

31. COMPRESSIONAL WAVE VELOCITIES IN BASALT AND DOLERITE SAMPLES RECOVERED DURING LEG 15¹

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INTRODUCTION

The velocity of propagation of compressional waves was investigated in fifty-two samples of basalt and dolerite recovered during Leg 15 of the Deep Sea Drilling Project. Velocity measurements of the selected specimens were first conducted at atmospheric pressure and then at intervals of higher confining pressure up to 7 kb. The velocity data presented here provide useful criteria for the correlation of rock types cored at Sites 146, 150, 151, 152, and 153 with seismic reflection, oblique reflection, and refraction profiles obtained from the Caribbean Basin.

PROCEDURE

Velocity measurements were performed using the modified pulse transmission method (Mattaboni and Schreiber, 1967) which was described in Volume 11 of the *Initial Reports of the Deep Sea Drilling Project* (Schreiber et al., 1972). The precision of our measurements is about 1 percent because of hysteresis observed between measurements performed under increasing and decreasing confining pressure. The hysteresis is caused by anelastic changes that occur within the specimen, and these changes are attributed to adjustments in the pore and crack geometry during the application of pressure.

Specimens one-half inch in diameter were cut from the cores in directions parallel to and perpendicular to the core axis in order to obtain information about possible velocity anisotropy. The ends of the specimens were trimmed flat to produce surfaces that were parallel to within 0.002 cm. The bulk density of each specimen was calculated on the basis of its dimensional measurements and mass. The error in the density value is ± 1 percent. Prior to measurement of the compressional wave velocities, the specimens were jacketed with 2-mil-thick copper foil which prevented pressurizing fluid from penetrating into pores or cracks present in the specimen. Thus the change in velocity as cracks and pores close under increasing pressure could be determined. Specimens were measured in the "as received" condition and were neither dried nor saturated prior to the velocity measurements.

RESULTS

At Site 146, located in the center of the Venezuela Basin, sixteen meters of Coniacian dolerite were recovered 756 meters below the sediment-water interface. The fine- to medium-grained dolerite is composed of equigranular, subophitic to ophitic intergrowths of plagioclase and augite with oxides and interstitial saponite (see Donnelly, "Basalts and Dolerites," for a complete discussion of petrology). The measured velocities of twenty-two specimens range from 4.39 to 5.57 km/sec at .25 kb to 5.26 to 6.03 km/sec at 7 kb (Table 1). The calculated in situ confining pressure of the dolerite at Site 146 is approximately 0.5 kb. The measured velocity range of the twenty-two specimens at 0.5 kb is 4.48 to 5.64 km/sec and the average is 5.08 km/sec.

At Site 150, located 35 km south of Site 146 in the Venezuela Basin, six meters of Coniacian dolerite were recovered 168 meters below the sediment-water interface. Although not as fresh as the dolerite of Site 146, the fine- to medium-grained dolerite of Site 150 is composed of equigranular, subophitic to ophitic intergrowths of plagioclase and augite with oxides and interstitial saponite (see Donnelly, "Basalts and Dolerites," for a complete discussion of petrology). The measured velocities of twelve specimens range from 3.85 to 5.05 km/sec at 0.25 kb to 5.06 to 5.76 km/sec at 7 kb (Table 1). The calculated in situ confining pressure of the dolerite at Site 150 is approximately 0.4 kb. The measured velocity range of the fifteen specimens at 0.4 kb is 4.03 to 5.12 km/sec and the average is 4.78 km/sec.

At Site 151, located at the southern end of the Beata Ridge, two thin basalt sills of Santonian age were sampled 338 meters below the sediment-water interface. The amygdaloidal, slightly altered basalt is composed of glomeroporphyritic plagioclase set in a groundmass of plagioclase, pyroxene, oxide grains, and interstitial micaceous substance (see Donnelly, "Basalts and Dolerites," for a complete discussion of petrology). Only a small amount of basalt was recovered at Site 151 and consequently only four specimens were analyzed. The measured velocities of the four specimens range from 4.00 to 4.21 km/sec at 0.25 kb to 4.81 to 5.17 km/sec at 7 kb (Table 1). The calculated in situ confining pressure of the basalt at Site 151 is approximately 0.4 kb. The measured velocity range of the four specimens at 0.4 kb is 4.09 to 4.32 km/sec and the average is 4.19 km/sec.

