Compressional-Wave Velocities in Basalts from the Juan de Fuca Ridge

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Compressional-wave velocities are reported to pressures of 10 kb for three samples of tholeiitic basalt dredged from the Juan de Fuca ridge. Average velocities for air-dried samples range from 3.90 km/sec at 0.2 kb to 6.44 km/sec at 10 kb. Low-pressure velocities are increased by as much as 25% with water saturation, whereas velocities above 3 kb are only slightly increased. Compressional-wave velocities for the basalts are clearly lower than seismic refraction velocities for lower oceanic crustal rocks near the Juan de Fuca ridge. The water-saturated basalt velocities are, however, within the range of reported velocities for layer 2 of the oceanic crust.

INTRODUCTION

Over the past two decades seismology has provided a wealth of data on the structure and elastic-wave velocities of the oceanic crust. However, little has been done on the interpretation of the velocity distributions within the oceanic crust in terms of rock composition. Dredge hauls have recovered numerous rock types, including a variety of metamorphics, volcanics, and plutonic rocks. Basalt appears to be particularly abundant in most oceanic areas [*Engel et al.*, 1965; *van Andel and Bowin*, 1968] and may represent a significant portion of the oceanic crust. Deep-sea drilling projects have also found basalt underlying the sediment cover in many oceanic localities.

In this paper compressional-wave velocities are reported at pressures to 10 kb for three samples of basalt dredged from the western edge of the median valley of the Juan de Fuca ridge at latitude 47°N and longitude 129°20′W. The basalts, which were recovered at a water depth of approximately 1350 fathoms, are fresh tholeiites in the form of well developed pillows with a thin rind of glass on their unfractured surfaces. The cores used for the measurements are free of the glassy rinds. Modal analyses of the three samples are given in Table 1. Maximum grain diameter is usually below 0.1 mm.

VELOCITY DATA

Compressional-wave velocities and bulk densities are given in Table 2 for perpendicular directions from cores 2.5 cm in diameter and 6.0 to 7.0 cm in length. Cores were obtained in only two perpendicular directions for sample JF-2. The first eight measurements were from samples stored open to the atmosphere for two months before coring. These samples will be referred to as air-dried. Measurements are also given in Table 2 for JF-1-1 after the core had been water-saturated and oven-dried. The water-saturated sample was immersed in water in a vacuum chamber after air had been evacuated from the pore spaces. The oven-dried sample was heated in excess of 100°C for 36 hours. The effect of water saturation and oven drying on the velocities is illustrated in Figure 1.

A pulse transmission technique similar to that described by *Birch* [1960] was used to obtain the velocities. Barium titanate transducers of 2-MHz frequencies generated and received the compressional waves. Pressure during the runs was measured with a calibrated manganin wire gage. Univis P-38 manufactured by Enco Corporation was used as a pressure medium on the high-pressure side of the intensifier.

Velocities in Table 2 are averages of readings taken during increasing and decreasing pressure. The hysteresis rarely exceeded 0.15 km/sec at low pressures and was considerably less at pressures above a few kilobars. The velocities re-

TABLE 1. Modal Analyses (percentages by volume)

Component	JF-1	JF-2	JF-3
Plagioclase	40	39	42
Clinopyroxene	41	35	39
Olivine	1	2	1
Opaques	6	8	7
Others*	12	16	11
Plagioclase Composition-An	58–65	59–68	58–66

* Principally basaltic glass and alteration products.

corded in Table 2 are believed to be accurate to better than 1%.

Discussion

The velocities in Table 2 are in agreement with earlier high-pressure studies of tholeiitic basalts from Connecticut [*Christensen*, 1968] and Hawaii [*Manghnani and Woollard*, 1968]. Velocities at 10 kb for 9 cores of tholeiitic basalt reported by Christensen ranged from 6.20 to 6.46 km/sec. The Hawaiian tholeiite velocities varied from 5.79 to 6.38 km/sec at 10 kb. The lower velocities were from highly vesicular specimens [*Manghnani and Woollard*, 1968].

Seismic refraction studies over the Juan de Fuca ridge by *Shor et al.* [1968] show that the ridge consists of a thin layer of sediments, presumably of variable thickness, underlain by a 5.0-km/sec layer with a thickness of 1.0 to 1.6 km. This 5.0-km/sec layer correlates with layer 2 of the oceanic crust. The oceanic layer, layer 3, varies from 5.0 km to about 3.0 km in thickness over the ridge crest and has a velocity of 6.7 to 6.9 km/sec. Mantle velocities in the crestal region of the ridge appear to be somewhat lower than normal.

