14. ACOUSTIC WAVE VELOCITY MEASUREMENTS OF OCEANIC CRUSTAL SAMPLES—DSDP, LEG 45

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INTRODUCTION

The primary objective of Leg 45 was to drill as deep a hole as possible into the oceanic crust. The prime site was selected in ocean crust 7 m.y. old, defined by magnetic anomaly 4 west of the Mid-Atlantic Ridge near 23°N. Two holes were drilled at this site: a single-bit pilot hole, which penetrated 95 meters into oceanic crust, and a multiple re-entry hole, which penetrated 576 meters. A second site was occupied east of the Mid-Atlantic Ridge axis on magnetic anomaly 5 (10 m.y.B.P.). The hole drilled was a single-bit pilot hole, which penetrated 96 meters into oceanic crust. Criteria for the drilling sites were that the holes be drilled in "normal" ocean crust, away from any fracture zone topography, and on a clearly delineated magnetic anomaly. Among the numerous on-board measurements performed on the retrieved core was compressional wave sound speed in selected samples, determined at 1 atm on wet (as-retrieved) samples, using the Hamilton Frame method (Boyce, 1973). This technique had been calibrated in our laboratory. The density of these samples was also determined. (See site descriptions, this volume.) At the same time, other samples were obtained from the retrieved cores for measurements in our on-shore laboratory. The primary purpose of this chapter is to report the results of these measurements and to compare them with those obtained from samples measured aboard D/V *Glomar Challenger*. A preliminary interpretation of the implications of these measurements with respect to the structure of layer 2 in the Atlantic Ocean is also included.

PROCEDURE

For our land-based laboratory measurements we selected samples to represent the principal lithologies recovered. We made no attempt at this time to provide a complete sample coverage based upon relative quantities of recovered lithologies. In that sense, our results will reflect a sampling bias. The selected samples were drilled from the recovered core sections with a 1/2-inch I.D. diamond core drill, and stored, with no particular caution about moisture content, for shipment to our laboratory.

Upon receipt of the cores, their ends were trimmed to yield right circular cylinders whose end faces were parallel to within approximately 0.005 cm. The samples were cleaned of cutting fluids by soaking them in acetone while heating them to about 60°C under suction. This was followed by drying at 110°C in air and storage in a desiccator. Bulk density was calculated from measurements of the mass of the dried samples, their lengths and diameters.

Compressional wave sound speed was measured at 1 atm and as a function of pressure to 6 kbar on the air-dried samples, and again after water saturation for several selected samples. The method used was the pulse transmission method, as modified by Mattaboni and Schreiber (1967). Samples were jacketed for all measurements under pressure in order to prevent the pressure medium (a mixture of 50% kerosene and 50% petroleum ether) from penetrating the specimen. We have modified our jacketing procedure. The sample was covered with a 0.013 cm (0.005 in.) copper foil sleeve so that about 1 mm of the sample extended beyond the sleeve at each end. The ends were painted with silver paint to provide a completely conductive path to the copper jacket, which was made the electrical ground. Transducers were placed on the ends of the sample, petroleum jelly was used to couple energy from one transducer to the sample and from the sample to the second transducer, and electrodes were placed on each transducer. Two latex surgical rubber sleeves with diameters 0.16 cm smaller than the sample were stretched and slid over each end assembly, and covered just less than half the sample. The ends of the rubber sleeves were tightened with pieces of wire to make the initial pressure seal. The ground lead was soldered to the copper in a small gap between the two sleeves.

To prepare samples saturated with water, selected cores were placed on a wire frame over a beaker of water in a vacuum chamber. The sample was heated at about 80°C under suction and then dropped into the water. The sample remained in the water for 12 to 24 hours. Each sample was removed from the water before a measurement and submerged in water under a pressure of 20 bars for several hours. The sample was assembled in a fashion similar to that described above, except that a tightly coiled spring (0.01 in. diameter) with a prepared copper sleeve over it was slid over the sample. All soldering was done in advance. The coil provided space for water squeezed out of the sample as it was subjected to hydrostatic pressure during determination of the compressional sound velocity (after Nur and Simmons, 1969). Measurements were made to 3 kbar on the saturated samples.

