Mantle phases recorded at Guam for distances between 1° and 52° (*)

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Summary. — An analysis of P and S arrivals recorded at Guam from 175 earthquakes which occurred along the seismic belt in the Western Pacific reveals differences between the travel times to that station and those recorded at Marcus, Midway, and Wake islands from earthquakes occurring in the same general area. Three possible explanations are offered to account for the observed discrepancies: (1) compressional phases observed at Marcus, Midway, and Wake are mantle-guided phases of the Pn type; (2) systematic errors in epicenter determinations of the type reported by Japanese authors for earthquakes in the Kurile, Japan, and Izu trench region are present; and (3) real differences exist in the upper-mantle velocity structure of the two regions in question through which the phases travelled. Either of the last two hypotheses is considered more acceptable than the first. The travel times to Guam are found to be similar for earthquakes north and south of the station, but for earthquakes to the north at distances greater than $\simeq 26°$, energy being transmitted to Guam appears to be absorbed or blocked. This may be explained by a high attenuation zone along paths sub-parallel to the Marianas, Izu, Japan, Kurile trenchs or by a shadow zone at Guam produced by the lateral refraction of energy by the downgoing lithospheric slab.

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RIASSUNTO. — Un esame di 175 scosse sismiche con epicentri situati lungo la cintura sismica del Pacifico occidentale e registrate a Guam rivela differenze fra i tempi di tragitto a questa stazione e quelli alle stazioni delle isole Marcus, Midway e Wake ottenuti per scosse con epicentri nella stessa zona in altri studi recenti. Tre possibili spiegazioni sono proposte in questo studio per giustificare le differenze osservate: 1) le fasi osservate a Marcus, Midway e Wake sono fasi guidate dal mantello, del tipo *Pn*; 2) errori sistematici del tipo menzionato da autori giapponesi per scosse nella zona delle fosse delle Kurili, del Giappone e di Izu sono presenti nelle determinazioni degli epicentri; 3) l'andamento della velocità con la profondità nel mantello superiore nelle regioni attraversate dalle fasi registrate a Guam è diverso da quello nelle regioni attraversate dalle fasi registrate a Marcus, Midway e Wake. Gli autori considerano le due ultime ipotesi più accettabili della prima. I tempi di tragitto a Guam sono simili per scosse a nord e a sud di questa stazione, ma per eventi a nord a distanze epicentrali superiori a 26°, l'energia sismica propagata verso Guam sembra essere assorbita o bloccata. Questo può essere spiegato o da una zona di forte assorbimento lungo tragitti sub-paralleli al sistema di fosse del Pacifico nord-occidentale (arco delle Isole Marianne, Izu, Giappone e Kurili) o da una zona d'ombra a Guam prodotta da rifrazione laterale dell'energia da parte della zona inclinata della litosfera sotto le fosse oceaniche.

INTRODUCTION

The purpose of the present work is to obtain a clearer picture of the velocity-depth distribution under the Western Pacific Ocean. Additional information on this region is presented here using earthquakes recorded at Guam during the period 1965-1971. This study was prompted by the observation of high frequency P and S phases recorded at hydrophone stations on Wake, Midway, and Eniwetok ([8]) and by results obtained from compressional and shear arrivals recorded at seismograph stations on Marcus, Midway, and Wake ([6]). The hydrophone arrivals, interpreted as mantle-guided phases possibly of the Pn and Sn type ([5, 6]), imply a zone of low attenuation for these frequencies in the upper mantle under the Northwestern Pacific Basin and under the East Caroline Basin-Ontong Java Plateau-Nauru Sea area. The seismograph arrivals suggest differences between the mantle velocity structure under the two regions as well as departures from the Jeffreys-Bullen model.

DATA (EVENTS NORTH OF GUAM)

The data analyzed consists of 73 shallow– and intermediate – focus earthquakes located along the portion of the circum-Pacific belt extending from Kamchatka to the Marianas Islands recorded at Guam, a

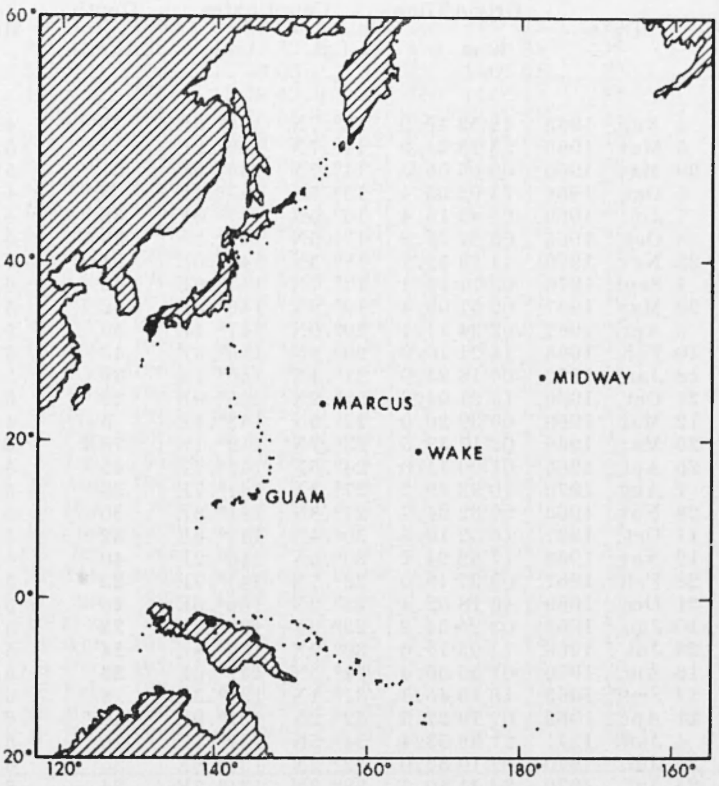

Fig. 1.

station which is part of the World-Wide Network of Standard Seismographs. The epicenter and station locations are shown in Figure 1. In general the events used here are from the same portion of the circum-Pacific belt as the events studied by Sutton and Walker ([6]). The range of epicentral distances is also about the same except for the range 1°-5°, for which Sutton and Walker have no data due to the absence of earthquakes at these distances from their stations.

