

## 42. HIGH-PRESSURE SEISMIC STUDIES OF LEG 69 AND 70 BASALTS<sup>1</sup>

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### ABSTRACT

Shear-wave and compressional-wave velocities of 26 basalt samples collected at Site 504 during Deep Sea Drilling Project Legs 69 and 70 were measured at elevated confining pressures. The young basalts have higher velocities than average DSDP basalts, because of their lack of alteration. Measurements of sample porosity are combined with laboratory and *in situ* velocity measurements to yield estimates of total crustal porosity: 13% at the top of Layer 2, and very low porosity below a depth of 2.0 km.

### INTRODUCTION

Laboratory studies of shear-wave ( $V_s$ ) and compressional-wave ( $V_p$ ) velocities in rocks recovered by ocean drilling are essential to the interpretation of marine geophysical measurements in petrological models. Studies of the basalts from Sites 504 and 505, drilled during Legs 69 and 70 of the Deep Sea Drilling Project, are of particular interest because of the wide range of geophysical experiments carried out during these cruises, which include a detailed seismic survey near Site 504 (Langseth et al., this volume), a complete program of well logging (Cann and Von Herzen, this volume), the employment of the packer experiment (Zoback and Anderson, this volume), and the oblique seismic experiment (Stephen, this volume). Site 504 is located on 5.9-m.y.-old crust in an area of elevated heat flow south of the Costa Rica Rift (1°13.6'N, 83°43.9'W). Site 505 is on crust 3.9 m.y. old in an area of low heat flow just to the north of Site 504 (1°54.8'N, 83°47.4'W).

Of particular significance, estimates of porosity in this young section of oceanic crust are derived from the measured physical properties of laboratory specimens. Together, the *in situ* and laboratory data can be used to impose significant limitations on models of a sealed oceanic crustal circulation system.

### SAMPLE DESCRIPTIONS, EXPERIMENTAL TECHNIQUES, AND DATA

Twenty-four of the 26 samples selected for velocity measurement from Site 504 are sparsely to moderately phyrlic plagioclase-olivine-clinopyroxene basalts. Plagioclase and olivine typically occur as euhedral and/or subhedral phenocrysts; clinopyroxene often occurs as isolated phenocrysts or as glomerocrystic clumps with plagioclase, granular clinopyroxene, and subhedral olivine in a spherulitic matrix of clinopyroxene and plagioclase. Opaque phases constitute up to 3% of some sam-

ples. Secondary minerals, including carbonates, iron oxides, phillipsite, clay minerals, and pyrite, are present in vesicles, cracks, groundmass, olivines, and, occasionally, plagioclase. Glassy margins, where seen, are altered to clay minerals. The remaining two samples are an altered basalt breccia with a smectite matrix (504B-32-1) and a highly fractured plagioclase-olivine-phyric basalt with fractures and veinlets filled with smectite and minor pyrite (504B-70-1). The three samples from Site 505 are sparsely phyrlic plagioclase-olivine pillow basalts with up to 2% chrome-spinel.

Compressional-wave and shear-wave velocities have been measured to 6.0-kbar confining pressure in 1-in.-long by 1-in.-diameter right cylindrical samples, using the pulse-transmission technique described in detail by Birch (1960). All velocities were obtained at room temperature, using water-saturated samples encased in copper jackets. A 100-mesh copper screen placed between the jackets and the rock cores provided space for water to drain from grain-boundary cracks as confining pressure increased, thus keeping pore pressure minimal.

In addition to wet-bulk densities ( $\rho$ ) and porosities ( $\phi$ ), compressional-wave and shear-wave velocities ( $V_p$  and  $V_s$ ), velocity ratios ( $V_p/V_s$ ), Poisson's ratios ( $\sigma$ ), bulk moduli ( $K$ ), and shear moduli ( $\mu$ ) are given in Table 1 at hydrostatic confining pressures to 6.0 kbar. The elastic constants were calculated from the velocities and densities, using equations summarized by Birch (1961).

