

## CHAPTER 41

### TSUNAMIS ALONG WEST COAST OF LUZON, PHILIPPINES

by

R. L. Wiegel, F. ASCE\*

#### INTRODUCTION

A detailed engineering study was made by Ebasco Services, Inc., (1977), for a proposed nuclear power plant in the Napot Point region of Bataan, between the entrance to Manila Bay and Subic Bay, Republic of the Philippines (about 14°-37-12'N, 120°-18-3/4'E), Figure 1. As a part of the oceanographic portion of this work, a study was made by the writer of the characteristics of tsunamis that had occurred in the region, and the statistics of occurrence (Wiegel, 1976). The study of tsunamis has been updated to the present time (May, 1980).

The location of the site is such that the large tsunamis generated in some areas of the Pacific Ocean (such as off the coasts of Chile, Alaska, Japan and Kamchatka) are not likely to reach Napot Point with any appreciable amplitude (see, for example, Wiegel, 1976). There is good evidence that this is the case. Owing to the relative stability from the standpoint of earthquakes (aseismic) of Borneo, the Malaya Peninsula, most of Indochina and the intervening China Sea (Gutenberg and Richter, 1949, pp. 82 and 93), there is probably little, if any, chance of tsunamis being generated in this region; this appears to be a fact (Berninghausen, 1969). The great eruption of Krakatoa and the tsunami generated by it was not noticed on tide gages at either Singapore or Hong Kong, so that it would be reasonable that it would not have been detected at Manila (Wharton, 1888). Also, the large tsunamis that have been generated in the Sulu Sea and the Celebes Sea do not seem to reach the site with any appreciable amplitude. Thus, the tsunamis of importance to the site are those which will be generated in the local seas off the west coast of Luzon. In order to establish this fact, information is presented on a number of tsunamis generated in other regions, especially those generated in the seas off the west coast of the Philippine Islands.

#### HISTORIC RECORD OF TSUNAMIS GENERATED OFF THE WEST COAST OF LUZON

A seismological station, established as a part of the Manila Central Observatory in 1865 (Saderra Masó and Smith, 1913), operated continuously until World War II. It was reestablished after the war. During the interval from about 1900 until the start of World War II, the seismological

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\* Professor of Civil Engineering, University of California, Berkeley.

station was directed by two scientists: first by the Rev. Miguel Saderra Masó, S.J., and then by the Rev. W. C. Repetti, S.J., both of whom were familiar with tsunamis and their relationship to earthquakes, and who were alert for their occurrence. Owing to this fortunate circumstance, there exist a number of references to historic tsunamis generated in the areas surrounding the Philippine Islands. The sources for finding these references, together with appropriate quotations from the references, are given in the paper. Records of more recent tsunamis are available from several sources. All references to tsunamis in the Philippines found by the writer have been included. In addition, several citations are given in which a statement is made that no tsunami waves were observed, and for which no statement on tsunami waves is given.

The fact that the two scientists mentioned above were familiar with tsunamis and their relationship to earthquakes is shown by the following quotations from three of their reports:

"These facts would appear to afford sufficient foundation for attributing the earthquakes which are confined to the Ilocos Provinces to movements and displacements of the first section or coastal range. The absence of seismic tidal waves and similar phenomena in the case of the two earthquakes mentioned [15 August 1897 and 14 November 1897] may be accounted for, partly by the relative smallness of the portion of the coast disturbed, partly by the fact that it is not the bottom of the sea which is affected, but merely a bordering ledge." -- Saderra Masó (1909)

"As this is one of the few Philippine instances of the waves or tsunamis caused by earthquakes [17 December 1677], it is certainly a pity that the author did not mention the region principally affected. It may be supposed that the waves were raised in the China Sea near the west coast of Cavite, Bataan and Zambeles." -- Saderra Masó (1927)

"Waves were observed at Mambajao, Camiguin Island, and the disturbances of the sea lasted about an hour. The International Summary placed the epicenter at 9.5°N, 128.8°E, but this is scarcely possible, because sea waves from this point could not have passed through the Suriago straits and across the Mindanao Sea without being noticed at other places." -- Repetti (1931), [earthquake of 18 July 1923]

The area to the east of the southern Philippines, bordering the Philippine Trench, and portions of the Celebes Sea, are much more active seismically than is the area off the west coast of central and northern Luzon, in the South China Sea. As commented on by Berninghausen (1969), most of the tsunamis which have been reported from the entire Southeast Asia region have been local in origin and relatively restricted in the extent of the regions affected. This is in agreement with the information contained in the additional references found during the present search, including the 17 August 1976 Moro Gulf tsunami, associated with a shallow local depth earthquake, magnitude determined to be about 7.9 (Badillo and Astilla, 1978).

