A CATALOG OF TSUNAMIS IN THE INDIAN OCEAN

B. K. Rastogi and R. K. Jaiswal
National Geophysical Research Institute,
Hyderabad, India

SUMMARY

A catalog of about ninety tsunamis in the Indian Ocean has been prepared from 326 BC to 2005 AD. In the nineteenth and twentieth centuries tsunamis have occurred once in three years or so. Sunda Arc is the most active region that has produced about seventy tsunamis. The source zones of the remaining tsunamis are Andaman-Nicobar islands, Burma-Bangladesh region in the eastern side, while Makran accretion zone and Kutch-Saurashtra region are in the west. These zones are subduction zones or zones of compression.

GENERAL DESCRIPTION

Tsunamis are not as common in the Indian Ocean as in the Pacific. As compared to average eight tsunamis per year in the Pacific, Indian Ocean has one in three years or so. A catalog of tsunamis presented here includes about ninety tsunamis in the Indian Ocean out of which over 70 tsunamis are from Sunda. Some 20 tsunamis are reported from rest of the Indian Ocean, though source region of five of them may be in Sunda arc. Hence, eighty percent of the tsunamis of the Indian Ocean originate in Sunda arc covering Java and Sumatra. Figure 1 shows the locations of significant tsunamis and Figure 2 shows the annual number. Table 1 gives the list of tsunamis from Sunda arc and Table 2 from rest of the Indian Ocean.

The Sunda belt extends northward to Andaman-Nicobar Islands where a few tsunamis have originated. Further north, Bangladesh-Myanmar coast has produced some well-documented tsunamis. Makran coast in the northwest is known to have generated at least one major tsunami. Karachi-Kutch coast region has also produced some possible tsunamis. Cause of tsunamis is mostly thrust-type earthquakes with vertical uplift in subduction zones and zones of compression. The seismic gap areas along the subduction zones are possible sites of future great earthquakes. Along the Sunda arc, great earthquakes of magnitude 8.5 or greater can repeat every two centuries at a site but smaller tsunamigenic earthquakes can repeat every few decades. Along Sunda Arc volcanic eruptions have also given rise to large tsunamis. There appears to have been a hiatus in tsunami generation in this region, with a significant gap in events occurring from around 1909 through 1967 (Tsunami Laboratory, Novosibirsk, Russia). The Carlsberg spreading ridge or old oceanic ridges like Chagos Ridge and Ninetyeast Ridge with normal faulting can give rise to local tsunamis. Many of the tsunamis and their effects are described in some details. However, tsunamis from Java region are not described in detail as they did not affect the countries other than Indonesia.

TSUNAMIS FROM SUNDA ARC REGION

Newcomb and McCann (1987) compiled historical records of earthquakes and tsunamis from Sunda arc region. Heck (1947), Berninghausen (1966), Litzin (1974) and USGS catalogs list some more. Updated list is given in **Table 1**. The Sumatra part of the Sunda arc had been much more active than Java part. Detailed description of some of the significant earthquakes and the tsunamis caused by them are given below:

Earthquakes/Tsunamis in Sumatra

11 Dec 1681. “Strong earthquake” shook the Sumatra mountains near Mentawai Archipelago and a seaquake was observed.

3 Nov 1756. Many houses collapsed in several towns of Sumatra near to Enganno Is. No tsunami was reported.

No date, 1770. Severe damage in the same general area as the 1756 event, but a tsunami was reported.

10-11 Feb 1797, Mw 8.2. A large earthquake and tsunami was observed in ports on the coast of the mainland and on the Batu Is. Waves of great force near Padang (0.99S 100.37E) The town was inundated and more than 300 fatalities occurred (Heck, 1947).

18 Mar 1818. A very strong shock associated with both tsunami and seaquake near to Enganno Is.

24 Nov 1833. The great earthquake of magnitude > 8.7 had maximum intensities and generated a tsunami over 550km along the south central coast of Sumatra that also caused

much damage to the coast. Numerous deaths occurred in W. Sumatra. This earthquake ruptured the plate margin from the southern island of Enggano to Batu.

5-6 Jan 1843, Mw 7.2. The earthquake caused severe damage, liquefaction and many fatalities in Nias Is. A tremendous tsunami wiped out towns on the east coast of Nias and mainland. The damage and associated tsunami were very localized. The village of Barus (2N 98.38E) and Palan Nias (Nias Is. 1.1N 97.55E) reported large waves on two days.

11 Nov 1852. Earthquake near Nias generated seaquake.

16 Feb 1861. A great earthquake of magnitude 8.5 ruptured a major segment of the plate boundary in northern Sumatra. The tsunami that was generated extended over 500km along the arc. Tsunami destroyed southern towns of Batu Is., and a town on the southwest side of Nias experienced a tsunami height of 7m. The earthquake and tsunami caused 1000s of fatalities at west coast of Sumatra. Two aftershocks on March 9 and April 26, 1861 also caused tsunamis. There was no major shock for almost 50years.

