pyroxenite (Table 1) is a consequence of weak preferred orientation of enstatite and olivine. Both pyroxenites have average grain size less than 0.8 mm.

The Czechoslovakian eclogite is an extremely massive, fresh rock with an average grain size of 0.5 mm. The rock contains approximately 53% garnet, 44% omphacite, 1% opaque, and 2% plagioclase-diopside symplectite. The Norwegian eclogite is slightly altered and somewhat coarser, with an average grain size of 0.8 mm. Modal analysis is 48% garnet, 46% omphacite, 3% hornblende, 2% phlogopite, and 1% opaque.

The Twin Sisters dunite sample is exceptional in that it is fine grained (average grain size 1.0 mm) and has a nearly random mineral orientation. The dunite contains 98% olivine, 1% serpentine, and less than 1% enstatite and opaque. Composition of the olivine is approximately Fo_{90}.

DATA

Velocities were recorded at 2-kbar intervals for both increasing and decreasing pressure. To assure that the samples had reached temperature equilibrium, time intervals between successive readings varied from 15 to 30 min. The velocities uncorrected for length changes due to compression are given in Table 2. Above 10 kbar, no apparent hysteresis was observed, whereas below approximately 10 kbar, velocities recorded during decreasing pressure were slightly higher than velocities obtained with increasing pressure. This is illustrated in Figure 2 for the Twin Sisters dunite. The hysteresis is similar to that discussed in detail by *Birch* [1960] and is primarily related to the adjustment of grain boundary porosity to changes in pressure. Velocities below 10 kbar in Table 2 are averages obtained during increasing and decreasing pressure.

The rock densities in Table 2 are bulk densities at atmospheric pressure, calculated from the weights and dimensions of the cores used for the 30-kbar runs. These compare favorably with the mean bulk densities from the larger cores calculated at 10 kbar (Table 1) and illustrate the homogeneity of the specimens.

PRESSURE DERIVATIVES OF COMPRESSIONAL WAVE VELOCITIES

To obtain accurate data on the changes of velocities with pressure, corrections have to be made to the data of Table 2 for shortening of the samples under compression. A common procedure, previously useful for rocks in which both compressional and shear velocities are determined, is to calculate adiabatic rock compressibilities and correct for change in length due to compression by using an iterative routine and the dynamically determined compressibilities [*Christensen and Shaw*, 1970; *Christensen and Ramanantoandro*, 1971]. For the rocks included in this study, length corrections at 10 kbar using this technique lower compressional wave velocities by approximately 0.02 km/s.

Volume compressions ($\Delta V/V_0$) of several minerals present in pyroxenites, dunites, and eclogites have been determined by *Bridgman* [1948, 1949] to pressures of approximately 30 and 40 kbar. Bridgman's data for several minerals pertinent to this study are given in Table 3. The olivine is described by Bridgman as peridote and probably is of composition similar to that of the Twin Sisters dunite. The North Carolina garnet is reported as almandite, whereas the British Columbia garnet is grossularite. Although the data are rather limited, there appear to be only minor changes in volume compressibility with composition for the garnets and pyroxenes.

The velocity data have been corrected for length changes at pressures between 10 and 30 kbar by using the volume compressions in Table 3 and the rock modal analyses. Linear compressions were assumed to equal one-third of the volume compressions. The corrected velocities above 10 kbar have been fitted to straight line solutions by the method of least squares, and the results are given in Table 4. Correlation coefficients of the linear least squares fits were better than 0.99 for all the rocks. The slopes of the solutions of Table 4 are estimated to be accurate to 10%.

DISCUSSION

The pressure coefficients of compressional wave velocities determined for rocks at pressures below 10 kbar have been discussed in several papers. *Birch* [1969] summarized much

TABLE 2. Compressional Wave Velocities as a Function of Pressure Uncorrected for Length Changes

	Velocity, km/s				
Pressure, bars	Pyroxenite, Stillwater, Montana ρ = 3.311 g/cm^3	Pyroxenite, Twin Sisters, Washington ρ = 3.286 g/cm^3	Dunite, Twin Sisters, Washington ρ = 3.309 g/cm^3	Eclogite, Sunnmöre, Norway ρ = 3.504 g/cm^3	Eclogite, Nové Dvory, Czechoslovakia ρ = 3.559 g/cm^3
10	7.651	7.623	7.842	7.501	8.248
2,000	7.895	7.816	8.275	7.972	8.324
4,000	7.967	7.894	8.372	8.112	8.375
6,000	8.010	7.930	8.434	8.173	8.402
8,000	8.052	7.962	8.470	8.225	8.430
10,000	8.081	8.000	8.498	8.270	8.453
12,000	8.117	8.029	8.527	8.292	8.475
14,000	8.151	8.061	8.548	8.320	8.502
16,000	8.180	8.090	8.576	8.342	8.525
18,000	8.212	8.118	8.605	8.365	8.545
20,000	8.248	8.150	8.632	8.390	8.572
22,000	8.280	8.181	8.655	8.418	8.591
24,000	8.311	8.209	8.684	8.435	8.617
26,000	8.341	8.239	8.708	8.462	8.642
28,000	8.376	8.272	8.732	8.485	8.663
30,000	8.408	8.301	8.761	8.508	8.690