Thirty-six of the citations included in the paper either mention specifically tsunamis generated in Philippine waters or possible seiches. Details are given in the original report, with a brief citation given

herein. Eleven were generated in the region of direct interest: seven are tsunamis, three are probably seiches, and one is for the case of a hill sinking in a bay. These eleven are marked by an asterisk (\*) in the appendix.

The tsunamis that have been observed in the area of interest must have been relatively small; if not, there should be observations to the contrary. Consider two tsunamis generated off the northwest coast of Luzon: 6 May 1924, Agno, Pangasiana. Saderra Masó (1925) states:

"... town of Agno on the west coast of Luzon at 16.1°N and 119.8°E, shortly after an earthquake, was invaded by four big sea waves which flooded its low portions and caused great consternation to the people but without doing considerable material damage nor harm to people.

"A similar occurrence took place in the same town on January 26 of 1872. It is reported that the town was flooded by sea waves shortly after an earthquake....

"In fact, Agno is the only important town existing in the north part of the Zambales coast nearest to the origin of the shocks; moreover its bay and the low alluvial plain where empties the River Balincaguin offered more favorable conditions to the advance of the waves caused by the earthquake than any other place of this west coast of Luzon generally high and cliffy."

There is evidence that the drawdown of the tsunami waves is as important as the runup. The following two tsunamis occurred in the general area of interest: 3 June 1862, water in the bay receded from Manila to Cavite and returned from that direction (Saderra Masó, 1927, p. 95; Repetti, 1935). 14 February 1934, at San Esteban the first movement of the sea was reported to have been a recession, and to such an extent that people hurried out on the exposed shore to gather fish which had been stranded (Repetti, 1934). In these two cases (and perhaps in others; there is no evidence one way or the other) a drawdown occurred first. If the source was a downward vertical tectonic displacement, a drawdown would occur first. The comment of Ludwig, Hayes and Ewing (1967) in their paper on the Manila Trench and Luzon Trough, indicates this to be the case.

In regard to the occurrence of an initial drawdown it is interesting to note that a common observation at widely scattered places was a deep recession of water before the arrival of the first wave during the Moro Gulf tsunami of 17 August 1976 (International Tsunami Information Center, 1976; Badillo and Astilla, 1978).

Essentially, no information was obtained on the "periods" of the tsunami waves generated off the northern and central west coast of Luzon. It is important to obtain this information, as it is useful in determining an estimate of the "width" of the tectonic (or volcanic or landslide) source of the tsunamis. The information obtained of the Moro Gulf tsunami of 17 August 1976 is useful in this respect. Badillo and Astilla (1978) state that the interval between waves was from one to five minutes.

Care must be exercised in obtaining information from the records of tidal gages owing to the natural frequency characteristics of bays (see, for example, Raichlen, 1972); however, very useful information can be obtained from them. Owing to this, the National Ocean Survey (NOAA, U.S. Department of Commerce) was contacted, and it was learned that they have

Philippine Islands tidal data on file in their archives as follows: Cavite, 1921 (3 months); Subic Bay, 1911-1912; Manila, 1901-1940. It was not possible, however, to obtain copies of these.

What can be determined about the heights of the tsunamis? There is good evidence that a large tsunami would be observed and documented. The rationale for this statement is the information available for other areas of the Philippine Islands; information on this follows.

#### TSUNAMIS IN THE SULU SEA AND THE CELEBES SEA

Devastating tsunamis have been generated in the Sulu Sea and in the Celebes Sea, but were of little importance as far as the vicinity of Manila Bay, Luzon. Three of these are described briefly below.

The epicenter of the subsea earthquake of 21 September 1897 was in the Sulu Sea, about 70 kilometers WNW of Zamboanga, Mindanao, about 70 kilometers NW of Isabela (Basilan Island), about 150 kilometers NNW of Jolo (Sulu Archipelago) and about 380 kilometers SSE of Cuyo Island (Cornoas, 1899; Saderra Masó, June 1909). According to Saderra Masó:

"... immense waves from the west which swept away everything near the shore that was at a less height than 7 meters above mean sea level [Isabela, Basilan Island]... They commenced with an ebb in which the level fell about 5 meters, followed by a series of floods and ebbs, one of the former being extraordinary in height [Zamboanga, Mindanao]... The greatest height reached by the flood was 1 meter [Jolo, Sulu Archipelago]... earthquake was followed by a tidal movement of the sea in which the water rose about 2 meters [Dapitan (NW of Mindanao)]... The port of Cuyo faces towards west. The first ebb was observed an hour and a half after the shock, the water receding during half an hour far beyond the lowest tide; then it returned, reaching within a few minutes the limit of the highest tides. There were alternate ebbs and floods in regular succession during more than one hour [Cuyo Island]."

