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11. Philippine, Solomon and New Hebrides Islands Tsunamis Observed along the Coast of Japan, 1971-1980.

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Abstract

During the past 10 years (1971–1980), seven tsunamis which generated in the Philippine, Solomon and New Hebrides Is. regions were observed by tide-gauges in Japan. According to the USCGS, (US Coast and Geodetic Survey), the earthquake magnitudes were in the range of M_s=7.2 to 7.9. These tsunamis caused much damages to villages near their origin with waves 1–4 meters high. From the amplitude-distance diagram, the tsunami magnitudes (Imamura-Iida scale: m) were determined to be m=1.5 to 2.5. In the present paper, tsunami amplitudes and travel times along the Japanese coast were investigated.

Maximum double amplitudes of the 1975 Philippine (Samar Is.) tsunami averaged about 20 cm with the wave period of 15 min, and southwestern Japan recorded a localized maximum of 40 cm. The initial wave front reached southwestern Japan in 3.5 hours and then propagated along northeastern Japan 1.0 hour later. The farther north the Philippine tsunami source is located the quicker the tsunami reaches Japan. Thus, a tsunami originating in the Luzon Is. area reaches Japan 30 min quicker than one originating in the Mindanao Is. area. The magnitudes of the Solomon-New Hebrides tsunamis depended on the earthquake magnitude. Double amplitudes were 10–20 cm along the Japanese coast and tsunami travel times were 6 to 8 hours.

1. Introduction

From 1968 to 1976, four tsunamis generated in the Philippine region were observed at Japanese tidal stations (JAPAN METEOROLOGICAL AGENCY, JMA, 1973, 1977, 1981). The behavior of the Luzon (Aug. 1, 1968) and Mindanao (Dec. 2, 1972) tsunamis was reported by the author (HATORI, 1969, 1974). Here the tsunami which was generated off the east coast of Samar Island on Oct. 31, 1975 is investigated and compared with other Philippine tsunamis.

Along the Solomon Trench, two large earthquakes (magnitude of 20-sec surface-wave, M_s=7.7 to 7.9) occurred in July 1971 and 1975 and another

Table 1. Data on earthquakes and tsunami originating in the Philippine area.

Date and time (GMT)	Earthquake			Tsunami	
	Epicenter		M_s	m*	Tsunami height
	Lat. (°N)	Long. (°E)			
1968 Aug. 1 20 : 19	16.5	122.2	7.3	1.5	
1972 Dec. 2 00 : 20	6.5	126.6	7.4	2	Yap 18 cm (2a), Guam 9 cm (2a).
1975 Oct. 31 08 : 28	12.5	126.0	7.2	2	Legaspi 28 cm (2a).
1976 Aug. 16 16 : 11	6.3	124.0	7.9	(2.5)	Letayen (Bongo I.) and Pagadian 4.3 m, Lebak 3.4 m, Sacol I. 3 m.

M_s: Earthquake magnitude (20-sec surface-wave).
* Tsunami magnitude on the Imamura-Iida scale. 2a: Double amplitude.

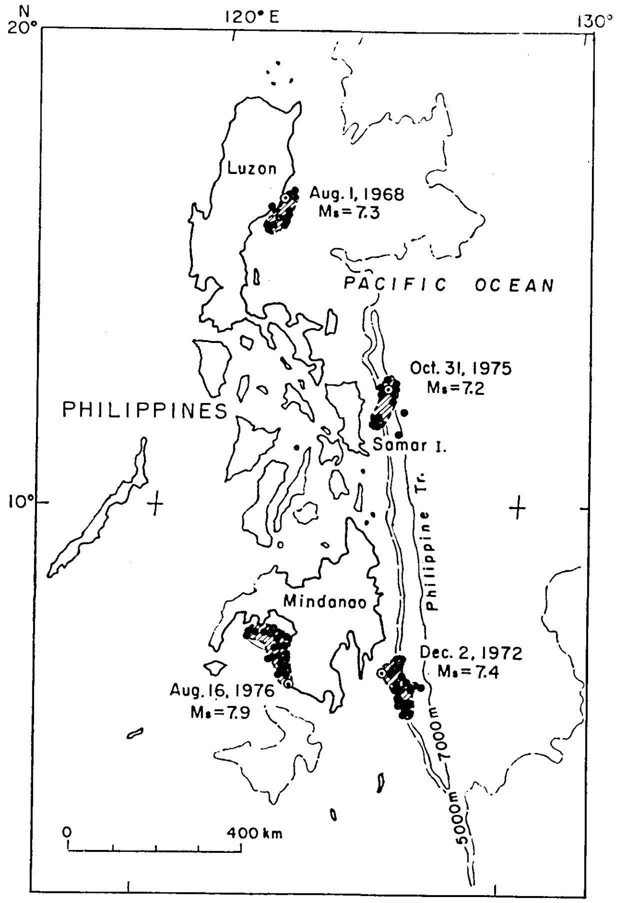

Fig. 1. Distribution of aftershock areas of the tsunamigenic earthquakes in the Philippine region (1968–1976).

Table 2. Data on earthquakes and tsunamis originating in the Solomon and New Hebrides Is. areas.

Date and time (GMT)	Earthquake			Tsunami	
	Epicenter		M_s	m*	Tsunami height
	Lat. (°S)	Long. (°E)			
1971 July 14 06 : 11	5.5	153.9	7.9	1.5	Rabaul 1.54 m (2a), S. New Ireland 3.07 m (2a).
1971 July 26 01 : 23	4.9	153.2	7.9	2	Rabaul 6.5 m (2a).
1974 Jan. 31 23 : 30	7.5	155.9	7.0		W. Choiseul I. 3.0–4.6 m (2a), Torokina (Bougainville) 100 cm (2a).
1974 Feb. 1 03 : 12	7.8	155.6	7.1		Shortland and Choiseul Is. 300–450 cm (2a).
1975 July 20 14 : 37	6.6	155.1	7.9	1.5	Torokina (Bougainville) 100–150 cm.
1975 July 20 19 : 54	7.1	155.2	7.7		
1980 July 17 19 : 42	12.5	165.9	7.9	2	Kona, Hawaii 26.8 cm (2a). Apia 8 cm (2a).