Table 1 – United States Coast and Geodetic Survey Data for Events North of Guam

Event No.	Date	Origin Time *h m s*	Coordinates Lat.	Coordinates Long.	Depth (km)	Mag.
1	1 Aug. 1965	18 53 49.9	13°.7N	145°.6E	33	4.3
2	5 May 1965	23 23 24.9	14°.7N	146°.2E	56	5.4
3	29 May 1965	00 05 36.3	14°.7N	146°.6E	61	5.2
4	5 Oct. 1968	22 02 53.4	15°.5N	147°.1E	N	4.5
5	7 Jul. 1969	04 43 15.4	16°.5N	147°.3E	38	5.7
6	8 Oct. 1966	03 52 23.8	17°.6N	147°.3E	30	5.0
7	22 Nov. 1970	11 53 59.1	18°.3N	146°.0E	91	5.5
8	1 Sept. 1970	05 11 16.1	17°.7N	147°.6E	40	6.3
9	20 May 1967	02 51 09.4	19°.8N	146°.0E	42	5.5
10	5 Apr. 1967	02 34 11.1	20°.0N	147°.1E	50	5.9
11	10 Feb. 1965	14 21 10.9	20°.8N	146°.3E	43	6.2
12	18 Jan. 1970	00 18 23.9	21°.4N	146°.7E	39	5.7
13	27 Oct. 1966	14 21 04.8	22°.2N	145°.9E	29	6.0
14	12 Mar. 1968	06 39 20.9	22°.6N	143°.4E	5	4.9
15	29 Mar. 1966	02 17 38.5	23°.7N	142°.1E	79R	5.9
16	25 Apr. 1965	01 00 11.0	24°.5N	142°.7E	15	5.6
17	7 Aug. 1970	10 33 29.2	27°.3N	141°.7E	33	5.4
18	28 Nov. 1965	20 32 24.7	27°.8N	141°.8E	36	5.9
19	11 Oct. 1967	15 52 16.8	30°.4N	142°.6E	32	5.5
20	12 Nov. 1965	17 52 24.1	30°.5N	140°.2E	40	6.6
21	28 Feb. 1967	09 37 18.0	32°.7N	141°.7E	23	5.5
22	21 Dec. 1969	10 18 02.4	28°.2N	130°.6E	28	5.6
23	10 Jan. 1969	03 20 54.9	29°.0N	130°.7E	33	5.5
24	28 Jul. 1969	13 03 17.6	30°.7N	132°.5E	24	5.6
25	16 Apr. 1970	01 55 56.4	34°.5N	141°.6E	35	5.2
26	17 Sept. 1969	18 40 45.8	31°.1N	131°.3E	8	6.2
27	21 Apr. 1969	07 19 27.5	32°.2N	131°.9E	41	6.1
28	4 Jan. 1971	21 08 53.4	34°.5N	137°.1E	40	5.6
29	26 Jul. 1970	07 10 36.0	32°.2N	131°.8E	35	6.1
30	25 Jul. 1970	22 41 10.7	32°.2N	131°.7E	34	6.1
31	19 Nov. 1967	12 06 59.5	36°.4N	141°.1E	41	5.5
32	9 Sept. 1969	05 15 37.7	35°.7N	137°.0E	29	5.5
33	4 Nov. 1967	13 26 47.4	37°.4N	141°.6E	46	5.7
34	17 Jan. 1967	11 59 31.5	38°.3N	142°.1E	44	5.9
35	14 Sept. 1970	09 44 53.6	38°.7N	142°.2E	44	5.6
36	16 Oct. 1970	05 26 13.3	39°.3N	140°.7E	24	5.9
37	12 Jun. 1968	13 41 50.7	39°.5N	142°.7E	44	6.0
38	16 May 1968	23 04 54.7	39°.8N	143°.1E	37	5.8
39	1 Apr. 1970	14 23 25.1	39°.8N	141°.8E	81	5.8
40	27 May 1970	19 05 39.0	40°.3N	143°.0E	33	5.7
41	24 Nov. 1968	21 20 59.9	40°.3N	142°.3E	51	5.9

Table 1 continued

Event No.	Date	Origin Time h m s	Coordinates Lat.	Long.	Depth (km)	Mag.
42	4 Dec. 1969	08 50 21.6	40°.7N	144°.7E	20	5.7
43	29 Mar. 1965	10 47 37.6	40°.8N	142°.8E	33	6.1
44	25 Jul. 1965	13 33 05.2	41°.3N	146°.6E	33	5.9
45	12 Nov. 1966	12 49 43.6	41°.8N	144°.1E	33	5.8
46	6 Dec. 1970	20 20 52.2	41°.8N	143°.5E	48	5.7
47	21 Sept. 1968	13 05 58.2	42°.2N	142°.6E	33	5.9
48	20 Jan. 1970	17 33 05.4	42°.5N	143°.0E	46	6.3
49	14 Aug. 1969	14 19 01.6	43°.1N	147°.5E	33	6.1
50	13 Aug. 1969	22 57 07.4	44°.0N	148°.1E	33	5.6
51	18 Mar. 1969	16 16 39.6	44°.1N	151°.0E	44	5.7
52	7 Dec. 1966	17 17 42.0	44°.3N	151°.7E	26	5.3
53	11 Jun. 1965	03 33 44.9	44°.7N	148°.7E	47	6.0
54	10 Mar. 1970	04 58 26.2	44°.8N	148°.9E	40	6.0
55	20 May 1968	21 09 44.8	44°.8N	150°.3E	38	5.8
56	10 Jun. 1970	16 17 48.7	44°.9N	149°.5E	57	5.7
57	19 Mar. 1967	04 01 36.7	45°.4N	151°.3E	33	6.5
58	1 Aug. 1969	23 43 44.9	45°.6N	150°.9E	38	5.6
59	4 Sept. 1969	03 08 52.0	46°.6N	153°.5E	33	5.4
60	5 Feb. 1970	12 46 38.2	47°.0N	154°.2E	33	5.5
61	8 Jan. 1971	14 45 29.5	47°.4N	154°.4E	32	5.6
62	20 Aug. 1969	07 50 05.5	47°.9N	153°.6E	73	5.8
63	3 Mar. 1966	03 25 28.0	48°.3N	154°.3E	45	5.9
64	13 Jun. 1969	08 48 29.5	49°.4N	155°.5E	64	5.9
65	3 Oct. 1965	14 45 26.8	49°.5N	156°.5E	33	5.9
66	22 Jun. 1969	02 33 52.8	49°.2N	158°.5E	33	5.6
67	21 Jun. 1966	23 06 25.9	50°.1N	157°.8E	14	5.8
68	16 Dec. 1967	20 53 58.3	51°.2N	157°.7E	24	5.5
69	8 Apr. 1966	01 46 44.9	51°.2N	157°.7E	47R	5.9
70	8 Oct. 1970	04 53 21.8	53°.8N	160°.4E	53	5.6
71	6 Feb. 1970	00 11 49.6	54°.6N	163°.6E	43	5.6
72	28 Mar. 1965	13 22 57.6	55°.1N	162°.1E	33	5.9
73	22 Nov. 1969	23 09 37.2	57°.8N	163°.5E	33	6.3

United States Coast and Geodetic Survey (C&GS) epicentral data are given in Table 1; and epicentral distances, observed travel times, and residuals based on expected travel times as taken from the Jeffreys-Bullen (J-B) tables (2) are given in Table 2.