RESULTS AND DISCUSSION

The results of these measurements are summarized in Table 1. The 1-atm shipboard measurements are also included together with a brief petrologic description of the portion of the core from which the sample was selected (see Site Reports, this volume, for detailed petrologic description). The results obtained on samples for which velocities were determined in a saturated condition are included in Table 1 under the measurement performed on the dry sample. The maximum error in determining density is ±1 per cent. The error in the velocity measurement is estimated to be ±1 per cent.

The data clearly indicate the effect of water saturation under zero pore pressure. As noted by Nur and Simmons (1969) and emphasized by Christensen and Salisbury (1975) for rocks recovered from the ocean floor, the velocities are higher for the saturated as compared with the dried specimens. Further, the scatter in the measurements performed on the saturated samples is somewhat less than that for the same samples measured dry, indicating that saturation tends to smooth out differences in velocity measurements obtained on the dry samples. The correlation coefficient for the relation between velocity and density of all the samples measured dry is 0.727; the empirical relation is $V_p = 0.379\rho - 4.79$ (at 0.5 kbar). This correlation is considerably improved over that reported for the much younger rocks recovered during Project FAMOUS (Schreiber and Fox, 1976). The measurements performed on *Glomar Challenger* are seen to yield consistent results with the 1 atm measurements performed in the laboratory.

We arrive now at an apparent dilemma. At 0.5 kbar, the average velocity (dry) for *all* the samples is 5.70 km/sec, with a standard deviation of 0.40. For the selected samples measured in the saturated condition, the average velocity at 0.5 kbar is 5.91 km/sec and the standard deviation is 0.35. For these same selected samples measured dry, the compressional wave velocity is 5.71 km/sec, with a standard deviation of 0.39 at the same pressure (similar to the average value for *all* dry samples at this pressure). For these samples, at least, there is no statistical difference between the *average* velocities wet or dry measured at 0.5 kbar. At this point, we must caution the reader. The dry measurements were obtained first and, as is characteristic of these data, there is an hysteresis between the results obtained with increasing pressure and those obtained with decreasing pressure. The hysteresis is usually in the direction of lower velocity, suggesting that the crack geometry and distribution of crack lengths have been altered anelastically. It is likely that, had the samples been run saturated first and then dry, a greater difference would have been found for the average velocities. Ideally, two separate samples, adjacent to each other, should have been taken for the two different conditions of measurement. This was precluded by the limited sampling permitted. In any case,

TABLE 1
Results of Measurements

Sample (Interval in cm)	Density (g/cm^2)		Pressure (Kbar) 0.001	0.25	0.50	0.75	1.0	1.5	2.0	3.0	4.0	5.0	6.0	Rock Type[a]
			Velocity (Km/sec)											
Hole 395														
11-2, 100-103	2.87		6.03	6.07	6.12	6.15	6.19	6.25	6.30	6.33	6.34	6.36	6.37	Vesicular fine-grained aphyric basalt
11-2, 120-123	2.94	(b)	6.06											
14-1, 102-104	2.74		4.82	5.19	5.29	5.36	5.39	5.43	5.45	5.50	5.54	5.57	5.59	Moderately altered basalt with small vesicles
	2.74	(a)	5.00	5.38	5.43	5.48	5.52	5.57	5.59	5.62				Moderately altered basalt with small vesicles
14-1, 112-114	2.61	(b)	4.37											
15-2, 93-95	2.82		4.23	5.29	5.45	5.54	5.62	5.71	5.77	5.86	5.92	5.96	6.00	Homogeneous fine-grained basalt. Fresh to moderately altered.
	2.82	(a)	5.40	5.70	5.76	5.79	5.82	5.88	5.90	6.02				Homogeneous fine-grained basalt. Fresh to moderately altered.
15-2, 3-5	2.92	(b)	5.34											
15-2, 130-132	2.96	(b)	6.02											Sub-ophitic basalt, olivine microphenocrysts
18-1, 131-133	2.72		3.72	4.61	4.80	4.93	5.02	5.22	5.37	5.59	5.75	5.84	5.87	15-30% serpentinized peridotite
18-1, 78-80	2.88	(b)	4.35											
18-1, 123-125	2.80	(b)	4.31											
18-2, 121-123	2.62		4.67	4.88	5.15	5.23	5.28	5.35	5.42	5.54	5.64	5.70	5.73	15-30% serpentinized peridotite
18-2, 90-92	2.74	(b)	4.89											
19-1, 45-47	2.54		4.49	4.96	5.14	5.18	5.21	5.26	5.30	5.37	5.49	5.51	5.58	Strongly weathered serpentinite.
19-1, 18-20	2.81	(b)	5.51											