At Site 152, located on the lower slope of the Nicaragua Rise at the Northern end of the Colombia Basin, twelve meters of Campanian basalt were sampled 473 meters below the sediment-water interface. The recovered basalt, like the slightly altered basalt of Site 151, is amygdaloidal

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TABLE 1
Summary of Leg 15 Compressional Wave Velocities Measured for Basalt and Dolerite Samples.^a

Sample	Orientation	Density (gm/cm ³)	Rock Type	1 atm.	Confining Pressure										
					0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00
146-41R-2(19-27)	Vert.	2.81	Dolerite	4.22	4.59	4.76	4.87	4.97	5.10	5.20	5.37	5.48	5.55	5.62	5.67
	Horz.	2.80	Dolerite	4.26	4.39	4.48	4.56	4.64	4.77	4.86	5.00	5.10	5.19	5.28	5.36
146-41R-2(104-113)	Horz.	2.74	Dolerite	4.42	4.60	4.68	4.75	4.80	4.91	5.00	5.12	5.23	5.32	5.38	5.43
146-42R-1(27-33)	Vert.	2.81	Dolerite	4.68	4.80	4.97	5.09	5.17	5.28	5.37	5.47	5.54	5.59	5.62	5.65
146-42R-1(117-123)	Horz.	2.88	Dolerite	5.00	5.14	5.20	5.25	5.30	5.38	5.45	5.58	5.68	5.77	5.85	5.91
146-42R-2(10-19)	Vert.	2.88	Dolerite	4.84	5.08	5.17	5.25	5.31	5.41	5.48	5.60	5.67	5.71	5.74	5.76
	Horz.	2.91	Dolerite	4.85	5.07	5.16	5.21	5.26	5.35	5.42	5.54	5.63	5.70	5.76	5.80
146-42R-2(93-101)	Vert.	2.87	Dolerite	5.00	5.20	5.28	5.32	5.38	5.46	5.52	5.63	5.71	5.78	5.84	5.89
146-42R-3(28-37)	Vert.	2.79	Dolerite	4.87	5.17	5.23	5.29	5.37	5.45	5.51	5.57	5.68	5.77	5.82	5.87
146-42R-3(135-145)	Vert.	2.88	Dolerite	5.13	5.26	5.36	5.45	5.51	5.59	5.64	5.71	5.75	5.77	5.79	5.80
	Horz.	2.89	Dolerite	5.02	5.14	5.21	5.27	5.32	5.41	5.48	5.61	5.70	5.78	5.82	5.85
146-43R-1(67-82)	Vert.	2.84	Dolerite	4.71	5.02	5.12	5.18	5.24	5.32	5.38	5.45	5.50	5.53	5.55	5.57
	Horz.	2.91	Dolerite	4.94	5.08	5.17	5.23	5.27	5.34	5.40	5.49	5.55	5.61	5.66	5.69
146-43R-1(144-151)	Vert.	2.90	Dolerite	4.97	5.13	5.23	5.32	5.40	5.50	5.57	5.66	5.71	5.74	5.77	5.80
	Horz.	2.85	Dolerite	4.80	4.92	5.04	5.13	5.20	5.31	5.40	5.50	5.56	5.61	5.66	5.70
146-43R-2(32-39)	Horz.	2.93	Dolerite	5.30	5.37	5.43	5.49	5.53	5.60	5.66	5.75	5.81	5.87	5.93	5.98
146-43R-3(0-10)	Vert.	2.91	Dolerite	4.98	5.18	5.27	5.33	5.38	5.46	5.52	5.61	5.66	5.69	5.71	5.72
	Horz.	2.76	Dolerite	4.55	4.80	4.91	5.00	5.08	5.21	5.30	5.41	5.50	5.57	5.62	5.68
146-43R-3-(119-131)	Vert.	3.04	Dolerite	4.98	5.05	5.10	5.16	5.22	5.31	5.38	5.48	5.55	5.60	5.65	5.68
146-43R-4(28-36)	Vert.	2.81	Dolerite	4.60	4.75	4.85	4.97	5.05	5.17	5.25	5.37	5.46	5.52	5.57	5.63
	Horz.	2.87	Dolerite	5.07	5.15	5.20	5.26	5.30	5.39	5.44	5.53	5.60	5.63	5.66	5.68
146-43R-4(131-138)	Vert.	2.94	Dolerite	5.46	5.57	5.64	5.69	5.73	5.80	5.86	5.92	5.98	6.00	6.02	6.03