Table 2 – Travel Times and Residuals for Events North of Guam

Event No.	Distance to Guam (degrees)	P Travel Times J-B (secs)	P Travel Times Observed * (secs)	P-residual (secs)	S Travel Times J-B (secs)	S Travel Times Observed * (secs)	S-residual (secs)
1	0.7	13.2	13.1 (14.1)	—0.1 (+0.9)	22.9	N.C. (N.C.)	— (—)
2	1.7	28.3	27.6 (27.6)	—0.7 (—0.7)	51.4	N.C. (N.C.)	— (—)
3	2.0	32.5	32.2 (32.2)	—0.3 (—0.3)	59.2	N.C. (N.C.)	— (—)
4	2.9	44.7	44.1 (46.6)	—0.6 (+1.9)	78.6	N.C. (N.C.)	— (—)
5	3.7	57.0	57.1 (57.1)	+0.1 (+0.1)	100.7	N.C. (100.6)	— (— 0.1)
6	4.7	70.3	70.0 (N.C.)	—0.3 (—)	124.2	123.2 (N.C.)	—1.0 (—)
7	4.9	72.4	74.4 (73.9)	+2.0 (+1.5)	125.5	N.C. (N.C.)	— (—)
8	4.9	73.2	72.4 (72.4)	—0.8 (—0.8)	129.2	N.C. (N.C.)	— (—)
9	6.3	93.5	95.6 (94.6)	+2.1 (+1.1)	164.4	N.C. (N.C.)	— (—)
10	6.8	99.6	98.9 (98.9)	—0.7 (—0.7)	173.6	N.C. (174.9)	— (+ 1.3)
11	7.4	107.9	N.A. (N.A.)	— (—)	189.2	N.A. (N.A.)	— (—)
12	8.0	117.2	116.6 (116.6)	—0.6 (—0.6)	207.9	203.6 (203.6)	—4.3 (— 4.3)
13	8.7	127.1	128.7 (127.2)	+1.6 (+0.1)	225.4	N.C. (223.2)	— (— 2.2)
14	9.2	136.1	N.A. (N.C.)	— (—)	241.0	N.A. (N.A.)	— (—)
15	10.5	149.6	152.5 (153.5)	+2.9 (+3.9)	266.3	N.A. (265.5)	— (— 0.8)
16	11.2	162.2	162.4 (162.4)	+0.2 (+0.2)	288.0	N.A. (290.4)	— (+ 2.4)
17	14.1	199.2	198.8 (198.8)	—0.4 (—0.4)	355.3	N.A. (355.8)	— (+ 0.5)
18	14.6	205.2	N.A. (N.A.)	— (—)	366.1	N.A. (N.A.)	— (—)
19	17.0	236.8	237.7 (237.2)	+0.9 (+0.4)	423.4	N.A. (N.C.)	— (—)
20	17.5	242.6	243.9 (243.9)	+1.3 (+1.3)	434.1	N.A. (441.9)	— (+ 7.8)
21	19.4	267.0	266.0 (264.0)	—1.0 (—3.0)	478.9	N.C. (482.0)	— (+ 3.1)
22	19.8	271.0	274.1 (274.1)	+3.1 (+3.1)	487.3	N.A. (N.C.)	— (—)
23	20.3	275.8	N.C. (N.C.)	— (—)	496.7	N.A. (N.A.)	— (—)
24	20.6	280.2	N.A. (N.A.)	— (—)	504.5	N.A. (N.A.)	— (—)
25	21.2	284.4	286.6 (287.6)	+2.2 (+3.2)	512.9	N.A. (515.6)	— (+ 2.7)
26	21.6	292.0	290.0 (290.0)	—2.0 (—2.0)	526.2	N.A. (530.2)	— (+ 4.0)
27	22.1	293.5	291.5 (291.5)	—2.0 (—2.0)	529.8	N.A. (533.5)	— (+ 3.7)
28	22.1	293.5	294.6 (294.6)	+1.1 (+1.1)	529.8	N.A. (540.6)	— (+10.8)
29	22.2	294.5	293.0 (293.0)	—1.5 (—1.5)	531.7	N.A. (536.0)	— (+ 4.3)
30	22.2	295.1	293.3 (293.3)	—1.8 (—1.8)	532.7	N.A. (535.3)	— (+ 2.6)
31	23.1	303.2	N.C. (N.A.)	— (—)	547.4	N.A. (556.5)	— (+ 9.1)
32	23.3	306.0	310.3 (312.3)	+4.3 (+6.3)	552.5	N.A. (554.3)	— (+ 1.8)
33	24.0	311.7	N.C. (N.A.)	— (—)	562.8	N.A. (568.3)	— (+ 5.5)
34	24.9	320.0	318.5 (318.5)	—1.5 (—1.5)	577.4	N.A. (581.5)	— (+ 4.1)
35	25.3	323.7	N.C. (322.4)	— (—1.3)	583.9	N.A. (590.4)	— (+ 6.5)
36	26.0	333.1	332.7 (330.7)	—0.4 (—2.4)	600.3	N.A. (612.7)	— (+12.4)
37	26.0	330.8	328.3 (328.3)	—2.5 (—2.5)	596.4	N.A. (N.C.)	— (—)
38	26.3	334.0	N.C. (331.3)	— (—2.7)	602.1	N.A. (605.3)	— (+ 3.2)
39	26.4	330.7	N.C. (N.C.)	— (—)	596.1	N.A. (N.C.)	— (—)
40	26.8	339.0	N.A. (341.0)	— (+2.0)	611.1	N.A. (617.0)	— (+ 5.9)
41	26.9	337.7	N.C. (N.A.)	— (—)	608.7	N.A. (N.C.)	— (—)
42	27.2	344.0	N.A. (N.A.)	— (—)	619.8	N.A. (N.A.)	— (—)
43	27.3	343.7	N.C. (343.4)	— (—0.3)	619.3	N.A. (622.4)	— (+ 3.1)
44	27.8	348.0	N.C. (N.A.)	— (—)	627.0	N.A. (N.A.)	— (—)
45	28.3	352.3	N.A. (N.C.)	— (—)	634.5	N.A. (N.C.)	— (—)
46	28.3	351.0	N.C. (347.8)	— (—2.2)	632.2	N.A. (629.8)	— (— 2.4)
47	28.7	356.4	N.C. (349.8)	— (—6.6)	641.9	N.A. (637.8)	— (— 4.1)
48	29.0	357.6	357.1 (357.1)	—0.5 (—0.5)	644.1	N.A. (646.6)	— (+ 2.5)
49	29.6	364.5	N.C. (364.4)	— (—0.1)	656.5	N.A. (N.C.)	— (—)
50	30.6	372.8	N.A. (N.C.)	— (—)	671.3	N.A. (677.6)	— (+ 6.3)

Table 1 continued

Event No.	Distance to Guam (degrees)	*P* Travel Times J-B (secs)	*P* Travel Times Observed * (secs)		*P*-residual (secs)		*S* Travel Times J-B (secs)	*S* Travel Times Observed * (secs)		*S*-residual (secs)	
51	31.0	375.5	N.A.	(N.A.)	—	(—)	675.9	N.A.	(N.A.)	—	(—)
52	31.3	380.2	N.A.	(N.A.)	—	(—)	684.3	N.A.	(N.A.)	—	(—)
53	31.3	378.1	N.C.	(379.1)	—	(+1.0)	680.5	N.A.	(681.1)	—	(+ 0.6)
54	31.4	379.8	N.C.	(N.A.)	—	(—)	683.6	N.A.	(677.8)	—	(—5.8)
55	31.6	381.3	N.C.	(N.C.)	—	(—)	686.3	N.A.	(N.C.)	—	(—)
56	31.6	379.5	N.A.	(N.C.)	—	(—)	683.1	N.A.	(675.3)	—	(— 7.8)
57	32.3	388.1	N.A.	(N.C.)	—	(—)	698.4	N.A.	(705.3)	—	(+ 6.9)
58	32.5	388.8	N.A.	(N.A.)	—	(—)	699.8	N.A.	(701.1)	—	(+ 1.3)
59	33.8	401.2	N.A.	(N.C.)	—	(—)	722.1	N.A.	(N.A.)	—	(—)
60	34.3	405.7	N.A.	(N.A.)	—	(—)	730.0	N.A.	(N.A.)	—	(—)
61	34.8	409.4	N.A.	(N.A.)	—	(—)	736.8	N.A.	(N.A.)	—	(—)
62	35.1	408.2	N.C.	(408.5)	—	(+0.3)	734.7	N.A.	(742.5)	—	(+ 7.8)
63	35.6	415.3	N.A.	(N.A.)	—	(—)	747.5	N.A.	(N.A.)	—	(—)
64	36.9	424.2	N.A.	(422.5)	—	(—1.7)	763.7	N.A.	(N.C.)	—	(—)
65	37.2	429.8	N.A.	(N.A.)	—	(—)	773.8	N.A.	(N.A.)	—	(—)
66	37.4	431.2	N.A.	(N.A.)	—	(—)	776.5	N.A.	(N.A.)	—	(—)
67	38.0	439.7	N.A.	(N.A.)	—	(—)	791.4	N.A.	(N.A.)	—	(—)
68	39.0	446.6	N.A.	(N.A.)	—	(—)	804.2	N.A.	(N.A.)	—	(—)
69	39.0	443.8	N.A.	(N.C.)	—	(—)	799.5	N.A.	(N.A.)	—	(—)
70	42.1	468.1	N.A.	(N.A.)	—	(—)	843.3	N.A.	(N.A.)	—	(—)
71	43.6	481.5	N.A.	(N.A.)	—	(—)	867.8	N.A.	(N.A.)	—	(—)
72	43.6	483.1	N.A.	(N.A.)	—	(—)	870.1	N.A.	(N.A.)	—	(—)
73	46.4	505.2	506.3	(500.8)	+1.1	(—4.4)	909.9	N.A.	(N.C.)	—	(—)