M_s: Earthquake magnitude (20-sec surface-wave).
* Tsunami magnitude on the Imamura-Iida scale. 2a: Double amplitude.

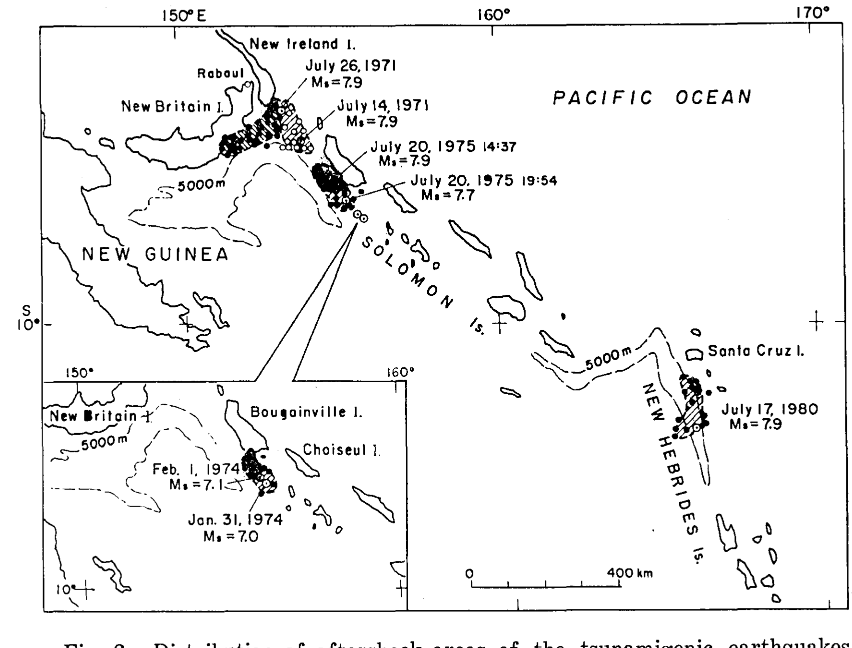

Fig. 2. Distribution of aftershock areas of the tsunamigenic earthquakes in the Solomon and New Hebrides Is. regions (1971–1980).

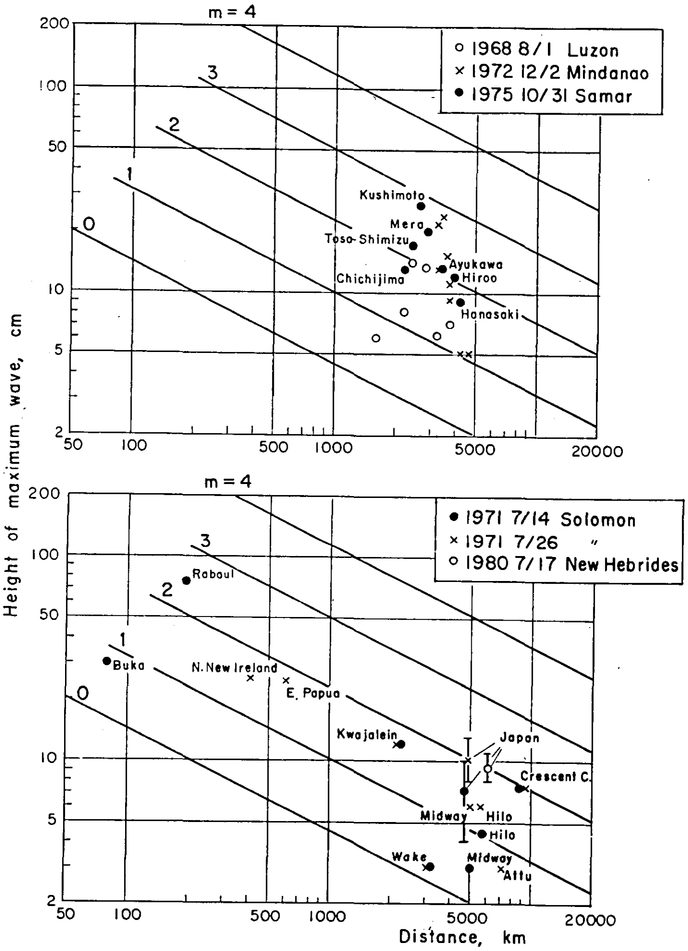

Fig. 3. Magnitude of the Philippine and Solomon-New Hebrides Is. tsunamis. Tsunami magnitude on the Imamura-Iida scale is classified by the attenuation of tsunami height (semi-amplitude of maximum wave) with distance from the epicenter.

large earthquake (M_s=7.9) occurred in the New Hebrides Islands region on July 17, 1980. Accompaning these earthquakes, four tsunamis were also observed at the Japanese tidal stations between 1971 and 1980. In the present paper, the aspects of the Philippine and Solomon-New Hebrides tsunamis are investigated with regard to the relation between tsunami magnitude and earthquake mechanism, and tsunami effects in Japan.

