Tsunami Catalog and Zones in Indonesia

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Tsunami Catalog and Zones in Indonesia

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ABSTRACT

Based on data compiled during the period 1600–1999, 105 tsunami have occurred in Indonesia. Ninety-five events (90%) of them were caused by earthquakes in a shallow region at subduction and plate boundaries, 9 (8%) by volcanic eruption, and one (1%) by a landslide. To clarify the regional characteristics of tsunami, we defined 6 zones; West and East Sunda, Banda, Makassar, Molucca and Irian Jaya, and made the histograms of earthquakes and tsunami by region by decade from 1600 to 1999. Seismic activities were found in East Sunda, Banda and Makassar are high and tsunami activities in West Sunda, Banda, and Molucca. An interval of about 100 years was found for high earthquake and tsunami activities in the period 1800–1999. The percentages of earthquakes accompanied by tsunami to all earthquakes in Banda and Molucca exceed 50%. In terms of human loss due to tsunami, West Sunda is the worst zone because of the devastating damage done by the 1883 Karakatau volcanic eruption. The tsunami potentials in Banda and Molucca in terms of both frequency and damage are very high. Tsunami activity in Banda since 1960 has been remarkably high.

1. INTRODUCTION

The Indonesian region and surrounding area have very complicated plate-convergences consisting of subduction, collision, back-arc thrusting and back-arc. As a result of this complexity, the region is considered one of the most tectonically active areas in the world. At least 460 earthquakes of magnitudes $M > 4.0$ have occurred every year (Ibrahim et al., 1989). Most historical large earthquakes in Indonesia have caused extensive damage and fatalities as reported by Utsu (1992) and Fauzi (1999). In addition to high seismic activity in the subducting zones, the Indonesian archipelago is characterized by high volcanic activity. Seventy-six volcanoes have erupted up to the present time (Kusumadinata, 1979).

Many of the major earthquakes in a shallow region under the sea have generated large tsunami that killed thousands of people. Eruptions of submarine volcanoes also have caused tsunami, typical example being the one generated by the 1883 Krakatau eruption in the Sunda strait, the most worst disaster caused by tsunami in recent centuries, which killed about 36,000 people.

Although tsunami has frequently attacked the Indonesian region, their nature mechanism, and regional characteristics are not well known. Furthermore, the frequency and regularity of tsunamigenic earthquakes/volcanoes needs further investigation. We have cataloged historical tsunami in Indonesia from 1600 to 1998 by compiling data from several sources. Their zones are determined in order to discuss regional frequency and characteristics.

2. TECTONICS SETTING AND ITS SEISMICITY

The complexity of the tectonics and plate boundaries, in the Indonesia and the surrounding area is shown in Fig. 1. The Indonesian archipelago is located along on complex convergence of the Eurasian, India-Australian, Caroline, and Philippine Sea plates and several minor ones. These plates have been moving relative to each other in a complicated manner (Hamilton, 1979). Typical plate motion can be summarized as follows: The relative motion of the Eurasian plate to the India-Australian one is approximately northward, whereas that of the Philippine Sea plate is approximately west by northwest. The Philippine Sea plate relative to the Caroline one is moving approximately east by southeast near the Aru trench and west by northwest

KEY WORDS: Tsunami, earthquake, seismicity, volcano, catalog, zoning

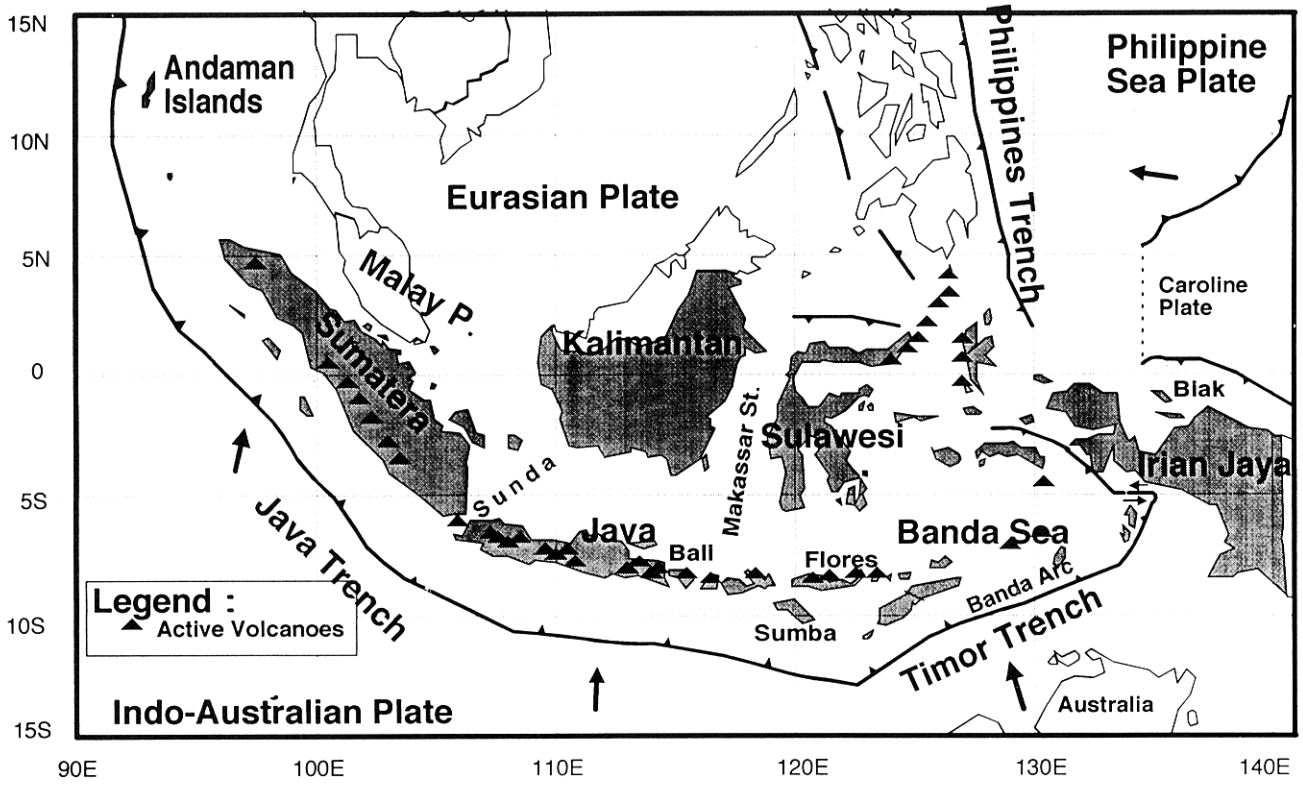

Fig. 1 Tectonics and plate boundaries in Indonesia. Large arrows indicate the direction of plate motion, triangles active volcanoes.

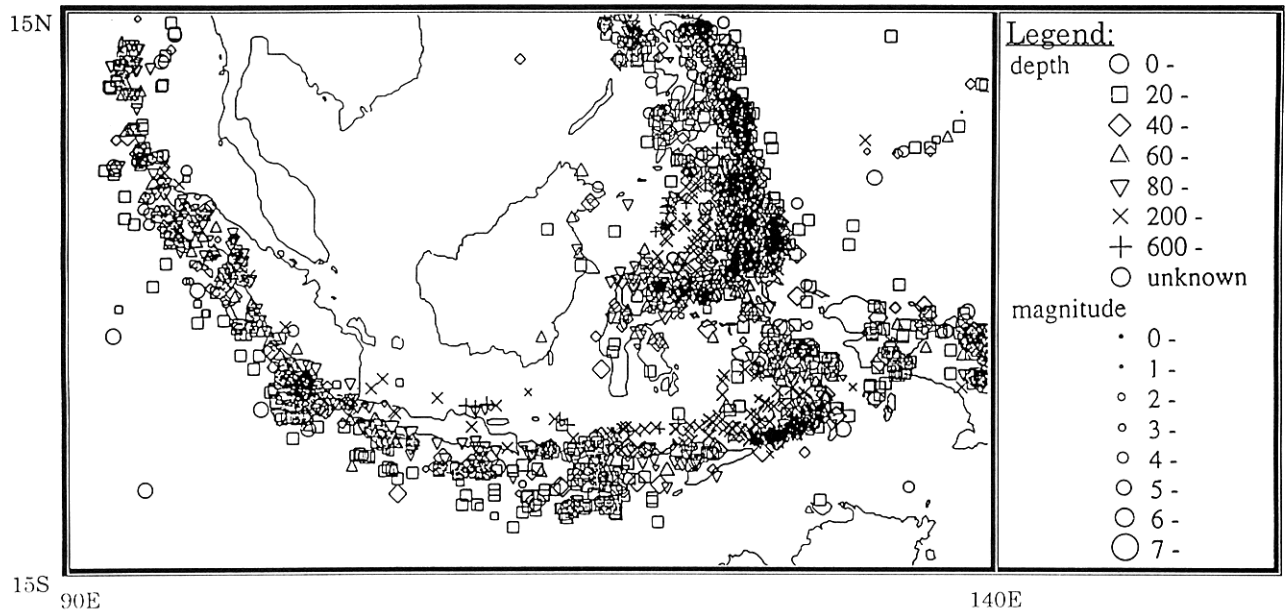

Fig. 2 Seismicity map of the Indonesian region (after Puspito, 1996). Data from ISC (International Seismological Center) for the period 1984 to 1993, including 2,738 earthquakes.

near the Yap trench.

The Indonesian archipelago consists of five active island arcs (Hamilton, 1979; Puspito, 1993;Puspito & Shimazaki, 1995); the Sunda, Banda, Sangihe, Halmahera, and North Sulawesi arcs. The Sunda arc which resulted from the convergence of the Indian Ocean and Eurasian plates extends westward from Sumba through Java, Sumatra and the Andaman Islands. In the east Sunda arc, Banda arc extends eastward from Sumba passing the Tanimbar Islands, then curving sharply counter-clockwise trending a westward in the island of Ceram and Buru. The Banda arc resulted from the collision of the southeastern part of the Eurasian and Australian plates. To

the northern part of this arc, the Sangihe and Halmahera arcs in the Molluca Sea region were caused by the activities of two opposing subductions of the Molucca Sea plate, simultaneous subduction eastward beneath the Sangihe and westward below the Halmahera.