* N.A., Not apparent;
N.C., Not clear;
( ), Arrivals on LPZ seismographs.

Compressional Arrivals, 0°.7-26°.0 (Events No. 1-37).

The frequency of the observed arrivals on the short-period vertical seismograph (SPZ) appears to be that of the refracted mantle *P* ($\simeq$ 1 Hz); lower-frequency components of the phase appear on the long-period vertical seismograph (LPZ). The travel times on both SPZ and LPZ are generally in good agreement with the times expected from the J-B tables. In only one case, event No. 32, do both SPZ and LPZ readings give a travel time residual larger than 4 seconds. No other significant phases, other than the first arrivals, are observed. Poor signal-to-noise ratios, low magnitudes, or combinations of both are the possible reasons for which some events (Nos. 6, 11, 14, 18, 23, 24, 31, 33 and 35) in this group do not have clear (N.C.) or apparent (N.A.) arrivals.

Compressional Arrivals, 26°.3-46°.4 (Events No. 38-73).

In this distance range the refracted mantle *P* is either not apparent or not clear on the SPZ, and with the possible exception of surface waves no other phases are observed. The travel times of the few compressional arrivals seen on the LPZ within this distance range generally agree with the expected times from the J-B tables. In two cases, events No. 47 and 73, the residuals are larger than 4 sec, however LPZ readings are less precise than SPZ readings due both to lower record speed and to lower-frequency content of the arrivals on these records.

Shear Arrivals, 0°.7-10°.5 (Events No. 1-15).

There is little data on shear arrivals within this distance range, due to difficulty in picking the beginnings of these phases. When the beginnings can be identified on either the SPZ or the LPZ seismograms, the residuals are mostly negative.

Shear Arrivals, 11°.2-32°.5 (Events No. 16-58).

All shear arrivals are observed on the LPZ seismograms and are the normal long-period *S*. Most show positive travel time residuals, in a few cases the residuals being quite large (10.8 sec for event No. 28; 9.1 sec for No. 31; and 12.4 sec for No. 36). The generally larger size of the *S* travel time residuals compared to that of the *P* residuals is explained by the lower speed of the LPZ records and lower frequency content of the *S* phase.

Shear Arrivals, 33°.8-46°.4 (Events No. 59-73).

With the exception of one event (No. 62), showing a positive residual, no *S* arrivals are observed on either the SPZ or LPZ instruments in this distance range.

DISCUSSION (EVENTS NORTH OF GUAM).

Most of the *P* travel times of this study are generally in agreement with the times given in the J-B Tables, in contrast, somewhat, to the results of Sutton and Walker. In their study, *P* travel times of shallow – and intermediate – focus events were consistently early for epicentral distances less than 23° and close to J-B times for distances greater than 23°. Their data were recorded mostly at Marcus Island (but also at Midway and Wake) from earthquakes having their epicenters in locations similar to those of the earthquakes used in this study. A discussion of three possible explanations for these differences follows.

One possible explanation is that the compressional arrivals observed on seismographs by Sutton and Walker at distances less than 23° are not, as they suggest, normal refracted mantle P phases; but are, in fact, Pn phases. But, if this were the case, the apparent frequency of the Pn's should be higher than actually observed ($\simeq$ 1 Hz) by Sutton and Walker since Sn's, which generally have less energy than Pn's at higher frequencies, were observed on the seismographs to have frequencies greater than 1 Hz. Such an explanation therefore does not seem probable at this time.

Another explanation is systematic errors in epicenter determinations. Utsu (7), Yamakawa et al. (9), Kishio and Yamakawa (3), and Ichikawa (1) all found that epicenter locations for the Kurile, Japan, and Izu trench regions, based on data from local stations, generally lie 20 to 30 km on the oceanic side of C&GS epicenter determinations. Similar findings have been obtained by Mitronovas et al. (4) for Tongan earthquakes. If these locally determined epicenters are more accurate than the C&GS determinations, some of the early arrivals on seismographs at Marcus, Midway, and Wake could be attributed to errors in epicentral determinations, since a 20 or 30 km error would account for 3 or 4 seconds of the 3- to 7- second residuals generally observed. Also, because of the orientation of these epicenter errors (essentially E-W in the Japan area), C&GS and locally determined epicenters would have similar travel times to Guam. Thus, for epicentral distances of less than 23°, discrepancies between the results of our two studies could, in part, be attributed to systematic errors in epicentral determinations.

When considering distances greater than 23°, residuals at Guam, Marcus, Midway, and Wake are similar in travel times; i.e., on time. However, the locations of the earthquakes and the arguments just presented indicate that these arrivals also should be early at Marcus, Midway, and Wake and on time at Guam. Instead, we find that travel times are generally on time at all stations. This observation seems to weaken the argument that errors in epicenters may be the cause of differences in the two studies.

The third and final explanation which will be offered here is that the discrepancies observed in the two studies are real. In general great circle paths to Guam for events up to 26° of epicentral distance are confined to the Marianas-Izu-Japan trench region, while for distances greater than 26°, the paths to Guam from epicenters distributed along the Kurile trench, traverse a region better described as typical oceanic basin. Paths for all distances to Marcus, Midway, and Wake could also be described as typically oceanic. Thus a comparison of the results of this study and those of Sutton and Walker suggests that the velocity structure of the uppermost part of the mantle under the Marianas-Izu-Japan trench system differs from that under the Northwestern Pacific Basin. A change is suggested from a model characterized by higher than J-B upper-mantle velocities under the region sampled by the oceanic basin-type paths studied by Sutton and Walker to the J-B type of upper-mantle velocities for paths along the trench system above the sinking slab of the lithospheric plate, as in the case of the data presented here from the Guam station.

