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28. HIGH-PRESSURE VELOCITY MEASUREMENTS OF JURASSIC BASALT, LEG 129[1]

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ABSTRACT

Compressional wave velocities and densities were measured for 6 basalt samples from ODP Hole 801B and 16 samples from ODP Hole 801C, a site that represents the first drilling of Jurassic-age crustal rocks in the Pacific basin. Incremental measurements, taken to a total pressure of 200 MPa, show a systematic decrease in velocity with increasing porosity and a related increase with increasing wet-bulk density. A comparison of the plot of porosity vs. compressional wave velocity with the theoretical equation from Wyllie et al. (1958) suggests this equation is inappropriate for oceanic basalts because of mineral alteration in high porosity samples. Also of interest is the dramatic change in velocity across a hydrothermal boundary. Basalts below this hydrothermal layer have a mean velocity of 6.05 km/s at 60 MPa while those above show a mean velocity of 4.55 km/s at 60 MPa. The low velocity values of the basalts above the hydrothermal deposit may be attributed to the higher porosity and composition observed in these rocks; the higher porosity is possibly the result of increased exposure to circulating seawater.

INTRODUCTION

One of the goals of Leg 129 was to establish a geophysical reference hole in the oldest Pacific crust to serve as a compliment to the well-established young Pacific crust reference at Hole 504B (1°13.6′N, 83°43.9′W). Site 801 (18°38.5′N, 156°21.6′E) provided an end to this goal with the penetration of 133 m of Jurassic basalt (Fig. 1); preliminary age assignments suggest this is the oldest *in-situ* ocean floor basalt recovered to date. The volcanic pile sampled at Site 801 consisted of two distinct basalt groups. The lowermost unit has been classified as a tholeiitic basalt (Floyd and Castillo, this volume) and is largely distributed as extrusive pillows and flows. This unit is capped by a thin (<10 m) silica and iron hydrothermal deposit which is in turn overlain by highly altered, alkali-olivine basalts occurring as both extrusive pillows and flows and as intrusive sills (Floyd and Castillo, this volume). Figure 2 illustrates the stratigraphic relationships between the igneous units and suggests the likely correlation of material recovered from Holes 801B and 801C.

Age relationships between the units are not entirely clear. It has been suggested that the alkali-olivine basalt postdates the hydrothermal layer and that these basalts may have immediately covered the hydrothermal layer thereby enhancing its preservation (Shipboard Scientific Party, 1990). Floyd et al. (1991) have concluded that further hydrothermal development was probably restricted by the eruption of off-axis alkalic basalts. More recently, K-Ar dating of samples of both basalt groups indicate younger ages for the alkali-olivine basalts than the tholeiites (Pringle, this volume). Indeed, the weathering observed in both groups seems consistent with an interpretation in which the stratigraphic sequence reflects the timing of events; tholeiitic basalts were extruded first followed by deposition of the hydrothermal layer with both later covered by alkali-olivine basalt flows.

We have measured compressional wave velocities, porosities, and bulk densities of samples collected from both basalt groups. Such measurements provide ground truth in the interpretation of oceanic crustal sections by comparison of systematic variations in properties and changes noted in logging runs. In addition, they provide a good approximation of *in-situ* velocity for the construction of synthetic seismograms and the interpretation of refraction and reflection studies.

EXPERIMENTAL PROCEDURE

We collected a total of 22 samples from Site 801 basalts; 6 samples were taken from Hole 801B and 16 from reentry Hole 801C. All samples from Hole 801B and Samples 801C-1R-3, 96 cm, through 801C-2R-3, 95 cm, are stratigraphically higher than the hydrothermal layer while the remainder of the Hole 801C suite occurs beneath this horizon. Velocity as a function of pressure is tabulated in Table 1. The ends of minicore samples were trimmed and polished at right angles resulting in right cylinders with diameters of approximately 2.5 cm and lengths between 2 and 4 cm. Sample volume was calculated by careful measurement of the minicore diameters and lengths. Water-saturated samples were weighed and bulk densities were calculated from the weights and volumes; porosities were calculated from measured dry and wet densities.