As a result of this complicated plate-convergence, the Indonesian region has very high seismic activity. Figure 2 shows a seismicity map of the region based on ISC (International Seismological Center) data (Puspito, 1996). The map shows that most shallow earthquakes have been located along plate boundaries, but that the maximum depth of seismicity varies. Along the Sunda arc the deepest seismicity changes abruptly near the Sunda Strait (which separates Sumatra from Java).Earthquakes in the northwest of the Sunda Strait do not exceed a depth of 250 km, whereas the of that stait the maximum depth is 650 km with a gap in seismicity between 300 to 500 km. In the Banda Sea, the Benioff-Wadati seismic zone is a basin-shaped zone that plunges gently westward to a depth of about 650 km. In the Molucca Sea region the Benioff-Wadati seismic zone dips westward to a depth of 650 km beneath Sangihe, and another zone dips eastward to a depth of 250 km below Halmahera.

Taking into consideration the above tectonics, the Indonesian region is divisible into 6 zones (shown in Fig. 2).

- Zone-A: The West Sunda arc includes the northwest Sunda Strait; i.e., Sumatra and the Andaman Islands.
- Zone-B: The East Sunda arc includes the area in the region in the East Sunda Strait to Sumba; i.e., Java, Bali, Lombok, Sumbawa, and Sumba
- Zone-C: The Banda arc covers the are of the Banda Sea; i.e., Flores, the Timor and Banda Islands, the Tanimbar Islands, and Ceram and Buru.
- Zone-D: The Makassar Strait.
- Zona-E: The Molucca Sea, Sangihe and Halmahera
- Zone-F: The North Irian Jaya.

3. TSUNAMI CATALOG IN RELATION TO EARTHQUAKES AND VOLCANOES

3.1 Earthquakes

In Indonesia, about 460 earthquakes of magnitudes greater than 4.0 have occurred every year. The percentages of earthquakes at shallow, intermediate, and deep depths respectively are 61%, 34%, and 5% (Ibrahim et al., 1989). Most earthquakes occure beneath the sea along the seismic zones shown in Fig. 2. Many of the large shallow earthquakes in the Indonesian region, both the inter-plate and intra-plate types, have caused severe damage and killed thousands of people. A list of the destructive earthquakes that occurred in the Indonesian region from 1800 to 1998 is given in Table 1. The table is compiled from Arnold (1985), Ibrahim et al. (1989), Utsu(1992) and Fauzi(1999) and plus recent earthquake data. During the period of tabulation, at least 183 destructive earthquakes occurred which killed an estimated 11,000 people. The number of destructive earthquakes and the fatalities suffered are shown.

3.2 Tsunami

The historical tsunami data for the Indonesia from 1600 to 1992 compiled from a catalog of destructive earthquakes in the world published by Utsu (1992) is cross checked with data collected by Berninghausen (1966, 1969), Cox (1970), Arnold (1985) and Ismail (1989). In addition, data compiled added have been added. A list of tsunami that occurred in the Indonesian region from 1600 to 1998 is given in Table 2. It shows that 105 tsunami have struck the region, of which 95 have been generated by earthquakes, 9 by volcanic eruptions, and 1 by a landslide. These tsunami have caused many injures and the deaths of killed about 54,100 people. Table 2 gives the number of tsunami and fatalities by zone. The tsunamigenic earthquake locations are shown by a solid circles in Fig. 4.

Data for the years before 1970 were not well reported, whereas, recent tsunami such as *the* 1992 *Flores*, 1994 *East Java*, 1995 *East Timor*,1996 *Sulawesi*, and 1996 *Irian Jaya tsunamis*, which were investigated by an International Tsunami Survey Team have been well surveyed (Tek et al., 1993; Synolakis et al., 1995; Tsuji et al., 1995a and 1995b; Efim et al., 1997; Imamura et al., 1997).

3.3 Volcanoes

As a result of subducting and tectonic processes, the Indonesia has very high volcanic activities (Fig. 1). Most of Indonesian's volcanoes are in the Sunda-Banda arc, a 3,000-km-long line of volcanoes, extending from northern Sumatra to the Banda Sea. These volcanoes are the resulte of subduction of the Ind-Australian plate beneath the Eurasian

Table 1 Destructive earthquakes activity around Indonesia

Zone	Region	Number of disastrous earthquakes	Percentage of occurrences	Number of fatalities	Percentage of fatalities
A	Western Sunda arc	35	19.1 %	716	6.7 %
B	Eastern Sunda arc	82	44.8 %	2502	24.9 %
C	Banda arc	20	10.9 %	285	2.7 %
D	Makassar Strait	10	5.5 %	2	0.0 %
E	Molucca Sea	23	12.6 %	340	3.2 %
F	Northern Irian Jaya	13	7.1 %	6,738	63.2 %
Total		183	100 %	10,663	100 %

Table 2 Tsunami activity around Indonesia

Zone	Region	Number of tsunami	Percentage of occurrences	Number of fatalities	Percentage of fatalities
A	Western Sunda arc	16	15.3 %	36,360	67.7 %
B	Eastern Sunda arc	10	9.5 %	3,261	6.0 %
C	Banda arc	35	32.3 %	5,570	10.3 %
D	Makassar Strait	9	8.6 %	1,023	1.9 %
E	Molucca Sea	32	30.8 %	7,576	13.9 %
F	Northern Irian Jaya	3	2.9 %	357	0.7 %
Total		105	100 %	54,147	100 %

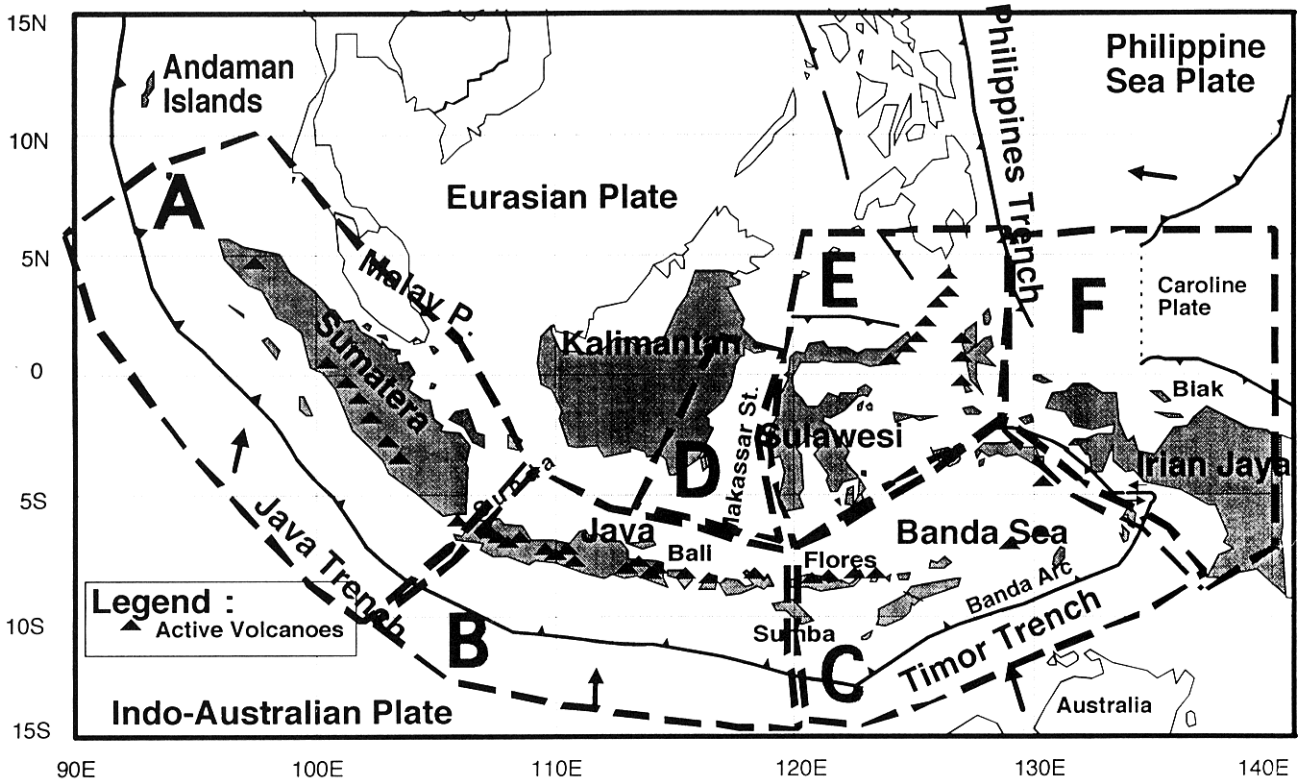

Fig. 3 Seismotectonics of 6 Indonesian zones (Zones-A, B, C, D, E, and F). Dotted lines show the boundaries of each zone.