Before moving on to a discussion of shear arrivals, it should be noted that while the normal-refracted mantle P comes in at Guam with travel times consistent with those expected from the J-B tables for distances less than 26°, this phase is either absent or poorly recorded for epicentral distances beyond 26°. Therefore, for distances greater than 26°, it would seem that compressional energy of approximately 1 Hz is effectively blocked or absorbed when travelling towards Guam, while towards Marcus, Midway, and Wake it is efficiently propagated. Possible explanations for this apparent loss of energy are: (1) changes in the attenuation which seems to become very high in a direction sub-parallel to the trench system; (2) a shadow zone at Guam produced by the lateral refraction of energy by the downgoing lithospheric slab.

On comparing the shear arrivals presented here with those of Sutton and Walker, it appears that while throughout the whole epicentral distance range only the normal long-period S is observed at Guam, at Marcus, Midway, and Wake it is observed only for distances beyond $\simeq$ 20°, while for shorter distances the high-frequency (guided) S is observed at these three stations. This absence of Sn arrivals at Guam has previously been reported by Molnar and Oliver ([5]). In the distance range where the long-period S is observed both at Guam and at Wake, Midway, and Marcus, both the size and the sign of the residuals are in agreement, i.e., later than Jeffreys-Bullen.

Data (events south of Guam)

The data analyzed consists of 102 shallow- and intermediate-focus earthquakes located along that portion of the circum-Pacific belt extending from the Caroline Islands to the Fiji-Tonga area recorded at Guam. Given in Table 3 are C&GS epicentral data for the events south of Guam; and epicentral distances, observed travel times, and residuals based on expected travel times as taken from the J-B tables (2) are given in Table 4. The epicentral locations are shown in Figure 1. These locations coincide with those of only a few of the events studied by Sutton and Walker at Marcus and Wake (no arrivals were recorded from this region at Midway). Also, due to the immediate proximity of Guam to the earthquake zone, additional data are available for the epicentral distance range 1°-6°, the range not covered by Sutton and Walker. Throughout the entire distance range the compressional-arrival travel times to Guam agree with the expected times from the J-B tables. In only four cases, events Nos. 96, 110, 115, and 169 are the residuals larger than $\pm$ 4 seconds. The shear arrivals are almost never well recorded at distances less than $\simeq$ 17° and their residuals are randomly positive and negative and occasionally become quite large. The same considerations made for the events north of Guam, concerning the relative size of *P* and *S* residuals and the " not clear" and "not apparent" arrivals, are also valid here. The observed phases appear to be the normal refracted *P* and *S* mantle arrivals at all distances.

Discussion (events south of Guam)

Great circle paths for this group of events are affected by the New Britain, New Hebrides, Vityaz, and Tonga trenches, the extent depending on epicentral distance and the paths could not be defined as typical oceanic basin paths. The compressional-arrival travel time residuals show that the J-B model would be an acceptable one for the region sampled by these paths to Guam. Our negligible travel time residuals and the consistently late travel times for paths from the same region to Marcus and Wake indicate differences between the two studies for which an explanation should be found. We will again consider the three explanations already presented for differences in the two studies for the area to the north of Guam and examine their applicability to the differences in the two studies for the area to the south of Guam.

Table 3 – United States Coast and Geodetic Survey Data for Events South of Guam

Event No.	Date	Origin Time h m s	Coordinates Lat.	Long.	Depth (km)	Mag.
74	16 Sept. 1970	01 49 20.5	13°.0N	144°.4E	47	6.0
75	28 Mar. 1965	18 18 40.0	13°.4N	145°.8E	43	4.4
76	14 Nov. 1970	04 51 37.8	12°.6N	143°.3E	95	5.5
77	4 Mar. 1970	03 30 35.4	12°.1N	143°.7E	33	6.2
78	19 Nov. 1967	17 23 48.0	12°.0N	143°.5E	22	4.6
79	23 Dec. 1970	11 42 47.4	12°.3N	142°.9E	49	5.7
80	7 Jan. 1967	13 34 48.3	11°.8N	142°.7E	36	5.6
81	7 Dec. 1966	16 59 29.2	11°.9N	142°.6E	33R	5.1
82	25 Aug. 1967	22 58 48.3	12°.2N	140°.9E	33R	5.1
83	26 Aug. 1967	00 50 00.6	12°.2N	140°.8E	33R	4.5
84	25 Aug. 1967	22 54 18.3	12°.2N	140°.8E	33R	4.9
85	26 Aug. 1967	02 07 08.9	12°.2N	140°.8E	30	5.3
86	26 Aug. 1967	00 36 42.1	12°.2N	140°.7E	33	6.1
87	26 Aug. 1967	00 53 17.4	12°.2N	140°.7E	14	5.3
88	26 Aug. 1967	03 29 58.5	12°.2N	140°.7E	30	4.8
89	26 Aug. 1967	01 41 49.8	12°.2N	140°.7E	33R	4.9
90	26 Aug. 1967	10 25 13.5	12°.2N	140°.7E	33R	4.6
91	26 Aug. 1967	05 25 17.4	12°.1N	140°.7E	33R	4.7
92	26 Aug. 1967	12 24 23.6	12°.1N	140°.7E	42	4.8
93	26 Aug. 1967	05 46 50.1	12°.1N	140°.6E	33R	4.8
94	26 Aug. 1967	07 55 00.0	12°.1N	140°.6E	33R	4.8
95	24 Apr. 1965	21 55 26.5	11°.4N	140°.1E	59	5.7
96	4 Mar. 1967	22 41 14.5	7°.8N	146°.2E	20	5.1
97	12 Jan. 1971	14 42 15.2	9°.9N	138°.2E	33	5.5
98	27 Jan. 1969	13 15 24.4	8°.8N	137°.7E	5	5.5
99	19 Apr. 1965	05 21 30.3	2°.9S	147°.6E	5	5.0
100	23 Oct. 1968	21 04 41.3	3°.3S	143°.3E	12	6.1
101	14 May 1970	08 32 42.2	3°.4S	145°.2E	29	5.6
102	4 Jan. 1967	16 30 28.0	3°.2S	142°.2E	19	5.5
103	10 Jan. 1965	23 45 38.0	3°.4S	146°.1E	24	5.2
104	17 Apr. 1968	19 57 03.0	3°.6S	145°.3E	23	5.0
105	28 Feb. 1969	15 57 44.2	3°.4S	142°.9E	80	5.7
106	10 Jan. 1971	07 43 47.1	3°.0S	139°.7E	33	5.9
107	10 Jan. 1971	07 53 52.6	3°.0S	139°.7E	33	5.6
108	10 Jan. 1971	10 45 06.8	3°.0S	139°.6E	36	6.1
109	10 Jan. 1971	16 07 45.9	3°.1S	139°.8E	33	5.7
110	10 Jan. 1971	19 34 22.3	3°.1S	139°.7E	39	5.7
111	15 Jan. 1971	07 28 38.4	3°.0S	139°.5E	33	6.0
112	12 Jan. 1971	14 57 11.6	3°.2S	140°.0E	33	5.8
113	10 Jan. 1971	07 17 03.7	3°.1S	139°.7E	33	7.3
114	10 Jan. 1971	08 44 32.6	3°.2S	139°.7E	21	5.5
115	10 Jan. 1971	14 29 56.3	3°.2S	139°.8E	28	5.8
116	10 Jan. 1971	19 13 36.8	3°.2S	139°.8E	33	5.8
117	10 Jan. 1971	22 14 37.4	3°.2S	139°.9E	30	6.1
118	21 Jul. 1968	06 09 41.8	3°.2S	150°.5E	33R	5.4
119	21 Jul. 1968	05 52 10.4	3°.2S	150°.7E	5	5.3
120	10 Jan. 1971	16 38 36.0	3°.4S	148°.0E	27	5.5
121	16 Jan. 1971	15 16 24.4	3°.4S	139°.5E	33	5.9
122	16 Apr. 1969	01 22 47.5	3°.5S	151°.0E	39	5.7
123	1 Nov. 1970	11 07 40.7	4°.8S	145°.7E	33	5.5