The traveltimes of compressional waves were measured by the pulse transmission technique using a mercury delay line (Birch, 1960). The velocities are estimated to be accurate to better than 1% (Christensen and Shaw, 1970). All samples were water-saturated prior to the measurements, and pore pressures were maintained at values lower than external pressures by placing a 100-mesh screen between the samples and copper jackets. The screening requires considerable time in the process of sample preparation; however, it is essential that water be allowed to drain from the pore spaces during the application of pressure. All comparative results are given at 60 MPa, an approximation to expected downhole pressures.

DISCUSSION

Figure 3 shows the relationship between compressional wave velocity and porosity for both basalt types. The data are compared with solutions of the equation of Wyllie et al. (1958) which relates measured velocity with porosity as:

$$\frac{1}{V_m} = \frac{\phi}{V_f} + \frac{1-\phi}{V_r} \quad , \qquad (1)$$

where ϕ is the fractional porosity, V_m is the measured velocity, V_r is the rock velocity, and V_f is the velocity of the interstitial fluid. The dashed line in Figure 3 shows a solution to the above equation calculated by substituting 1.44 km/s for the interstitial fluid velocity (fresh water) and 6.28 km/s for the rock velocity. A least squares solution for the measured basalt data (solid line, Fig. 3) using the above equation shows reasonable correlation but gives both a lower value for rock velocity and, more importantly, a lower value for the interstitial fluid velocity. The data's

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Figure 1. Map of the west central Pacific Ocean showing the location of Sites 800, 801, and 802. Map after Chase et al. (1971). Contour interval is 2 km.

departure from this ideal relationship suggests strongly that the decrease in velocity is a function of both porosity and composition and therefore demonstrates the general inappropriateness of the Wyllie equation in describing these submarine basalts.

Velocities for the tholeiites, while plotting in the vicinity of the y-axis intercept (6.28 km/s) of the calculated curve, show some scatter. This suggests that the velocity for these rocks may depend more on factors other than porosity. This is further demonstrated by a plot of porosity vs. wet-bulk density (Fig. 4) which shows a clear linear correspondence between density and porosity in the alkali-olivine basalts. Since the porosities of the tholeiites are low, the scatter in tholeiite velocities must be related to composition.

Compressional wave velocity is linearly proportional to wet-bulk density in these basalt samples as well (Fig. 5), with distinct separation of the two basalt types. These results suggest that the density and hence the velocity of these samples is a function of porosity and composition in the alkali-olivine basalts and compositionally related in the tholeiites. The dramatic change in velocity between the two