20-1, 22-24	2.72		4.63	5.50	5.61	5.68	5.73	5.79	5.89	5.94	6.00	6.01	6.01	Plag-ol phyric basalt, mod. altered, 1% vesicles
20-1, 28-30	2.82	(b)	5.39											Fairly fresh plag-ol phyric basalt
Hole 395A														
13-1, 132-134	2.75		5.53	5.72	5.76	5.80	5.84	5.89	5.94	6.01	6.06	6.10	6.11	Fresh to mod. altered plag-ol phyric basalt
13-1, 132-134	2.86	(b)	5.54											
14-2, 95-97	2.75		5.53	5.78	5.84	5.88	5.92	5.98	6.04	6.14	6.20	6.23	6.25	Fresh to mod. altered plag-ol phyric basalt
14-2, 116-118	2.85	(b)	5.65											
15-2, 96-98	2.76		5.35	5.62	5.70	5.75	5.80	5.87	5.93	6.03	6.09	6.13	6.14	Vuggy and vesicular plag-ol phyric basalt
15-2, 76-78	2.84	(b)	5.45											
15-2, 128-130	2.85	(b)	5.72											
15-3, 119-121	2.81		5.81	5.95	5.99	6.03	6.05	6.10	6.14	6.21	6.27	6.32	6.37	Plag-ol phyric basalt
15-3, 83-85	2.87	(b)	5.60											
15-5, 33-35	2.80		5.69	5.92	5.96	6.00	6.03	6.07	6.11	6.20	6.27	6.32	6.35	Plag-ol phyric basalt
15-5, 33-35	2.80	(a)	5.85	6.08	6.15	6.21	6.25	6.30	6.33	6.36				
15-5, 24-26	2.87	(b)	5.78											
17-1, 60-62	2.81		5.21	5.88	5.98	6.01	6.04	6.08	6.11	6.15	6.19	6.23	6.26	Somewhat altered plag-ol-cpx phyric basalt
17-1, 60-62	2.81	(a)	5.72	6.08	6.16	6.19	6.22	6.26	6.29	6.34				
17-1, 98-100	2.74	(b)	4.37											
17-1, 110-114	2.87	(b)	5.25											
22-1, 104-105	2.83		5.78	5.88	5.96	6.01	6.04	6.10	6.17	6.23	6.28	6.31	6.33	Moderately altered plag-ol-cpx phyric basalt
22-1, 100-102	2.88	(b)	5.89											
24-2, 129-131	2.70		5.24	5.45	5.57	5.65	5.71	5.78	5.84	5.91	5.97	6.01	6.04	Moderately altered plag-ol-cpx phyric basalt
24-2, 143-145	2.84	(b)	5.15											
28-1, 54-56	2.70		4.00	4.44	4.92	5.21	5.40	5.68	5.80	5.97	6.08	6.17	6.24	Moderately altered plag-ol-cpx phyric basalt
28-1, 54-56	2.70	(a)	4.59	5.14	5.26	5.37	5.47	5.63	5.76	5.93				
28-1, 58-60	2.78	(b)	4.85											
56-2, 85-87	2.83		5.61	5.71	5.79	5.81	5.84	5.88	5.92	5.98	6.03	6.05	6.05	Fine-grained aphyric basalt with clay minerals in veins
56-2, 79-81	2.91	(b)	5.65											
61-2, 93-95	2.85		5.21	5.97	6.08	6.15	6.23	6.32	6.35	6.39	6.41	6.42	6.43	Plag-ol doleritic basalt
61-2, 79-81	2.91	(b)	5.65											Plag-ol doleritic basalt
61-2, 147-149	2.84		5.88	5.99	6.02	6.05	6.07	6.14	6.20	6.30	6.38	6.42	6.45	
61-3, 88-90	2.87		5.64	6.00	6.17	6.25	6.31	6.39	6.44	6.49	6.54	6.58	6.59	Plag-ol doleritic basalt
63-1, 50-52	2.83		5.79	5.98	6.07	6.11	6.14	6.18	6.22	6.27	6.30	6.33	6.36	Plag-ol-cpx doleritic basalt altered along cracks, coated with chlorite, carbonate
63-1, 38-40	2.90	(b)	5.95											
63-1, 145-142	2.83		5.87	5.97	6.03	6.06	6.08	6.13	6.19	6.27	6.33	6.36	6.38	
63-1, 145-142	2.83	(a)	5.86	6.24	6.28	6.32	6.34	6.39	6.45	6.47				
63-4, 128	2.72		5.05	5.28	5.45	5.59	5.68	5.75	5.80	5.86	5.90	5.94	5.97	Plag-ol-cpx doleritic basalt altered along cracks, coated with chlorite, carbonate
63-4, 32-34	2.87	(b)	5.52											
64-1, 75	2.86		5.82	6.06	6.16	6.21	6.25	6.31	6.35	6.42	6.47	6.50	6.53	
Site 396														
16-4, 74-76	2.77		5.42	5.90	5.96	5.99	6.01	6.02	6.05	6.08	6.13	6.15	6.16	Fine grained glassy plag-ol phyric basalt
18-2, 88-91	2.72		5.60	5.83	5.85	5.87	5.89	5.92	5.96	5.98	6.02	6.05	6.06	Fine grained glassy plag-ol phyric basalt
22-4, 120-122	2.69		5.23	5.40	5.47	5.54	5.58	5.64	5.69	5.74	5.79	5.84	5.86	Fine grained glassy plag-ol phyric basalt
24-1, 85-87	2.73		5.50	6.03	6.06	6.07	6.08	6.09	6.10	6.11	6.13	6.15	6.16	
24-3, 114-115	2.76		5.16	5.55	5.63	5.66	5.70	5.74	5.78	5.84	5.90	5.96.	5.99	