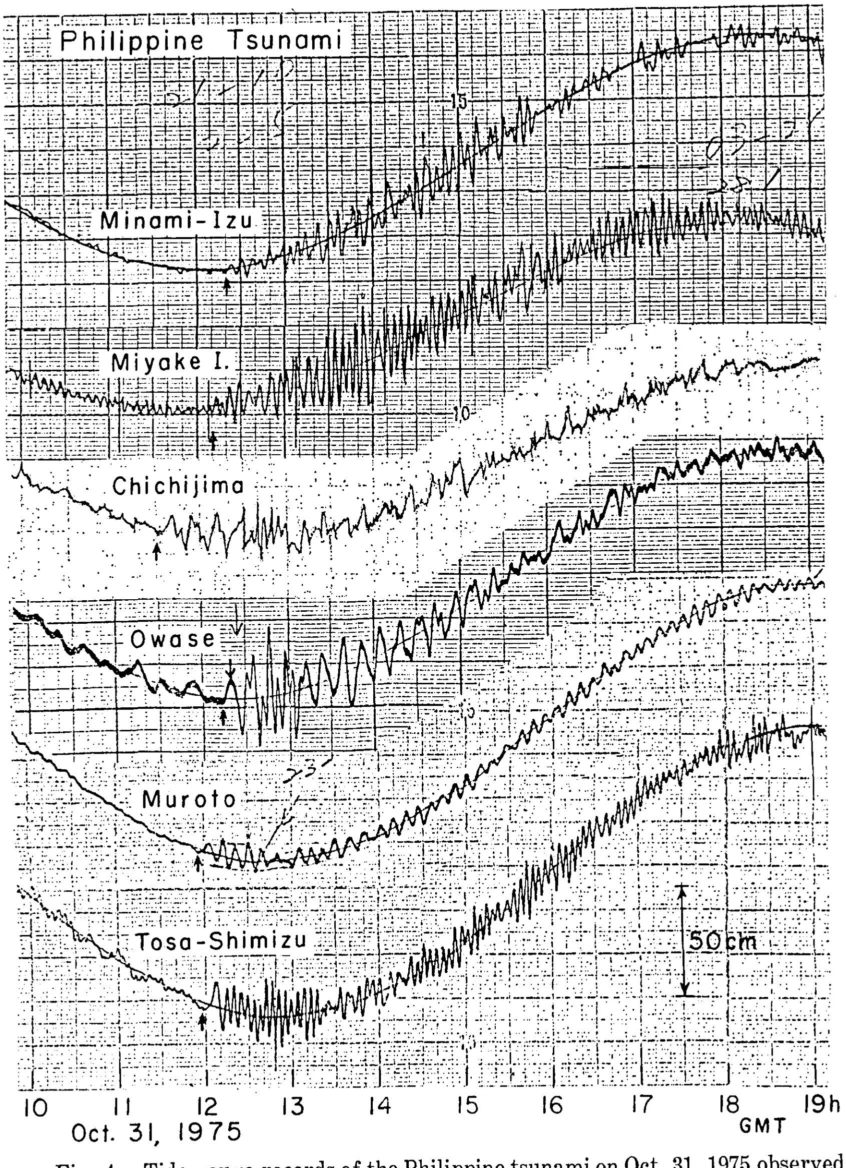

Fig. 4. Tide-gauge records of the Philippine tsunami on Oct. 31. 1975 observed at the Japanese tide stations. The locations are shown in Figs. 8 and 9.

2. Earthquake data

Tsunamigenic earthquake data taken from the PDE reports of the USCGS is listed in Tables 1 and 2. The earthquake magnitudes, M_s, were in the 7.0 to 7.9 range. Figures 1 and 2 show the aftershock areas of the

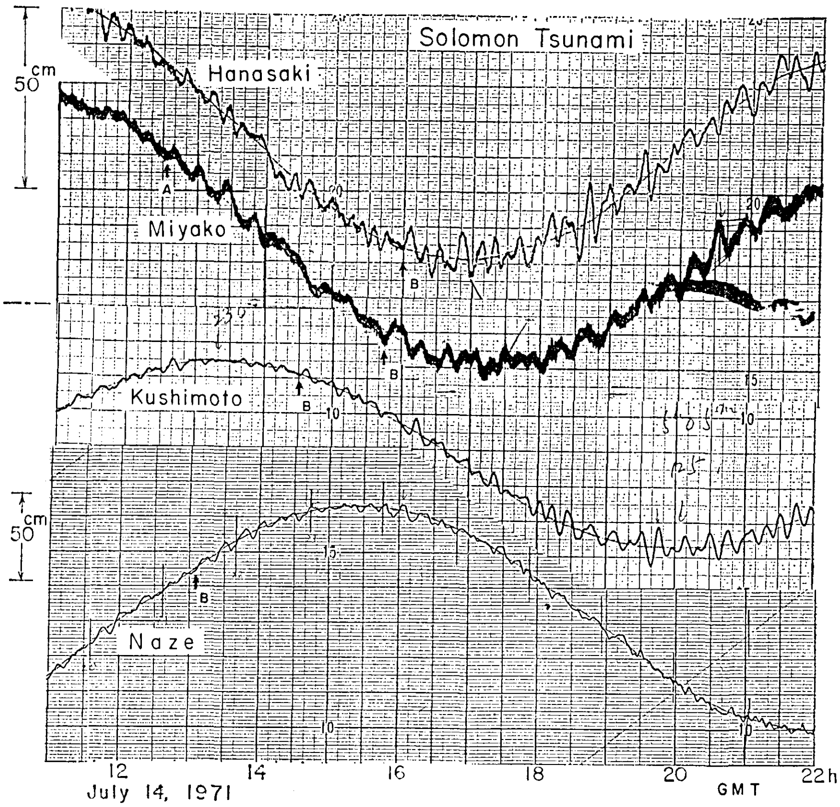

Fig. 5. Tide-gauge records of the Solomon Is. tsunami on July 14, 1971 observed at the Japanese tide stations.

tsunamigenic earthquakes. The aftershock areas, except of the West Mindanao earthquake on Aug. 16, 1976, lay on the island arc, parallel to bathymetric contours. The length of the aftershock areas was 100–300 km. In the Solomon Islands region (Fig. 2), large tsunamigenic earthquakes ($M_s \geq 7.5$) occurred in pairs (LAY and KANAMORI, 1980).

According to the analyses of P-wave first-motion and long-period surface-wave, the 1976 West Mindanao earthquake was caused by a thrust type dipping 24°NE at a depth of 33 km (ACHARYA, 1978). On the contrary, the Solomon earthquakes on July 14 and 26, 1971 were caused by a high-angle (dip angle 40–45° at the depth of 40–50 km) thrust fault slipping 1.3 m (LAY and KANAMORI, 1980). In the central New Hebrides Islands region, the focal mechanism of earthquakes was also characterized by high-angle thrusts at the depth of about 20 to 50 km (CHUNG and KANAMORI, 1978).