Table 3 Volcanic generated tsunami

Volcano Name	Location	Coordinates	Zone	Eruption (year)	Fatalities (human)
G. Krakatau	Sunda Strait	5.8S 106.3E	A	1883 1928	36,000 -
G. Tambora	Sumbawa	-	B	1815	-
G. Rokatinda	Flores	8.6S 121.7E 8.4S 121.7E	C C	1927 1928	226 -
G. Ruang	Sangir Island	2.2U 125.4E	E	1889	-
G. Awu	Sangir Island	3.5U 125.5E	E	1856 1892	3,000 -
G. Gamalama	North Mollucas	0.0 128.0E	E	1871	4,000
Total				9 events	43,226

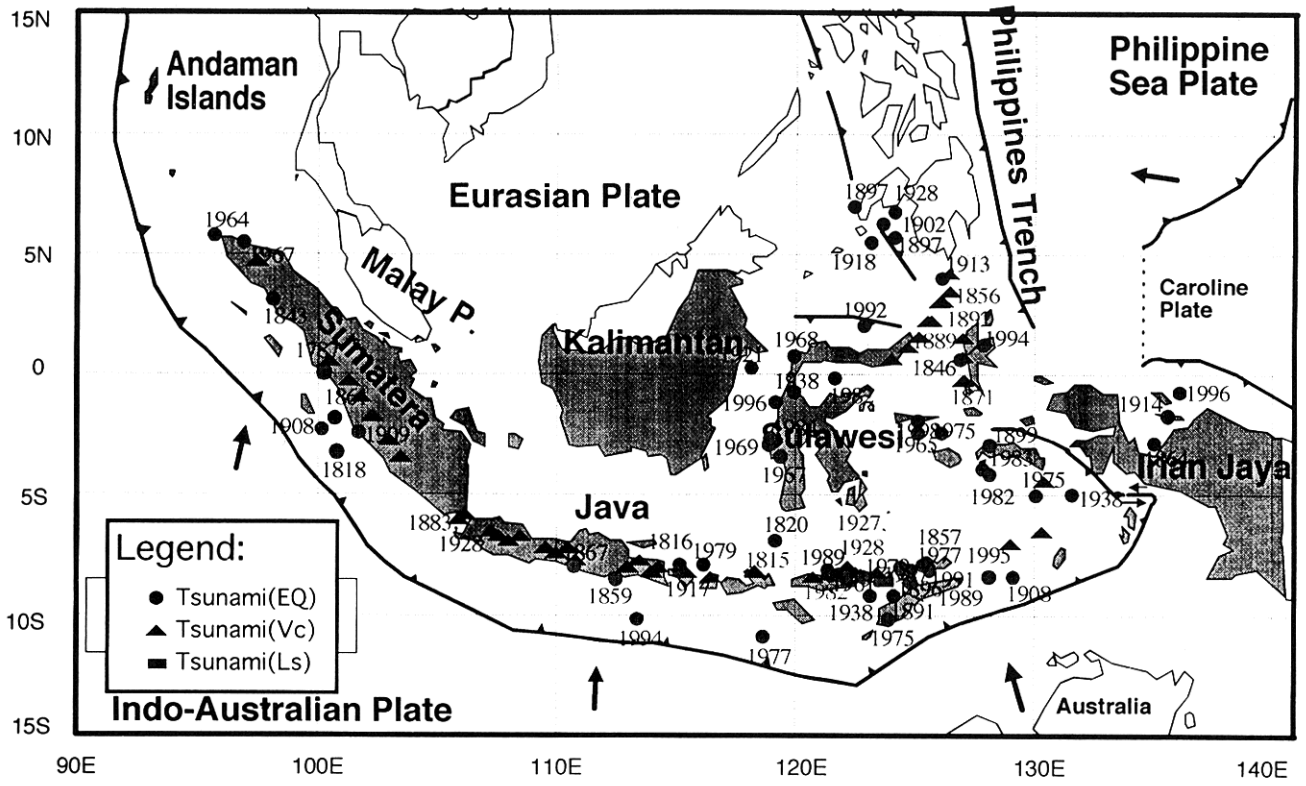

Fig. 4 Location of tsunami and year of their occurrence. Solid circles, triangles and a square respectively indicate tsunamigenic earthquakes, volcanoes and a landslides.

plate. About one-fourth of them are located in the north of the Sunda-Banda arc where there is complex tectonics. The volcanoes at Sulawesi, Halmahera, and Sangihe in the Molucca Sea are products of the Molucca Sea plate boundary which is simultaneously subducting westward beneath Sangihe and eastward beneath Halmahera (Hamilton, 1979; Puspito, 1993).

The Indonesia has 76 volcanoes that have erupted in historical times, the largest number of all the world's volcanic regions (Kusumadinate, 1979). These volcanoes have erupted about 1,170 times placing Indonesia second in the number of eruptions. Volcanoes have the potential to generate tsunami are listed in Table 3. At least 9 tsunami generated by volcanic eruptions occurred between 1600 and 1998, (see Table 3). These volcanic tsunami are indicated by triangles in Fig. 4.

These tsunami have caused the deaths of about 43,200 people. The largest in terms of magnitude and damage was the tsunami generated by the 1883 Krakatau eruption in the Sunda Strait. It claimed about 36,000 victims and is considered to have been the worst tsunami disaster in recent centuries. Krakatau had a long history of eruption: Caldera collapse about 416 AD destroyed the ancient Krakatau shape forming a caldera 7 km wide. Remnants of this volcano formed the Verlaten and Lang Islands, and subsequently the Rakata, Danan and Perbuwatan volcanoes, coalescing to create the pre-1883 Krakatau Island. The caldera collapse during the catastrophic eruption of 1883 destroyed the Danan and Perbuwatan volcanoes and left only a remnant of the Rakata volcano. The post-collapse cone of Anak Krakatau (meaning the child of Krakatau) that formed inside the 1883 caldera and has frequently erupted since 1928 (Simskin and Fiske, 1983).

4. TSUNAMI GENERATION AND ZONES IN INDONESIA

Tsunami are generated by several kinds of geophysical phenomena; earthquakes, volcanoes, landslides, debris flows. In Indonesia, earthquakes are considered the primary source of tsunami generation. Table 4 is a tabulation of the destructive earthquakes that occurred during between 1800 and 1999 and of the tsunami caused by earthquakes between 1600 and 1999 by zone and by decade. Two hundred seventy-eight large earthquakes occurred during those years, 95 (34%) of which were followed by tsunami. Table 5 gives the number of tsunami caused by earthquakes and other phenomena by zone and by decade. The percentage generated by earthquakes is about 90% of the total number of tsunami in Indonesia.

To clarify the frequency and regularity of tsunamigenic earthquakes in time and space, the compiled data has been plotted by zone and by decade. Figure 6 shows the number of destructive earthquakes by zone and by decade and Fig.7 the number of tsunami cuased by earthquakes, volcanic eruptions, and landslides by zone and by decade. Tsunami and destructive earthquakes occurrence are described and discussed by zone in the following sections.

4.1 Zone A: West Sunda arc

The west Sunda arc is the region in the northwest Sunda Strait; the Sumatra and Andaman Islands in Fig. 3. Figure 2 shows the seismicity, which in this region is controlled by

Table 4 Destructive earthquakes and tsunami caused by earthquakes by zone and by decade.

	Zone-A		Zone-B		Zone-C		Zone-D		Zone-E		Zone-F		All-Zone	
Year	TS	EQ	TS	EQ	TS	EQ	TS	EQ	TS	EQ	TS	EQ	TS	EQ
1600-1609														
1610-1619														
1620-1629					1								1	
1630-1639					1								1	
1640-1649					1								1	
1650-1659									1				1	
1660-1669														
1670-1679					2				2				4	
1680-1689														
1690-1699														
1700-1709									1				1	
1710-1719					1				1				2	
1720-1729														
1730-1739														
1740-1749														
1750-1759									2				2	
1760-1769									1				1	
1770-1779									1				1	
1780-1789														
1790-1799	2												2	
1800-1809					1								1	
1810-1819	1		1		1								3	
1820-1829		1					1	1					1	2
1830-1839	1	2		4		1				1			1	8
1840-1849	1			3	2				1	1			4	4
1850-1859		1	1	5	3	1			5	4			9	11
1860-1869	3	1	3	7		1				1	1	1	7	11
1870-1879		3		5		1								9
1880-1889				1										1
1890-1899		1		5	2	3			3				5	9
1900-1909	4	1		3	1	1		1	1				6	6
1910-1919		1	1	5		1			2		1		4	7
1920-1929		2		5		1	2	3	1	2		1	3	14
1930-1939		8		7	2	2	1	1		4			3	22
1940-1949		1		1				1						3
1950-1959				3										3
1960-1969	2	3		7	1	1	3		1	1			7	12
1970-1979		5	2	12	4	1		1	1	1		6	7	26
1980-1989		2		6	6	5	1	2	1	5		5	8	25
1990-1999		3	1	3	3	1	1		3	3	1		9	10
Total-1	14	35	9	82	32	20	9	10	28	23	3	13	95	183
Percentages of Total-1	14.7%	19.1%	9.5%	44.8%	33.7%	10.9%	9.5%	5.5%	29.5%	12.6%	3.2%	7.1%	100%	100%
Total-2 (TS+EQ)	49		91		52		19		51		16		278	
Percentages of Total-2	17.6%		32.7%		18.7%		6.8%		18.3%		5.8%		100%	

EQ = Destructive earthquakes in the period 1800 to 1999

TS = Tsunami due to earthquakes in the period 1600 to 1999

Table 5 Tsunami caused by the earthquakes, volcanoes, and landslides by zone and by decade.

	Zone-A		Zone-B		Zone-C			Zone-D		Zone-E		Zone-F		All-Zone		
Year	TE	TV	TE	TV	TE	TV	TL	TE	TV	TE	TV	TE	TV	TE	TV	TL
1600-1609																
1610-1619																
1620-1629					1									1		
1630-1639					1									1		
1640-1649					1									1		
1650-1659										1				1		
1660-1669																
1670-1679					2					2				4		
1680-1689																
1690-1699																
1700-1709										1				1		
1710-1719					1					1				2		
1720-1729																
1730-1739																
1740-1749																
1750-1759										2				2		
1760-1769										1				1		
1770-1779										1				1		
1780-1789																
1790-1799	2													2		
1800-1809					1									1		
1810-1819	1		1	1	1									3	1	
1820-1829								1						1		
1830-1839	1													1		
1840-1849	1				2					1				4		
1850-1859			1		3					5	1			9	1	
1860-1869	3		3									1		7		
1870-1879											1				1	
1880-1889		1									1				2	
1890-1899					2					3	1			5	1	
1900-1909	4				1					1				6		
1910 1919			1							2		1		4		
1920-1929		1				2		2		1				3	3	
1930-1939					2			1						3		
1940-1949																
1950 1959																
1960-1969	2				1			3		1				7		
1970-1979			2		4		1			1				7		1
1980-1989					6			1		1				8		
1990-1999			1		3			1		3		1		9		
Total-1	14	2	9	1	32	2	1	9	0	28	4	3	0	95	9	1
Percentages of Total-1	14.7 %	22.2 %	9.5 %	11.1 %	33.7 %	22.2 %	100 %	9.5 %	0.0 %	29.5 %	44.4 %	3.2 %	0.0 %	100 %	100 %	100 %
Total-2 (TE+TV+TL)	16		10		35			9		32		3		105		
Percentages of Total-2	15.2 %		9.5 %		33.3 %			8.6 %		30.5 %		2.9 %		100 %		

