Crustal Layer of Seismic Velocity 6.9 to 7.6 Kilometers per Second under the Deep Oceans

Abstract. *Refraction measurements made in the deep ocean between the Marshall and Hawaiian islands reveal a layer of seismic velocity 7.3 kilometers per second between the 6.8 kilometer per second oceanic crustal layer and the mantle. This layer, normally masked as a second arrival, is revealed by continuous air gun refraction data. The layer may be widespread in the deep oceans.*

A basal crustal layer with a seismic velocity of 6.9 to 7.6 km/sec (average, 7.3 km/sec) underlying the normal (about 6.8 km/sec) crustal layer was revealed by refraction measurements in the deep-ocean region between the Marshall and the Hawaiian islands in January 1969. The instrumentation consisted of sonobuoys, precision echo sounder recorders, and a 20 to 40 cubic inch air cannon employed as a repetitive signal source. The measurements were made from the R.V. *Mahi* by the Hawaii Institute of Geophysics (*1*).

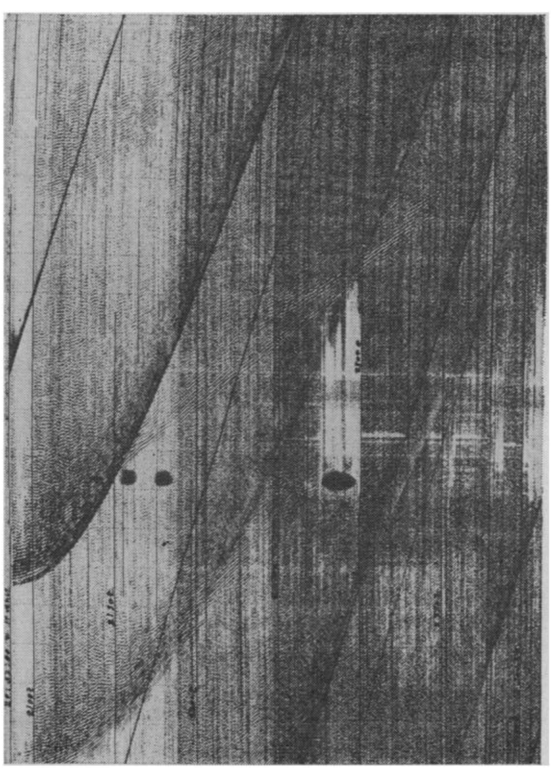
The repetitive signal source resulted in a greater density of data than has heretofore been obtainable in deep-ocean refraction work. The extraordinary density of data and the mode of presentation provided by the recorders permitted phase correlations (*2*), which brought out refraction arrivals that ordinarily are masked and not recognized, because they never appear as a first arrival or appear only as very short segments of first arrivals at a range at which data from explosive sources are often widely spaced. The combination of the instruments used (*1, 2*), which intensified the coverage, produced the type of record shown in Fig. 1. The refractions are clearly delineated, and the usually masked 6.9 to 7.6 km/sec layer is clearly revealed. In Fig. 2, lines have been superimposed on this record to identify schematically the refraction arrivals. It is to be noted that the layer in question is buried in the other arrivals and is apparent only because of the readily identified phase correlation. Also shown in Fig. 2 is the seismic crustal section calculated from the refraction arrivals.

The seismic section given in Fig. 2 for this unreversed profile was obtained from a simple refraction interpretation; horizontal, homogeneous, isotropic layers were assumed. However, comparison of the data with the theoretical reflection and refraction travel times and comparison with results from

Table 1. Calculated velocities and depths of the earth's deep crustal layer and the mantle at several locations.

Sonobuoy location		Water depth (km)	Deep crustal layer		Mantle	
Latitude	Longitude		Velocity (km/sec)	Depth* (km)	Velocity† (km/sec)	Depth* (km)
12°05′N	175°12′W	5.4	7.6	10.4	8.5	13.7
12°18′N	174°45′W	5.4	7.5	11.7	(8.3)	≧ 12.1
12°30′N	174°22′W	5.4	7.5	10.3	(8.3)	
16°10′N	165°38′W	5.3	7.4	8.1	7.9	13.6
16°20′N	165°20′W	5.3	7.3	8.5	8.5	13.0
16°30′N	165°02′W	5.3	7.4	7.4	(8.3)	≧ 10.1
19°10′N	160°52′W	4.9	7.1	7.5	8.0	10.0
19°50′N	159°55′W	4.5	6.9	6.7	8.0	10.3

* Below sea level. † Parentheses indicate poorly determined velocity.