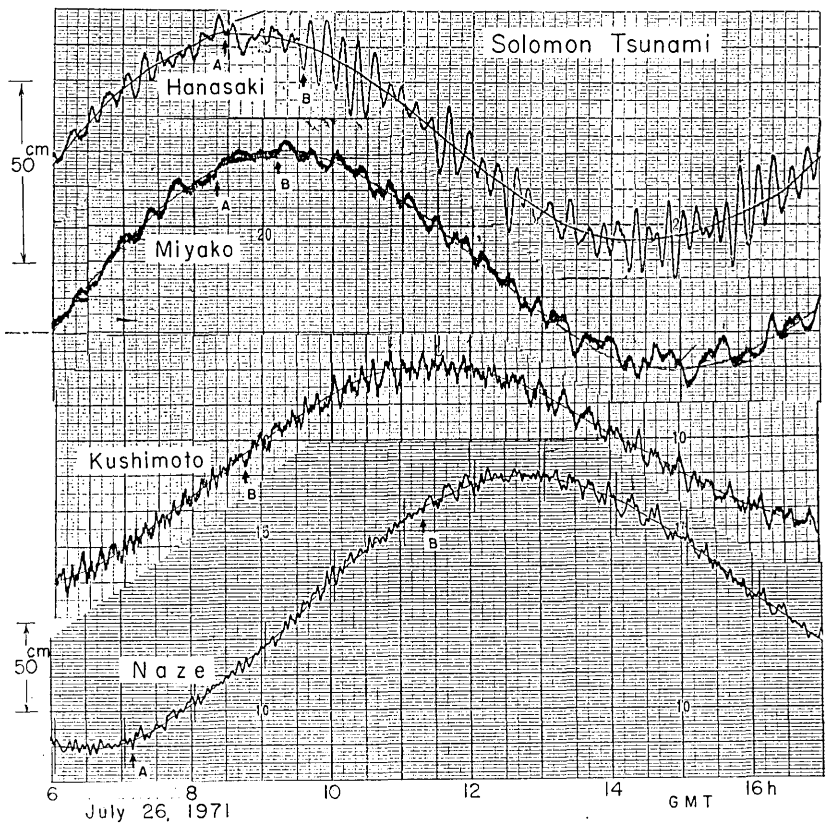

Fig. 6. Tide-gauge records of the Solomon Is. tsunami on July 26, 1971 observed at the Japanese tide stations.

3. Tsunami magnitude

Tsunami height data at coastal area near the source and other Pacific regions have been reported by "Tsunami Newsletter" (International Tsunami Information Center, Honolulu), "Annual Summary of Information on Natural Disasters" (UNESCO) and by USCGS. Data related to this study are listed in Tables 1 and 2. Most of these tsunamis inundated 2-3 m in coastal areas around the source. The West Mindanao tsunami on Aug. 16, 1976 was the largest. Inundation heights on the west coast of Mindanao Is. were 3-4 m, and about 5,000 persons were killed by the earthquake and tsunami (NAKAMURA, 1977; LIMETA, 1980). Small waves of 18-24 cm were observed at Japanese tidal stations (JMA, 1981).

Using the author's method (HATORI, 1979), which is based on the attenuation of wave-height with distance from the epicenter, the tsunami magnitude on the Imamura-Iida scale, m, is determined in Fig. 3. The wave-

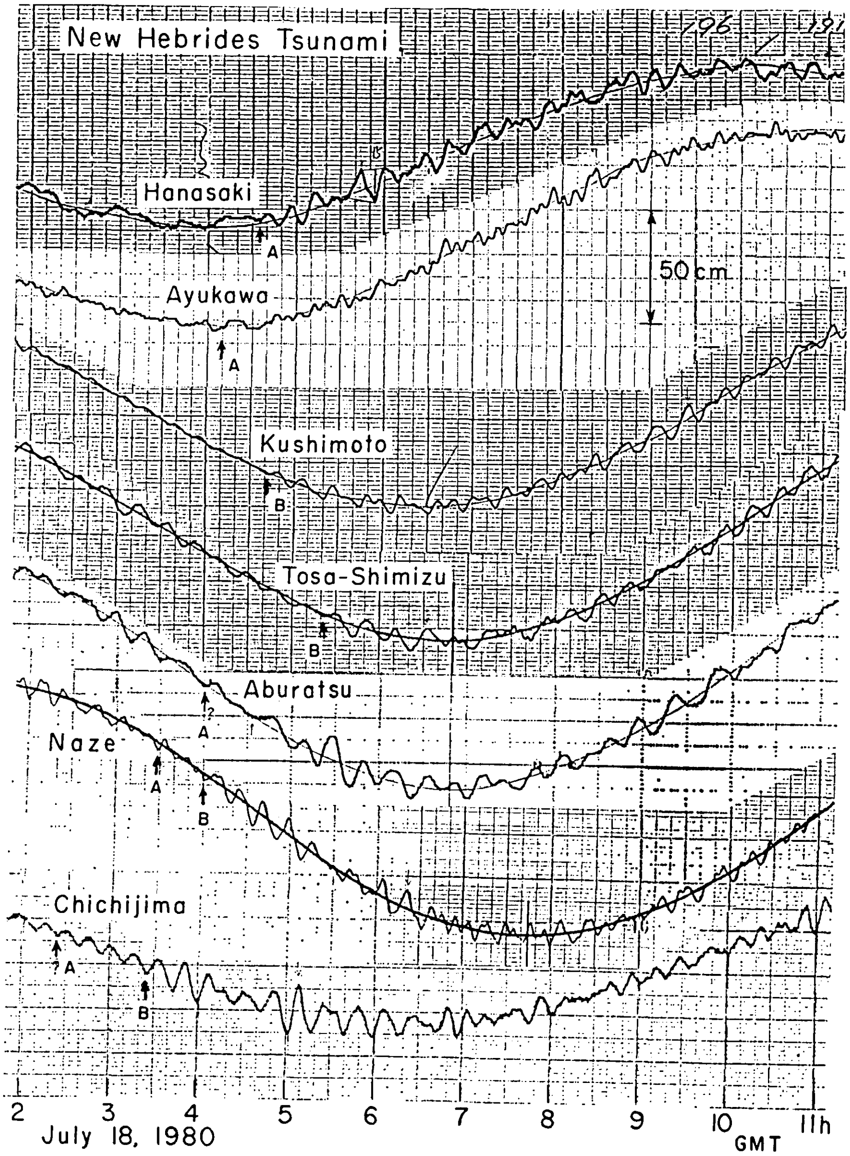

Fig. 7. Tide-gauge records of the New Hebrides Is. tsunami on July 17, 1980 observed at the Japanese tide stations.