### DISCUSSION

The relationships between velocity and density are important because they provide a means of estimating crustal densities from seismic-refraction data. Figure 1 shows compressional-wave and shear-wave velocities at 1.0 kbar plotted versus wet-bulk density for the samples we have studied from Sites 504 and 505. The curves are non-linear best fits for 77 sea-floor basalts from the Deep Sea Drilling Project given by Christensen and Salisbury (1975). With the exception of two samples (a breccia and a highly fractured basalt), the velocities and densities are relatively high compared with similar data from other sites. This is not surprising, because the petrography of these rocks shows minimal amounts of

<sup>1</sup> Cann, J. R., Langseth, M. G., Honnorez, J., Von Herzen, R. P., White, R. P., et al., *Init. Repts. DSDP, 69*: Washington (U.S. Govt. Printing Office).

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Table 1. Compressional-wave and shear-wave velocities and elastic constants.

Sample	P (kb)	$V_p$ (km/s)	$V_s$ (km/s)	$V_p/V_s$	$\rho$	$(\text{Mb}^{-1})$	$\mu$ (Mb)
<b>Leg 69:</b>							
504A-7-1, 54-56 cm $\rho = 2.84 \text{ g/cm}^3$ $\phi = 4.4\%$	0.2	5.60	3.03	1.85	0.29	0.54	0.26
	0.4	5.64	3.05	1.85	0.29	0.55	0.26
	0.6	5.68	3.07	1.85	0.29	0.56	0.27
	0.8	5.70	3.08	1.85	0.29	0.56	0.27
	1.0	5.72	3.09	1.85	0.29	0.57	0.27
	2.0	5.80	3.11	1.86	0.30	0.59	0.27
	4.0	5.88	3.13	1.88	0.30	0.61	0.28
6.0	6.03	3.16	1.91	0.31	0.66	0.28	
504B-3-2, 17-19 cm $\rho = 2.79 \text{ g/cm}^3$ $\phi = 3.3\%$	0.2	5.98	3.24	1.85	0.29	0.61	0.29
	0.4	6.09	3.25	1.87	0.30	0.64	0.29
	0.6	6.13	3.27	1.87	0.30	0.65	0.30
	0.8	6.15	3.28	1.88	0.30	0.66	0.30
	1.0	6.18	3.29	1.88	0.30	0.66	0.30
	2.0	6.24	3.31	1.89	0.30	0.68	0.31
	4.0	6.27	3.34	1.88	0.30	0.68	0.31
6.0	6.29	3.35	1.88	0.30	0.69	0.31	
504B-5-1, 80-82 cm $\rho = 2.86 \text{ g/cm}^3$ $\phi = 1.1\%$	0.2	6.37	3.35	1.90	0.31	0.73	0.32
	0.4	6.39	3.37	1.90	0.31	0.73	0.32
	0.6	6.41	3.39	1.89	0.31	0.74	0.33
	0.8	6.43	3.41	1.89	0.30	0.74	0.33
	1.0	6.44	3.42	1.88	0.30	0.74	0.33
	2.0	6.50	3.46	1.88	0.30	0.75	0.34
	4.0	6.55	3.50	1.87	0.30	0.76	0.35
6.0	6.57	3.52	1.87	0.30	0.76	0.36	
504B-7-5, 87-89 cm $\rho = 2.89 \text{ g/cm}^3$ $\phi = 0.8\%$	0.2	6.18	3.25	1.90	0.31	0.70	0.31
	0.4	6.21	3.27	1.90	0.31	0.70	0.31
	0.6	6.23	3.29	1.89	0.31	0.70	0.31
	0.8	6.24	3.30	1.89	0.31	0.71	0.31
	1.0	6.26	3.31	1.89	0.31	0.71	0.32
	2.0	6.30	3.33	1.89	0.31	0.72	0.32