In July 19, 1979 there was one tsunami caused by a landslide (TL) at Lomblen, in Zone-C

TE=Tsunami due to Earthquakes

TV=Tsunami due to Volcanoes

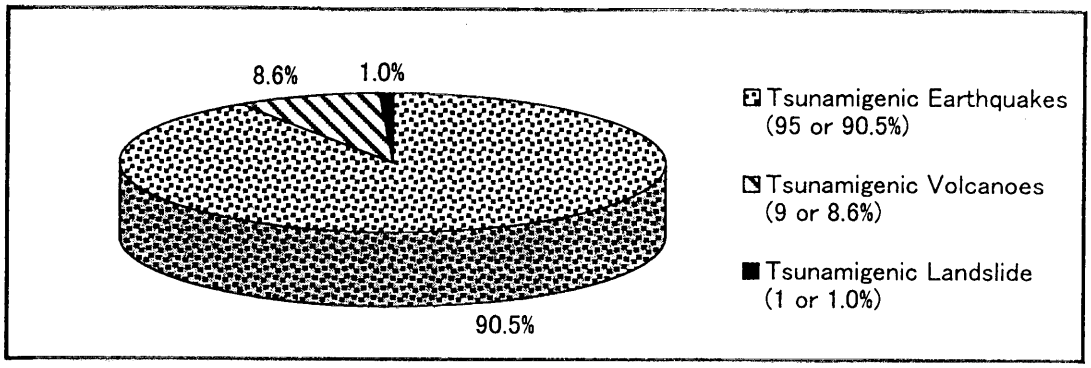

Fig. 5 Percentages of tsunami caused by earthquakes (EQ), volcanoes (VC) and landslides (LS).

the activities of two tectonic elements; (i) subduction of the Indian Ocean plate beneath the Eurasian plate, and (ii) the great Sumatra fault located in Sumatra from its southernmost part near the Sunda Strait to its northernmost part near the Andaman Islands. From 1800 to 1998, 35 destructive earthquakes occurred in this arc (Table 1), about 19% of the total number of destructive earthquakes that took place in Indonesia. Recent destructive earthquakes in the region were the 1994 Liwa (M = 6.8) and 1995 Kerinci (M = 7.0) earthquakes caused by activity of the great Sumatra fault. From this data, the average interval of the occurrence of a destructive earthquakes is estimated to be about 5 – 6 years.

Tables 2 and 5 show that 16 tsunami occurred in zone A (west Sunda arc) between 1600 and 1999, about 15% of the total number of tsunami generated. Fourteen tsunami were generated by earthquake, and 2 by volcanic eruptions. Thirteen of the 14 tsunami earthquakes -generated were reported or observed on the Indian Ocean side of coastal Sumatra. The other was in the Malaca Strait at the tip of northeastern Sumatera (*the* 1967 *Sigli Tsunami*). Therefore, these earthquakes can be considered mainly results of the subduction of the Indian Ocean plate beneath the Eurasian plate. This type of earthquake, which usually is characterized by a thrusting fault mechanism, has marked potential for generating tsunami. The two volcanic tsunami were generated by the eruptions of Krakatau in 1883 and 1928 (Tables 3). The 16 tsunami in zone A (west Sunda arc) killed about 36,360 people. The greatest number of fatalities was caused *by the Krakatau tsunami* of 1883 with the highest recorded run-up of 36 m. The number of tsunami in Fig. 7 is not sufficient to estimate the average frequency for the period 1600 to 1999, but in the period 1790 to 1998, 14 tsunamis generated by earthquakes in the region were reported. Based onthis number, the average interval between seismic tsunami is estimated to be about 15 years.

4.2 Zone B: East Sunda arc

This arc covers the region from the eastern part of the Sunda Strait to Sumba (see Fig. 3). Eighty-two destructive earthquakes have been reported in this zone (Table 1), about 45% of the total number reported destructive earthquakes. The seismicity in zone B (east Sunda arc) mainly is controlled by the action of the Indian Ocean plate subducting beneath the Eurasian plate. The seismicity depth reaches about 650 km with a gap in seismicity between 300 to 500 km (Fig. 2). Destructive earthquakes in zone have killed at least 2,502 people. The most recent destructive earthquake was the 1998 East Java earthquake (M = 6.5) which killed 4 people in Malang in the east of Java. Figure 5 shows that from 1800 to 1998 there were 82 destructive earthquakes in this region. The average interval is estimated to be about 2 – 3 years, indicating extremely high activity.

Then tsunami occurred in zone B (see Table 2), about 10% of the total number reported in Indonesia. Nine tsunami generated by earthquakes and one by volcanic eruption. The two types of earthquakes that generated tsunami in this region are subduction and back-arc thrusting earthquakes. The subduction earthquakes that generated tsunami had one of two mechanisms, thrusting fault (e.g., *the* 1994 *East Java Tsunami*) or normal (e.g., *the* 1977 *Sumba Tsunami*) fault mechanism (Puspito, 1996) . The back-arc-thrusting zone lies east-west in the north of the Bali-Lombok-Sumbawa Islands. The one volcanic tsunami was generated by the eruptions of Tambora in 1915 (see Tables 3). The last tsunami was *the* 1994 *East Java Tsunami* (Moment magnitude $M_w = 7.6$) that killed 238 people. Totally, tsunami that occurred in zone B killed 3,261 people. The average interval between tsunami is estimated to be about 10 – 15 years.

4.3 Zone C: Banda arc

This arc is located in the areaof the Banda Sea, and Flores, Timor, Tanimbar, Ceram and Buru islands (Fig. 3). The seismicity in this region mainly is caused by the subduction or collision of the Australian plate beneath the southeastern part of the Eurasian plate. There has been 20 destructive earthquakes in this region (Table 1), about 11 % of the total reported in Indonesia. Totally, destructive earthquakes that have occurred in zone C have killed at least 285 people. The average interval between destructive earthquakes is estimated to be about 9 – 10 years.

The Banda arc sea area is the most tsunami active region. Thirty-four tsunami occurred between 1600 and 1998 (Table 2), which is about 33 % of the total number. Thirty-two tsunami were generated by earthquakes associated with activities of the Banda subduction zone, 2 by volcanoes and 1 by a landslide. Shallow earthquakes usually are related to thrusting fault mechanism, except in the northern part of the Banda arc

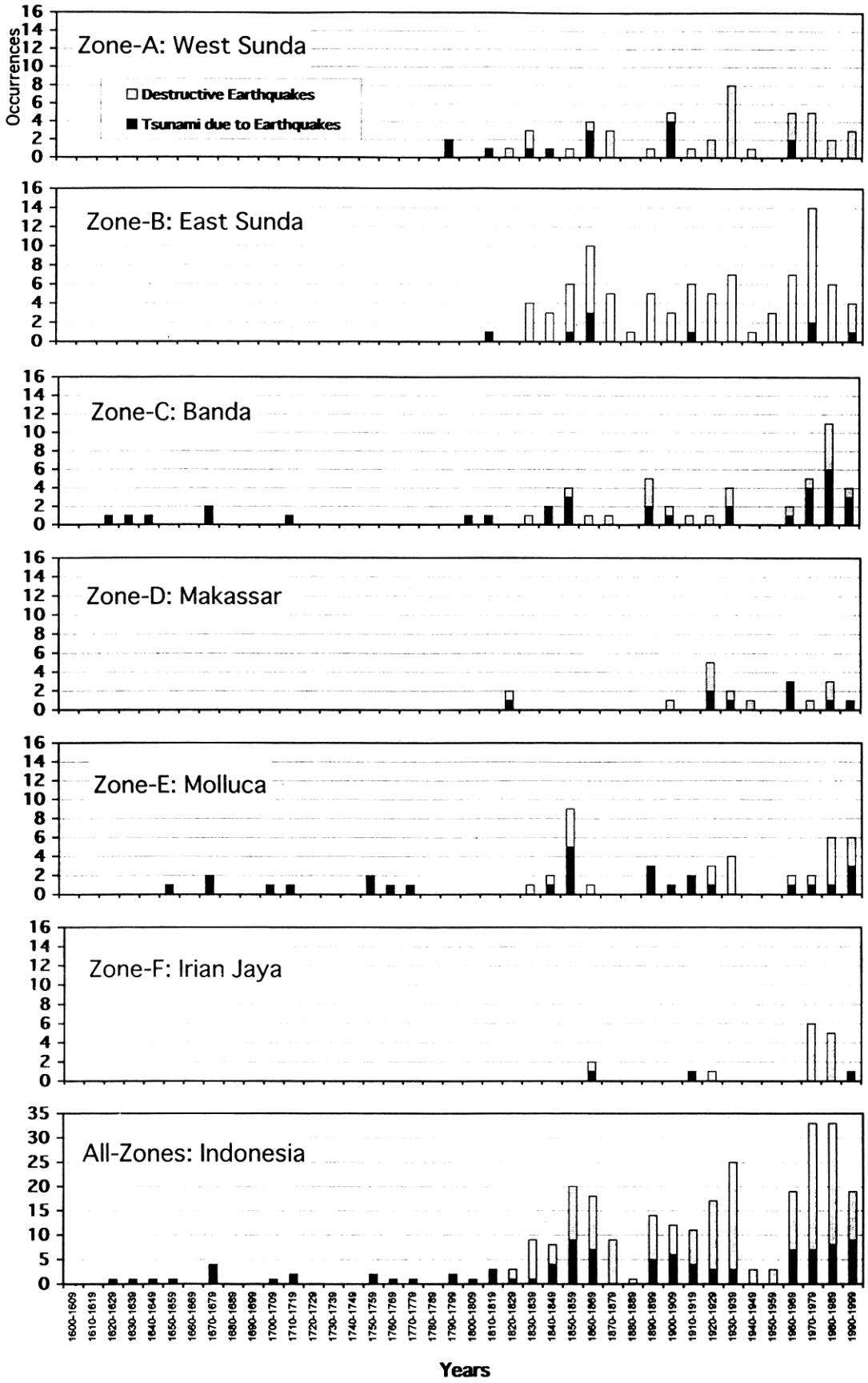

Fig. 6 Histogram of destructive earthquakes (1800–1999) and tsunami caused by earthquakes (1600–1999) by zone and by decade.