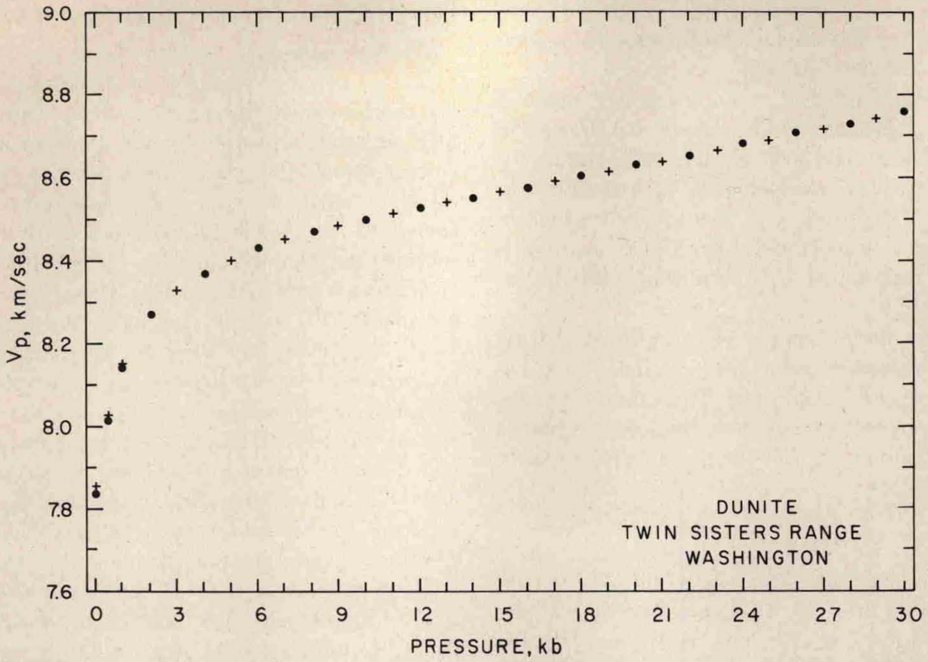

Fig. 2. Experimental points for the Twin Sisters dunite. Dots indicate measurements with increasing pressure; crosses indicate measurements with decreasing pressure.

of the data for dunites available prior to 1968 and compared the data with single-crystal measurements, porous forsterite velocities reported by *Schreiber and Anderson* [1967], and pressure coefficients calculated from the relationships

$$\frac{1}{V_p}\frac{dV_p}{dP} \approx \frac{3}{2K_s} - 1.04\frac{d\sigma}{dP}$$

and

$$\frac{1}{V_p}\frac{dV_p}{dP} = \frac{1}{6K}\frac{13\lambda + 14\mu}{\lambda + 2\mu}$$

where K is the bulk modulus, σ is Poisson's ratio, and λ and μ are Lamé's constants. Birch concluded that the pressure coefficients of velocity measured for dunite to 10 kbar are probably too high because of residual porosity, and with the available data, estimates of the pressure coefficient of velocity at 100 kbar are uncertain by approximately 50%. *Christensen and Ramananantoandro* [1971] also found that the pressure coefficients of velocities in dunites determined to 10 kbar were influenced significantly by porosity. It was shown that between 2 and 10 kbar, pressure derivatives of velocity for unaltered dunites are relatively high, whereas dunites with serpentinization along grain boundaries have significantly lower pressure derivatives of velocity, which are in better agreement with single-crystal measurements.

The compressional wave velocity data to 30 kbar (Table 2) show that pressures higher than 10 kbar are necessary to obtain significant pressure coefficients of velocities in rocks. This is illustrated in Figure 2 for the Twin Sisters dunite. The initial rapid increase of velocity with increasing pressure to approximately 2 kbar has been interpreted in many studies as a result of closure of grain boundary cracks. Between approximately 2 and 10 kbar the effect of porosity on velocities is much less than that observed at lower pressures, but it nevertheless is significant in determining pressure coefficients of velocities. Above approximately 10 kbar there appears to be little deviation from a linear relation between velocity and pressure. This suggests that the effects of grain boundary porosity on rock velocities are not eliminated until pressures of approximately 10 kbar are reached. Thus because of porosity, compressional wave velocity data for rocks determined at pressures below 10 kbar are unreliable for extrapolation to higher pressures.

Wang [1973] has recently reported 0.013 km s^{-1} $kbar^{-1}$ as the pressure coefficient of compressional wave velocity for a bronzitite from the Stillwater complex based on measurements to 25 kbar. This value is in good agreement with the velocity data determined to 30 kbar for the pyroxenites included in the present study (Table 4). Wang noted that

TABLE 3. Volume Compression of Olivine, Garnet, and Pyroxene

Pressure, kg/cm^2	Olivine, Egypt	Garnet, North Carolina	Garnet, British Columbia	Hypersthene, Labrador	Diopside, New York
0	0.0000	0.0000	0.0000	0.0000	0.0000
10,000	0.0079	0.0054	0.0064	0.0101	0.0088
20,000	0.0156	0.0107	0.0125	0.0191	0.0169
30,000	0.0231	0.0159	0.0185	0.0272	0.0245
40,000	0.0304	...	...	0.0347	0.0318

Data from *Bridgman* [1948, 1949].