	4.0	6.32	3.37	1.88	0.30	0.72	0.33
6.0	6.34	3.38	1.88	0.30	0.72	0.33	
504B-8-3, 68-70 cm $\rho = 2.89 \text{ g/cm}^3$ $\phi = 1.5\%$	0.2	6.05	3.23	1.87	0.30	0.66	0.30
	0.4	6.08	3.24	1.88	0.30	0.66	0.30
	0.6	6.12	3.25	1.88	0.30	0.68	0.31
	0.8	6.14	3.26	1.88	0.30	0.68	0.31
	1.0	6.16	3.26	1.89	0.31	0.69	0.31
	2.0	6.22	3.29	1.89	0.31	0.70	0.31
	4.0	6.29	3.32	1.89	0.31	0.72	0.32
6.0	6.35	3.34	1.90	0.31	0.74	0.32	
504B-9-1, 135-137 cm $\rho = 2.85 \text{ g/cm}^3$ $\phi = 2.5\%$	0.2	5.82	3.17	1.84	0.29	0.58	0.29
	0.4	5.84	3.19	1.83	0.29	0.59	0.29
	0.6	5.85	3.21	1.82	0.28	0.58	0.29
	0.8	5.86	3.22	1.82	0.28	0.58	0.30
	1.0	5.88	3.23	1.82	0.28	0.59	0.30
	2.0	5.91	3.26	1.81	0.28	0.59	0.30
	4.0	5.95	3.29	1.81	0.28	0.60	0.31
6.0	5.98	3.31	1.81	0.28	0.60	0.31	
504B-11-2, 130-132 cm $\rho = 2.91 \text{ g/cm}^3$ $\phi = 1.9\%$	0.2	6.08	3.24	1.88	0.30	0.67	0.31
	0.4	6.14	3.29	1.87	0.30	0.68	0.32
	0.6	6.19	3.33	1.86	0.30	0.68	0.32
	0.8	6.23	3.34	1.87	0.30	0.70	0.32
	1.0	6.26	3.35	1.87	0.30	0.71	0.33
	2.0	6.33	3.37	1.88	0.30	0.73	0.33
	4.0	6.38	3.38	1.89	0.30	0.74	0.33
6.0	6.41	3.39	1.89	0.31	0.75	0.34	
504B-13-2, 121-123 cm $\rho = 2.86 \text{ g/cm}^3$ $\phi = 1.9\%$	0.2	5.92	3.20	1.85	0.29	0.61	0.29
	0.4	5.95	3.24	1.84	0.29	0.61	0.30
	0.6	5.98	3.27	1.83	0.29	0.62	0.31
	0.8	6.00	3.29	1.82	0.29	0.62	0.31
	1.0	6.02	3.30	1.82	0.29	0.62	0.31
	2.0	6.10	3.33	1.83	0.29	0.64	0.32
	4.0	6.21	3.34	1.86	0.30	0.68	0.32
6.0	6.27	3.34	1.88	0.30	0.70	0.32	
504B-15-4, 98-100 cm $\rho = 2.88 \text{ g/cm}^3$ $\phi = 2.1\%$	0.2	6.13	3.29	1.86	0.30	0.67	0.31
	0.4	6.22	3.34	1.86	0.30	0.69	0.32
	0.6	6.27	3.37	1.86	0.30	0.70	0.33
	0.8	6.31	3.39	1.86	0.30	0.71	0.33
	1.0	6.33	3.40	1.86	0.30	0.71	0.33
	2.0	6.38	3.43	1.86	0.30	0.72	0.34
	4.0	6.39	3.44	1.86	0.30	0.72	0.34
6.0	6.39	3.45	1.85	0.29	0.72	0.34	
504B-16-2, 19-21 cm $\rho = 2.93 \text{ g/cm}^3$ $\phi = 1.2\%$	0.2	6.21	3.25	1.91	0.31	0.72	0.31
	0.4	6.23	3.30	1.89	0.30	0.71	0.32
	0.6	6.25	3.33	1.88	0.30	0.71	0.32
	0.8	6.26	3.36	1.86	0.30	0.71	0.33
	1.0	6.28	3.38	1.86	0.30	0.71	0.33
	2.0	6.34	3.49	1.82	0.28	0.70	0.36
	4.0	6.43	3.66	1.76	0.26	0.69	0.39
6.0	6.49	3.78	1.72	0.24	0.68	0.42	
504B-18-2, 103-105 cm $\rho = 2.80 \text{ g/cm}^3$ $\phi = 1.1\%$	0.2	5.94	3.18	1.87	0.30	0.61	0.28
	0.4	5.95	3.19	1.87	0.30	0.61	0.28
	0.6	5.96	3.20	1.86	0.30	0.61	0.29
	0.8	5.97	3.21	1.86	0.30	0.61	0.29
	1.0	5.98	3.21	1.86	0.30	0.62	0.29

Table 1. (Continued).