Pressures in the upper part of layer 2 over the ridge range from 0.3 to about 0.5 kb. Average compressional-wave velocities for the air-dried basalts are 4.2 km/sec to 4.7 km/sec at corresponding pressures. These velocities are slightly lower than the observed 5.0-km/sec velocity of layer 2. Velocities for the water-saturated sample indicate that increased water saturation of the air-dried samples will result in velocities in agreement with the velocity of layer 2. This increase in velocity with water saturation has been investigated in detail at atmospheric pressure by *Dortman and Magid* [1968, 1969]. The results of these studies are in agreement with the low-pressure measurements in Table 2. The velocities in Table 2 show, however, that with increasing pressure the differences in velocity for air-dried and water-saturated basalts decrease. Above a few kilobars, compressional-wave velocities for the saturated sample are less than 0.1 km/sec higher than

TABLE 2. Compressional-Wave Velocities in Kilometers per Second as a Function of Pressure for Basalts from the Juan de Fuca Ridge

Sample	Bulk Density, g/cm³	p = 0.20 kb	p = 0.40 kb	p = 0.60 kb	p = 0.80 kb	p = 1.0 kb	p = 2.0 kb	p = 4.0 kb	p = 6.0 kb	p = 8.0 kb	p = 10.0 kb
JF-1-1	2.873	3.87	4.46	4.89	5.20	5.40	5.96	6.26	6.36	6.40	6.42
JF-1-2	2.847	3.86	4.41	4.84	5.16	5.38	5.93	6.29	6.39	6.43	6.44
JF-1-3	2.864	3.93	4.58	4.90	5.18	5.41	5.96	6.32	6.43	6.48	6.49
Mean	2.861	3.89	4.48	4.88	5.13	5.40	5.95	6.29	6.40	6.44	6.45
JF-2-1	2.862	3.80	4.40	4.81	5.15	5.34	5.88	6.19	6.31	6.35	6.40
JF-2-3	2.854	3.65	4.21	4.62	4.98	5.18	5.86	6.24	6.38	6.41	6.46
Mean	2.858	3.72	4.30	4.71	5.07	5.26	5.87	6.22	6.34	6.38	6.43
JF-3-1	2.868	4.34	4.86	5.27	5.55	5.70	6.18	6.40	6.47	6.51	6.53
JF-3-2	2.863	3.92	4.24	4.96	5.32	5.48	5.97	6.24	6.33	6.37	6.39
JF-3-3	2.849	3.38	4.45	4.90	5.24	5.40	5.91	6.24	6.35	6.39	6.41
Mean	2.860	4.03	4.52	5.04	5.37	5.52	6.02	6.29	6.39	6.42	6.44
JF-1-1*	2.901	5.10	5.37	5.56	5.69	5.77	6.07	6.30	6.39	6.44	6.47
JF-1-1†	2.868	3.63	4.26	4.64	4.94	5.11	5.73	6.17	6.31	6.37	6.40

* Water-saturated.
† Oven-dried.

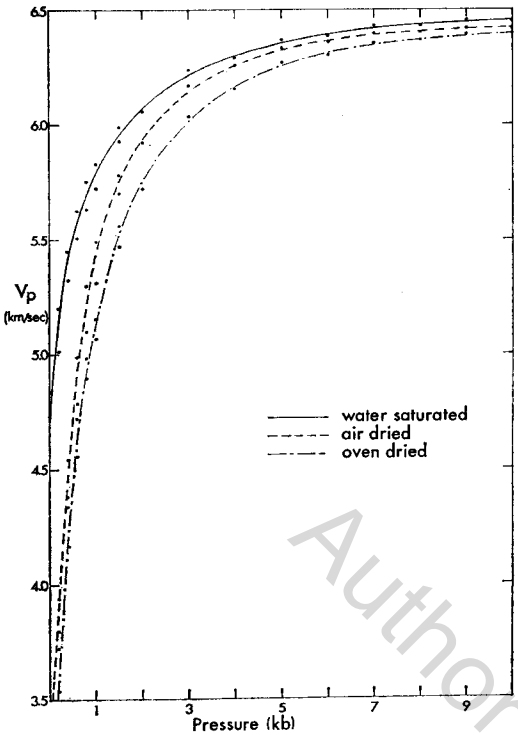

Fig. 1. Compressional-wave velocities for sample JF1-1.

velocities for the air-dried and oven-dried sample.

Velocities obtained by seismic refraction studies for the lower oceanic crust in the region of the Juan de Fuca ridge and in other oceanic regions are considerably higher than the velocities reported in Table 2. Hence the lower oceanic crust must be composed of some rock type other than tholeiitic basalt.

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