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10. SEISMIC VELOCITIES, DENSITIES, AND ELASTIC CONSTANTS OF VOLCANIC BRECCIAS AND BASALT FROM DEEP SEA DRILLING PROJECT LEG 59

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INTRODUCTION

Prior to the Deep Sea Drilling Project the composition of the oceanic crust could only be inferred from seismic-refraction and gravity data and the recovery of a wide variety of dredged rocks. Through the success of the Deep Sea Drilling Project, it is now clear that the top of oceanic Layer 2 usually consists of basalt. Several laboratory studies (e.g., Fox et al., 1972; Christensen and Shaw, 1970; Hyndman and Drury, 1976) have demonstrated that the seismic velocities of oceanic basalt are similar to velocities reported from refraction studies of Layer 2 and that the variability in Layer 2 velocities has many causes, the most important being fracturing and sea-floor alteration produced by the interaction of basalt and sea water (Christensen and Salisbury, 1973).

To date, most reported measurements of velocities in oceanic basalts are from samples obtained from the main ocean basins. With the exception of an earlier study of velocities and related elastic properties of a suite of rocks from DSDP Sites 292, 293, 294, and 296 located in the Philippine Sea (Christensen et al., 1975; Fountain et al., 1975), elastic properties have not been determined for oceanic rocks from marginal basins. In this chapter compressional- and shear-wave velocities and elastic constants are reported at elevated confining pressures for basalt and volcanic breccias from Holes 447A, 448, and 448A.

EXPERIMENTAL TECHNIQUE AND DATA

Acoustic velocities (Table 1) were measured as a function of hydrostatic pressure using the pulse-transmission method (Birch, 1960). The samples were water-saturated and enclosed in impervious copper jackets. To keep pore pressure minimal, water from the saturated samples was allowed to drain from the rock pore spaces into 100-mesh screens placed between the rock cores and copper jackets. Because of the relatively fragile nature of the vesicular basalts, maximum confining pressures were limited to approximately 0.6 kbar. The densities reported in Table 1 are bulk densities obtained from the weights and dimensions of the saturated samples.

Poisson's ratio (σ), bulk modulus (K), shear modulus (μ), Lamé's constant (λ), Young's modulus (E), seismic parameter (ϕ), and compressibility (β) are given in Table 2 at various pressures. The elastic constants were calculated from the velocities and densities using the equations summarized by Birch (1961). The velocities and densities used in the calculations were corrected for dimension changes at high pressures using an iterative routine and the dynamically determined compressibilities.

Table 1. Compressional (*P*) and shear (*S*) wave velocities.

