.2%.

2. Experimental Results and Discussion

2.1. Data

The primary data determined in our ultrasonic experiments were the pulse-repetition frequencies $F_i(p)$ in each specimen for both *P* and *S* waves at 296 (±1)°K as a function of hydrostatic pressure to about 7.5 kb. From these $F_i(p)$ data, sound velocities at zero-pressure were found by extrapolation of high-pressure data back to the zero-pressure point (see, for example, *Mizutani et al.* [1970], p. 2743). These values represent crack-free but not pore-free velocities. Values of *P* and *S* velocities evaluated at zero-pressure are entered in the 4th and 5th columns of Table 1, and an estimated total uncertainty in the velocities is indicated. This uncertainty includes estimated experimental errors and variations in velocities due to an apparent anisotropy of the specimen. The apparent anisotropy of each specimen was observed to be small, possibly because of the way our specimens were prepared (see footnote 1). The anisotropy was less than 0.3% of the velocities listed in Table 1.

As is seen from Table 1, our samples contain about 2 to 3% porosity. Isotropic elastic properties at zero-porosity must be evaluated from acoustic measurements made on our porous samples. *Weil* [1964, p. 217] and *Walsh* [1965] discussed how the elastic properties of nonporous polycrystalline aggregates can be evaluated from elastic data obtained on a porous aggregate. We used, as in our earlier work with rutile and quartz [*Chung and Simmons*, 1969, p. 135], the Weil-Hashin relation for the shear and bulk

cracks). The anisotropy of a polycrystalline specimen produced by hot-pressing methods can be reduced by cutting a sample out of the hot-pressed disk at the 45° angle from the direction of hot-pressing and by subsequent heat treatment of the sample.

moduli with constants k_1 and k_2. Numerical values of k_1 (for the shear modulus) and k_2 (for the adiabatic bulk modulus) found for our samples are tabulated in the 6th and 7th columns of Table 1, and they were used to obtain the zero-porosity elastic properties of various olivines. The zero-porosity elastic properties of olivine as a function of the Fe/Mg ratio are summarized in Table 2.

2.2. *Comparison with Literature Data*

The elastic parameters of various olivines widely used in the geophysical discussion are tabulated in Table 3. These include experimental values measured on natural olivine rocks and synthetic aggregate-samples as well as gem- and they are probably not representative of Tables 2 and 3 reveals the following:

1. *For forsterite,* the present elasticity data are consistent (within the stated experimental uncertainties) with the corresponding data cited under references *d* and *e*, Table 3. In light of these data, the elastic properties of forsterite reported in references *a*, *b*, and *c* are too low and they are probably not representative of the intrinsic properties of forsterite.

2. *For peridot* (with about 93% Fo), literature data cited in references *f* and *g* are slightly higher than the present values. It is interesting to note the bulk modulus of peridot (with about 93% Fo) according to references *f* and *g* is slightly higher than that of forsterite. The result of the present work indicates that, contrary to the observation of *f* and *g*, the value of the bulk modulus decreases slightly with increasing the Fe/Mg ratio in olivine.

3. *For hortonolite* (with about 50% Fo), the present data somewhat differ from values reported in references *l* and *m*. The apparent difference may be associated with the composition of the samples studied by the authors cited as they are reflected in the sample densities. Additional data for a hortonolite sample from the type locality in Monroe, New York, became available in the literature since the present paper was submitted for publication. *Mao et al.* [1970] reported *P* and *S* velocities of hortonolite dunite ($\rho = 3.934$ g/cm^3) with the ($Fo_{37}Fa_{57}Te_6$) composition as 7.46 and 4.05 km/sec, respectively. These new data appear to be quite consistent with the present data for 50% Fo after an allowance for the slightly higher iron content. As discussed by Mao et al., the lower values of *P* and *S* velocities for the Mooihoek dunite measured by *Birch* [1960] and *Simmons* [1964] may be due to alteration to serpentine.

4. *For fayalite,* the present data differ by a few per cent from the literature values cited in references *n*, *o*, and *p*. For example, values of the bulk modulus as reported by *Adams* [1931], *Mizutani et al.* [1970], and *Fujisawa* [1970] are 1.04, 1.10, and 1.164 mb, respectively, and these values may be compared with 1.22 mb found from the present work.

3. Generalization and Discussion

Some generalization about the elastic properties in the forsterite-fayalite solid-solution series can be made from Table 2. An iron substitution in the olivine lattice results in a systematic decrease in the velocity of both *P* and *S* waves. The iron increases the density but reduces the bulk modulus of olivine (thus

TABLE 2. Zero-Pressure Elastic Properties of Olivine as a Function of Fe/Mg Ratio (at 296°K)

Property	Unit	Olivine Composition, mole %						
		100% Fo	95% Fo	90% Fo	85% Fo	80% Fo	50% Fo	100% Fa
ρ_0	g/cm^3	3.217	3.273	3.330	3.386	3.440	3.780	4.393
$\bar{m}$	gram	20.12	20.58	21.00	21.48	21.93	24.60	29.10
V_p	km/sec	8.534	8.422	8.317	8.216	8.116	7.534	6.637
V_s	km/sec	4.977	4.892	4.815	4.739	4.663	4.213	3.494
μ	mb	0.797	0.783	0.772	0.760	0.748	0.671	0.536
K_s	mb	1.281	1.277	1.274	1.272	1.269	1.251	1.220
σ_s		0.242	0.245	0.248	0.251	0.254	0.273	0.308
Φ	(km/sec)^2	39.8	39.0	38.3	37.6	36.9	33.1	27.8
V_Φ	km/sec	6.309	6.245	6.189	6.132	6.075	5.753	5.273