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Compressional and Shear Wave Velocities at Pressures to 10 Kilobars for Basalts from the East Pacific Rise

Nikolas I. Christensen

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Summary

Compressional and shear wave velocities are reported to pressures of 10 kb for 15 cores of basalt dredged from the East Pacific Rise between 8° N and 13° N latitude. The compressional wave velocities are similar to previous measurements for basalts dredged from the Mid-Atlantic Ridge and the Juan de Fuca Ridge. Shear wave velocities for the East Pacific Rise basalts show a systematic increase with increasing density. The ratio of compressional to shear wave velocity for oceanic basalt is generally between 1·80 and 1·90. Poisson's ratio at 10 kb is 0·28 for all the basalts included in this study.

Introduction

In an earlier paper (Christensen & Shaw 1970) compressional wave velocities were reported to pressures of 10 kb for a suite of mafic igneous and low grade metamorphic rocks dredged from the Mid-Atlantic Ridge. The results demonstrated that basalt, altered basalt, chlorite-rich greenstone, and dolerite could all be major constituents of layer 2 of the oceanic crust. The compressional wave velocities of these rocks, however, were much lower than seismic velocities of the main oceanic crustal layer (layer 3). Shear wave velocities were reported for three of the Mid-Atlantic Ridge rocks. For these rocks the data suggested that the ratio of compressional to shear wave velocity may be an important parameter for the identification of rock type from seismic velocities.

Although our observations were consistent with many petrologic models of the oceanic crust several questions remained. Of prime importance was the necessity of comparing the velocities and elastic moduli of Mid-Atlantic Ridge rocks with those obtained from samples dredged from other ridge systems. Thus additional measurements were needed to establish whether or not our interpretations based upon the measurements from the Mid-Atlantic Ridge samples apply to the entire oceanic crust. It was also important to compare the velocity–density relations determined for the Mid-Atlantic Ridge rocks with those from additional oceanic rocks.

Description of specimens and experimental data

In this paper compressional and shear wave velocities are reported as a function of hydrostatic pressure for five basalts dredged near the East Pacific Rise. Samples EPR 1 and EPR 2 were collected from the crest of the rise at 12° 23′ N and 103° 52′ W at water depths between 1405 and 1440 fm. Sample EPR 3 was dredged from the ridge crest at 8° 09′ N and 103° 09′ W at a depth of 1125 fm. EPR 4 was collected at 8° 90′ N and 103° 23′ W at 1980 fm. The fifth sample, EPR 5, was dredged approximately 500 km west of the rise crest (12° 56′ N, 110° 24′ W) from a water depth of 5445 fm.

The basalts contain approximately 45 per cent clinopyroxene and 40 per cent plagioclase by volume, the remainder being opaque minerals and olivine. EPR 1 and EPR 2 are extremely fine grain basalts with subvariolitic textures. Vesicles do not appear to be present in either sample. EPR 3 and EPR 4 are slightly vesicular basalts with variolitic textures. EPR 5 has an intergranular texture and contains approximately 3 per cent by volume vesicles. All the basalts are virtually free of alteration and glass.

Velocities measured in three mutually perpendicular cores from each sample using the pulse transmission technique described in detail by Birch (1960) and Christensen & Shaw (1970) are given in Table 1. The bulk densities in Table 1 were calculated from the weights and dimensions of the samples. All velocities were measured at room temperature from water saturated samples.

The ratio of compressional to shear velocity (V_p/V_s), Poisson's ratio (σ), the seismic parameter (ϕ), the bulk modulus (K), compressibility (β), the shear modulus (μ), Young's modulus (E), and Lamé's constant (λ) calculated at selected pressures for each rock are given in Table 2. The equations relating these constants to velocities and density are summarized by Birch (1961). Mean velocities and densities used for the calculations were corrected for dimension changes using an iterative routine and the dynamically determined compressibilities.

Discussion

The elastic constants (Table 2) agree well with those reported for basalt W–4–15 from the Mid-Atlantic Ridge (Christensen & Shaw 1970). At pressures above a few kilobars the ratios of V_p and V_s are 1·82 for all of the East Pacific Rise basalts and the corresponding Poisson's ratios are 0·28. At lower pressures Poisson's ratios are slightly higher, reflecting the influence of grain boundary cracks on the velocities. This relationship between V_p and V_s should prove extremely useful in the positive identification of transformed shear waves from refraction investigations in basaltic portions of the oceanic crust.