The tsunami that is described above apparently did not reach Manila, or at least it was so small by then that it was not noticed. It is important for two reasons. It shows that a large tsunami has been observed at a number of locations, and it appears that this may be the largest tsunami that occurred in the Philippines during the past three hundred years, probably larger than the Moro Gulf tsunami of 17 August 1976. The maximum run-up elevation of the tsunami, at a distance of about 70 kilometers from the surface, was about 7 meters above mean sea level.

Another example is the earthquake of 15 August 1918 off southern Mindanao, with a magnitude of 8-1/4 (Gutenberg and Richter, 1949). Its epicenter was located between 5° and 6°N and between 124° and 125°E in the Celebes Sea. This region is active seismically, and many more tsunamis have been generated in the Celebes Sea than off the northern and central west coast of Luzon. Saderra Masó (1918) quotes eyewitness accounts such as:

"... Sarangani Bay ... a tidal wave as high as 24 feet at some points and at the Constabulary station at Glan [Cotabato] to a height of 18 feet ... at Port Lebak, reports that a tidal wave at his place was

between 6 and 8 feet ... south of Port Lebak for some forty miles there was a tidal wave variously estimated at from 20 to 25 feet."

On 17 August (local time; 16 August GMT time), another major earthquake (magnitude 7.9, or 8.0  $M_s$ ) occurred in the Celebes Sea (Moro Gulf), at 06.26°N, 124.2°E (International Tsunami Information Center, 1976; Stratta, et al., 1977; Badillo and Astilla, 1978; Pararas-Caryannis and Wigen, 1978; Acharya, 1978), generating a large tsunami. Some comments from the report by The Reverend Victor L. Badillo (Director of Manila Observatory) and Zinnia C. Astilla (1978), follow.

"The Moro Gulf tsunami of 17 August 1976 was the most disastrous tsunami experienced by the Philippines. There have been more severe tsunamis, but areas hit were less populated and had less manmade structures (p. 9)... When the sea had spent its fury and rolled back to its normal cadence, the survivors looked upon scenes of death and destruction. About 8,000 were dead or missing. About 10,000 were injured and about 90,000 were homeless (p. 1)... A common observation at widely scattered places was a deep recession of the water before the arrival of the first wave ... Some persons ran out to the newly exposed sea bottom out of curiosity or to pick up stranded fish (p. 6)... Estimates of wave heights had to be based on qualitative descriptions of the waves being as tall as a coconut tree, a two storey house, twice a man's height, etc., or had to be deduced from photographs of damaged structures ... Places where waves were reported to be higher than five meters are: Linek (Maguindanao), Kalanganan (Cotabato City), Pagadian City, Sacol Island (Zamboanga City), Lebak (Sultan Kudarat). At Lebak waves may have been as high as nine meters (p. 5)\*... That there were three or four waves were indicated by the majority of respondents. The largest number was seven, reported by one person. One thing is definite-- there was more than one wave. Majority of respondents estimated the interval between waves to be between one to five minutes. As many considered the first wave to be the most destructive as considered it was the third. At the time of the earthquake the last quarter moon was some 30 degrees above the eastern horizon, so that there was enough light to see."

The International Tsunami Information Center (1976) gives some additional information on the tsunami waves:

"... Based on the survey of the affected area, it was concluded that maximum waves in the entire Moro Gulf area were in the order of 14-15 feet, which were considerably less than what had been reported in the newspapers. Such large waves were experienced at Alicia, Pagadian City, Bongo Island, Resa Bay, Lebak, and the east coasts of Basilan and Jolo islands. Based on the distribution of wave heights along the coastline of Moro Gulf, estimates of travel times of the tsunami to each point, and the directional failure of structures, both by the earthquake and the tsunami, it was concluded that the earthquake and the tsunami generating area was in

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\* A listing of tsunami wave heights at various localities is given in Table 1 of the report by Badillo and Astilla.

the upper part of Moro Gulf, somewhat south of Baganian Peninsula and having an orientation from southeast to northwest." (p. 6)

In the U. S. Department of Commerce, NOAA publication (1978, p. 71), it is stated that the wave was recorded on the Davao tidegage with a maximum amplitude of 35 cm.

Additional information on the tsunami, and its effect on shorelines and structures, is given in the report by Stratta, et al. (1977).

For some details on the tectonics of the region, see Hamilton (1977). He believes the earthquake occurred along a subduction zone which is breaking through on the west side of the Sangihe ridge-Halmahera arc collision aggregate. Stewart and Cohn (1977) state that the 1976 event represents the first seismic evidence for a subduction zone in this area.