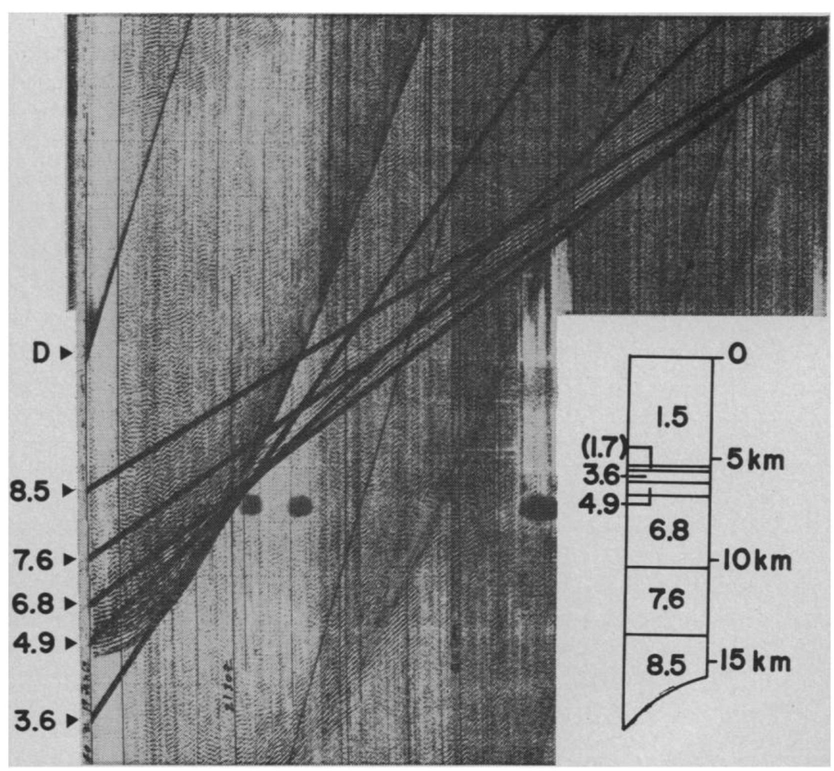


Fig. 1 (left). Seismogram made on a precision echo-sounder recorder with the use of a sonobuoy and a repetitive signal source. Fig. 2 (right). The same seismogram as in Fig. 1 with lines superimposed to indicate schematically the refraction interpretation. Insert shows the flat-layer solution.

adjacent profiles indicate that the interpretation given is reliable. Full utilization of the reflection data will probably increase the precision of the interpretations somewhat. Table 1 shows the pertinent data for eight similar crustal sections that were obtained during the cruise. [See (*2*) for parts of the geologic column not of primary interest here and for details of the analysis techniques and results.]

As indicated in Table 1, mantle refractions were clearly obtained with the air gun source. A few arrivals were verified by the use of explosives and conventional records (*1, 2*).

The somewhat irregular nature of the refraction arrival line suggests that the interface either is irregular or consists of a thin zone of subordinate interfaces rather than a sharply defined plane.

The observations were taken along a thousand-kilometer-long line running roughly northeast from near the Marshall Islands to southwest of the Hawaiian Islands in water depths averaging over 5 km (*2*). The extent and deep-ocean environment of these observations suggest that the 6.9 to 7.6 km/sec (average, 7.3 km/sec) crustal layer may be fairly widespread throughout the south-central Pacific Ocean. Although similar velocity values have been reported from such oceanic environments as the Caribbean Sea (*3*) and, in the Pacific Ocean, the Shatsky Rise (*4*) and the Hawaiian Arch and Deep (*5*), the layer has not been a generally accepted feature of classical deep-ocean basin structure. For example, Ewing, Raitt, and Shor and Raitt (*6*) in their reviews of the literature indicate that the deepest oceanic crustal layer has a characteristic velocity of around 6.8 km/sec in the great majority of cases.

If the 7.3 km/sec layer is widely present, as our measurements suggest (*7*), the implications are several, such as: (i) a widespread change in composition or a polymorphic transition at this interface; (ii) a higher than heretofore accepted mean density of the earth's crust affecting depths determined from gravity anomalies and perhaps density distributions consistent with the moment of inertia; (iii) an effect on the dispersion of seismic surface waves requiring a reconsideration of current interpretations.