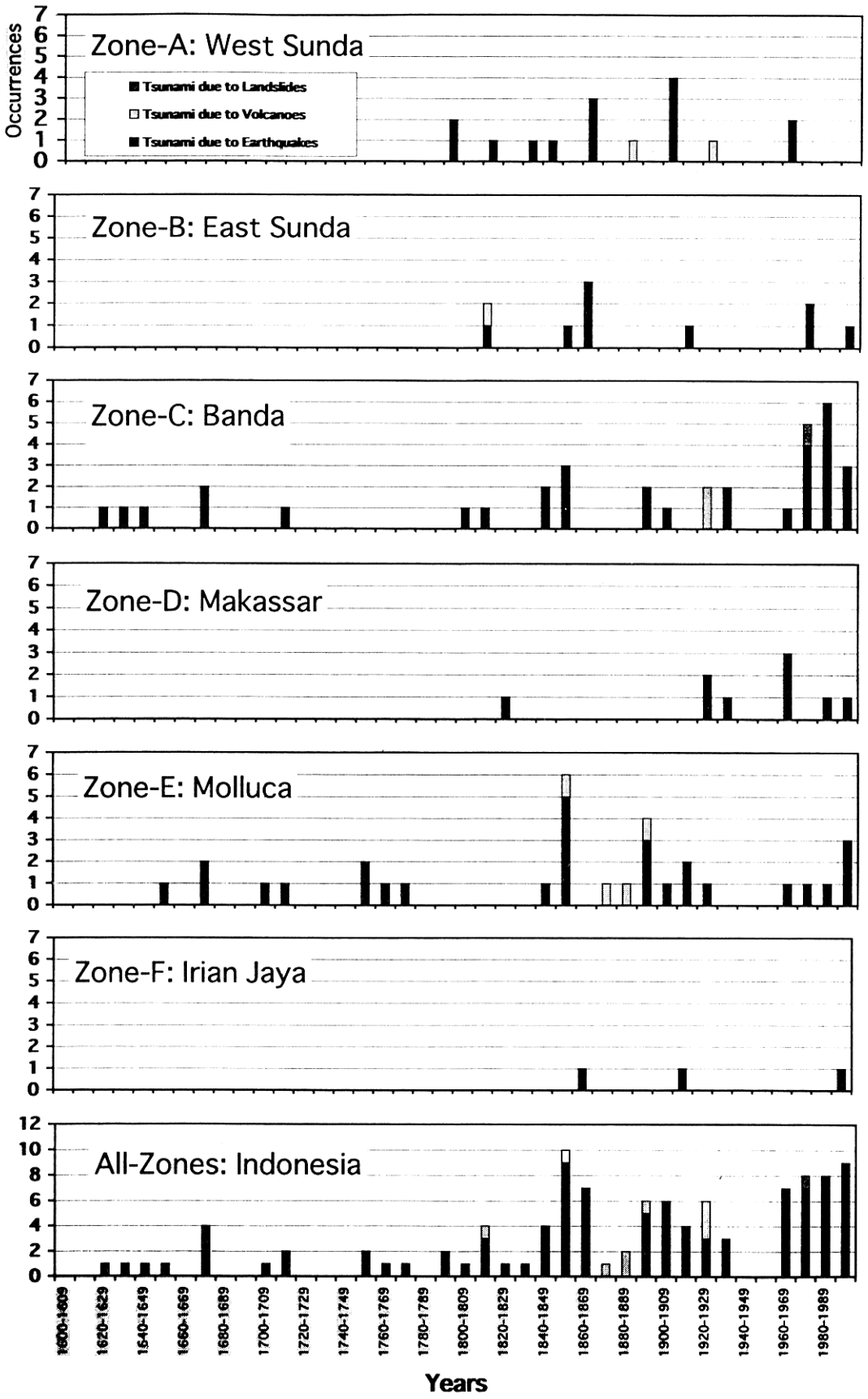

Fig. 7 Histogram of tsunami caused by earthquakes, volcanoes and landslides by zone and by decade.

where the 1975 Bandanaira tsunami was generated by a shallow strike-slip earthquake (Puspito, 1996). The two volcanic tsunamis were generated by the eruptions of Rokatenda in 1927 and 1928 (Tables 3). The 1979 Lomblen tsunami is the only one generated by a landslide. That landslide was reported to be not triggered by an earthquake (Tsuji & Husni, 1998). These 34 tsunami that occurred in the Banda arc have causedthe deaths of 5,570 people, mostly on Flores Island, and at Bandanaira and Amboina on Ceram island. Of them, *the* 1674 *Amboina Tsunami* is reported to have had a run-up of 80–100 m and to have killed at least 2,340 people (Iida, 1983),and the 1992 Flores earthquake and tsunami to have killed 1952 people (Tsuji et al., 1995a). Figure 7 shows that tsunamis in the Banda arc have long history of report since 1620. The average interval between seismic tsunami is estimated to be about 10–12 years.

4.4 Zone D: Makassa Strait

The Makassar strait region is at the western coast of Sulawesi and eastern coast of Borneo (Fig. 3). Seismic activity in this region is very low compared to that in other zones (Fig. 2). The earthquakes are mostly shallow depth ones resulted from activities in the back-arc-opening zone in the Makassar Strait and the high activity of the Palu-Koro fault that runs north-south on Sulawesi. Ten destructive earthquakes occurred in this region (Table 1), about 6 % of the total number reported in Indonesia. They were caused by activity of the Palu-Koro fault. The average interval in this region is estimated to be about 20 years.

Table 2 shows that 9 have tsunamis occurred in the Makassar Strait, about 9 % of the past tsunami reported in Indonesia. All were generated by earthquakes in the back-arc opening zone, in which earthquakes usually have the normal fault mechanism. The 1968 Central Sulawesi tsunami was generated by a shallow earthquake that had a normal fault mechanism (Puspito, 1996). The 9 tsunami that occurred in the Makassar Strait struck the western coast of Sulawesi killing at least 1,023 people. The average interval between seismic tsunami is estimated to be about 15 – 20 years.

4.5 Zone E: Molucca Sea

This zone which includes the Sangihe and Halmahera arcs in northeastern Indonesia (Fig.3) is considered the most tectonically complex region. Its complex tectonics can be seen in the seismic complexity shown in Fig. 2. This seismicity is the result of subduction of the Molucca Sea plate where the plate simultaneously subducts eastward beneath Sangihe and westward below Halmahera. Twenty-three destructive earthquakes have occurred in this region (Table 1), about 17 % of the total number of the destructive earthquakes reported in Indonesia. These earthquakes killed at least 340 people. The average interval is estimated to be about 8 – 10 years.

The Molucca Sea also is considered an active tsunami region, 32 tsunami having occurred there (Table 2), about 31% of the total number reported in Indonesia. Twenty-eight tsunami were generated by earthquakes and 4 by volcanic eruptions. Shallow earthquakes in this region predominantly have had thrusting fault mechanism, as in the Molucca Sea collision zone (Puspito, 1996). Two of the 4 volcanic tsunami were generated by the eruptions of Awu in the Sangihe arc in 1856 and 1892 (Table 3). The 1856 Awu volcanic tsunami killed at least 3,000 people in the region, and the 1 generated by the Ruang volcano, Sangihe in 1889 and another by Gamalama volcano, North Molluca in 1871 have caused the deaths of at least 4,000 people. Totally, 32 tsunami in the Molucca sea killed about 7,600 people. Figure 6 shows that the tsunami in the Molucca Sea region have been reported since 1650. The average interval between seismic tsunami is estimated to be about 10 years.

4.6 Zone F: North Irian Jaya

This region, which covers the northern part of Irian Jaya and Biak, is tectonically characterized by the activities of the Caroline subduction zone and Sorong fault (Fig. 1). Most earthquakes that occurred in this zone have been in the shallow (Fig. 2). These usually are caused by thrusting and/or strike-slip fault types (Puspito, 1996). Thirteen destructive earthquakes have occurred in zone F since 1860, about 7 % of the total number reported in Indonesia. They killed at least 6,738 people. The last destructive earthquake in this region was the 1989 Irian Jaya (M = 5.8) earthquake which killed at least 120 people. The average interval between destructive earthquakes is estimated to be about 10 – 15 years.

Only 3 tsunami have occurred in Zone F (Table 2), about 3 % of the total number reported in Indonesia. These tsunami have killed at least 357 people in Biak and along the northern coast of Irian Jaya. Two tsunami were generated by shallow earthquakes associated with the activity in the Caroline subduction zone. One was the 1996 Irian Jaya tsunami that struck Biak as well as the northern coast of Irian Jaya. Its run-up exceeded 7 m on the back side of Biak Island and killed 107 people (Imamura et al., 1997). Figure 6 shows that the available tsunami data is not sufficient to estimate the average interval between seismic tsunami in this region.

5. CONCLUSIONS

Historical tsunami data for the period 1600 to 1999 and destructive earthquake data reported from 1800 to 1999 have been compiled. Due to the lack of historical data before the 19th century, the limited number and time distribution of the data compiled limit any analysis. The following remarks, however, can be made;.

At least 105 tsunami and 183 destructive earthquakes have occurred throughout the Indonesian archipelago from 1600 to 1999 and from 1800 to 1999. The number of tsunami is 95 (90%) generated by earthquakes, 9 (8%) by volcanic eruption, and 1 (1%) tsunami by a landslide. These tsunami have caused injures and casualties, and killed at least 54,100 people, of which about 43,200 deaths have been due to volcanic tsunami. Destructive earthquakes have killed at least 10,600 people.