Table 3 continued

Event No.	Date	Origin Time h m s	Coordinates Lat.	Long.	Depth (km)	Mag.
124	31 Oct. 1970	17 53 09.3	4°.9S	145°.5E	42	6.0
125	12 Feb. 1966	23 37 54.0	3°.7S	152°.0E	36	5.5
126	12 Nov. 1970	06 07 12.4	5°.1S	145°.1E	15	5.9
127	19 Feb. 1970	22 55 03.5	4°.5S	140°.1E	26	5.7
128	19 Jul. 1970	09 22 40.1	3°.8S	152°.4E	20	5.5
129	8 Nov. 1970	22 35 46.7	3°.4S	135°.6E	33	6.2
130	28 Aug. 1970	01 02 48.9	4°.6S	153°.1E	88	5.9
131	6 May 1965	14 24 04.3	6°.1S	149°.1E	74	6.0
132	19 May 1970	14 48 35.3	5°.2S	152°.3E	65	5.6
133	12 Aug. 1965	12 57 09.7	5°.3S	152°.2E	41	5.9
134	20 May 1968	17 20 22.4	5°.0S	153°.3E	45	5.3
135	26 Aug. 1969	16 58 02.3	5°.8S	151°.2E	59	5.6
136	28 Dec. 1970	20 03 25.1	5°.2S	153°.6E	61	6.0
137	3 Sept. 1965	21 38 53.6	5°.2S	153°.7E	54	5.9
138	22 Dec. 1969	03 43 47.5	5°.7S	153°.6E	44	5.5
139	12 Nov. 1966	15 56 04.7	4°.8S	134°.2E	33R	5.4
140	18 Apr. 1969	12 32 03.4	4°.5S	132°.7E	33	5.5
141	5 Jul. 1969	01 44 01.1	3°.8S	131°.5E	33	5.5
142	28 Mar. 1970	07 45 59.9	6°.3S	154°.6E	64	5.9
143	30 Mar. 1965	10 25 22.0	6°.4S	154°.5E	70	5.2
144	23 Sept. 1970	12 04 54.2	6°.5S	154°.6E	33	5.7
145	17 Jul. 1965	12 47 49.4	7°.2S	153°.6E	28	5.7
146	16 Dec. 1970	19 53 40.8	4°.7S	130°.8E	33	5.6
147	26 Jul. 1965	14 45 15.5	7°.4S	155°.9E	48	4.9
148	28 Apr. 1970	01 12 14.4	8°.1S	156°.4E	5	5.6
149	4 Oct. 1970	16 56 54.3	6°.8S	130°.4E	92	5.6
150	25 Jun. 1970	05 13 58.6	7°.9S	158°.7E	69	6.1
151	3 Aug. 1970	07 01 11.9	7°.9S	158°.7E	67	5.9
152	2 Jun. 1968	08 18 36.2	8°.1S	158°.6E	35	5.6
153	14 Jun. 1969	03 22 56.8	7°.9S	159°.0E	62	6.0
154	5 Jan. 1969	13 26 39.9	8°.0S	158°.9E	47	6.4
155	6 Sept. 1969	16 08 03.2	8°.9S	157°.9E	10	5.8
156	18 May 1969	00 15 31.5	9°.0S	158°.4E	16	5.6
157	19 Jan. 1968	06 04 38.2	9°.4S	158°.4E	33	6.0
158	17 Jul. 1965	07 20 30.5	9°.7S	159°.8E	23	6.4
159	5 May 1967	15 00 07.7	10°.5S	161°.3E	41	5.4
160	19 Aug. 1970	02 11 09.4	10°.5S	161°.5E	33	5.7
161	29 Dec. 1970	02 26 12.2	10°.5S	161°.4E	72	6.1
162	16 Feb. 1965	02 58 26.0	11°.2S	162°.5E	25	4.8
163	2 Dec. 1970	15 54 19.9	11°.0S	163°.3E	33	5.8
164	6 Jan. 1969	15 39 00.9	10°.5S	164°.5E	32	6.2
165	9 Dec. 1967	10 50 46.6	10°.9S	164°.2E	33	5.5
166	9 Mar. 1967	18 02 45.7	10°.7S	166°.3E	59	6.4
167	12 May 1968	17 10 32.0	12°.3S	166°.7E	41	5.5
168	1 Aug. 1965	20 34 19.6	13°.3S	165°.8E	28	5.9
169	20 May 1965	00 40 10.9	14°.7S	167°.4E	16	5.6
170	11 Aug. 1965	22 31 48.9	15°.8S	167°.2E	33	6.4
171	12 Aug. 1965	08 01 43.3	15°.9S	167°.5E	25	6.3
172	20 Jan. 1968	16 41 27.1	16°.2S	178°.1E	21	5.6
173	8 Oct. 1966	00 12 18.1	16°.4S	177°.6W	33	5.7
174	6 Oct. 1968	08 47 02.0	14°.7S	175°.6W	35	5.4
175	5 Jan. 1965	18 05 58.6	20°.3S	174°.1W	33	6.0