At low pressures Poisson's ratios for the East Pacific Rise basalts show a slight decrease with increasing pressure. In contrast, Poisson's ratio for the Mid-Atlantic Ridge basalt W–4–15 was observed to increase with increasing pressure. This difference is apparently related to the degree of water saturation of the samples. The Mid-Atlantic Ridge samples were only partially water saturated, whereas the East Pacific Rise samples were totally saturated. Increasing water saturation increases low pressure compressional wave velocities, but has little effect on shear velocities (Dortman & Magid 1969; Nur & Simmons 1969; Christensen 1970a) thereby increasing Poisson's ratio. At pressures above a few kilobars grain boundary cracks are closed for most rocks and water saturation has little influence on velocities and elastic constants.

In Fig. 1 compressional wave velocities and densities of the East Pacific Rise basalts are compared with previous measurements at 10 kb of basalts from the Mid-Atlantic Ridge (Christensen & Shaw 1970) and the Juan de Fuca Ridge (Christensen 1970a). The velocities tend to increase with increasing density and fall between the lines of mean atomic weight 21 and 22 determined experimentally by Birch (1960, 1961). Also shown in Fig. 1 are Manghnani & Woollard's (1968) least-square fit for eight cores of Hawaiian basalt. The scatter from a perfect linear relationship is probably due to many factors including variable vesicularity, alteration, glass content, and bulk chemistry.

Table 1

Compressional (P) and shear (S) wave velocities (km s^{-1})