height in Fig. 3 means half-amplitude of the maximum wave above the ordinary tidal level on records. On the average, the magnitude of the Philippine tsunamis in 1972 and 1975 is determined to be $m=2$, and that of the 1968 Luzon tsunami $m=1.5$. The magnitudes of the Solomon tsunamis on July 14 and 26, 1971 are $m=1.5$ and 2, respectively. From the

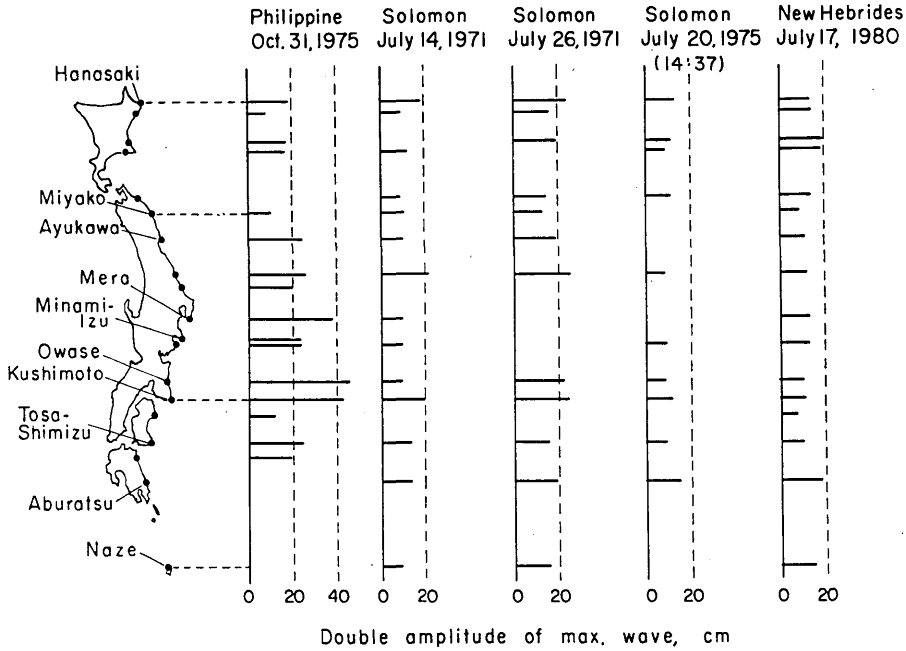

Fig. 8. Distributions of the maximum double amplitude of the Philippine and Solomon-New Hebrides tsunamis along the Japanese coast.

Table 3. The Philippine tsunami of Oct. 31, 1975, as recorded by the Japanese tidal stations. The wave originated near the earthquake epicenter (12.5°N, 126.0°E, M_s=7.2, USCGS) off Samar Is., at 08: 28 (GMT), Oct. 31, 1975.

Tide stations	Initial wave			Maximum wave		
	Travel time	Rise	Period	τ	Double ampl.	H
	h m	cm	min	h m	cm	cm
Hanasaki	?				18	9
Kushiro	?				10	5
Hiroo	5 36	3	18	2 52	18	12
Urakawa	5 44	2	8	1 10	17	10
Miyako	?				10	7
Miyagi-Enoshima	4 47	2	20	5 00	9	5
Ayukawa	?				25	13
Onahama	?				27	10
Hitachi	?				20	14
Mera	4 07 ?	6	10	50	38	20
Miyake Is.	3 34	6	10	1 44	44	24
Hachijo Is.	3 32 ?	8	12	55	50	26
Chichijima (Bonin Is.)	3 03	9	13	1 00	20	13
Minami-Izu	3 52	4	8	2 16	24	13
Omaezaki	3 58 ?	3	14	1 35	25	14
Owase	3 44	10	14	33	46	32
Kushimoto	3 30	11	12	1 03	43	27
Muroto	3 28	5	10	35	12	8
Tosa-Shimizu	3 30	13	8	43	25	17
Aburatsu	?					
Naha	?					

τ: Time interval between the arrival of wave front and the maximum wave crest.
H: Tsunami height above ordinary tides.

Table 4. The Solomon Is. tsunami of July 14, 1971, as recorded by the Japanese tidal stations. The wave originated near the earthquake epicenter (5.5° S, 153.9° E, M_s=7.9, USCGS) near New Ireland Is. at 06 : 11 (GMT), July 14, 1971.

Tide stations	Initial wave						Maximum wave		
	A			B			C	Double ampl.	H
	Travel time	Rise	Period	Travel time	Rise	Period			
	h m	cm	min	h m	cm	min	h m	cm	cm
							15th		
Hanasaki				9 49	6	14	3 38	18	10
Kushiro				12 08	3	15	7 23	9	4
Urakawa				8 39	3	10	10 11	12	6
Hachinohe				9 35	4	32	5 55	8	6
Miyako	6 22	2	20	9 35	4	20	5 32	11	6
Ayukawa				8 38	4	12	7 46	10	6
Onahama	6 29	3	12	8 01	5	12	3 50	23	14
Mera				7 14	3	15	6 15	10	4
Uchiura				8 02	4	18	11 08	6	4
Omaezaki				10 29	6	15	6 37	10	6
Owase				8 25	3	12	7 01	10	6
Kushimoto				8 19	3	15	4 46	19	11
Tosa-Shimizu	6 19	4	18				9 05	14	8
Aburatsu				9 49	3	16	2 34	13	8
Naze				6 17	3	16	0 18	8	4

A: The wave front was so indefinite that it was determined with the aid of the refraction diagram. B: Evident wave commences. C: Occurrence time (JST) of crest. H: Semi-amplitude above ordinary tides.