Sample	P (kb)	$V_p$ (km/s)	$V_s$ (km/s)	$V_p/V_s$	$\rho$	$(\text{Mb}^{-1})$	$\mu$ (Mb)
<b>Leg 69: (Cont.)</b>							
504B-18-2, 103-104 cm (Cont.)	2.0	6.02	3.23	1.86	0.30	0.63	0.29
	4.0	6.06	3.23	1.88	0.30	0.64	0.29
	6.0	6.08	3.24	1.88	0.30	0.65	0.29
504B-21-3, 143-145 cm $\rho = 2.88 \text{ g/cm}^3$ $\phi = 1.7\%$	0.2	6.04	3.28	1.84	0.29	0.64	0.31
	0.4	6.10	3.29	1.85	0.29	0.66	0.31
	0.6	6.13	3.30	1.86	0.30	0.66	0.31
	0.8	6.16	3.31	1.86	0.30	0.67	0.32
	1.0	6.17	3.32	1.86	0.30	0.67	0.32
	2.0	6.22	3.34	1.86	0.30	0.69	0.32
	4.0	6.25	3.35	1.87	0.30	0.70	0.32
6.0	6.28	3.36	1.87	0.30	0.70	0.33	
504B-22-1, 6-8 cm $\rho = 2.83 \text{ g/cm}^3$ $\phi = 2.7\%$	0.2	6.05	3.25	1.86	0.30	0.64	0.30
	0.4	6.07	3.27	1.86	0.30	0.64	0.30
	0.6	6.08	3.29	1.85	0.29	0.64	0.31
	0.8	6.10	3.31	1.84	0.29	0.64	0.31
	1.0	6.11	3.32	1.84	0.29	0.64	0.31
	2.0	6.16	3.36	1.83	0.29	0.65	0.32
	4.0	6.22	3.40	1.83	0.29	0.66	0.33
6.0	6.24	3.44	1.81	0.28	0.66	0.34	
504B-24-2, 7-9 cm $\rho = 2.88 \text{ g/cm}^3$ $\phi = 1.1\%$	0.2	6.42	3.34	1.92	0.31	0.76	0.32
	0.4	6.43	3.37	1.91	0.31	0.75	0.33
	0.6	6.44	3.39	1.90	0.31	0.75	0.33
	0.8	6.45	3.41	1.89	0.31	0.75	0.34
	1.0	6.46	3.43	1.88	0.30	0.75	0.34
	2.0	6.48	3.49	1.86	0.30	0.74	0.35
	4.0	6.48	3.51	1.85	0.29	0.74	0.36
6.0	6.48	3.51	1.85	0.29	0.74	0.36	
504B-27-1, 69-71 cm $\rho = 2.90 \text{ g/cm}^3$ $\phi = 2.3\%$	0.2	6.00	3.26	1.84	0.29	0.63	0.31
	0.4	6.04	3.30	1.83	0.29	0.64	0.32
	0.6	6.07	3.33	1.82	0.28	0.64	0.32
	0.8	6.09	3.35	1.82	0.28	0.64	0.33
	1.0	6.11	3.36	1.82	0.28	0.65	0.33
	2.0	6.20	3.40	1.82	0.28	0.67	0.34
	4.0	6.28	3.43	1.83	0.29	0.69	0.34
6.0	6.33	3.44	1.84	0.29	0.71	0.34	
504B-28-3, 105-107 cm $\rho = 2.85 \text{ g/cm}^3$ $\phi = 3.3\%$	0.2	5.81	3.15	1.84	0.29	0.59	0.28
	0.4	5.85	3.18	1.84	0.29	0.59	0.29
	0.6	5.87	3.19	1.84	0.29	0.60	0.29
	0.8	5.89	3.21	1.83	0.29	0.60	0.29
	1.0	5.91	3.22	1.84	0.29	0.60	0.30
	2.0	5.95	3.27	1.82	0.28	0.60	0.31
	4.0	6.00	3.32	1.81	0.28	0.61	0.31
6.0	6.05	3.33	1.82	0.28	0.62	0.32	
505B-2-1, 70-72 cm $\rho = 2.83 \text{ g/cm}^3$ $\phi = 2.0\%$	0.2	5.81	3.24	1.79	0.27	0.56	0.30
	0.4	5.88	3.26	1.80	0.28	0.58	0.30
	0.6	5.93	3.28	1.81	0.28	0.59	0.30
	0.8	5.97	3.29	1.81	0.28	0.60	0.31
	1.0	6.02	3.30	1.82	0.29	0.62	0.31
	2.0	6.16	3.33	1.85	0.29	0.66	0.31
	4.0	6.28	3.36	1.87	0.30	0.69	0.32
6.0	6.30	3.38	1.86	0.30	0.69	0.32	
505B-3-2, 71-73 cm $\rho = 2.84 \text{ g/cm}^3$ $\phi = 2.5\%$	0.2	5.86	3.32	1.77	0.26	0.56	0.31
	0.4	5.91	3.34	1.77	0.27	0.57	0.32
	0.6	5.96	3.36	1.77	0.27	0.58	0.32
	0.8	5.99	3.38	1.77	0.27	0.59	0.32
	1.0	6.02	3.39	1.78	0.27	0.59	0.33
	2.0	6.09					