#### SEISMIC AND GEOLOGIC INFORMATION

Papers on the seismicity of the region and geological studies of the region are of great use in interpreting the historical information that has been obtained on tsunamis and to estimate future tsunamis. Of great importance are the many papers of the Rev. Miguel Saderra Masó, S.J. (1909; 1927), and the Rev. William C. Repetti, S.J. (1930; 1931a; 1931b; 1946), of the Seismological Station, Manila Central Observatory (Weather Bureau, Philippine Islands). Barazongi and Dorman (1969) plotted the epicenters of 29,553 earthquakes which occurred during the interval 1 January 1961- 31 December 1967. Earthquakes with shallow focal depths are the most important from the standpoint of the generation of tsunamis. Their Plate 3 shows the epicenters for earthquakes with focal depths between 0 and 100 kilometers.

Saderra Maso and Repetti did not assign magnitudes to earthquakes, as the techniques to do so had not yet been developed. The magnitude and focal depth have been shown to be important to the generation of tsunamis (see, for example, Iida, 1970). Gutenberg and Richter (1949) determined the magnitudes for a large number of earthquakes. A list of the earthquake dates, times, locations and magnitudes for Region 22 (Philippine Islands) is not included herein owing to space limitations. For an update on this, see Sevilla, et al. (1965), Damasco (1970), Rowlett and Lelleher (1976), Acharya (1978); also, see NOAA tapes.

Work has been done on the relationship between earthquakes and structure of the Philippines (Willis, 1944), and on the submarine morphology of the Philippines (Irving, 1951). The term "Philippine rift" was used by Irving rather than the term "Philippine fault" as being more descriptive of the situation. Irving shows instrumentally determined epicenters of Philippine earthquakes for the period 1900-1945.

Geophysical studies have been made in recent years of the region in the South China Sea off the coast of Northern and Central Luzon, specifically studies of the Manila Trench and the West Luzon Trough\* (Ludwig

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\*Murphy (1973) refers to the long West Luzon Trough as "graben-like." This paper discusses the relationship of the Manila Trench and the West Luzon Trough with the West Taiwan Foldbelt and the Philippine Trench.

Hayes and Ewing, 1967; Hayes and Ludwig, 1967; Ludwig, 1970). Ludwig, Hayes and Ewing (1967) state:

"The west wall of the trench is a remnant of the original sea floor which has been depressed. The steps in the western wall of the trench are interpreted as normal faulting and are most likely caused by extensional forces introduced in the oceanic crustal plate as it is being further depressed. The steps and perched ledges of transparent sediments, which form the foot of the west wall, attest to the downward movement and recent activity. The perched ledges indicate post-depositional subsidence and (perhaps) extension of the sea floor near the axis of the trench. This is further evidenced by eastward dipping stratified beds beneath the floor of the trench (profiles E-F and L-N), suggesting downward movement with respect to the east wall. The alternative explanation is that the perched ledges were formed by erosion; however, no direct evidence is available at present to support it."

This is in agreement with the observations of several tsunamis in which a substantial drawdown of the water occurred first, that is, a downward vertical tectonic displacement probably was the source of the tsunamis. A similar drawdown seems to occur in the large tsunamis generated in the Celebes Sea (Badillo and Astilla, 1978).

Hayes and Ludwig (1967) present a map of the earthquake hypocenters of central Luzon, the Manila Trench and the West Luzon Trough, Figure 1. In comparing the locations of the plots, one must be aware of the accuracy of the locations. Gutenberg and Richter (1949) state:

"Epicenters have in general not been determined more closely than the nearest quarter degree of latitude and longitude except for unusually favorable shocks. More accurate revision would involve considering the effect of geocentric latitude, which may amount to as much as 0.4 degree in extreme cases...."

Hayes and Ludwig (1967, p. 546) state:

"Accuracies are estimated at several tens of kilometers for good determination to  $\pm 100$  km or more for poor ones...."

Salient features of the bathymetry west of Luzon are given by Ludwig, Hayes and Ewing (1967), as are seismic reflection profiles across the Manila Trench and West Luzon Trough. Some conclusions reached by the investigators have been cited earlier in this report, in context with the possible generation of tsunamis.

For additional analyses of the tectonics of this area, see the papers by Murphy (1973) and Rowlett and Kelleher (1976). For details of studies of adjacent regions, such as the Sulu Sea, Celebes Sea, Bareda Sea and Molucca Sea, see Krause (1966) and Hamilton (1977).