Japanese data, the magnitude of the 1980 New Hebrides tsunami seems to be $m=2$. From the definition of tsunami magnitude, tsunami energy is reduced by one-fifth for the decreasing magnitude by a unit.

According to the statistical relation between the earthquake and tsunami magnitude (HATORI, 1979), these tsunami magnitudes were consistently with seismic moment. For example, the seismic moments of the Solomon earthquakes on July 14 and 26, 1971 were 1.2×10^{28} and 1.8×10^{28} dyne-cm, respectively (LAY and KANAMORI, 1980).

4. Tsunami data in Japan

Figures 4 to 7 show some tide-gauge records of the Philippine and Solomon-New Hebrides tsunamis observed along the Japanese coast. The locations of the tidal stations are shown in Figs. 8 and 9. Principal features of records at various stations are summarized in Tables 3 to 7.

Table 5. The Solomon Is. tsunami of July 26, 1971, as recorded by the Japanese tidal stations. The wave originated near the earthquake epicenter (4.9° S, 153.2° E, M_s=7.9, USCGS) near New Ireland Is. at 01 : 23 (GMT), July 26, 1971.

Tide stations	Initial wave						Maximum wave		
	A			B			C	Double ampl.	H
	Travel time	Rise	Period	Travel time	Rise	Period			
	h m	cm	min	h m	cm	min	h m	cm	cm
							27th		
Hanasaki	7 05	3	17	8 10	7	12	0 52	24	13
Kushiro	7 10 ?	2	18	10 33	5	22	10 44	17	10
Urakawa				8 25	5	10	4 31	20	10
Hachinohe	7 17 ?	3	30	11 35	7	32	3 10	15	10
Miyako	6 57	2	12	7 50	3	20	4 59	13	8
							26th		
Ayukawa				8 24	6	8	23 50	18	13
Onahama				7 07	7	15	21 30	26	10
Uchiura				8 07	5	10	19 48	13	8
							27th		
Owase	6 12?	4	17	7 30	3	14	0 25	22	15
							26th		
Kushimoto				7 23	6	18	19 51	24	12
							27th		
Tosa-Shimizu				9 39	7		0 20	16	10
							26th		
Aburatsu				7 47	5	15	23 33	19	12
Naze	5 45	5	14	9 54	5	15	23 13	15	9

A: The wave front was so indefinite that it was determined with the aid of the refraction diagram. B: Evident wave commences. C: Occurrence time (JST) of crest. H: Semi-amplitude above ordinary tides.

The waves of symbol *A* were read from the records with the aid of the refraction diagrams (Figs. 10 and 11) and those of symbol *B* have the phase of a relatively evident arrival.

Figure 8 shows the distributions of the maximum double amplitude along the Japanese coast. For the 1975 Philippine tsunami, the wave amplitude in southwestern Japan was 40 cm, larger than other places due to the convergence of refracted waves. Amplitudes for the Solomon-New Hebrides tsunamis were 10–20 cm. Wave periods of these tsunamis were 10–20 min.

Figures 9–11 show the refraction diagrams of the 1975 Philippine, the 1971 Solomon and the 1980 New Hebrides tsunamis. The observed travel times at some Japanese tidal stations are shown. The travel time of the

Table 6. The Solomon Is. tsunami of July 20, 1975, as recorded by the Japanese tidal stations. The wave originated near the earthquake epicenter (6.6° S, 155.1° E, M_s=7.9, USCGS) near Bougainville Is. at 14 : 37 (GMT), July 20, 1975.

Tide stations	Initial wave A Travel time		Initial wave A Rise	Initial wave A Period	Initial wave B Travel time		Initial wave B Rise	Initial wave B Period	Maximum wave C		Maximum wave Double ampl.	Maximum wave H
	h	m	cm	min	h	m	cm	min	h (21th)	m	cm	cm
Hanasaki	7	27	3	12	12	03	4	12	18	48	12	9
Hiroo					7	51	3	16	18	43	10	6
Urakawa	7	15	2	13	7	58	3	13	20	31	9	5
Hachinohe	7	11?	2						15	45	11	6
Onahama	6	25?	2	10					15	26	8	4
Chichijima	6	11?	3	14					18	40	10	5
Omaezaki	6	31	3	12	7	55	3	12	16	48	9	5
Owase					9	13	3	10	14	02	8	5
Kushimoto	6	16	4	22					19	09	12	8
Tosa-Shimizu	6	21?	3	18					23	14	8	5
Aburatsu					10	33	3		23	37	15	8

A: The wave front was so indefinite that it was determined with the aid of the refraction diagram. B: Evident wave commences. C: Occurrence time (JST) of crest. H: Semi-amplitude above ordinary tides.

1975 Philippine (Samar Is.) tsunami for southwestern Japan was 3.5 hours. For the 1968 Luzon and 1972 Mindanao tsunamis, the travel times were 3 and 4 hours, respectively (HATORI, 1969, 1974). The travel times of the Solomon-New Hebrides tsunamis to southwestern Japan were 6 to 8 hours. The farther south the source is located the longer the travel time to Japan.

5. Conclusion

The behavior of the Philippine and Solomon-New Hebrides tsunamis were investigated using tide-gauge records observed in Japan. These tsunami magnitudes were estimated to be m=1.5–2.5, but the effects of the tsunamis along the Japanese coast were evidently small. Although the Solomon earthquakes occurred by a high-angle thrust faulting, the tsunami magnitudes were average because of the relatively deep sources.

The initial wave front of the Solomon-New Hebrides tsunamis reached southwestern Japan in 6 to 8 hours and those of the Philippine (Luzon to Mindanao) tsunamis took 3 to 4 hours. The wave amplitudes along south-

Table 7. The New Hebrides Is. tsunami of July 17, 1980, as recorded by the Japanese tidal stations. The wave originated near the earthquake epicenter (12.47° S, 166.26° E, M_s=7.9, USCGS) near Santa Cruz Is., at 19 : 42 (GMT), July 17, 1980.