Table 1. (Continued).

Sample	P (kb)	$V_p$ (km/s)	$V_s$ (km/s)	$V_p/V_s$	$\rho$	$\kappa$ ( $\text{Mb}^{-1}$ )	$\mu$ (Mb)
<b>Leg 70: (Cont.)</b>							
504B-40-3, 23-25 cm $\rho = 2.93 \text{ g/cm}^3$ $\phi = 0.7\%$	0.2	6.41	3.41	1.88	0.30	0.75	0.34
	0.4	6.46	3.45	1.87	0.30	0.76	0.35
	0.6	6.48	3.47	1.87	0.30	0.76	0.35
	0.8	6.50	3.49	1.86	0.30	0.76	0.36
	1.0	6.52	3.50	1.86	0.30	0.77	0.36
	2.0	6.58	3.53	1.86	0.30	0.78	0.37
	4.0	6.62	3.54	1.87	0.30	0.80	0.37
6.0	6.65	3.55	1.87	0.30	0.81	0.37	
504B-41-3, 15-17 cm $\rho = 2.92 \text{ g/cm}^3$ $\phi = 0.1\%$	0.2	6.43	3.51	1.83	0.29	0.73	0.36
	0.4	6.50	3.57	1.82	0.28	0.74	0.37
	0.6	6.55	3.60	1.82	0.28	0.75	0.38
	0.8	6.58	3.61	1.82	0.28	0.76	0.38
	1.0	6.61	3.62	1.83	0.29	0.77	0.38
	2.0	6.66	3.65	1.82	0.29	0.78	0.39
	4.0	6.71	3.66	1.83	0.29	0.79	0.39
6.0	6.76	3.67	1.84	0.29	0.81	0.39	
504B-43-2, 18-20 cm $\rho = 2.89 \text{ g/cm}^3$ $\phi = 2.8\%$	0.2	6.06	3.17	1.91	0.31	0.67	0.29
	0.4	6.12	3.21	1.91	0.31	0.69	0.30
	0.6	6.15	3.24	1.90	0.31	0.69	0.30
	0.8	6.18	3.26	1.90	0.31	0.69	0.31
	1.0	6.20	3.28	1.89	0.31	0.70	0.31
	2.0	6.26	3.33	1.88	0.30	0.71	0.32
	4.0	6.33	3.39	1.87	0.30	0.72	0.33
6.0	6.38	3.42	1.87	0.30	0.73	0.34	
504B-47-4, 97-99 cm $\rho = 2.93 \text{ g/cm}^3$ $\phi = 1.5\%$	0.2	6.21	3.41	1.82	0.28	0.68	0.34
	0.4	6.27	3.43	1.83	0.29	0.69	0.34
	0.6	6.32	3.45	1.83	0.29	0.71	0.35
	0.8	6.34	3.47	1.83	0.29	0.71	0.35
	1.0	6.37	3.48	1.83	0.29	0.72	0.36
	2.0	6.44	3.49	1.85	0.29	0.74	0.36
	4.0	6.52	3.50	1.86	0.30	0.77	0.36