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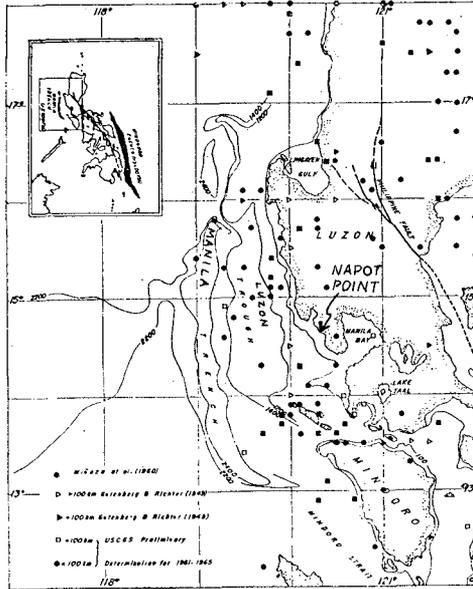


Fig. 1. Earthquake hypocenter map of central Luzon, Manila Trench—  
the area outlined on the inset of the regional geography. Location of the Philippine Fault is  
taken from ALLEN (1962). Contours in nominal fathoms.  
(From Hayes and Ludwig, 1967)

#### APPENDIX: PHILIPPINE TSUNAMIS

September 1627, northern Luzon (Repetti, 1946).

"... trees were overthrown by the terrific force of the waves of the sea, which invaded the land for a distance of a league, and in that area the land could not be seen."

\*30 November 1645, Manila (Saderra Masó, 1927).

"Of this most disastrous earthquake all the writers about the Philippines both ancient and modern give notice ... The disturbance of the Pasig River was so tremendous that its waters invaded parts of the town and even passed over the bridge."

Repetti (1940) believes the earthquake of 14 February 1934 more severe.

\*7 December 1677, S and SW Luzon (Saderra Masó, 1927 quotes Fr. Diaz):

"Some people who were navigating related the dangers of foundering that they encountered because of the high waves caused by the earthquakes, which at placed invaded the coast and flooded large inland tracks of land with great damage."

\*1744, Northern Luzon (Repetti, 1946)

"In the *Diccionario Ibanag-Español* there is mention of earthquakes under the word ALLUYU, meaning great waves ... 'The sea enters the river with great force....'"

December 1770, Manila (Repetti, 1946). The expression "the sea was agitated" that appears in Berninghausen's (1969) paper was "... a very strong south wind, which agitated the sea ..." in Repetti's paper.

\*9 November 1828, Manila (Repetti, 1946, p. 173).

"After the earthquake, the river rose to the same height that it reaches in the rainy season and inundated the lowland near its banks. The next day it fell as much below its ordinary level...."

\*18 January 1830, Manila and nearby provinces (Repetti, 1946, quoting an article in the Singapore *Chronicle* of 25 March 1830):

"...having made the best of his way to the river, he was there 'taken aback,' as the water came rushing up the steps several feet ... but the water quickly retreated, and broke upon the opposite bank with a noise resembling thunder, and then gradually subsided."

22 March 1840, Sorsogon Province (Saderra Masó, 1927, p. 91).

"A large tract of the northern shore of the bay where the town of Sorsogon is located sank five feet, the advance of the sea causing considerable material and personal loss."

Saderra Masó quotes a report of 22 February 1843 by the Governor of Albay:

"As a result of the earthquakes felt in the town of Sorsogon in March 1840 ... surely the bottom of the bay underwent a change because today boats of great draft can drop anchor where formerly small craft grounded at low tide, ... the sea submerged a great portion of the shore and the nearer houses of the water front...."

\*16 September 1852, Manila and western provinces (Saderra Masó, 1927, p. 93).

"This destructive earthquake made itself felt with violence in west Rizal and Bulacan, SW Nueva Ecija and the provinces of Cavite, Batangas, Bataan, Zambales, Tarlac and Pampanga.... A hill called Ubamba in the Subic Bay sank completely."

\*3 June 1862, South Luzon (Saderra Masó, 1927, p. 95).

"It is stated that the water in the bay receded from Manila to Cavite and returned from that direction...."

Repetti (1946), quoting works dating to 1865, states:

"... Earthquake in Manila. J. Winchester, captain of the English frigate *Caribbean* and D. Cobbs, captain of the English frigate *John Banks* describe the action in the Bay of Manila: '3 June, 7<sup>h</sup>30<sup>m</sup> p.m. we saw a wave coming on us from the SE to NW. It struck us with such force that it came over the deck which it covered completely. The frigate shook and shivered strongly as if it had struck bottom. The water boiled around the ship in strong convulsions...."

16 August 1869, Southeastern Luzon and eastern Visayan (Repetti, 1946).

"... and the sea was disturbed ... A small island, among the many at the north end of Ticao, is said to have disappeared."

\*26 January 1872, Agno, Zambales Province (Saderra Masó, 1927). Intensity VII, Rossi-Forel scale, "earthquake and tidal wave." Repetti (1946) states:

"... It is reported that the town was flooded by sea waves shortly after an earthquake and, as it is said, noises like explosions were heard, which excited and terrified the people."