Sample (intervals in cm)	Wet-bulk Density (g/cm^3)	Mode	Velocity (km/s) at Various Pressures (kbar) 0.2	0.4	0.6	0.8	1.0	2.0	4.0	6.0
447A-14-1, 74–76	2.735	*P*	5.58	5.66	5.70	5.73	5.76	5.88	5.99	6.04
(flow basalt)	2.735	*S*	2.92	2.95	2.97	2.99	3.01	3.08	3.20	3.25
447A-25-2, 24–26	2.831	*P*	6.00	6.09	6.14	6.18	6.22	6.33	6.45	6.56
(flow basalt)	2.831	*S*	3.26	3.29	3.31	3.33	3.34	3.36	3.37	3.37
447A-26-4, 30–33	2.684	*P*	5.05	5.15	5.20	5.24	5.28	5.40	5.58	5.71
(flow basalt)	2.684	*S*	2.58	2.63	2.66	2.69	2.71	2.78	2.86	2.91
447A-29-1, 93–96	2.506	*P*	4.31	4.41	4.50	4.57	4.62	4.84	5.13	5.32
(breccia)	2.506	*S*	2.51	2.56	2.60	2.64	2.67	2.77	2.90	2.97
448-48-3, 57–59	2.229	*P*	3.70	3.75	3.77	—	—	—	—	—
(vesicular basalt)	2.229	*S*	1.84	1.92	1.96	—	—	—	—	—
448-48-3, 59–61	2.196	*P*	3.84	3.88	3.90	—	—	—	—	—
(vesicular basalt)	2.196	*S*	1.93	1.96	1.98	—	—	—	—	—
448-48-3, 61–64 cm	2.230	*P*	3.60	3.64	3.66	—	—	—	—	—
(vesicular basalt)	2.230	*S*	1.81	1.84	1.86	—	—	—	—	—
448-56-4, 124–127 (breccia)	2.087	*P*	3.25	3.32	3.37	3.41	3.44	3.57	3.75	3.87
448-56-4, 127–130 (breccia)	2.076	*P*	3.18	3.22	3.25	3.27	3.29	3.39	3.57	3.72
448-56-4, 134–137 (breccia)	2.064	*P*	3.65	3.69	3.73	3.75	3.76	3.81	3.90	4.12
448A-35-2, 81–84	1.980[a]	*P*	2.83	2.86	2.89	2.89	2.92	—	—	—
(breccia)	1.980[a]	*S*	1.38	1.42	1.46	1.51	1.55	—	—	—
448A-57-1, 16–18	2.597	*P*	4.40	4.45	4.49	4.52	4.53	4.60	4.73	4.84
(flow basalt)	2.597	*S*	2.47	2.50	2.52	2.53	2.54	2.56	2.58	2.59

[a] Reflects 5% correction due to chipped sample cylinder.

VELOCITY-DENSITY RELATIONS

Shear- and compressional-wave velocities at 0.4 kbar confining pressure are plotted against the wet-bulk densities of the samples in Figure 1. As can be seen in the distribution of both compressional and shear velocities, the flow basalts are faster than the vesicular basalts, whereas the breccia velocities display a wide variation. The fast breccia sample from Hole 447A is well cemented and contains considerable quartz in its matrix. The effect of the quartz can be seen in the elastic constants (Table 2). With the exception of this breccia and one flow basalt sample (448A-57-1), values for Poisson's ratio of the samples are between 0.29 and 0.34 at low pressures. The presence of quartz (Poisson's ratio = 0.08) in this breccia sample lowered its Poisson's ratio to 0.25 (Birch, 1961). It is interesting to note that all of the parameters computed for the quartz-rich breccia are similar to those of the lowest-density flow basalt rather than to the other breccia sample.

Table 2. Elastic constants.