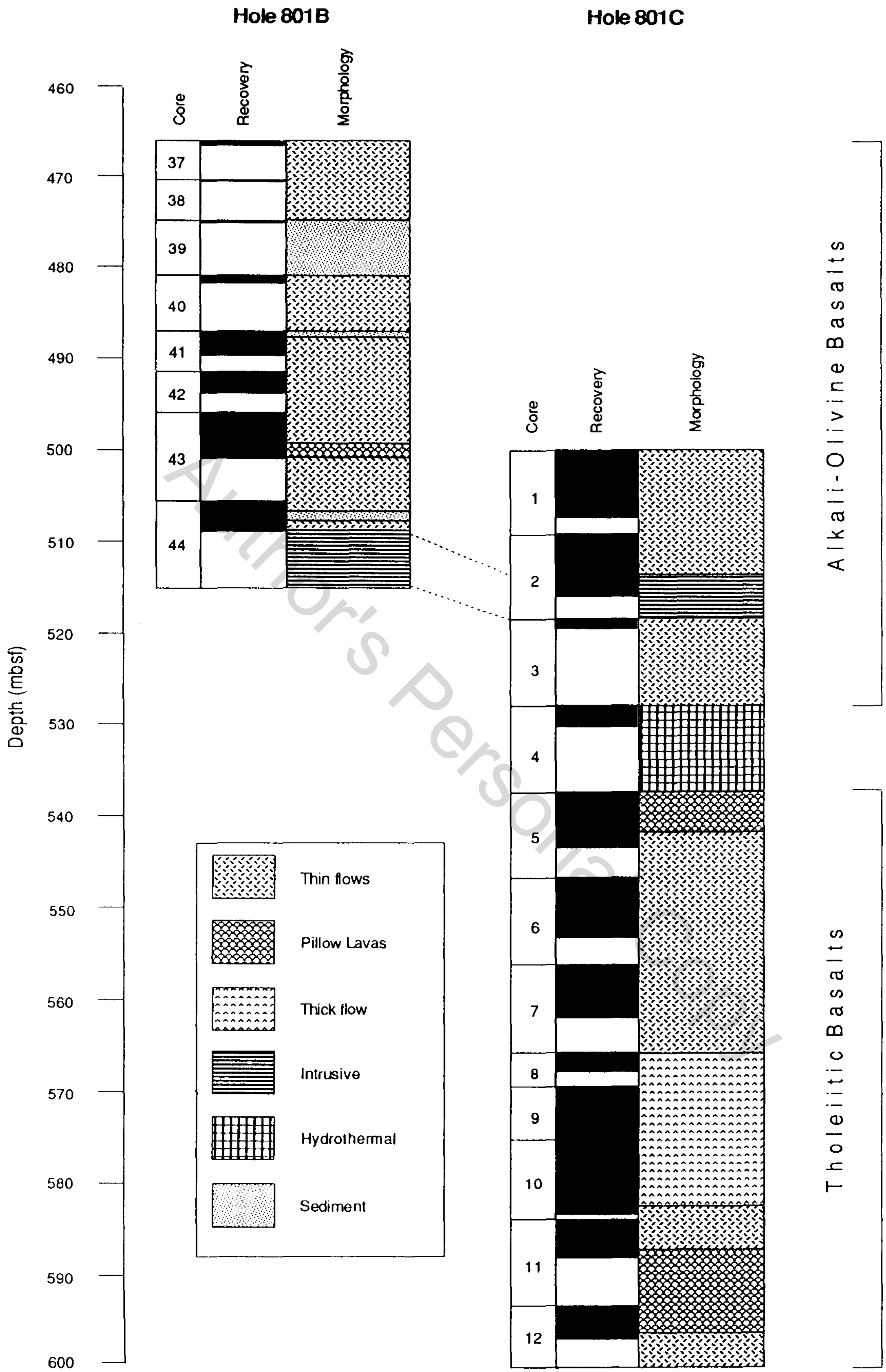

Figure 2. Stratigraphic relationships between Hole 801B and Hole 801C showing major morphologic units. Depth is given in meters below seafloor (after Shipboard Scientific Party, 1990).

Table 1. Summary of velocity data from Site 801.

Sample (cm)	Depth (mbsf)	Total depth (mbsf)	Bulk density (g/cm^3)	Porosity (%)	V_p (km/s) at pressure (MPa)						
					10.00	20.00	40.00	60.00	80.00	100.00	200.00
129-801B-											
37R-1, 40	466.50	6140.30	2.34	9.92	3.53	3.56	3.59	3.62	3.64	3.67	3.75
40R-1, 27	483.27	6157.07	2.468	7.10	3.94	4.00	4.06	4.10	4.13	4.15	4.25
41R-1, 63	488.23	6162.03	2.644	3.76	4.95	5.01	5.06	5.09	5.12	5.14	5.23
43R-1, 37	502.07	6175.87	2.668	3.25	5.19	5.23	5.28	5.32	5.34	5.36	5.43
43R-1, 81	502.51	6176.31	2.672	5.26	4.42	4.51	4.62	4.69	4.75	4.79	4.94
44R-2, 60	513.30	6187.10	2.63	4.53	4.30	4.41	4.51	4.58	4.62	4.66	4.77
128-801C-											
1R-3, 96	514.96	6188.96	2.52	6.87	4.14	4.19	4.25	4.28	4.31	4.34	4.43
2R-1, 19	520.39	6194.39	2.528	5.31	4.24	4.29	4.32	4.35	4.38	4.40	4.48
2R-3, 95	524.15	6198.15	2.66	3.08	4.70	4.78	4.87	4.92	4.96	4.98	5.07
5R-4, 125	554.25	6228.25	2.807	0.06	6.08	6.10	6.13	6.14	6.15	6.16	6.18
5R-4, 138	554.38	6228.38	2.854	0.00	6.21	6.24	6.27	6.28	6.29	6.30	6.33
7R-2, 2	569.02	6243.02	2.732	0.04	5.06	5.10	5.13	5.15	5.16	5.17	5.21
7R-4, 102	573.02	6247.02	2.899	0.10	5.99	6.03	6.09	6.12	6.15	6.17	6.23
8R-2, 67	579.07	6253.07	2.848	0.05	5.64	5.70	5.77	5.81	5.84	5.86	5.91
9R-2, 51	582.61	6256.61	2.938	0.02	6.09	6.13	6.18	6.20	6.22	6.24	6.28
9R-3, 70	584.30	6258.30	2.907	0.06	5.89	5.95	6.01	6.05	6.07	6.09	6.15
9R-4, 21	585.31	6259.31	2.886	0.13	5.77	5.86	5.94	5.98	6.01	6.02	6.06
10R-1, 09	585.99	6259.99	2.956	0.06	6.13	6.18	6.23	6.25	6.27	6.28	6.32
10R-3, 113	590.03	6264.03	2.879	0.05	6.12	6.15	6.17	6.19	6.20	6.21	6.24
10R-5, 39	592.29	6266.29	2.948	0.07	6.02	6.10	6.19	6.24	6.27	6.29	6.36
11R-2, 30	597.10	6271.10	2.923	0.02	5.98	6.03	6.10	6.13	6.16	6.18	6.22
12R-3, 40	605.70	6279.70	2.963	0.04	6.09	6.12	6.15	6.18	6.19	6.20	6.23