6.0	6.54	3.51	1.86	0.30	0.77	0.36	
504B-52-1, 93-95 cm $\rho = 2.87 \text{ g/cm}^3$ $\phi = 2.8\%$	0.2	5.99	3.05	1.96	0.32	0.67	0.27
	0.4	6.03	3.08	1.96	0.32	0.68	0.27
	0.6	6.08	3.11	1.95	0.32	0.69	0.28
	0.8	6.11	3.13	1.95	0.32	0.70	0.28
	1.0	6.14	3.15	1.95	0.32	0.70	0.28
	2.0	6.25	3.22	1.94	0.32	0.72	0.30
	4.0	6.37	3.33	1.91	0.31	0.74	0.32
6.0	6.41	3.39	1.89	0.31	0.74	0.33	
504B-57-2, 53-55 cm $\rho = 2.91 \text{ g/cm}^3$ $\phi = 1.7\%$	0.2	5.88	3.30	1.78	0.27	0.58	0.32
	0.4	5.93	3.33	1.78	0.27	0.59	0.32
	0.6	5.97	3.35	1.78	0.27	0.60	0.33
	0.8	6.01	3.37	1.78	0.27	0.61	0.33
	1.0	6.04	3.38	1.79	0.27	0.62	0.33
	2.0	6.16	3.41	1.81	0.28	0.65	0.34
	4.0	6.30	3.43	1.84	0.29	0.70	0.34
6.0	6.37	3.45	1.85	0.29	0.72	0.35	
504B-63-1, 103-105 cm $\rho = 2.93 \text{ g/cm}^3$ $\phi = 0.6\%$	0.2	6.31	3.25	1.94	0.32	0.75	0.31
	0.4	6.36	3.28	1.94	0.32	0.77	0.32
	0.6	6.39	3.29	1.94	0.32	0.77	0.32
	0.8	6.42	3.31	1.94	0.32	0.78	0.32
	1.0	6.43	3.33	1.93	0.32	0.78	0.33
	2.0	6.46	3.39	1.91	0.31	0.77	0.34
	4.0	6.48	3.44	1.88	0.30	0.77	0.35
6.0	6.49	3.46	1.88	0.30	0.77	0.35	
504B-70-1, 10-12 cm $\rho = 2.73 \text{ g/cm}^3$ $\phi = 4.6\%$	0.2	5.07	2.76	1.84	0.29	0.42	0.21
	0.4	5.15	2.79	1.85	0.29	0.44	0.21
	0.6	5.20	2.81	1.85	0.29	0.45	0.22
	0.8	5.25	2.83	1.86	0.30	0.46	0.22
	1.0	5.29	2.84	1.86	0.30	0.47	0.22
	2.0	5.42	2.87	1.89	0.31	0.50	0.23
	4.0	5.55	2.90	1.91	0.31	0.54	0.23
6.0	5.63	2.92	1.93	0.32	0.56	0.23	

alteration products, typical of young tholeiites in many oceanic regions.