14 July 1880, Luzon (Centeno & Garcia, 1883). Repetti (1946) lists this as 15 July 1880, on the east coast of Luzon, just east of Manila.

"At Quinanliman the depression had a wide extent, but was very irregular in depth: the greatest depth was four metres at the centre line DE of the submerged surface ..." (Centeno & Garcia, p. 78)

26 and 27 August 1883. Eruption of Krakatoa (Wharton, 1888), Sunda Strait between Sumatra and Java. See comments in main body of paper.

23 July 1885, near northwest coast of Mindanao (Saderra Masó, June 1909).

"These facts locate the focus of the disturbance in the sea, opposite the northwestern coast ... no mention is made of any extraordinary commotion of the sea although the observer spoken of lived in a place on the coast and describes—with almost painful attention to detail—everything abnormal which he observed during the earthquake."

5 February 1889, in the Celebes Sea (Saderra Masó, June 1909).

"At the time of this earthquake the steamer *Churruca* was underway from Zamboanga to Cotabato, passing over the very region which, according to our opinion contained the focus ... the water became turbid with mud rising from the bottom of the sea and formed whirls. No great waves could be seen from aboard the vessel, nor are such mentioned in the reports from Zamboanga and Cotabato."

21 September 1897, E and SE part of the Sulu Sea (Saderra Masó, June 1909). Details of this great event given in the main body of present paper.

"The great tsunami ... is of special interest, since it is almost the only one to be found in the seismic annals of the Philippines."

21 August 1902, northern Illana Bay, Mindanao (Saderra Masó, June 1909).

"Great fissures and landslides were caused, both on land and in the sea, the latter being proved by the fact that the cables which connected Cotabato with several military posts in southern Mindanao were broken ... a clear proof of the displacements which must have taken place on the bottom of the bay."

15 August 1918, Mag. 8¼ (G&R\*, 1949). Celebes Sea, between 124° and 125°E and 5° and 6°N (Saderra Masó, 1918, also Dec. 1918).

"Captain Malone ... reports that the earthquake ... was later followed by a tidal wave reaching as high as 24 feet at some points and at the Constabulary station at Glan to a height of 18 feet, thereby destroying all of the houses that had been shaken down by the shock and drowning a number of people ... All native vintas were either destroyed or taken out to sea .... L.B. Kidwell, who has a saw-mill at Port Lebak, reports that the tidal wave at his place was between 6 and 8

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\*G&R refers to Gutenberg and Richter.

feet, killing six people and carrying a number of logs quite a distance inland.... To the south of Port Lebak for some 40 miles there was a tidal wave variously estimated at from 20 to 25 feet."

11 November 1921, Mag. 7½, epicenter 8N, 127E (G&R, 1949). Off SE coast of Mindanao, in southern part of the Philippi-Deep (Saderra Masó, 1923).

"The most unusual effect of the second earthquake was a tide-wave which invaded the few bays with low lands there existing, Manay being the one which sustained greater loss in structures and crops. ... The tide-wave was also noticed in great Sanguir Island."

10-11 November 1922, Chile, Coquimbo earthquake (Selga, 1923). Although the earthquake epicenter was thousands of miles from the Philippines, the tsunami was recorded by the tide gage in Zamboanga. Selga (1923) states:

"... the mareogram shows that the seismic wave arrived at Zamboanga on 12th November, 1922, at 2 hours 40 min p.m. standard time of the 120th meridian east of Greenwich ... Five crests and five troughs are clearly discernible ... the period of the wave is 100 minutes, if derived from the maximums; 106 minutes if derived from the minimums..."

The tide station at Manila was not operating at the time of this tsunami.

2 March 1923, Mag. 7.2 (G&R, 1949). Berninghausen [incorrectly?] lists as 23 Feb. 1923. Mindanao, epic. 6°45'N, 123°35'E (Repetti, 1931).

"The position given by the International Summary, 6°N, 125°E, can scarcely be admitted because it is inland, and sea waves were reported as making into the Rio Grande River at Cotabato."

18 July 1923, Mambajao, Camiguin, epicenter 9°20'N, 125°E, Repetti (1931).

"Waves were observed at Mambajao, Camiguin Island, and the disturbance of the sea lasted about an hour."

14 April 1924, Mag. 8.3, epicenter 6½N, 126½E (G&R, 1949), off Pacific Coast. SE Mindanao (Saderra Masó, 1925).

"A large tract of the sea shore of Mati, at the head of the small Pujada Bay, separated from the ocean by a narrow peninsula, sunk about half a meter... The disturbance caused by shocks in the sea was not so great as the maremoto which followed the earthquake of November 1921 originated near the same coasts. On board of a steamer at anchor in the Caraga Bay, about 150 kilometers NNW of the epicenter, two sharp shocks followed by ... similar to the effect of the keel striking against a rock. The sea became suddenly and terribly rough causing in the boat such strong jerks that threatened to break the anchor chains; at the same time big waves were seen to break against the cliffs of the near coast."