Note: (a) = Sample saturated. Dry samples have no letter designation; (b) = shipboard measurement.

[a]See Site Reports for details

it is clear that the *averaged* saturated velocities would exceed 5.7± km/sec.

The average compressional wave velocity for layer 2 at Site 395, based on extensive ocean bottom seismometer measurements, is 4.6 km/sec (Hussong et al., this volume). These refraction-determined velocities range between 3.2 and 4.9 km/sec for different lines shot in different directions. No consistent anisotropy was determined. The dilemma is the difference between the velocities determined by the OBS refraction studies and these laboratory results.

Houtz and Ewing (1976) have studied the distribution of layer 2 velocities in the world's oceans. They find an increase in velocity with age as one progresses from the accreting ridge axis. For crust about 7 to 10 m.y. old, the age of crust at Site 395, their data indicate a velocity of about 3.5 to 4.5 km/sec, in good agreement with the results of Hussong et al. (this volume). A similar inconsistency between refraction and laboratory-determined velocity is reported for the younger rocks recovered during Project FAMOUS (Hyndman and Drury, 1976; Schreiber and Fox, 1976). It has been suggested previously (Fox et al., 1973) that disrupted crust could explain the lower velocity for layer 2 found by the seismic refraction technique. This disturbed condition of the upper layer of oceanic crust also appears to provide an explanation for the data reported from the area of Project FAMOUS, and to apply equally to the region drilled by Leg 45. The ultramafic rock embedded in the basalt recovered at Site 395 attests to the preservation of disruption of the oceanic crustal layer, perhaps extending through some of layer 3 and presumably having its origin in the mechanics of emplacement at the accreting margins. The possibility of off-axis activity cannot be excluded, however.

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