Identification number	Bulk density	Mode	$P=$ 0·2 kb	$P=$ 0·4 kb	$P=$ 0·6 kb	$P=$ 0·8 kb	$P=$ 1·0 kb	$P=$ 2·0 kb	$P=$ 4·0 kb	$P=$ 6·0 kb	$P=4$ 8·0 kb	$P=$ 10·0kb
EPR 1–1	2·943	P	6·42	6·44	6·47	6·49	6·505	6·587	6·680	6·716	6·742	6·754
EPR 1–2	2·958	P	6·31	6·35	6·39	6·42	6·450	6·564	6·686	6·742	6·776	6·791
EPR 1–3	2·957	P	6·30	6·33	6·36	6·39	6·426	6·520	6·625	6·670	6·696	6·716
Mean	2·953	P	6·34	6·37	6·41	6·43	6·460	6·557	6·664	6·709	6·738	6·754
EPR 1–1	2·943	S	3·41	3·44	3·48	3·50	3·525	3·605	3·681	3·705	3·714	3·722
EPR 1–2	2·958	S	3·40	3·42	3·45	3·47	3·485	3·568	3·662	3·695	3·708	3·714
EPR 1–3	2·957	S	3·33	3·38	3·41	3·44	3·460	3·550	3·639	3·668	3·676	3·684
Mean	2·953	S	3·38	3·41	3·45	3·47	3·490	3·574	3·661	3·689	3·699	3·707
EPR 2–1	2·937	P	6·24	6·31	6·36	6·41	6·447	6·574	6·691	6·738	6·758	6·767
EPR 2–2	2·944	P	6·25	6·31	6·36	6·41	6·445	6·574	6·682	6·727	6·752	6·763
EPR 2–3	2·953	P	6·29	6·37	6·43	6·47	6·515	6·640	6·751	6·800	6·820	6·831
Mean	2·945	P	6·26	6·33	6·38	6·43	6·469	6·596	6·708	6·755	6·777	6·787
EPR 2–1	2·937	S	3·25	3·31	3·37	3·43	3·470	3·592	3·681	3·706	3·715	3·721
EPR 2–2	2·944	S	3·25	3·33	3·38	3·44	3·481	3·602	3·693	3·710	3·720	3·729
EPR 2–3	2·953	S	3·24	3·33	3·42	3·48	3·525	3·645	3·724	3·738	3·750	3·757
Mean	2·945	S	3·25	3·32	3·39	3·45	3·492	3·613	3·699	3·718	3·728	3·736
EPR 3–1	2·868	P	6·26	6·34	6·39	6·44	6·476	6·600	6·707	6·747	6·760	6·765
EPR 3–2	2·865	P	6·15	6·21	6·25	6·29	6·325	6·455	6·595	6·665	6·695	6·702
EPR 3–3	2·881	P	6·25	6·33	6·38	6·43	6·464	6·585	6·994	6·741	6·757	6·764
Mean	2·871	P	6·22	6·29	6·34	6·39	6·422	6·547	6·765	6·718	6·737	6·744
EPR 3–1	2·868	S	3·20	3·36	3·43	3·46	3·494	3·590	3·660	3·674	3·685	3·695
EPR 3–2	2·865	S	3·10	3·22	3·33	3·40	3·401	3·580	3·667	3·682	3·698	3·706
EPR 3–3	2·881	S	3·15	3·25	3·40	3·45	3·491	3·608	3·696	3·714	3·732	3·741
Mean	2·871	S	3·15	3·28	3·39	3·44	3·462	3·593	3·674	3·690	3·705	3·714
EPR 4–1	2·872	P	5·95	6·03	6·10	6·17	6·235	6·432	6·580	6·643	6·665	6·674
EPR 4–2	2·876	P	5·85	5·98	6·10	6·18	6·250	6·465	6·626	6·692	6·722	6·734
EPR 4–3	2·883	P	6·04	6·11	6·17	6·21	6·256	6·401	6·546	6·619	6·661	6·673
Mean	2·877	P	5·95	6·04	6·12	6·34	6·247	6·433	6·584	6·651	6·683	6·694
EPR 4–1	2·872	S	3·00	3·12	3·19	3·26	3·320	3·500	3·611	3·644	3·654	3·661
EPR 4–2	2·876	S	2·89	2·98	3·14	3·26	3·320	3·516	3·649	3·682	3·695	3·705
EPR 4–3	2·883	S	3·18	3·26	3·30	3·35	3·381	3·490	3·590	3·623	3·640	3·649
Mean	2·877	S	3·02	3·12	3·21	3·29	3·340	3·502	3·617	3·650	3·663	3·672
EPR 5–1	2·829	P	5·94	5·96	5·98	6·01	6·023	6·095	6·182	6·235	6·264	6·282
EPR 5–2	2·830	P	5·85	5·88	5·91	5·93	5·948	6·023	6·118	6·174	6·205	6·225
EPR 5–3	2·810	P	5·69	5·73	5·76	5·78	5·805	5·900	6·015	6·080	6·108	6·125
Mean	2·823	P	5·83	5·86	5·88	5·91	5·925	6·006	6·095	6·163	6·192	6·211
EPR 5–1	2·829	S	3·17	3·21	3·24	3·27	3·291	3·368	3·432	3·458	3·470	3·480
EPR 5–2	2·830	S	3·14	3·12	3·20	3·22	3·240	3·315	3·388	3·414	3·423	3·430
EPR 5–3	2·810	S	3·00	3·04	3·07	3·09	3·111	3·200	3·291	3·323	3·337	3·346
Mean	2·823	S	3·10	3·12	3·17	3·19	3·214	3·294	3·370	3·398	3·410	3·419