TABLE 4 – TRAVEL TIMES AND RESIDUALS FOR EVENTS SOUTH OF GUAM

Event No.	Distance to Guam (degrees)	P Travel Times J-B (secs)	P Travel Times Observed * (secs)	P-residual (secs)	S Travel Times J-B (secs)	S Travel Times Observed * (secs	S-residual (secs)
74	0.7	14.7	13.5 (13.5)	—1.2 (—1.2)	26.2	N.C. (N.C.)	— (—)
75	0.9	16.4	15.5 (N.C.)	—0.9 (—)	29.1	N.C. (N.C.)	— (—)
76	1.8	30.7	31.2 (31.2)	+0.5 (+0.5)	58.8	N.C. (54.2)	— (— 4.6)
77	1.9	30.0	28.4 (28.6)	—1.6 (—1.4)	52.6	N.C. (N.C.)	— (—)
78	2.1	34.1	33.0 (N.A.)	—1.1 (—)	59.5	56.0 (N.A.)	—3.5 (—)
79	2.3	36.7	35.1 (35.1)	—1.6 (—1.6)	65.6	N.C. (60.6)	— (— 5.0)
80	2.8	43.0	43.7 (45.7)	+0.7 (+2.7)	75.9	74.7 (N.C.)	—1.2 (—)
81	2.8	43.2	42.3 (N.C.)	—0.9 (—)	76.1	N.C. (N.C.)	— (—)
82	4.1	62.4	63.7 (N.C.)	+1.3 (—)	110.3	N.A. (N.C.)	— (—)
83	4.2	63.7	64.9 (N.C.)	+1.2 (—)	112.6	N.C. (N.C.)	— (—)
84	4.2	63.7	65.2 (N.C.)	+1.5 (—)	112.6	N.A. (N.C.)	— (—)
85	4.2	64.0	65.1 (67.1)	+1.1 (+3.1)	113.1	N.A. (N.C.)	— (—)
86	4.3	65.0	64.4 (63.9)	—0.6 (—1.1)	114.9	N.A. (N.C.)	— (—)
87	4.3	67.0	66.6 (N.C.)	—0.4 (—)	118.0	N.A. (N.C.)	— (—)
88	4.3	65.3	65.6 (65.5)	+0.2 (—)	115.4	N.A. (N.C.)	— (—)
89	4.3	65.0	65.2 (N.C.)	+0.2 (—)	114.9	N.A. (N.C.)	— (—)
90	4.3	65.0	64.5 (N.C.)	+0.5 (—)	114.9	N.A. (N.C.)	— (—)
91	4.4	65.5	66.1 (66.1)	+0.6 (+0.6)	115.7	N.A. (N.C.)	— (—)
92	4.4	65.4	65.4 (N.A.)	+0.0 (—)	115.5	N.C. (N.C.)	— (—)
93	4.4	66.8	65.9 (N.C.)	—0.9 (—)	118.1	N.C. (N.C.)	— (—)
94	4.4	66.8	67.0 (N.A.)	+0.2 (—)	118.1	N.A. (N.A.)	— (—)
95	5.2	76.7	76.5 (76.5)	—0.2 (—0.2)	134.1	N.C. (137.5)	— (+ 3.4)
96	5.9	88.3	83.0 (N.A.)	—5.3 (—)	156.2	N.C. (N.C.)	— (—)
97	7.5	109.9	108.6 (N.C.)	—1.3 (—)	194.9	192.6 (192.6)	— 2.3 (— 2.3)
98	8.5	126.9	127.1 (127.1)	+0.2 (+0.2)	224.6	214.6 (N.C.)	—10.0 (—)
99	16.7	235.7	N.C. (N.A.)	— (—)	420.5	N.A. (N.A.)	— (—)
100	16.9	238.1	238.7 (238.7)	+0.6 (+0.6)	425.2	N.C. (N.C.)	— (—)
101	16.9	236.4	236.8 (235.8)	+0.4 (—0.6)	422.7	N.A. (N.C.)	— (—)
102	17.0	237.8	N.A. (N.A.)	— (—)	424.8	N.A. (N.A.)	— (—)
103	17.0	237.5	N.A. (N.A.)	— (—)	424.5	N.A. (N.A.)	— (—)
104	17.1	239.7	N.A. (N.A.)	— (—)	428.4	N.A. (N.A.)	— (—)
105	17.1	234.6	N.A. (N.A.)	— (—)	420.1	N.A. (N.A.)	— (—)
106	17.3	240.8	242.4 (N.C.)	+1.6 (—)	430.7	N.C. (N.C.)	—) —)
107	17.3	240.8	241.9 (N.C.)	+1.1 (—)	430.7	N.C. (N.C.)	— (—)
108	17.4	241.0	242.2 (N.C.)	+1.2 (—)	431.1	N.A. (N.C.)	— (—)
109	17.4	241.6	244.1 (N.C.)	+2.5 (—)	432.2	N.A. (434.1)	— (+ 1.9)
110	17.4	241.6	245.7 (245.7)	+4.1 (+4.1)	432.3	N.A. (441.7)	— (+ 9.4)
111	17.4	241.5	N.R. (N.A.)	— (—)	432.1	N.R. (N.A.)	— (—)
112	17.4	242.1	N.C. (N.A.)	— (—)	433.1	N.A. (N.C.)	— (—)
113	17.4	242.0	241.3 (241.3)	—0.7 (—0.7)	432.9	N.C. (N.C.)	— (—)
114	17.5	244.6	246.4 (N.C.)	+1.8 (—)	437.3	N.A. (N.C.)	— (—)
115	17.5	242.8	248.7 (246.7)	+5.9 (+3.9)	434.4	N.A. (N.C.)	— (—)
116	17.5	242.8	N.C. (N.C.)	— (—)	434.4	N.A. (437.2)	— (+ 2.8)
117	17.5	242.8	246.6 (246.6)	+3.8 (+3.8)	434.3	N.A. (438.6)	— (+ 4.3)
118	17.6	244.6	242.7 (N.C.)	—1.9 (—)	437.6	N.A. (N.C.)	— (—)
119	17.7	248.8	248.6 (248.6)	—0.2 (—0.2)	444.4	N.A. (445.6)	— (+ 1.2)
120	17.7	245.6	N.C. (245.0)	— (—0.6)	439.3	N.A. (446.0)	— (+ 6.7)
121	17.8	246.3	N.A. (N.A.)	— (—)	440.7	N.A. (N.A.)	— (—)
122	18.1	249.8	248.5 (248.5)	—1.3 (—1.3)	447.1	N.A. (456.5)	— (+ 9.4)
123	18.4	253.6	253.6 (251.3)	—0.0 (—2.3)	454.0	N.A. (456.3)	— (+ 2.3)
124	18.4	254.1	253.7 (253.7)	—0.4 (—0.4)	455.1	N.A. (460.7)	— (+ 5.1)