Sample (intervals in cm)	Pressure (kbar)	V_p/V_s	σ	ϕ $(km/s)^2$	K (Mb)	β (Mb^{-1})	μ (Mb)	E (Mb)	λ (Mb)
447A-14-1, 74–76 (flow basalt)	0.4	1.92	0.31	20.42	0.56	1.79	0.24	0.63	0.40
	1.0	1.91	0.31	21.07	0.58	1.73	0.25	0.65	0.41
	2.0	1.91	0.31	21.88	0.60	1.66	0.26	0.68	0.43
	6.0	1.86	0.30	22.25	0.62	1.62	0.29	0.75	0.41
447A-25-2, 24–26 (flow basalt)	0.4	1.85	0.29	22.65	0.64	1.56	0.31	0.79	0.44
	1.0	1.86	0.30	23.79	0.67	1.48	0.32	0.82	0.46
	2.0	1.88	0.30	24.97	0.71	1.41	0.32	0.83	0.50
	6.0	1.95	0.32	27.75	0.79	1.26	0.32	0.85	0.58
447-26-4, 30–33 (flow basalt)	0.4	1.96	0.32	17.29	0.46	2.16	0.19	0.49	0.34
	1.0	1.95	0.32	18.06	0.49	2.06	0.20	0.52	0.35
	2.0	1.94	0.32	18.81	0.51	1.98	0.21	0.55	0.37
	6.0	1.96	0.32	21.16	0.57	1.74	0.23	0.60	0.42
447A-29-1, 93–96 (breccia)	0.4	1.72	0.25	10.70	0.27	3.72	0.16	0.41	0.16
	1.0	1.73	0.25	11.81	0.30	3.36	0.18	0.45	0.18
	2.0	1.75	0.26	13.14	0.33	3.01	0.19	0.48	0.20
	6.0	1.79	0.27	16.36	0.42	2.40	0.22	0.56	0.27
448-48-3, 57–59 (vesicular basalt)	0.4	1.95	0.32	9.14	0.20	4.90	0.08	0.22	0.15
448-48-3, 59–61 (vesicular basalt)	0.4	1.98	0.33	9.92	0.22	4.57	0.08	0.22	0.16
448-48-3, 61–64 (vesicular basalt)	0.4	1.98	0.33	8.72	0.19	5.13	0.08	0.20	0.14
448A-35-2, 81–84 (breccia)	0.4	2.01	0.34	5.48	0.10	9.62	0.04	0.10	0.08
	1.0	1.88	0.30	5.29	0.10	9.91	0.05	0.12	0.07
448A-57-1, 16–18 (flow basalt)	0.4	1.78	0.27	11.55	0.30	3.33	0.16	0.41	0.19
	1.0	1.78	0.27	11.89	0.31	3.22	0.17	0.43	0.20
	2.0	1.80	0.28	12.36	0.32	3.09	0.17	0.44	0.21
	6.0	1.87	0.30	14.29	0.38	2.64	0.18	0.46	0.26

Note: σ = Poisson's ratio; ϕ = seismic parameter; K = bulk modulus; β = compressibility; μ = shear modulus; E = Young's modulus; λ = Lamé's constant.

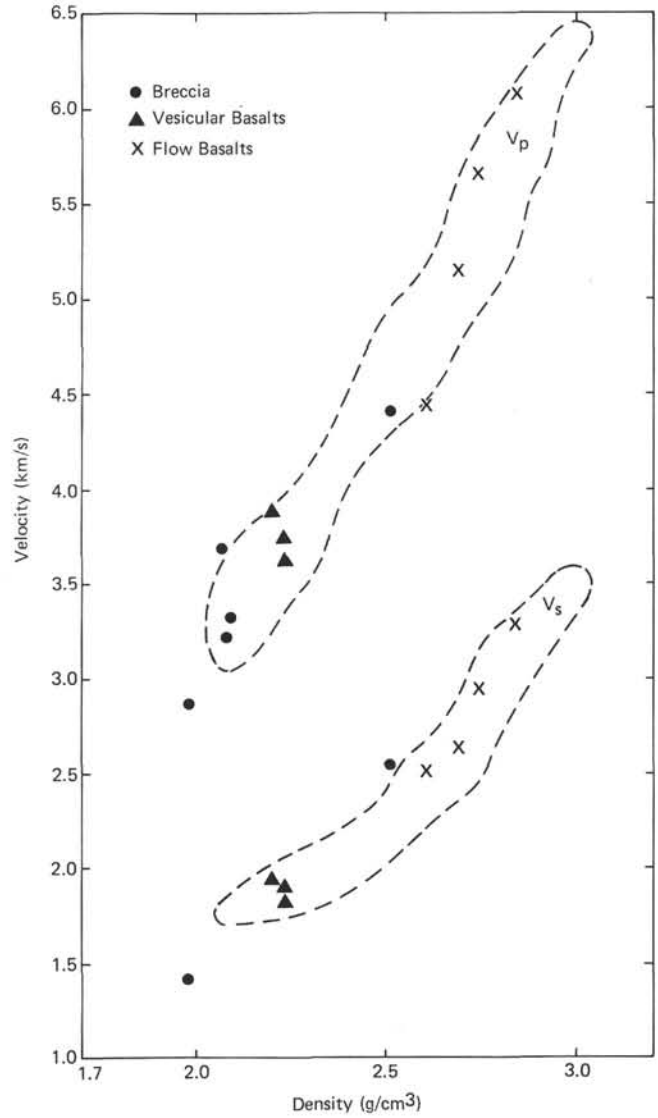

Figure 1. Wet-bulk density versus compressional- and shear-wave velocity at 0.4 kbar for breccias, vesicular basalts, and flow basalts from Leg 59. (Dashed lines enclose previous data for oceanic basalts from Christensen and Salisbury, 1973.)