Table 2

Elastic constants calculated from V_p, V_s, and ρ

Identification number	Pressure, kb	V_p/V_s	σ	ϕ, $(km\ s^{-1})^2$	K, Mb	β, Mb^{-1}	μ, Mb	E, Mb	λ, Mb
EPR 1	0·4	1·87	0·30	25·1	0·74	1·35	0·34	0·89	0·51
	1·0	1·85	0·29	25·5	0·75	1·34	0·36	0·93	0·52
	2·0	1·83	0·29	25·9	0·78	1·30	0·38	0·97	0·52
	6·0	1·82	0·28	26·7	0·80	1·26	0·40	1·03	0·53
	10·0	1·82	0·28	27·1	0·81	1·24	0·41	1·05	0·54
EPR 2	0·4	1·91	0·31	25·4	0·75	1·34	0·32	0·85	0·53
	1·0	1·85	0·29	25·6	0·75	1·33	0·36	0·93	0·51
	2·0	1·83	0·29	26·1	0·77	1·30	0·38	0·99	0·51
	6·0	1·82	0·28	27·1	0·80	1·25	0·41	1·05	0·53
	10·0	1·82	0·28	27·2	0·81	1·23	0·41	1·06	0·54
EPR 3	0·4	1·91	0·31	25·2	0·73	1·38	0·31	0·81	0·52
	1·0	1·85	0·30	25·2	0·73	1·38	0·34	0·89	0·50
	2·0	1·82	0·28	25·6	0·74	1·36	0·37	0·95	0·49
	6·0	1·82	0·28	26·8	0·78	1·29	0·39	1·01	0·52
	10·0	1·82	0·28	26·9	0·78	1·28	0·40	1·02	0·52
EPR 4	0·4	1·94	0·32	23·5	0·68	1·48	0·28	0·74	0·49
	1·0	1·87	0·30	24·1	0·70	1·44	0·32	0·83	0·48
	2·0	1·84	0·29	25·0	0·72	1·39	0·35	0·91	0·49
	6·0	1·82	0·28	26·3	0·76	1·31	0·38	0·99	0·51
	10·0	1·82	0·28	26·6	0·78	1·29	0·39	1·00	0·52
EPR 5	0·4	1·88	0·30	21·4	0·60	1·66	0·27	0·27	0·42
	1·0	1·84	0·29	21·3	0·60	1·66	0·29	0·75	0·41
	2·0	1·82	0·28	21·6	0·61	1·64	0·31	0·79	0·41
	6·0	1·82	0·28	22·5	0·64	1·56	0·32	0·84	0·42
	10·0	1·82	0·28	22·8	0·65	1·53	0·33	0·85	0·43

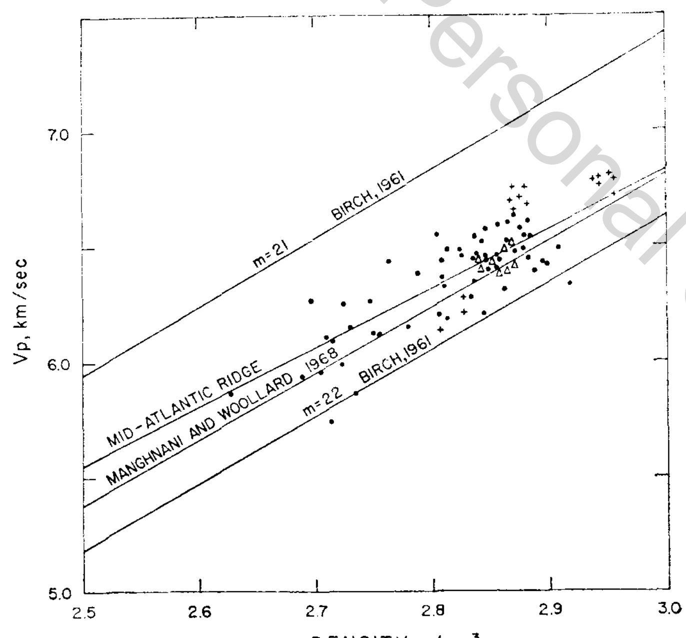

FIG. 1. Compressional wave velocities at 10kb as a function of bulk densities for basaltic rocks from the Mid-Atlantic Ridge (·), the Juan de Fuca Ridge (△), and the East Pacific Rise (+).

Two of the East Pacific Rise samples (EPR 1 and EPR 2) are extremely massive basalts with little or no alteration and are free of glass and vesicles. These samples are higher in density and velocity than previously studied oceanic basalts (Fig. 1). The velocities of these two rocks at pressures between 1 and 2 kb (Table 1) are, however, lower than seismic velocities of the lower oceanic crust, thus suggesting that even massive basalt can not be a major constituent of the lower oceanic crust. This is in agreement with earlier conclusions based upon laboratory velocities by Christensen (1970b) and Christensen & Shaw (1970).

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Department of Geological Sciences,
University of Washington,
Seattle, Washington 98195.

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