Although small, much of the variability of velocity in the samples appears to be related to the porosity (Fig. 2). Porosities (percent pore volume) were determined from the dimensions and weights of the saturated and dried cores. The average porosity of our samples (2%) is significantly less than means reported previously for young, unaltered sea-floor basalts (e.g., 7.8%; Hyndman and Drury, 1976). The data displayed in Figure 2

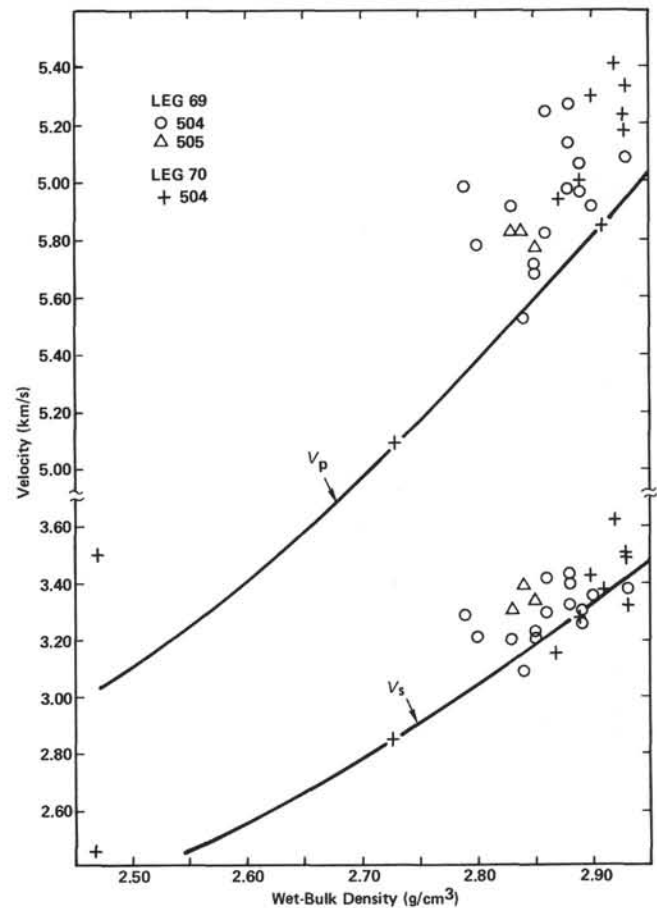


Figure 1. Seismic velocity at 1.0 kb versus wet-bulk density. Upper curve represents compressional velocity ( $V_p$ ), lower curve shear velocity ( $V_s$ ) from Christensen and Salisbury (1975).

can be fit well using the Wyllie equation (Wyllie et al., 1958):

$$1/V_m = (\phi/V_f) + (1 - \phi)/V_r,$$

where  $V_m$  is the measured velocity,  $V_f$  the fluid velocity,  $V_r$  the matrix or rock velocity, and  $\phi$  the porosity expressed as a fraction. The two brecciated, altered samples fall off the curve, because their  $V_r$  value differs from that of fresh rock. Most of the samples plot in the porosity range 1 to 3%, leading us to suggest that basalts of approximately 2% porosity make up the matrix of rock for the large-scale fracture system.

From Figure 2, the velocity of the 2%-porosity rock, 6.2 km/s, can be inserted into the Wyllie equation as  $V_r$ .  $V_m$ , the measured velocity, can be taken from the seismic-refraction results of Langseth et al. (this volume). Thus, a rough estimate of crustal porosity can be made. Velocities at the top of Layer 2 at Site 504 are on the order of 4.5 km/s, which can be explained by a fracture porosity of 11%, or a 13% overall porosity. At a depth of 1 km into Layer 2, velocities increase to around 6.0 km/s, indicating that much of the porosity has been