Tsunami activity seems to be correled with the seismotectonic characteristics of the region. The Banda arc and Molluca Sea zones, considered the most tectonically active regions, are also the most active tsunami regions. At least 34

Table A-1 List of destructive earthquakes in Indonesia for the period 1800 to 1999

Year	M	D	h m s	Lat.	Lon.	Mag./ Depth (km)	Dead/ Injured	Observed Area Province:Location	Zone
1821	12	05		-		-	-	C Java: Jepara	B
1828	12	29		-		-	100	S Sulawesi: Bulu Kumba	D
1830	03	28	01 00	-		-	0	Maluku: ambon	C
1833	01	28	05 00	-		-	0	W Java: Jakarta	B
1834	10	10		-		-	0	W Java: Bogor	B
1835	08	26				-	-	W Sumatera: Padang	A
1835	11	01		- 4.0	128.0	-	149/60	Maluku: Ambon, Haruku	E
1836	03	22		-		-	-	E java: Mojokerto	B
1837	01	21		-		-	-	Maluku: Ambon	A
1837	11	28		-		-	-	NTB: Bima	B
1840	01	04		-		-	-	C Java: Perworejo	B
1843	05	25		-		-	-	W Java: Bogor	B
1844	02	15		-		-	-	W Java: Cianjur	B
1845	02	08		-		-	56	N Sulawesi: Manado, Minahasa	E
1852	01	09		-		-	-	S Sumatera: Teluk Betung	A
1852	10	15		-		-	-	C Java: Kebumen	B
1852	12	20		-		-	-	W java: Bogor	B
1853	10	30		-		-	-	W Java: Cerebon	B
1855	07	14		-		-	34	Maluku: Ternate, Halmahera	E
1856	01	19		-		-	-	C Java: Semarang	B
1858	02	27		-		-	-	Maluku: Ternate	E
1858	06	04		-		-	-	Maluku: Ternate	E
1858	11	09		-		-	-	Maluku: Ambon	C
1859	07	05		-		-	-	E Java: Tulungagung	B
1859	10	08		-		-	-	Maluku: Halmahera Is.	E
1861	02	16		-		-	-	N Sumatera: Tapanuli, Sibolga	A
1862	03	29		-		-	-	Bali: Buleleng	B
1862	05	24		-		-	-	W Java: Kerawang	B
1862	09	15		-		-	-	Maluku: Bandanaera	C
1862	11	20		-		-	-	E Java: Madiun	B
1863	08	13		-		-	-	C Java: Banyumas	B
1864	05	23		-		-	250	Irian Jaya: Arfak	F
1865	07	17		-		-	-	C Java: Banyu Biru	B
1866	04	02		-		-	-	C Java: Ambarawa	B
1867	06	10		-		-	5	C Java: Jogyakarta	B
1867	11	03		-		-	-	Maluku: Ternate	E
1871	03	27		-		-	-	C Java: Banyumas	B
1871	08	18		-		-	-	Bengkulu	A
1872	10	10		-		-	-	C. Java: Salatiga	B
1873	02	05		-		-	-	W. Java: Ciamis	B
1873	08	19		-		-	-	N. Sumatera: Mandailing	A
1873	10	07		-		-	-	N Sumatera: Tapanuli	A
1875	10	25		-		-	7	W. Java: Kuningan	B
1876	05	28		-		-	-	Maluku: Seram	C
1877	02	21		-		-	-	C. Java: Kedu	B
1889	11	04		-		-	-	E. Java: Pasuruan	B
1890	07	11		-		-	-	Bali: Negara	B
1890	11	23		-		-	-	Maluku: Bandanaera	C
1890	12	12	07 50 L	-6.5	111.0	-	Many	C. Java: Pati, Juwana	B
1892	05	17		-		-	-	N. Sumatera: Prapat	A
1896	04	18		-		-	250	NTT: Timor Is	C
1896	07	01		-		-		E. Java: Lumajang	B
1896	08	15		-		-	-	E. Java: Wlingi	B
1896	08	20		-		-	-	E. Java: Tulungagung	B
1898	01	17		-		-	-	Maluku: Ambon	C
1900	01	14		-		-	-	W. Java: Sukabumi	B
1902	07	27		-		-	-	Bengkulu: Lais	A
1902	08	31		-		-	-	E. Java: Sedayu	B
1903	02	14		-		-	-	Maluku: Bandanaera	C

Table A-1 continued

1903	02	27		-	-	-	W. Java: Banten	B
1907	07	30		-	-	-	C Sulawesi: Lemo	D
1910	12	18		-	-	-	W. Java: Cianjur	B
1912	01	21		-	-	-	W. Java: Sukabumi	B
1914	06	26	19 06 U	-4.0	102.5	7.6	20/20	Bengkulu: Kepahiyang	A
1915	12	01		-	-	-	E Java: Madiun	B
1916	09	09		-	-	0	C. Java: Maos	B
1917	01	21		-	-	1500	Bali	B
1919	11	21		-	-	0	Irian Jaya: North Irian	F
1920	05			-	-	-	Maluku: Ambon, Banda	C
1921	04	01		-	-	-	N Sumatera: Tapanuli	A
1921	10	10		-	-	-	Irian Jaya: Sentani	F
1923	04	19		-	-	-	E. Kalimantan: Tarakan	D
1923	05	12		-7.3	105.8	-	-	W. Java: Banten	B
1923	05	15		-7.7	109.2	-	-	C. Java: Maos	B
1924	04	13		0.3	118.2	-	-	E. Kalimantan	D
1924	11	12		-7.3	109.8	-	609	C Java: Wonosobo	B
1924	12	02		-7.3	109.9		115	C Java: Wonosobo (after shock)	B
1925	02	14			-	-	0	E. Kalimantan: Tarakan	D
1925	07	24			-	-	0	Maluku: Bacan Is.	E
1926	06	28	03 23 U	-0.7	100.6	6.8	222/many	W. Sumatera: Singkarak	A
1926	12	13			-	-	I=few	C Java: Prupuk	B
1927	12	01		-0.5	119.5	-	50/50	C. Sulawesi: Donggala	E
1930	04	27			-	-	0	Bali	B
1931	01	21		-7.3	108.9	-	0	C Java: Bumiayu	B
1931	09	25			-	-	0	S. Sumatera	A
1932	05	14		0.5	126.0	-	6,I=115	N Sulawesi: Tondano	E
1932	09	09		-3.5	128.3	-	0	Maluku: Seram	C
1933	06	25		-5.0	104.2	7.5	76	S. Sumatera : Kota Agung, Liwa	A
1934	09	21		1.0	99.0	-	0	N Sumatera: South Tapanuli	A
1935	12	28		-0.3	97.9	-	0	N Sumatera: Batu Island	A
1936	03	01			-	-	-	E Java	B
1936	04	01		3.6	126.7	-	0	N. Sulawesi: Sangir	E
1936	08	23		6.1	94.7	7.1	91/20	Aceh: Banda Aceh	A
1936	09	19		3.5	97.5	-	17	N. Sumatera: Tapanuli	A
1936	10	19		-2.0	126.0	-	0	Maluku: Molluca, Sanana	E
1936	10	27		-0.2	98.8	-	0	North Sumatera: Tapanuli	A
1937	09	27		-8.7	110.8	-	1	C. Java: Yogyakarta	B
1938	05	20		-0.7	120.3	-	Few	C. Sulawesi: Tomini Gulf	E
1938	08	18		-3.8	102.8	-	-	Bengkulu	A
1938	10	20		-9.2	123.2	-	-	NTT: Flores	C
1938	10	30		-8.9	115.8	-	-	Bali	B
1939	06	27		-6.9	108.5	-	-	C Java:	B
1939	08	11		-6.5	112.4	-	-	E. Java	B
1939	12	22		0.0	123.0	-	-	C. Selawesi	D
1941	10	11		0.6	97.6	-	0	N. Sumatera: Tapanuli	A
1941	11	09		-1.4	121.1	-	-	N. Sulawesi: Gorontalo	D
1943	07	23		-8.6	109.9	-	213/4896	C. Java: Yogyakarta	B
1950	06	19	12 36 54 U	-6.2	112.5		-	E. Java:	B
1954	11	02	08 24 54 U		-	6.75	0	NTB: Bima	B
1958	10	20	01 12 30 U	-9.5	112.5	6.7/100	8	E. Java: Malang	B
1960	04	29	09 16 20 U	-0.5	121.5	-	0	C. Sulawesi: Una-una	E
1960	10	10	21 44 40 U	-8.0	112.5	-	0	E Java: Tulungagung	B
1961	03	16	18 21 04 U	-8.1	122.3	-	1	NTT: Flores	C
1961	05	07	04 32 05 U	-8.5	112.0	-		E. Java	B
1962	12	21	00 44 20 U	-9.0	112.0	-/64		E Java: Wlingi	B
1963	06	27	11 46 58 U	-8.3	112.2	-/180		E Java: ponorogo	B
1963	12	16	02 45 35 U	-6.2	105.4	5.0/55	0	W. Java : Labuan	B
1964	01	04	22 45 U	-1.9	102.3	6.7	110/147	Sumatra:	A
1964	04	02	01 11 55 U	5.9	95.7	5.2/132	0	Aceh:	A
1965	07	25	03 40 40 U	2.0	99.3	5.3/98	0	N. Sumatera: Tapanuli	A
1967	02	19	22 14 55 U	-8.5	113.5	6.2/80	54/370	E Java: Malang	B
1969	11	02	18 53 07 U	-6.5	107.1	5.4/57	0	W Java: Sukabumi	B
1971	01	10	07 17 03 U	-3.1	140.1	7.3/N	0	Irian Jaya: Sentani	F