Repetti (1931) states:

"Sea waves were reported from Mati and Caraga...."

\*6 May 1924, Agno, Pangasinan (Saderra Masó, 1925).

"At about midnight of the 6th of May, the town of Agno on the west coast of Luzon at 16.1°N and 119.8°E, shortly after an earthquake, was invaded by four big sea waves which flooded its low portions and caused great consternation to the people but without doing considerable material damage nor harm to persons."

30 August 1924, Mag. 7.3 (G&R, 1949), epic. 9°N, 126°40'E (Repetti, 1931).

"A sea wave was noticed at Bislig Hinatuan situated on bays whose trend is slightly more in the direction of our position."

5 May 1925, Mag. 6.75 (G&R, 1949). Southern Negros (Saderra Masó, 1926).

"Its origin lay under the sea near the south coast of Negros Island not far from 9.3°N and 122.7°E ... Moreover, only the said south coast was invaded by the waves caused by the earthquake."

25 May 1925, Mag. 6.25, epicenter 12.5°N, 122.5°E (G&R, 1949). Tablas and Romblon Islands (Saderra Masó, 1926).

"... A small earthquake wave developed and flooded some small low villages on the SE coast of Tablas. The steamer *Compeador* felt distinctly the shock while navigating SW of Romblon Island."

Repetti (1931) states:

"Sea waves observed at Tugdan in the east coast of Tablas Island."

13 November 1925, Mag. 7.3 (G&R, 1949), Philippine Deep, NE of Samar Island, near 125.5°E and 13.0°N (Saderra Masó, 1926).

"... cracks opened and the low shores were flooded by the waves caused by the earthquake; many fishermen lost their fishing boats and several were drowned. Numerous native houses on this and on Laoang Island were destroyed. On the coast of Samar not only native houses but ... more substantial constructions suffered considerable damage."

Repetti (1931) states:

"Sea waves were observed along the north coast of Samar."

19 December 1928, Cotabato, Mindanao, Mag. 7.3, epic. 7°N, 124°E (G&R, 1949). Seismological Dispatches (Georgetown Univ., Dec. 1928) state:

"MANILA, P.I., Dec. 24, 1928. Rocked by an earthquake, and swept by a tidal wave, Cotabato, capital of Mindanao Province, was practically destroyed on Wednesday night."

28 December 1928, Cotabato, Mindanao, Mag. 6.9; epicenter 7.5°N, 123°E (G&R, 1949). Not listed by Repetti (1931a,b). Berninghausen (1969):

"Destructive earthquake reported ... Wave probably struck the coast near Cotabato which is inland (Georgetown Univ., 1926)."

The reference (1926) must be wrong and is (1928) instead, and no mention of tsunami waves is given in the original reference. The statement of Berninghausen seems to apply to the earthquake of 19 December 1928.

13 June 1929, Mag. 7.2 (G&R, 1949), Hinatuan earthquake, epicenter over western slope of the Mindanao Deep, 8°20'N, 126°53'E (Repetti, 1930).

"Thousands of dead fish of all kinds and all sizes, up to 30 inches, were seen floating in the ocean and case up on shore. They had evidently been killed by the concussion of the shocks.... A small sea-wave came in." (NOTE: Hinatuan, due west of the epicenter.)

\*14 February 1934, Mag. 7.6 (G&R, 1949). China Sea off west coast of Luzon, epicenter 17°20'N, 119°20'E (Repetti, 1934).

"At San Esteban the first movement of the sea was reported to have been a recession, and to such a noticeable extent that the people hurried out on the exposed shore to gather fish which had been left stranded. Some persons narrowly escaped drowning when the water returned.... We can not be certain that the entire reported change of depth occurred suddenly. The changes in sea bottom conditions as given in the various reports of the cable ship and the shocks felt while repairing the cable suggest that the cable break of March 2nd was due to slumping set up by the earthquake of February 14th."

Repetti (1940) makes the following very important statement:

"The earthquake of particular interest in this present series is that of February 14, 1934, at 3:59:35 G.M.T. The records of this earthquake obtained throughout the world show that it was the strongest earthquake in the Philippines of which we have definite evidence. The famous Manila earthquakes of 1645, 1658, 1863, and 1880 were far more destructive but we are of the opinion that the destructive was due to a very great extent to the type of weakness of construction and deterioration, thus giving an exaggerated estimate of the severity of the earthquakes."