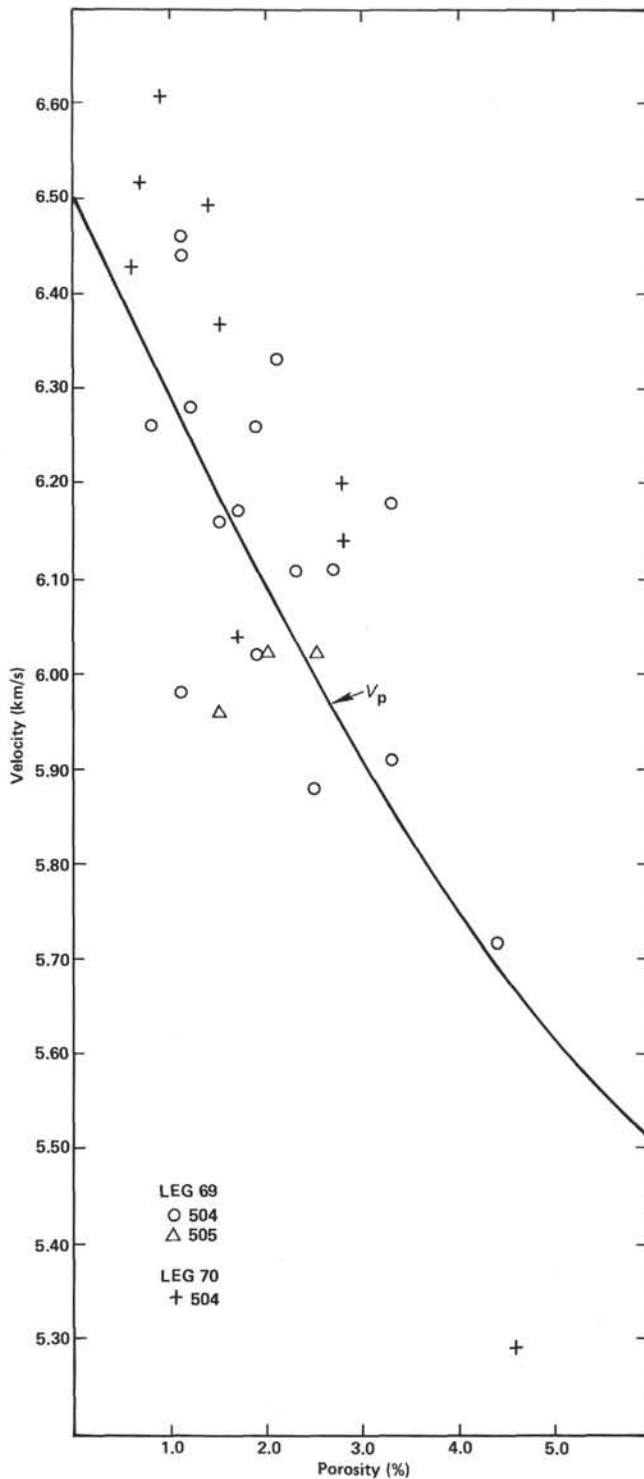


Figure 2. Compressional-wave velocity versus effective porosity. Curve is the Wyllie equation; details in text.

closed, only a few percent remaining in both fracture and small-scale porosity. Finally, at 2.0 km into Layer 2 the velocities increase to 6.5 km/s and higher, indicating that even the small-scale porosity no longer exists.

Two factors are important in modifying these results. The first is vein filling and low-temperature alteration; both work to decrease porosity for a given velocity by lowering the matrix velocity,  $V_r$ . Thus, to the extent that we know that smectite breccias exist in the upper crust at Site 504, the fracture porosity estimates are somewhat high. The second factor is more important at depth and has an effect opposite to that described above. Alteration of a higher grade, such as that responsible for the Layer 2/Layer 3 boundary (see Christensen and Salisbury, 1975) may actually increase  $V_r$ , such that the velocities of 6.5 km/s recorded from 2.0 km may well represent, for example, a rock of 2% porosity with a matrix velocity ( $V_r$ ) of 7.0 km/s. Christensen and Wilkens (in press) saw just such an increase in matrix velocities with depth in a bore hole in Iceland, while small-scale porosity remained open at a depth of 2.0 km.

An understanding of porosity in the oceanic crust is important in that it can provide information about permeability available for hydrothermal circulation. In particular, it is the large-scale fracture porosity that must allow free movement of water through the upper crust. High water/rock ratios calculated from isotopic abundances in altered basalts (Lawrence and Drever, in press) requires a large flux. The data in this report suggest that extensive alteration of the oceanic crust in this area does not extend to great depths.

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