150-11-2(11-29)	Vert.	2.74	Dolerite	4.40	4.65	4.75	4.80	4.85	4.93	5.01	5.11	5.18	5.25	5.31	5.36
	Horz.	2.79	Dolerite	4.65	4.82	4.92	4.99	5.04	5.13	5.19	5.29	5.36	5.43	5.48	5.50
150-11-2(74-81)	Vert.	2.56	Dolerite	3.68	3.85	4.08	4.18	4.28	4.42	4.52	4.67	4.79	4.88	4.97	5.06
	Horz.	2.75	Dolerite	4.15	4.34	4.44	4.51	4.58	4.67	4.74	4.86	4.95	5.03	5.10	5.15
150-12-1(0-15)	Vert.	2.89	Dolerite	4.71	4.94	5.06	5.15	5.23	5.34	5.42	5.52	5.58	5.61	5.64	5.66
	Horz.	2.80	Dolerite	4.60	4.98	5.05	5.10	5.14	5.20	5.26	5.38	5.46	5.53	5.59	5.65
150-12-1(119-131)	Vert.	2.79	Dolerite	4.47	4.60	4.70	4.77	4.72	4.89	4.96	5.03	5.11	5.18	5.23	5.28
	Horz.	2.69	Dolerite	4.66	4.70	4.73	4.75	4.77	4.82	4.87	4.95	5.02	5.10	5.11	5.20
150-12-2(26-42)	Vert.	2.78	Dolerite	4.60	4.86	4.96	5.04	5.08	5.18	5.26	5.38	5.48	5.54	5.57	5.58
	Horz.	2.78	Dolerite	4.73	4.87	4.93	4.98	5.02	4.08	5.13	5.23	5.30	5.36	5.42	5.47
150-12-2(107-120)	Vert.	2.80	Dolerite	4.78	5.00	5.06	5.11	5.16	5.23	5.30	5.41	5.51	5.60	5.68	5.76
	Horz.	2.90	Dolerite	4.82	5.05	5.17	5.24	5.30	5.38	5.44	5.55	5.61	5.66	5.70	5.73
151-14-1(109-111)	Horz.	2.58	Basalt	3.92	4.12	4.17	4.20	4.23	4.29	4.34	4.45	4.55	4.65	4.73	4.82
151-14-1(130-137)	Horz.	2.58	Basalt	3.74	4.00	4.13	4.22	4.28	4.37	4.45	4.56	4.66	4.73	4.78	4.81
151-15-1(138-153)	Vert.	2.67	Basalt	4.08	4.18	4.21	4.24	4.27	4.32	4.38	4.49	4.60	4.68	4.77	4.85
	Horz.	2.69	Basalt	3.96	4.21	4.37	4.47	4.55	4.66	4.72	4.83	4.93	5.02	5.10	4.17
152-23-1(71-76)	Horz.	2.56	Basalt	3.81	4.19	4.24	4.29	4.34	4.40	4.47	4.55	4.61	4.67	4.73	4.79
152-23-1(118-127)	Vert.	2.60	Basalt	3.90	4.02	4.10	4.16	4.21	4.29	4.35	4.45	4.55	4.65	4.72	4.78
	Horz.	2.64	Basalt	4.07	4.28	4.38	4.45	4.50	4.59	4.66	4.76	4.83	4.87	4.89	4.91
152-24-1(11-19)	Horz.	2.72	Basalt	4.30	4.48	4.53	4.57	4.60	4.66	4.71	4.79	4.85	4.88	4.95	4.98
152-24-2(47-55)	Vert.	2.63	Basalt	3.83	3.95	4.03	4.12	4.21	4.33	4.43	4.58	4.67	4.74	4.80	4.85
152-24-2(136-150)	Vert.	2.64	Basalt	3.66	3.98	4.05	4.14	4.21	4.32	4.42	4.58	4.68	4.76	4.80	4.82
	Horz.	2.55	Basalt	3.39	3.69	3.84	3.95	4.01	4.17	4.28	4.44	4.54	4.61	4.66	4.68
153-19-1(140-150)	Vert.	2.95	Basalt	4.43	4.66	4.79	4.87	4.95	5.07	5.16	5.29	5.39	5.46	5.51	5.55
153-20-1(10-23)	Vert.	2.87	Basalt	4.96	5.21	5.29	5.36	5.41	5.50	5.56	5.66	5.73	5.78	5.80	5.83
	Horz.	2.86	Basalt	4.95	5.05	5.15	5.22	5.27	5.34	5.38	5.45	5.51	5.53	5.55	5.56
153-20-1(126-132)	Vert.	2.72	Basalt	4.11	4.32	4.43	4.52	4.60	4.71	4.79	4.91	5.00	5.09	5.17	5.25
	Horz.	2.72	Basalt	4.12	4.34	4.46	4.55	4.63	4.76	4.85	5.00	5.12	5.21	5.29	5.37
153-20-2(6-16)	Vert.	2.72	Basalt	4.43	4.57	4.67	4.73	4.79	4.89	4.96	5.05	5.10	5.15	5.18	5.21
153-20-2(123-129)	Vert.	2.81	Basalt	4.67	4.84	4.91	4.98	5.02	5.10	5.16	5.25	5.32	5.37	5.42	5.45