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References and Notes

1. This layer was first reported by G. H. Sutton, G. L. Maynard, D. M. Hussong, in paper 15, presented at the April 1969 annual meeting of the Seismological Society of America, St. Louis, Mo. (April 1969); it was discussed further by G. L. Maynard, G. H. Sutton, D. M. Hussong, in paper O132, presented at the annual meeting of the American Geophysical Union, Washington, D.C. (April 1969) [see also *Trans. Amer. Geophys. Union* **50**, 206 (1969)].
2. G. L. Maynard, G. H. Sutton, D. M. Hussong, two papers in preparation.
3. C. B. Officer, J. I. Ewing, J. F. Hennion, D. G. Harkrider, D. E. Miller, *Phys. Chem. Earth* **3**, 17 (1959); H. W. Menard, *J. Geophys. Res.* **72**, 3061 (1967); J. I. Ewing, J. Antoine, M. Ewing, *J. Geophys. Res.* **65**, 4087 (1960). A layer with refraction velocity of 7.0 to 7.5 km/sec is a well-known feature of the "mid-ocean" ridges, certain oceanic margin areas, and some trenches and their associated ridges. See, for example, B. C. Heezen and M. Ewing, in *The Sea*, M. N. Hill, Ed. (Interscience, New York, 1963), vol. 3, p. 388; X. Le Pichon, R. E. Houtz, C. L. Drake, J. E. Nafe, *J. Geophys. Res.* **70**, 319 (1965); M. Talwani, G. H. Sutton, J. W. Worzel, *ibid.* **64**, 1545 (1959); R. E. Houtz and J. I. Ewing, *Bull. Seismol. Soc. Amer.* **54**, 867 (1964); E. T. Bunce, D. A. Fahlquist, J. W. Clough, *J. Geophys. Res.* **74**, 3082 (1969).
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5. A. S. Furumoto, G. P. Woollard, J. F. Campbell, D. M. Hussong, in *The Crust and Upper Mantle of the Pacific Area, Monograph 12*, L. Knopoff, C. L. Drake, P. J. Hart, Eds. (American Geophysical Union, Washington, D.C., 1968), p. 94.
6. J. I. Ewing, in *The Earth's Crust and Upper Mantle, Monograph 13*, P. J. Hart, Ed. (American Geophysical Union, Washington, D.C., 1969), p. 220; R. W. Raitt, in *The Sea*, M. N. Hill, Ed. (Interscience, New York, 1963), vol. 3, p. 85; G. G. Shor, Jr., and R. W. Raitt, in *The Earth's Crust and Upper Mantle, Monograph 13*, P. J. Hart, Ed. (American Geophysical Union, Washington, D.C., 1969), p. 225. See also J. I. Ewing, in *The Sea*, M. N. Hill, Ed. (Interscience, New York, 1963), vol. 3, p. 103.
7. More recent work reveals that the 7.5 km/sec layer is not confined to the area considered here: D. M. Hussong (personal communication) finds the layer in the deep ocean north of Hawaii. D. M. Hussong, A. A. Nowroozi, M. E. Odegard, and G. H. Sutton reported the layer 180 km west of San Francisco in paper S16, presented at the fall meeting of the American Geophysical Union, San Francisco (December 1969) [see also *Trans. Amer. Geophys. Union* **50**, 644 (1969)].
8. This work was supported by the National Science Foundation under grant GA 1639 and by the Office of Naval Research under contract Nonr 3748(05). Hawaii Institute of Geophysics Contribution No. 317.

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Bradykinin Inhibition by Butylated Hydroxyanisole

Abstract. *Concentrations of butylated hydroxyanisole as low as 8×10^{-9} mole per liter can inhibit detectably the contraction of smooth muscle elicited by bradykinin. The mechanism of the inhibitory effect of this food grade anti-oxidant is apparently complex, and the effect is only partially reversible.*

Bradykinin's contractive action on smooth muscle is inhibited by agents generally classed as tranquilizers (*1*). We now report similar inhibition of bradykinin activity by butylated hydroxyanisole (BHA), an antioxidant widely used for the preservation of foods containing unsaturated lipids.

Assays of this inhibitory effect were made with a 2- to 3-cm section of the terminal segment of a guinea pig ileum suspended in a 5-ml capacity perfusion bath held at 37°C. Changes in length of the ileum were recorded with a standard kymograph. The gut was equilibrated against Tyrode's buffer containing 2 mg of atropine and 40 μg of pyribenzamine per liter by flowing the solution through the cell at a rate of 15 ml per minute for 1 hour before use.

After equilibration the flow of Tyrode's buffer through the cell was suspended, and a 0.2-ml portion of test solution containing pure bradykinin and the antioxidant were injected into the cell. Test solutions were made from stock solutions of butylated hydroxyanisole (Nutritional Biochemicals) dissolved in water and synthetic bradykinin (BRS 640, Sandoz) dissolved in Tyrode's buffer. After exposure for 30 seconds to a test solution, the mixture was flushed from the cell, and the entire procedure was repeated with another kinin mixture. The response of the gut to a solution containing only pure kinin was used throughout the analyses as a control. The height of the peak traced on the kymograph chart when the gut was in contact with the kinin-containing solution was taken as

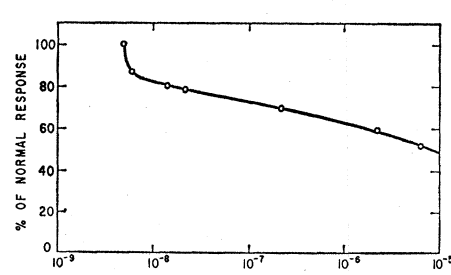

Fig. 1. Suppression of ileum response to test solutions of bradykinin containing increasing amounts of BHA. Gut was freed of reaction mixtures by flushing Tyrode's buffer through the cell at a rate of 15 ml/min for 10 minutes between each point determination. The raw data were corrected for irreversible decreases in gut sensitivity due to exposure to BHA.