Table 4 continued

Event No.	Distance to Guam (degrees)	*P* Travel Times J-B (secs)	*P* Travel Times Observed * (secs)	*P*-residual (secs)	*S* Travel Times J-B (secs)	*S* Travel Times Observed * (secs)	*S*-residual (secs)
125	18.6	256.6	N.A. (N.C.)	— (—)	459.6	N.A. (N.A.)	— (—)
126	18.6	259.2	259.6 (259.6)	+0.4 (+0.4)	463.8	N.A. (471.6)	— (+ 7.8)
127	18.7	258.2	259.5 (N.C.)	+1.3 (—)	462.2	N.A. (468.5)	— (+ 6.3)
128	18.9	261.4	261.9 (261.9)	+0.5 (+0.5)	467.9	N.A. (N.C.)	— (—)
129	19.3	264.7	261.3 (261.3)	—3.4 (—3.4)	475.0	N.A. (N.C.)	— (—)
130	19.9	266.5	265.1 (265.1)	—1.4 (—1.4)	480.3	N.A. (479.1)	— (— 1.2)
131	20.1	269.8	268.7 (268.7)	—1.1 (—1.1)	486.2	N.A. (N.C.)	— (—)
132	20.1	271.0	270.2 (270.2)	—0.8 (—0.8)	488.4	N.A. (N.C.)	— (—)
133	20.2	273.7	272.3 (272.3)	—1.4 (—1.4)	492.9	N.C. (N.C.)	— (—)
134	20.3	274.8	275.6 (275.6)	+0.8 (+0.8)	495.1	N.A. (N.A.)	— (—)
135	20.3	273.6	272.7 (272.7)	—0.9 (—0.9)	493.1	N.A. (501.7)	— (+ 8.6)
136	20.6	276.6	276.9 (276.9)	+0.3 (+0.3)	498.7	N.A. (N.C.)	— (—)
137	20.7	277.6	277.4 (N.A.)	+0.2 (—)	500.5	N.A. (N.C.)	— (—)
138	21.1	282.8	281.5 (N.A.)	—1.3 (—)	509.9	N.A. (N.A.)	— (—)
139	21.2	284.9	285.3 (285.3)	+0.4 (+0.4)	513.7	N.A. (N.C.)	— (—)
140	21.7	290.2	291.1 (291.1)	+0.9 (+0.9)	523.7	N.A. (528.6)	— (+ 4.9)
141	21.9	291.5	290.9 (290.9)	—0.6 (—0.6)	526.0	N.A. (518.9)	— (— 7.1)
142	22.0	290.6	288.1 (288.1)	—2.5 (—2.5)	524.7	N.A. (516.1)	— (— 8.6)
143	22.1	290.5	N.A. (N.A.)	— (—)	524.6	N.A. (N.A.)	— (—)
144	22.2	295.1	293.3 (293.3)	—1.8 (—1.8)	532.8	N.A. (N.C.)	— (—)
145	22.5	298.2	300.1 (300.1)	+1.9 (+1.9)	538.2	N.A. (538.6)	— (+ 0.4)
146	23.0	302.8	N.A. (N.A.)	— (—)	546.7	N.A. (N.A.)	— (—)
147	23.6	307.3	N.A. (N.A.)	— (—)	554.9	N.A. (N.A.)	— (—)
148	24.5	320.9	320.1 (N.C.)	—0.8 (—)	578.6	N.A. (N.C.)	— (—)
149	24.9	315.9	N.C. (315.2)	— (—0.7)	569.8	N.A. (N.C.)	— (—)
150	25.4	322.9	320.4 (320.4)	—2.5 (—2.5)	582.3	N.A. (N.C.)	— (—)
151	25.4	323.1	321.1 (321.1)	—2.0 (—2.0)	582.6	N.A. (N.C.)	— (—)
152	25.6	327.2	327.8 (N.C.)	+0.6 (—)	590.0	N.A. (588.8)	— (— 1.2)
153	25.6	325.1	324.2 (324.2)	—0.9 (—0.9)	586.2	N.A. (587.2)	— (+ 1.0)
154	25.6	326.8	325.1 (325.1)	—1.7 (—1.7)	589.2	N.A. (586.1)	— (— 3.1)
155	25.9	333.7	331.8 (331.8)	—1.9 (—1.9)	601.2	N.A. (N.C.)	— (—)
156	26.2	335.9	N.C. (N.C.)	— (—)	605.3	N.A. (N.C.)	— (—)
157	26.6	336.7	333.8 (336.8)	—2.9 (+0.1)	607.0	N.A. (611.8)	— (+ 4.8)
158	27.5	347.1	346.0 (346.0)	—1.1 (—1.1)	625.2	N.A. (637.5)	— (+12.3)
159	29.0	358.2	357.3 (360.3)	—0.9 (+2.1)	645.2	N.A. (640.3)	— (— 4.9)
160	29.1	360.0	N.C. (N.C.)	— (—)	648.4	N.A. (N.C.)	— (—)
161	29.1	355.7	353.8 (353.8)	—1.9 (—1.9)	640.8	N.A. (N.C.)	— (—)
162	30.3	371.3	N.A. (N.A.)	— (—)	668.4	N.A. (N.A.)	— (—)
163	30.6	372.8	375.6 (N.C.)	+2.8 (—)	671.2	N.A. (668.1)	— (— 3.1)
164	30.9	375.9	376.1 (376.1)	+0.2 (+0.2)	676.7	N.A. (679.1)	— (+ 2.4)
165	31.0	376.9	N.A. (N.C.)	— (—)	678.5	N.A. (N.C.)	— (—)
166	32.2	384.7	N.A. (N.A.)	— (—)	692.4	N.A. (N.C.)	— (—)
167	33.7	399.1	N.A. (N.A.)	— (—)	718.3	N.A. (N.A.)	— (—)
168	33.9	402.5	N.A. (N.A.)	— (—)	724.2	N.A. (N.A.)	— (—)
169	36.0	421.9	416.6 (416.6)	—5.3 (—5.3)	759.0	N.A. (755.1)	— (— 3.9)
170	36.7	425.6	424.6 (424.6)	—1.0 (—1.0)	766.2	N.A. (N.C.)	— (—)
171	36.9	428.9	427.7 (427.7)	—1.2 (—1.2)	772.1	N.A. (N.C.)	— (—)
172	44.3	489.9	488.9 (488.9)	—1.0 (—1.0)	882.1	N.A. (888.9)	— (+ 6.8)
173	47.6	514.7	514.9 (N.C.)	+0.2 (—)	927.0	N.A. (N.C.)	— (—)
174	48.2	519.1	N.C. (N.C.)	— (—)	935.0	N.A. (N.C.)	— (—)
175	52.6	552.8	553.9 (553.9)	+1.1 (+1.1)	996.2	N.A. (N.C.)	— (—)

* N.A., Not apparent;
N.C., Not clear;
N.R., No record;
( ), Arrivals on LPZ seismographs.

Concerning the first explanation, it appears unlikely that the differences can be attributed to the recording of *P* phases in one study and *Pn* phases in the other. The travel times and apparent frequencies of the compressional phases recorded in both studies strongly suggest that in both cases only the normal mantle-refracted *P* phases are observed.

Concerning the second explanation, systematic errors in epicenters in the New Guinea, New Britain, Solomon Islands region — similar to those found in the Japan and Tonga regions — would place many of the epicenters southwest of their C&GS locations. Arrivals which generally appear late by 2 or 3 sec at Marcus and Wake would then have travel times closer to J-B times if the locally determined epicenters were, in fact, the actual epicenters. Because of the orientation of the epicenter errors, the effect of these errors would not be as large at Guam as at Marcus and Wake.

Concerning the third explanation, it is apparent — from the location of great circle paths from the epicenters to Guam, Marcus and Wake — that the travel paths of the two studies differ. Travel paths to Guam generally lie somewhat parallel to the trench systems, whereas travel paths to Marcus and Wake are more normal to the trench systems. Therefore, a greater portion of the travel paths to Guam are in mantle material proximate to the downgoing lithospheric plate, as compared with the travel paths to Marcus and Wake. These latter travel paths are mostly under the East Caroline Basin-Ontong Java Plateau-Nauru Sea area. If the differences in the results of these two studies for the area south of Guam are real, it seems reasonable to attribute these differences to the dissimilarities in travel paths.

Although our shear-arrival travel time residuals seem to suggest somewhat lower velocities with respect to the J-B model, we do not attribute much weight to these data because of their poor quality. No direct comparison with Sutton and Walker's data is possible since *S* waves do not seem to be well transmitted to Marcus and Wake. No *Sn* phases were observed at Guam.

Conclusions.

The results of this study can be summarized as follows: the structure of the mantle close to and in the island arc-trench regions sampled by our data for events to the north of Guam appears to be similar to that of the island arc-trench region sampled by the paths for events to the south of Guam and is consistent with a Jeffreys-Bullen type model. A comparison of our travel time residuals with those of Sutton and Walker (6) suggests that differences exist between the mantle velocity structure of these areas and that of deep ocean basins. Part of these differences may be real, or may, in part, be attributed to systematic errors in epicenter locations. Also, compressional energy seems to be absorbed or blocked for events at distances greater than 26° with travel paths to Guam, whereas events at similar distances are efficiently propagated to Marcus, Midway, and Wake. This apparent absorption of energy is explainable either by high attenuation in the mantle underlying the island-arc regions or a lateral refraction of energy by the downgoing lithospheric slab. Also, *Pn* and *Sn* phases which are efficiently propagated to Marcus, Midway, and Wake are not observed at Guam,

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