Table A-1 continued

1971	02	04	15 33 22 U	-0.6	98.8	6.3/N	0	N Sumatera: Sibolga	A
1971	06	16	14 44 22 -	-7.2	109.1	5.2/35	1/6	C. Java: Bantar Kaung	B
1972	09	06	08 00 25 U	-2.5	119.1	5.8/36	0	S. Sulawesi: Mamuju	D
1972	11	04	21 36 54 -	-8.4	112.2	6.0/126	0	E. Java:	B
1972	12	19	14 47 00 U	-6.9	107.8	4.5/vs	0	W Java: Sumedang	B
1973	11	26	08 51 12 U	-6.8	106.6	4.9/62	0	W Java: Pelabuhan ratu	B
1974	02	27	00 21 57 U	2.7	125.4	5.2/N	0	N. Sulawesi: Siau Island	E
1974	11	09	19 10 55 U	-6.5	105.3	6.1/51	0	W. Java: banten	B
1975	07	30	09 17 11 U	-9.9	123.9	6.1/30	0	NTT: Kupang	C
1976	02	14	20 31 49 U	-7.2	109.3	5.6/22	0	C Java: Purwokerto	B
1976	06	20	20 56 31 U	3.2	96.3	6.1/33	0	Aceh: Kota Cane	A
1976	06	25	19 18 29 U	-3.2	142.8	6.8/-	6000	Irian Jaya : Jayapura	F
1976	06	25	19 18 55 U	-4.6	139.8	7.0/33	0	Irian Jaya: Bime, Eipomek	F
1976	07	14	07 13 22 U	-8.2	114.9	6.2/N	I=3759	Bali: Seririt Busung biru	B
1976	10	29	02 51 01 U	-4.7	140.2	6.0/30	108	Irian Jaya, Nalca, Bime	F
1977	01	26	13 11 29 U	-8.25	115.3	5.0/N	0	Bali: Bangli	B
1977	03	08	23 17 28 U	0.45	100.0	5.5/22	0	W. Sumatera: Pasaman	A
1979	04	28	03 29 57 U	0.54	98.78	5.8/78	73	W. Sumatera: Marapi	A
1979	05	30	09 38 53	-8.21	115.95	6.1/25	37	NTB: Lombok	B
1979	07	23	05 52 52	-2.57	140.31	5.3/15	0	Irian Jaya: Sentani Jayapura	F
1979	09	12	05 17 51	-1.68	136.04	6.4/5	2/5	Irian Jaya: Japen, Serui	F
1979	10	20	01 41 10	-8.25	115.85	6.0/38	0	Bali: Karang Asem	B
1979	11	02	15 53 03	-7.66	108.25	6.1/62	10/12	W. Java: Tasikmalaya	B
1979	12	15	00 02 42	-3.3	102.71	5.8/33	0	Bengkulu	A
1979	12	17	19 58 24	-8.39	115.89	5.6/33	24/619	Bali: Karang asem	B
1980	02	22	03 51 45	-1.61	124.93	5.3/26	0	N. Sulawesi: Manado	E
1980	04	16	12 18 21	-8.08	108.8	5.8/84	0	W Java: Tasikmalaya	B
1980	08	17	09 01 56	-3.77	128.24	5.4/24	0	Maluku: Ambon	C
1981	01	01	-		-	-	0	C. Java: Karanganyer	B
1981	01	19	15 11 U	- 4.6	139.3	6.8	261	Irian Jaya: Jayawijaya Mts.	F
1981	03	13	23 22 35	-8.76	110.43	5.6/51	0	C. Java: Yogyakarta	B
1982	02	10	16 17 52	-6.86	106.94	5.5/39	0/4	W. Java: Sukabumi	B
1982	08	06	20 40 52	-8.38	120.58	5.9/45	0	NTT: Flores Island, Ruteng	C
1982	08	23	23 30 09	-2.31	120.97	5.4/54	0	C Sulawesi: Una-una	E
1982	12	25	01 54 10	-9.54	116.78	4.4/33	13/417	NTT: Flores Island	C
1983	04	04	02 51 34	5.72	94.72	6.6/78	0	Aceh	A
1983	10	16	05 32 29	1.08	121.05	6.0/40	0	C. Sulawesi: Toli-toli	D
1983	10	22	-		-	-	-	N. Sulawesu: Sangihe Island	E
1983	10	25	00 36 23 U	1.13	120.86	5.8/33	2/45	C. Sulawesi	D
1983	10	31	17 37 56 U	-9.02	119.18	6.0/83	0	NTT: Sumba Waingapu	B
1984	08	27	13 41 26 U	1.76	99.08	5.1/33	0	N. Sumatera: Tapanuli	E
1985	04	13	01 06 00	-9.25	114.19	6.2/98	0	Bali: Denpasar	B
1985	09	15	01 29 23	-4.09	136.2	5.7/10	10	Irian Jaya; Fak-fak	F
1985	11	17	00 56 27 U	-2.82	141.62	4.9/16	0	Irian Jaya: Biak	F
1987	10	25	16 54 00 U	-2.10	138.2	6.7/30	0	Irian Jaya: West jayapura	F
1987	04	25	19 22 07 U	2.1	98.8	6.0/30	0	N. Sumatera: Tarutung	A
1988	08	17	23 09 40 U	1.5	124.75	5.2/N	1/some	N. Sulawesi: Manado	E
1989	07	14	20 42 40 U	-8.08	123.13	6.4/10	0/7	NTT: Alor Island	C
1989	07	31	17 07 28 U	-8.05	121.38	6.3/14	0	NTT: Maumere-Flores	C
1989	08	01	00 18 05 U	-4.5	139.02	6.0/14	117/145	Irian Jaya: Wamena	F
1990	07	06	00 16 21 U	-6.7	107.8	-/34	0/121	W Java: Majalengka	B
1990	11	15	09 35 19 L	3.2	98.1	4.6/-	0/100	Aceh : southeast Aceh	A
1991	07	04	-	-10.2	126.4	-/33	22/181	NTT= Alor Island	C
1992	02	04	01 58 19 U	-7.2	109.00	5/-	0	C. Java: Brebes	B
1994	01	21	03 24 28 U	1.6	127.6	6.8/-	2	Maluku: Kao-Halmahera	E
1994	02	15	17 07 45 U	-5.0	104.3	6.2/N	200/1351	Lampung: Liwa, west lampung	A
1994	10	08	21 44 49 U	-1.14	128.05	6.3/35	1/9	Maluku: Obi Isl.	E
1994	10	13	05 04 25 U	-1.16	128.23	5.9/60	0	Maluku: Obi Isl.	E
1995	10	07	01 09 L	-2.1	101.3	7.0	20	West Sumatera: Kerinci	A
1998	09	30	13 34 U	-8.3	112.6	6.5	4/many	East Java: Malang	B

Note:

- MDHm: month, day, hour, and minute, L: Local time, U: UTC
- M: Magnitude,
- D: death/ I: injury

Table A-2 List of tsunamis in Indonesia for the period 1600 to 1999

Year M D h m	Lat. Lon.	M/Dp	Tm	H(m)	Dead/ Injure	Observed Area Province: location	Zone
1629 08 01		7	4	15-90		Maluku: Banda Naera	C
1630/31 - -			1			Maluku: BandaNaera	C
1648						Maluku: Amboina	C
1657 12			1			Maluku: Buru Island	E
1673 05 20			1	Moderat e		Maluku: Near Halmahera	E
1673 08 12			1			Maluku: Ternate, Amboina	E
1674 02 17			2	80-100	2342	Maluku: Near Ambon	C
1674 05 06			1			Maluku: Amboina, Hitu	C
1708 11 28			2	Big		Maluku: Amboina	E
1710 03 06			1.5			Maluku: Banda Naera	C
1711 09 05			1	Moderat e		Maluku: Amboina bay	E
1754 08 18			1			Maluku:Amboina, Near Haruku,	E
1754 09 07			1			Maluku: Haruku	E
1763 09 01			0?			Maluku; Ambon	E
1775 04 19			0?			Maluku:Ambon	E
1797 02 10	0.58 100,2			Strong		W. Sumatera, Padang	A
1799				16		Sumatera	A
1802 08 25			1?	Very big		Maluku: Banda Sea, Amboina,	C
1814			1?			Maluku: Banda Sea, Kiser	C
1815 04 11		Volc		3.5		NTB: Sumbawa, G. Tambora	B
1816 11 27 21 15U	- 8.0 115.2	-			10253	Bali	B
1818 13 18	-3.5 100.5					Bengkulu	A
1820 12 29	- 7.0 119.0	7.5	3.5	18-24	500	S. Sulawesi:B. Kumba, Sumbawa	D
1833 01 29						W. Sumatra: Padang, Priana	A
1833 11 24						Bengkulu	A
1841 11 26			1.5	2.4-2.7		Maluku: Bandanaera (south cost)	C
1841 12 16			1?	1.2-1.5		Maluku: Amboina, Buru	C
1843 01 5-6	2.08 98.23			Large		N. Sumatera: Barus Is.. G. Sitoli	A
1846 02 14	0.5 127.3			1.2-16	Many	Maluku Ternate Island	E
1852 11 26		8	2	8		Maluku: Ambon, Banda Naera	C
1856 03 02	3.5 125.5	Volc	2		3000	N Sul: Awu Is.: Great Sanger	E
1857 05 13 18 30L	-8.0 125.5	7.0	1.5	3.3	40	NTT: Banda sea, Timor, Dili	C
1858 12 13			2			N Sulawesi , Sangihe, Tondano	E
1859 06 28			3	9		Maluku: Halmahera,	E
1859 07 29			1?	Moderat e		N. Celebes: Manado, Manila Bay	E
1859 09 25				Strong		Maluku: Maluku, Banda Naera	C
1859 10 20	-8.11 111.07			Strong		E. Java: Pacitan	B
1859 10 25			1			N Sulawesi: , Manado, Kema	E
1861 02 16		8.4			50	Sumatra: Batu Is., Nias Is.	A
1861 06 05			1			E. Java: Karawang, Pakis	B
1861 09 25	-2.04 100.6		1			Sumatra: Padang, Indrapura	A
1862 04 08						Java Sea: Lenor	B
1864 05 23	-3.0 135.0	-		2.4-3.0	250	Irian Jaya: Geelvink Bay	F
1864						W. Sumatra: Padang, Batu	A