units is significant. The upper alkali-olivine basalt unit (Table 1, Cores 801C-1R through 801C-2R) is characterized by low velocities, ranging from 3.62 to 5.32 km/s at 60 MPa with a mean of 4.55 km/s. The tholeiitic basalts have considerably higher velocities than the alkali-olivine basalts, ranging from 5.15 to 6.28 km/s at 60 MPa, with a mean of 6.05 km/s. While we view the difference in velocity between the two basalt types as largely due to composition and porosity, we recognize that other factors such as grain size, microfracture orientation, and crystal structure may also have a bearing on velocity difference. A plot of compressional wave velocity vs. depth (Fig. 6) illustrates the separation of the two basalt types into distinctive fields. These fields seem to correspond roughly to velocities recorded from sonobuoy data collected during MESOPAC II and FM35-12 expeditions (Shipboard Scientific Party, 1990). A complete understanding of the relationship between the refraction data and the results listed here will require further study.

In an analysis of refraction data from both the Atlantic and Pacific basins, Houtz and Ewing (1976) recognized the presence of a low velocity basement layer which thinned away from ridge crests and then reappeared in Mesozoic-age crust. They concluded that the layer, referred to as 2A (Talwani et al., 1976), increased in velocity from 3.3 km/s at ridge crests to 4.0 km/s on the roughly 30-m.y.-old flanks. Such low velocity basement material has been attributed to the presence of large cracks and fissures, particularly in young material (Hyndman and Drury, 1976). Houtz and Ewing (1976) also recognized a strong acoustic boundary between layers 2A and 2B. They suggested that the disappearance of layer 2A was either caused by hydrothermal circulation diagenetically filling in pore spaces and cracks with precipitates and thereby increasing velocity with time, or by repeated intrusion of higher velocity basalts into the existing crust. Their calculations showed that the paucity of layer 2A data in the Pacific corresponded roughly to the Cretaceous and Jurassic magnetic quiet zones and suggested that there may be some connection between the magnetic properties and the apparent reappearance of layer 2A in these areas.

The alkali-olivine basalts found at the present site and associated with the Jurassic Quiet Zone have velocities which are similar to, or only slightly higher than, those described for acoustic layer 2A. No data currently exist to indicate widespread lateral continuity of this thin, low-velocity layer throughout the Jurassic Quiet Zone and indeed, detection of a layer of such limited vertical extent as seen at Site 801 seems impractical. Still, at this site the layer exists and is associated with the quiet zone as previously described.