^aThe calculated in situ lithostatic pressure of these samples is approximately 0.5 kb.

and composed of glomeroporphyritic plagioclase set in a groundmass of plagioclase, pyroxene, oxide grains and interstitial, micaceous, alteration material. The amygdules are filled with a very fine-grained micaceous substance (see Donnelly, "Basalts and Dolerites," for a complete discussion of petrology). The measured velocities of the seven samples range from 3.69 to 4.48 km/sec at 0.25 kb to 4.68

to 4.91 km/sec at 7 kb (Table 1). The calculated in situ confining pressure of the basalt at Site 152 is approximately 0.4 kb. The measured velocity range of the seven specimens at 0.4 kb is 3.78 to 4.51 km/sec and the average is 4.13 km/sec.

At Site 153, located at the southern end of the Beata Ridge, six meters of Coniacian basalt were sampled 758

meters below the sediment-water interface. The upper basalt (Core 19) is fine-grained and composed of plagioclase laths intergrown with pyroxene and interstitial oxide grains and glass (or altered glass-saponite). Although composed of the same mineral assemblage as the upper basalt, the lower basalt sample (Core 20) is coarser grained and is characterized by subophitic and intergranular textures (see Donnelly, "Basalts and Dolerites," for a complete discussion of petrology). The measured velocities of the seven samples range from 4.32 to 5.21 km/sec at 0.25 kb to 5.21 to 5.83 km/sec at 7 kb. The calculated in situ confining pressure of the basalt at Site 153 is approximately 0.5 kb. The measured velocity range of seven specimens at 0.5 kb is 4.43 to 5.29 km/sec and the average is 4.81 km/sec.

The mineral constituents of the igneous rocks recovered at Sites 146, 151, 152, and 153 are similar. The textures and the degrees of alteration of the igneous samples, however, are variable. The dolerite samples of Sites 146 and 150 are characterized by subophitic and ophitic textures; the basalt of Site 153 is characterized by intergranular and subophitic textures; the basalts of Sites 151 and 152 are characterized by glomeroporphyritic clusters set in a fine-grained matrix with amygdules. The twenty-two dolerite samples from Site 146 had the highest average compressional wave velocities (5.08 km/sec at 0.5 kb). The twelve dolerite samples from Site 150, although texturally similar to the samples of Site 146, were more severely altered and the average compressional wave velocities are lower (4.82 km/sec at 0.5 kb). The seven intergranular to subophitic basalt specimens from Site 153 have measured compressional wave velocities similar to those of the dolerite at Site 150 (4.81 km/sec at 0.5 kb). The altered, glomeroporphyritic, fine-grained, amygdaloidal basalts of Sites 151 (4 samples) and 152 (7 samples) have measured compressional wave velocities (Site 151 - 4.22 km/sec at 0.5 kb; Site 152 - 4.16 km/sec at 0.5 kb), that are lower than those of the coarser-grained basalt of Site 153 and the dolerite of Sites 146 and 160. These results suggest that an increase in grain size raises the compressional wave velocity and an increase in the degree of alteration (low temperature) lowers the compressional wave velocity of rocks of similar composition.