Table A-2 continued

1867	06	10		- 7.8	110.5	-			327	C. Java: Djokjakarta, Soerakarta	B
1871	03	03		0.0	128.0	Volc	4?	25	400	Maluku: Tagulandang Is. Buhias	E
1883	08	26		-5.8	106.3	Volc		35	36000	Sumatera: Sunda St., Java,	A
1889	09	06		2.2	125.4	Volc	1			N. Sulawesi: Ruang: Sangihe,	E
1891	10	06	04 45	-9.0	124.0	7.0	2			Timor: Timor Island	C
1892	06	02				Volc.	1			N. Sulawesi: Awu Is: Sangihe	E
1896	04	18							250	NTT: Timor Is., Alor	C
1897	01	03		6.0	122,7	8.2		-	100	N. Sulawesi: Sulu: Mindanao	E
1897	09	21	05 15	7.1	122,1	8.2		2-6	100	N. Sulawesi: Sambuaga, Sulu	E
1899	09	29	17 03U	- 3.0	128.5	7.1	2?	3-6	3864	Maluku: Seram (South Coast)	E
1902	08	21	19 17U	6.3	123.6	-			Many	N. Sulawesi: Mindanao, Illama	E
1904	07	04								W. Sumatra: Siri-siri	A
1907	01	-								Sumatra : Western Coast	A
1908	02	06		-2.0	100.0					W. Sumatra	A
1908	03	24	20 00	-8.7	124.7	6.6	1	25		NTT: NE Timor, Atapupu, Ende	C
1909	06	03	18 41U	- 2.5	101.5	7.3			200	Sumatra: Kerinci-Jambi	A
1913	03	14	08 45	4.8	126.6					N. Sulawesi: Passages, Sangihe	E
1914	05	26							few	Irian Jaya: Yapen Island	F
1917	01	20		- 8.3	115.0	-			1300	Bali (D=157 by Tsunami?)	B
1918	08	15	12 18	5.5	123.0	8.2	2.5	7	many	N. Sulawesi: Mindanao, Lebak	E
1921	05	14		0.42	117.5		T			C. Sulawesi.: Sangkulirang	D
1927	08	07	12.37L	-8.6	121.7	Volc	1.5		226	NTT; Paloeweh Is.:Rokatinda	C
1927	12	01		-0.7	119.7	6.3		15		C Sulawesi, Palu	D
1928	03	26		-5.8	106.3	Volc				S. Sumatera: Sunda St., Lampung	A
1928	08	04		-8.4	121.7	Volc	1			NTT;Paloeweh Is.:Rokatinda Volc	C
1928	12	19	11 37L	7.0	124.0	7.3	T			N. Sulawesi:Celebes sea	E
1938	02	01	19 40	-5.0	131.3	8.6	1.5			Maluku: Banda sea: Banda Is	C
1938	05	19	17 08	-1.0	120.0	7.6	1.5	3		C. Sulawesi; Nambara	D
1938	10	20	02 19	-9.2	123.2	6.5	no			NTT: East Flores: Larantuka	C
1961	03	16	13 45	-8.2	122.0	6.3	no		2/6	NTT: Middle Flores	C
1964	04	02	01 11U	5.8	95.6	7.0			110/479	Sumatra:	A
1965	01	24	00 11U	- 2.4	126.0	7.5/33	2?		71	Maluku: Seram Sea, Sanana	E
1967	04	11	05 09	-3.7	119.3	4.9/51			58/100	S. Sulawesi; Tinambung	D
1967	04	12		5.3	96.5	6.5		big		N Sumatera: Sigli	A
1968	08	14	22 14U	0.7	119.7	7.3/23		8-10	392	C Sulawesi; Tambu	D
1969	02	23	00 36U	- 3.1	118.8	6.1/13		10	64/97	S. Sulawessi: Majene	D
1975	01	15	09 42	-5.0	130.0	5.9		-	0	Maluku: Banda Naera	C
1975	03	05		-2.4	126.1	6.5	1	1.2	0	Maluku: Sula Island, Sanana	E
1975	07	30	09 17	-10.1	123.8	6.1	no			NTT: Timor: Kupang	C
1977	08	19	06 08U	-11.1	118.5	7.0/33	3		316	NTB; Sumbawa Island	B
1977	08	27	07 12	-8.0	125.3	6.8	no		2/25	NTT; Flores: Atauro Island	C
1979	07	18	night			LS	1.5		620	NTT: Flores: Lomblen	C
1979	12	17	19 58U	- 8.4	115.9	6.6			27/200	NTB: Sumbawa, Bali, Lombok	B
1982	03	12		-4.4	128.1	5.8				Maluku: Ambon	C
1982	08	19		-0.1	121.6	5.2				N. Sulawesi; Tomini Bay	E
1982	12	25		-8.4	123.0	5.6	1?		13/400	NTT; Larantuka, (Landslide)	C
1983	03	12	00 54	-4.0	127.9	5.8/33			0	Maluku; Ambon	C
1984	01	08		-2.94	118.7	5.9				S. Sulawesi: Mamuju	D
1987	11	26	0143U	- 8.4	124.3	5.8/28	1		83/108	NTT; East Flores Pantar Is.	C
1989	07	14	20 42	-8.1	125.1	6.2	0		7	NTT; Alor Island	C
1989	07	31	17 07	-8.1	121.4	6.3	0?		2-3	NTT; Flores: Maumere	C
1992	06	20		1.96	122.8	6.2	0			N Sulawesi: Kwandang	E
1991	07	04	11 43	-8.1	124.7	6.2	?		23/181	NTT; Alor Is: , Kalabahi	C

Table A-2 continued

1992	12	12	05 29U	- 8.5	121.9	7.5	3	11.2-26.2	1952/212 6	NTT: Flores, Babi Is.	C
1994	01	21	02 24U	1.0	127.7	7.2			7	Maluku: Halmahera	E
1994	06	02	18 17U	-10.7	113.1	7.2		19.1	238/400	E. Java: Banyuwangi	B
1995	05	14						4	8	Timor: Eastern part	C
1996	01	01	16.05L	- 1.1	118.8	7.8		3/63	9	C. Sulawesi :, Palu	D
1996	02	17	05 59U	-0.5	136.0	8.0		13.7	107	Irian Jaya: Biak Island	F
1998	11	28	2311L	-2.02	124,87	7.7		2.75	34	Maluku: Tabona, Taliabu	E

Note:

- MDHm: month, day, hour, and minute, L: Local time, and U: UTS
- M : Magnitude, Dp: depth in km
- Tm: tsunami magnitude
- Volc : Volcano
- Ls : landslide
- H : tsunami run-up height,
- D : death/ I : injured

Table A-3 Volcanoes active in the Indonesia archipelago

Volcano Name	Location	Eruption (years)
G. Krakatau	Sunda St.	1680, 1681, **1883**, 1898, 1927, **1928**, 1942, 1944-1953, 1958-1962, 1963-1968 1972, 1973
G. Tambora	Sumbawa	**1815**, 1819, between 1847-1913
G. Sangiang Api	Sumbawa	1512, 1517, 1821, 1860, 1911, 1912, 1927, 1953, 1964, 1965
Rokatenda	Flores	**1927**, **1928**, 1929, 1964, 1965, 1966, 1972, 1973
Niewerker	Banda Islands	1893, 1925, 1927, ?
G. Api Wetar	Banda Islands	1512, 1699, 1934
Wurlali, P. Damar	Banda Islands	1892
Serawerna, P. Teon	Banda Islands	1659, 1660, 1663, 1693, 1904
Laworkawra, P Nila	Banda Islands	1903, 1932
Legatala, P. Serua	Banda Islands	1683, 1687, 1692, 1693, 1694, 1844, 1858, 1859, 1919, 192
Banda Api	Banda Islands	1586, 1598-1602, 1609, 1615, 1632, 1683, 1690-1696, 1712, 1723, 1749 ?, 1762, 1765, 1766, 1773, 1775, ?, 1778, 1816, 1820, 1824, 1890, 1901, 1902
G. Colo	Sangir Islands	1898, between 1928-1948
Ruang	Sangir Islands	1808, 1810, 1836, 1840, 1856, 1870, 1871, 1874, **1889**, 1904, 1905, 1914, 1915, 1946, 1949
Krangetang, Api Siau	Sangir Islands	1675, 1712, 1825, 1864, 1883, 1886, 1887, 1892, 1899, 1900, 1905, 1922, 1924, 1926, 1930, 1935, 1940, 1941, 1947, 1948, 1949, 1953, 1961, 1967, 1970, 1971, 1974
Banua Wuhu	Sangir Islands	1835, 1889, 1895, 1904, 1918, 1919
Awu, Great Sanger	Sangir Islands	1640, 1641, between 1641-1677, 1711, 1812, **1856**, 1875, 1885, ?, **1892**, 1893, 1931, 1921, 1922, 1931, 1966,
Submarin	Sangir Islands	1922
Dukono	North Mollucas	1953
Gamalama	North Mollucas	1538, 1551, 1552, 1561, 1562, 1605, 1608, 1635, 1643, 1648, 1653, 1654, 1659, 1673, 1676, 1677, 1686, 1687, 1737, 1739, 1763, 1770, 1771, 1772, 1773, 1774, 1775, 1811, 1812, 1841-1821, 1824, 1831, 1833, 1835, 1838, 1839, 1840, 1841, 1842, 1843, 1844, 1847, 1849, 1850, 1858, 1859, 1860, 1862, 1863, 1864, 1865, 1868, 1869, **1871**, 1884, 1895, 1896, 1897, 1898, 1900, 1907, 1911, 1918, 1923, 1932, 1938, 1962
Kie Besi	North Mollucas	1646, 1760, 1781, ?, 1860, 1861, 1890

Note: **Boxed date**: eruption that generated tsunami

tsunami have occurred in the Banda arc, 32 in the Molluca Sea, 16 in the western Sunda arc, 10 in the east Sunda arc, and 9 in the Makassar Strait. North Irian Jaya region is the most tsunami-inactive one only 3 tsunami having occurred during the period from 1800 to 1999.

The average interval for the occurrence of seismic tsunami varies from zone to zone. About from 10 to 15 years is the average in the west Sunda arc, east Sunda arc, Banda Arc, and Molucca Sea regions, and from 15 to 20 years in the Makassar Strait.

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