Wallick and Steiner (this volume) found that while the alkali-olivine basalt layer generally shows reduced magnetic intensity, the reversed polarity intervals within the span of the tholeiitic basalt column are more likely to be the cause of the Jurassic Quiet Zone and, therefore, have little connection with the low velocity interval in that region. Further, while recognizing the possible importance of other factors, the current data seem to indicate that velocity differences correlate with porosity and composition; the altered state of these basalts suggests that this porosity may be secondary in nature, possibly the result of longer-lived exposure to ocean water circulation and resultant weathering. While the tholeiites were subject to the same phenomenon, sealing of the layer by hydrothermal activity may have prevented long-term access to the lower basalts thereby inhibiting the development of secondary porosity.

It is not clear at this time whether the sharp velocity increase seen across the alkali-olivine basalt\tholeiitic basalt boundary is representative of that described by Houtz and Ewing in their discussion of the occurrence of layer 2A. However, it seems likely that the basalts herein described owe their velocity contrast to a combination of high porosity in the low-velocity layer and to compositional differences between the two basalt species. We suspect that these variations are age-independent and are thus unrelated to the processes which show progressive thinning of the layer with increasing distance from spreading centers. It is hoped that future comparisons of these data with those observed at Hole 504B (Wilkens et al., 1983; Christensen and Salisbury, 1985) and the Atlantic reference site at Hole 418A (Christensen et al., 1980) will provide answers to questions concerning the effects of age on seismic velocity.

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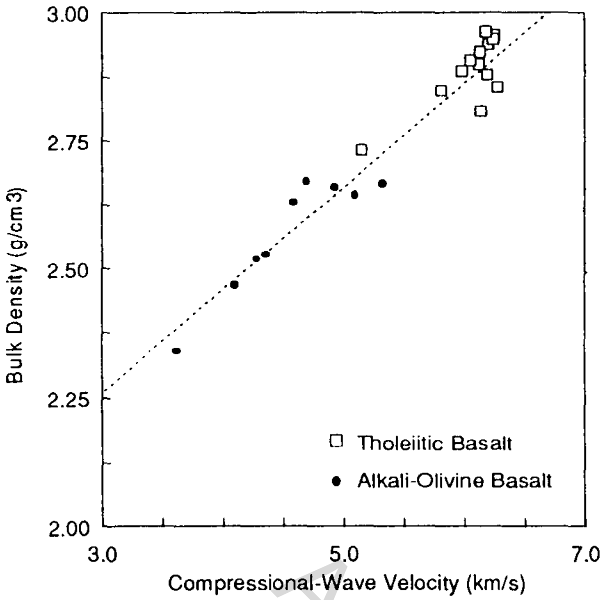

Figure 5. Compressional wave velocity (V_p) at 60 MPa vs. density for alkali-olivine basalts and tholeiitic basalts.

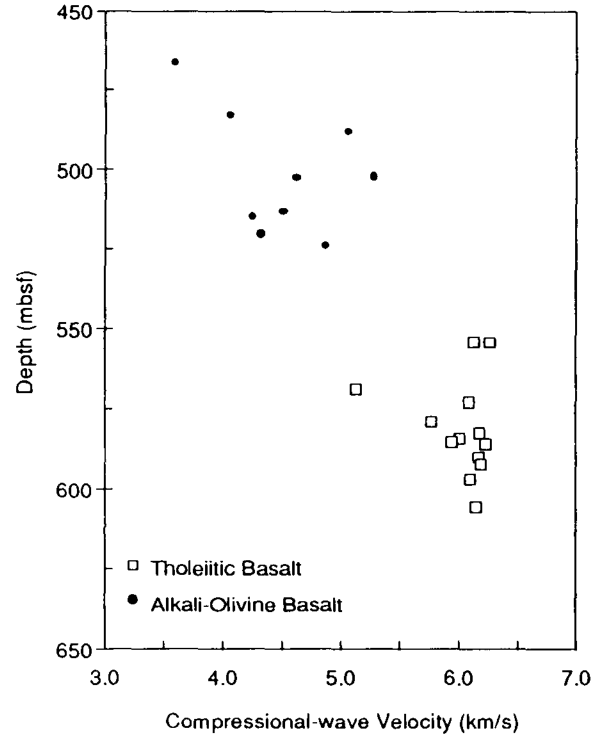

Figure 6. Compressional wave velocity (V_p) at 60 MPa vs. depth below the seafloor for alkali-olivine basalts and tholeiitic basalts.