26 November 1934, Mag. 6.25 (G&R, 1949), China Sea, 50 km off Manila Bay entrance, epicenter  $14^{\circ}10'N$ ,  $120^{\circ}10'E$  (Repetti, 1934). An article appeared in the *Philippine Times*, 14 November 1934. This event is listed herein owing to its location and because no sea waves were mentioned. See also: *Annual Report of the Philippine Weather Bureau: Fiscal Year 1951/52*, p. 18.

20 August 1937, Mag. 7.5, epicenter  $14.5N$ ,  $121.5E$ , (G&R, 1949), Alabat Island earthquake, off east coast of Luzon (Repetti, 1938).

"The water is said to have risen at the town of Queson at the south end of Alabat Island. This town is practically on Calauag Bay at the head of which there was a rise in the sea level. The people of the town of Calauag at the head of the bay reported that the water rose from low to high tide level in the space of ten minutes."

23 May 1938, Luzon; epicenter, China Sea (Repetti, 1938). No mention of waves.

24 January 1948, Iloilo Strait near southwest coast of Panay,  $11^{\circ}N$ ,  $122^{\circ}E$ , Richter Mag. 8.2 (Murphy and Ulrich, 1951a, p. 29).

"2 killed by tidal wave in Iloilo Strait."

\*29 December 1949, N. Luzon,  $M_s$  7.2, epicenter  $17^{\circ}30'N$ ,  $121^{\circ}30'E$ . (Murphy and Ulrich, 1951b, p. 47).

"Heavy property damage along northwest coast of Isabela Province and minor damage in Manila. One death from sea wave near Mercedes."

19 March 1952, Butuan, epicenter in Mindanao Sea about 50 km NNW of Butuan City (Weather Bureau, Geophysical Division, 1952). Murphy and Cloud (1954) state:

"The earthquake ... created sea waves that were recorded as waves only one-fourth foot at Yap Island and Apra Harbor and Tarague, Guam. A gage on Angaur Island, Palau I., showed a maximum oscillation of 2.2 feet."

24 May 1960, Chile. Although the earthquake epicenter was thousands of miles from the Philippines, tsunamis were experienced in the islands.

"... 'tsunamis' of slight magnitudes struck the eastern Coasts of the Philippines in the early morning (from 6:30 to 8:30 a.m.) of May 24, 1960. These waves, which brought the sea level from 2 to 8 feet higher than normal tide level, caused some damage to some towns situated near open bays along these coasts...."

31 March 1962, Antique earthquake (Philippine Weather Bureau, 1962).

"... generated a freak tidal wave that hit the coast of Dao ... the wave was caused by a vertical displacement at the epicenter region about five kilometers from the coast of Dao along a line of weakness running north to south from Marinduque to Zamboanga."

1 August 1968, Luzon, epicenter 16.5°N, 122.2°E (Coffman and Cloud, 1970).

"... generated a minor tsunami that was reported to have an amplitude of 6 to 8 centimeters in the Ryuku Islands... Honolulu, 0.1 foot; Attu, 0.3 foot; Wake Island, 0.3 foot; and Guam, 0.1 foot."

Also listed in the *Newsletter*, International Tsunami Information Center, (June 1980):

"Thus far in 1970 one tsunami has been reported to ITIC. The 12 07 08.6 GMT 10 January 1970 earthquake,  $M_s$  7.5, in Mindanao [P.I.] generated a weak tsunami that was recorded at the Malakal, Palau I., Caroline Islands Tide Station with a height of 0.06 m."

7 April 1970, Luzon east coast. Mag 7.3; epicenter 15.8°N, 121.7°E, (International Tsunami Information Center, June 1970):

"... The April 9, 1970 issue of the Manila Times Newspaper quoted observers near Dingalan Bay thus: 'Then the bay water line receded as far as 70 meters out into the ocean' ... 'And then the sea came surging inland, swamping huts built on the shore. He described the incoming waves as taller than a man.' ... ITIC has not received any marigraphic records to show that this event was other than local..."

31 October 1975, NE of Samar Island, Mag. 7.4 Richter scale (International Tsunami Information Center, 1975).

"... A tsunami was generated, and registered a maximum wave height of 10 cm at the Okinawa gage, 6 cm at Yap, and 6 cm at Wake Island. ITIC has received no reports to this date of wave heights or impact on the adjacent Philippine Islands coast."

U. S. Department of Commerce, NOAA (1875, p. 116) state:

"Generated a tsunami that killed one person and swept away about 30 houses on the east coast of Samar Island."

17 August 1976, (16 August GMT time), Moro Gulf (06.26°N, 124.02°E, Earthquake Mag. 7.9 or 8.0  $M_s$ ). A major local tsunami. Details not presented here, as they have been presented in the body of the paper.

14 January 1978, Panay, Philippines, 8.8°N, 122.4°E, (International Tsunami Information Center, June 1979).

"Slight tsunami activity recorded at Jolo Island, Philippines."