DISCUSSION

Figure 2 shows the location of seismic-refraction profiles and seismic sections reported for the Philippine Sea (Murauchi et al., 1968). The location of Sites 447 and 448 are also shown.

Seismic profiles of the Palau-Kyushu Ridge (Sections 22 and 26) show that the upper parts of the ridge consist of material with compressional wave velocities near 3.5 km/s. Laboratory velocities measured in breccias and vesicular basalts at pressures appropriate for depths in Holes 448 and 448A are in excellent agreement with the refraction velocities (Table 1, Figure 1). Velocities in tuffs from this region also fall in this range (see Carlson et al., this volume).

The structure reported at seismic Section 21 (Fig. 2) suggests normal oceanic crust at this location with a Layer-2 velocity of 5.1 km/s. The measured velocities of three flow basalts and one breccia from Hole 447A agree well with the refraction measurements.

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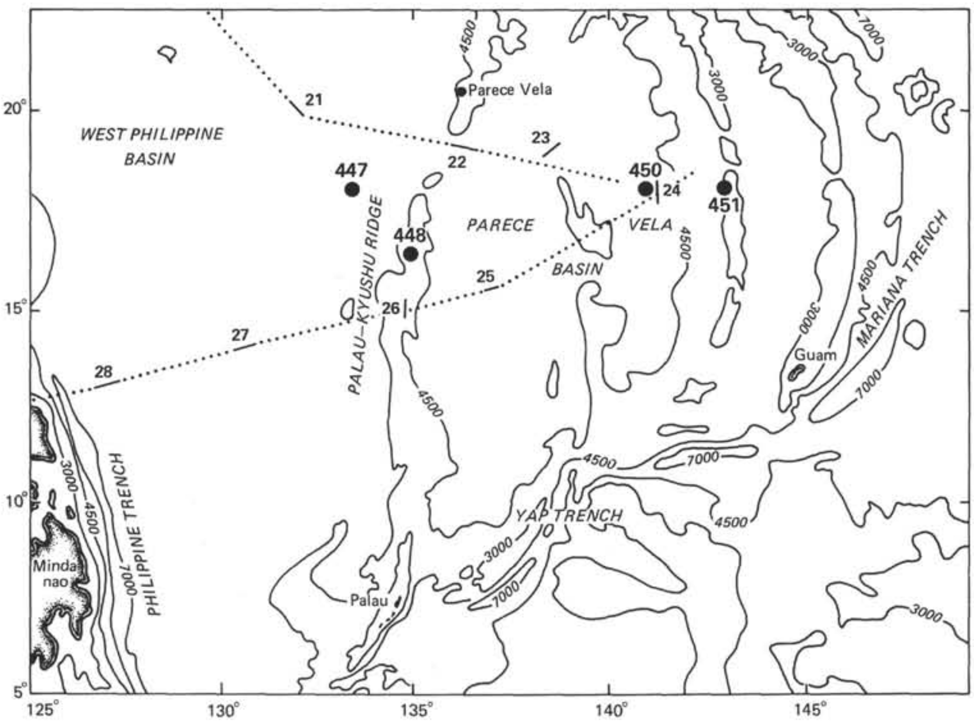

Figure 2. Geographic locations of Sites 447, 448, 450, 451 seismic-refraction profiles and seismic sections. (Adapted from Murauchi et al., 1968.)