Tide stations	Initial wave						Maximum wave		
	A			B			C	Double ampl.	H
	Travel time	Rise	Period	Travel time	Rise	Period			
	h m	cm	min	h m	cm	min	h m 18th	cm	cm
Hanasaki	8 53	3	17				14 43	13	8
Kushiro				10 56	4	20	20 12	15	8
Hiroo				9 22	6	12	20 32	19	11
Urakawa	8 28	3	16				16 24	18	10
Hachinohe				9 33	6	15	16 46	14	7
Miyako	8 24	4	24				15 48	9	5
Ofunato				9 13	3	16	19 43	10	5
Miyagi-Enoshima				8 48	1	10	17 03	3	1.5
Ayukawa	8 28	3	30				17 22	11	5
Onahama				8 50	3	17	19 50	12	8
Mera	7 53	4	8	8 58	3	10	16 26	13	8
Hachijo Is.	7 18	3	10	8 03	3	15	16 50	9	5
Chichijima	6 40?	3	16	7 41	6	18	14 08	21	12
Omaezaki				9 18	2	13	16 35	13	8
Toba				9 58	2	18	18 56	8	4
Uragami	8 10	3	20	8 58	5	15	18 44	8	5
Owase				9 00	4	20	15 00	10	5
Kushimoto				8 58	2	18	18 24	11	7
Muroto				9 11	2	10	15 24	7	4
Tosa-Shimizu				9 38	3	21	15 32	10	5
Aburatsu	8 18?	4	15	8 50	5	20	14 28	18	10
Naze	7 46	4	12	8 18	5	15	15 21	15	8
Naha							15 07	5	3

A: The wave front was so indefinite that it was determined with the aid of the refraction diagram. B: Evident wave commences. C: Occurrence time (JST) of crest. H: Semi-amplitude above ordinary tides.

western Japan for the Philippine tsunamis in 1968, 1972 and 1975 were relatively high due to the effect of the direction of the island arc. Future tsunamigenic earthquake ($M \geq 8$) occurring near the Philippine Trench should be watched.

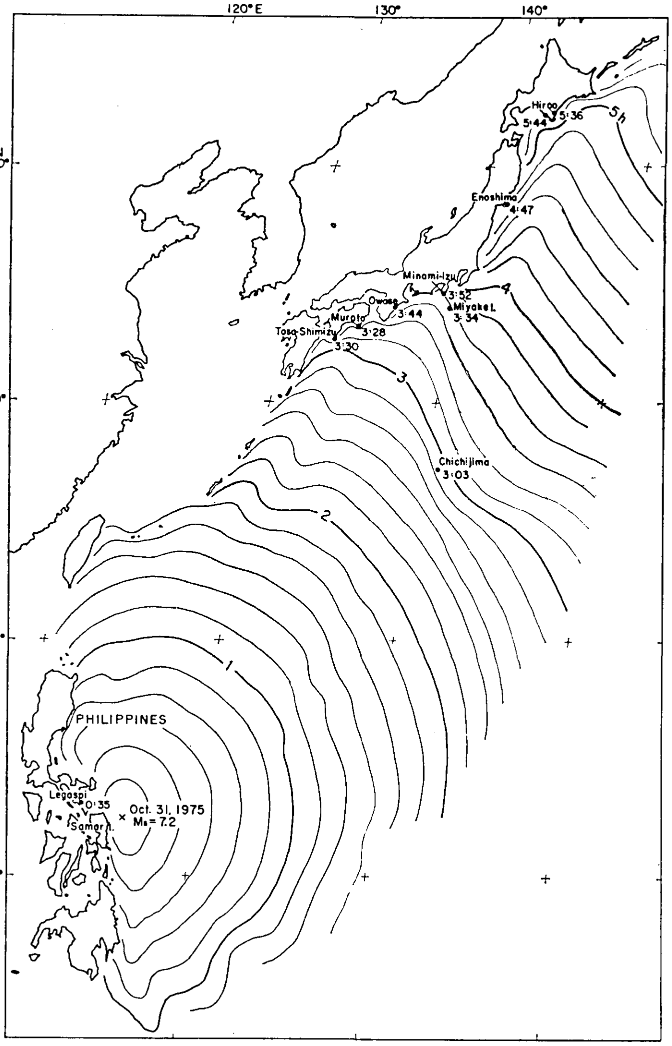

Fig. 9. Refraction diagram of the Philippine tsunami on Oct. 31, 1975 (time interval: 10 min). Travel times (h, m) observed at the Japanese tide stations are shown.

Acknowledgment

The author wishes to express his hearty thanks to the Japan Meteorological Agency and the Hydrographic Office for putting their tide-gauge records by the author's disposal and also to Mr. Masami Okada for supplying the tide-gauge records of the tsunamis.