The depth at which the basalt and dolerite rocks were recovered at the five sites correlates with the deepest acoustic reflector defined in the Caribbean Basin which has been called B" by Ewing et al. (1968). Published seismic refraction results define a 1-to-2-km-thick layer below B" which has velocities ranging from 3.5 to 4.6 km/sec (Edgar et al., 1971). Recently, analysis of sonobuoy data from the Venezuela and Colombia Basins reveals higher velocities (4.5-5.3 km/sec) for the material lying below acoustic Horizon B" (Ludwig, personal communication). The calculated in situ confining pressure for this layer below B" is approximately 0.5 to 1.0 kb. Inspection of the measured velocities of the dolerite and basalt samples collected during Leg 15 (see Table 1) shows that at confining pressures of 0.5 to 1.0 kb the dolerite (Sites 146 and 150) and the intergranular basalt (Site 153) have velocities ranging from 4.08 to 5.73 km/sec. The measured velocities of the fine-grained amygdaloidal basalts of Sites 151 and 152 have measured velocities at 0.5 to 1.0 kb of 3.84 to 4.60 km/sec.

The majority of the measured velocities of basalt and dolerite recovered during Leg 15 are compatible with the velocities recorded by seismic refraction techniques for the material lying below B" and above the upper crustal layer of the Caribbean basin. These results suggest that the material below B" may be composed of a thick sequence of basalt and dolerite or an assemblage of basalt and dolerite sills sandwiched between sedimentary rocks. It must be remembered, however, that the 4.0 to 5.0-km/sec range in compressional wave velocity at 0.5 to 1.0 kb is not a unique velocity range restricted to basalt. A wide range of consolidated sedimentary rocks have measured velocities in this range (see Anderson and Lieberman, 1968). Consequently, until the material below B" is sampled directly by dredging of tectonic escarpments or drilling, the composition of the 3.5 to 5.3-km/sec layer will be unresolved.

Seismic refraction results record crustal velocities beneath the 3.5 to 5.3-km/sec layer (Officer et al., 1959; Ewing et al., 1960; Edgar et al., 1971). The Grenada Trough, Aves Ridge, Venezuelan Basin and part of the Colombian Basin are characterized by velocities in the 6.0 to 6.3 km/sec range. Under the Beata Ridge, Nicaragua Plateau and part of the Colombia Basin, the upper crustal layer is characterized by velocities in the 5.0-5.5 km/sec range. The intergranular basalt and diabase specimens recovered during Leg 15 have measured velocities (see Table 1) at 1 to 2 kb (calculated in situ confining pressure) that are compatible with the published seismic refraction velocities recorded for the 5.0 to 5.5-km/sec crust under the Beata Ridge, Nicaragua Plateau and part of the Colombia Basin. Basalt and dolerite dredged from the western escarpment of the Beata Ridge also have measured velocities in the 5.0 to 5.5-km/sec range (Fox et al., 1970). The velocities of the basalts and diabase recovered during Leg 15, however, are too low to be considered as a possible constituent of the 6.0 to 6.3-km/sec layer which characterizes the upper crustal layer of the Grenada Trough, Aves Ridge and Venezuelan Basin. Granodiorite dredged from the southern end of the Aves Ridge has measured velocities in the 6.0 to 6.3-km/sec range at 1-2 kb confining pressure (Fox et al., 1971). Also, greenschist metabasalt (Na-enriched plagioclase, epidote, quartz, chlorite, and actinolite) has measured velocities in the 6.0 to 6.3-km/sec range at 1-2 kb (Christensen and Shaw, 1970; Fox et al., 1971). Although metabasalts of this type have been recovered frequently in dredges from tectonic escarpments associated with the mid-oceanic ridge, these rock types have not been recovered from escarpments within the Caribbean. Until more samples of the 6.0 to 6.3-km/sec upper crustal layer of the Caribbean are recovered by drilling and dredging, the composition of the layer will remain debatable.

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