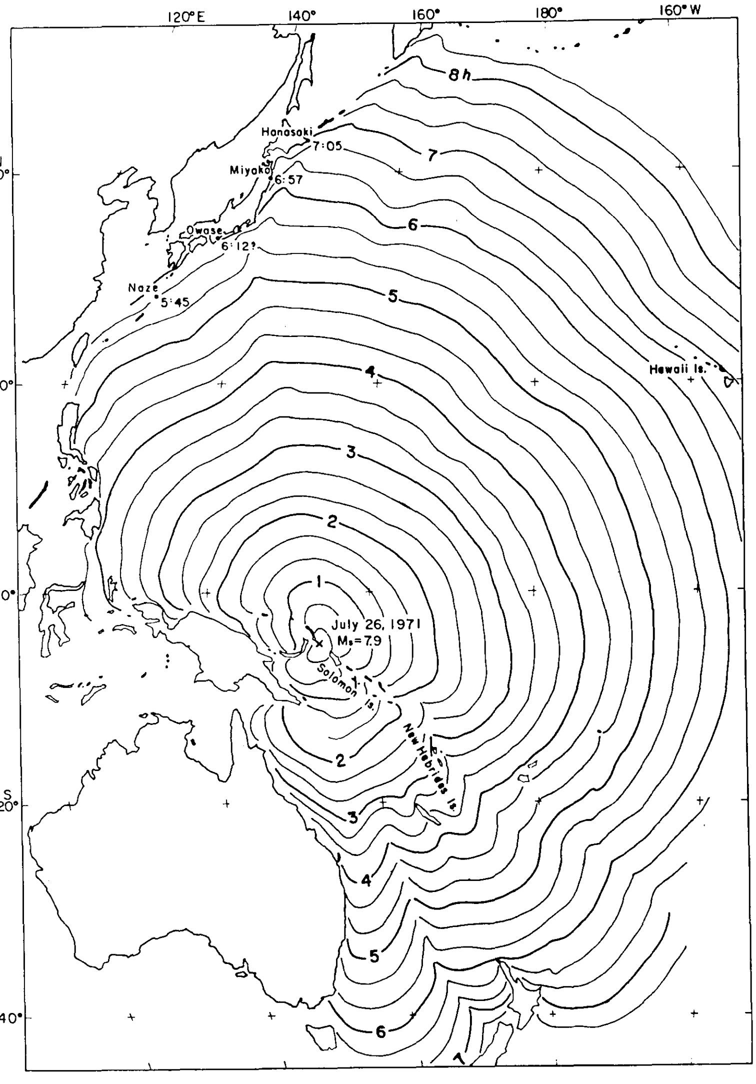

Fig. 10. Refraction diagram of the Solomon Is. tsunami on July 26, 1971 (time interval: 20 min). Travel times (h, m) observed at the Japanese tide stations are shown.

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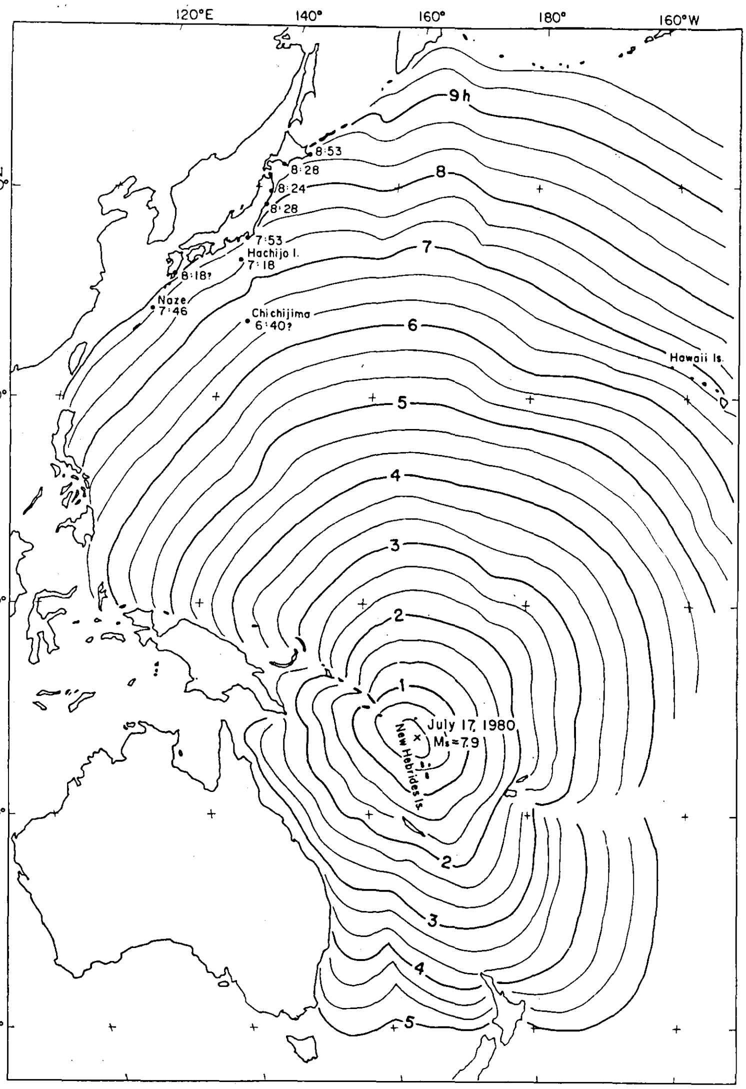

Fig. 11. Refraction diagram of the New Hebrides Is. tsunami on July 17, 1980 (time interval: 20 min). Travel times (h, m) observed at the Japanese tide stations are shown.

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11. 日本沿岸で観測したフィリピンおよびソロモン・ニューヘブリデス諸島の津波

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1971年から1980年に至る10年間に，フィリピンおよびソロモン・ニューヘブリデス諸島に発生した地震 (M_s=7.2〜7.9) により，日本沿岸で7個の小津波が観測された．本文では，各地の検潮記録をもとに，日本沿岸の波高分布と津波到達時間を調べた．これらの津波規模 (今村・飯田スケール，m) は，日本ならびに太平洋各地の津波データから推定すると，m=1.5〜2.5 と格付けされ，波源に近い沿岸では津波被害を受けた．

1975年10月のフィリピン (サマール島沖) 津波では，西日本沿岸の伝播時間は3.5時間前後で，紀伊半島沿岸の波高が比較的大きく，全振幅 40cm であった．1971年7月と1975年7月のソロモン諸島および1980年7月ニューヘブリデス諸島の地震による津波では，日本沿岸で全振幅 10〜20cm の津波を観測し，伝播時間は6〜8時間であった．いずれも津波規模は地震の規模に見合った標準型であったが，将来この海域に巨大地震がおきても，地理的条件から日本沿岸に対する津波の影響は小さいであろう．しかし，フィリピ海溝ぞいに M8以上の巨大地震による津波が起これば，島孤の向きによる効果で西日本沿岸に津波の影響を与える可能性がある．その津波伝播時間は，ルソン島沖津波で3時間，ミンダナオ島沖におこれば4時間となる．