The historic record shows that the strongest tsunami was associated with the volcanic eruption of Krakatau in Indonesia on 27 Aug. 1883. The 35m-high tsunami took a toll of 36,000 lives in western Java and southern Sumatra. Tsunami waves were observed throughout the Indian Ocean, the Pacific Ocean, the American West Coast, South America, and even as far away as the English Channel. On the facing coasts of Java and Sumatra the sea flood went many kilometers inland and caused such vast loss of life that one area was never resettled and is now the Ujung Kulon nature reserve.

Subsequent local tsunamis in the Sunda Strait were generated by the 1927 and 1928 eruptions of the new volcano of Anak Krakatau (Child of Krakatau) that formed in the area. Although large tsunamis were generated from these recent events, the heights of the waves attenuated rapidly away from the source region, because their periods and wavelengths were very short. There was no report of damage from these more recent tsunamis in the Sunda Strait (George, 2003).

According to ancient Japanese scriptures, the first known supercolossal eruption of Krakatau occurred in the year 416 A. D. – Some have reported it to occur in 535 A.D. The energy of this eruption is estimated to have been about 400 megatons of TNT, or the equivalent of 20,000 Hiroshima bombs. This violent early eruption destroyed the volcano, which collapsed and created a 7 km wide submarine caldera. The remnants of this earlier violent volcanic explosion were the three islands of Krakatau, Verlaten and Lang (Rakata, Panjang, and Sertung). Undoubtedly the 416 A.D. eruption/explosion/collapse generated a series of catastrophic tsunamis, which must have been much greater than those generated in 1883. The time of tsunami with wave height of several meters that affected Tamilnadu in India matches with this early Krakatau eruption. However, there are no other records to document the size of these early tsunamis or the destruction they caused. Subsequent to the 416 A.D. eruption and prior to 1883, three volcanic cones of Krakatau and at least one older caldera had combined again to form the island of Rakata.

4 Jan 1907, Ms 7.6. This event caused tsunamis that devastated Simeuleu, Nias and Batu Islands of Sumatra and extended over 950km as measured by tide gauges.

25 June 1914. M7.6 earthquake destroyed buildings in southern Sumatra. No tsunami was reported.

1935: Mw 7.7. Tsunami in SW Sumatra.

The 2004 Sumatra-Andaman earthquake of magnitude 9.3 generated 30m-high tsunami when upward slip of the ocean floor was up to 15m along a 1300 km long and 160 to 240km wide rupture. It was the deadliest tsunami killing about 300.000 people in 13 countries situated all around the Indian Ocean. The earthquake had created large thrust ridges, about 1500m high, which collapsed in places to produce large landslides, several kilometers across. The force of displaced water was such that blocks of rocks, massing millions of tons apiece, were dragged as much as 10km. An oceanic trench several kilometers wide was also formed. The run up in the India was 5m or less.

Magnitude 8.7 great Sumatra Earthquake of 28 Mar. 2005 with an upward movement of 2m of seafloor in an area of 400kmx100km generated locally damaging 4m-high tsunami that struck nearby islands and coastal Sumatra and was recorded by tidal stations in the Indian Ocean (asc.India.org). The earthquake and tsunami killed 665 people. The tsunami struck Nias Island with wave heights of 4-5 m. A 3-4m wave struck the islands of Banyak and Simeulue and the Singkil district of Sumatra. According to the Pacific Tsunami Warning Center (PTWC) tide gauges in the Indian Ocean recorded minor wave activity in the Australian Cocos Island (10-22cm), the Maldives (10cm), and Sri Lanka (25-30cm).

TSUNAMIS THAT AFFECTED THE INDIAN REGION AND VICINITY

Though rare, tsunamis have hit India earlier. The tsunamis in the Indian region and vicinity are listed in Table 2. The oldest record of tsunami is available from November 326 BC earthquake near the Indus delta /Kutch region that set off massive sea waves in the Arabian Sea. Alexander the Great was returning to Greece after his conquest and wanted to go back by a sea route. But a tsunami due to an earthquake of large magnitude destroyed the mighty Macedonian fleet (Lisitzin, 1974).

Poompuhar is a town in the southern part of India in the state of Tamil Nadu. It was a flourishing ancient town known as Kaveripattinam that was washed away in what is now recognized as an ancient Tsunami in about 500 AD This time matches with the Krakatoa explosion

There is mention of tsunami effect in scriptures at Nagapattinam in 900AD that destroyed a Budhist monastery. According to literature available in the library of Thondaiman kingdom in Puduckottai, Tamilnadu, it was during the reign of Raja Raja Chola that waves had washed away the monastery and several temples and killed hundreds of people. There is evidence of this in Kalaki Krishnamurty's book "Ponniyin Selvan- The Pinacle of Sacrifice". In the chapter "The Sea Rises", the author explains how the sea had risen very high and the black mountain of water moved forward. The sea inundated warehouses and sheds and began to flow into the streets. Ships and boats seemed suspended in mid-air, precariously poised on the water peaks. The book also describes how an elephant was swallowed by the gushing water.

Tsunami has been observed in the North Indian Ocean on the Iranian coast from a local earthquake between 1st April and 9th May 1008 (Murty et al., 1999).

An earthquake occurred during 1524 A.D. off the coast of Dabhol, Maharashtra and. a resulting large tsunami caused considerable alarm to the Portuguese fleet that was assembled in the area (Bendick and Bilham, 1999).

A tsunami is known to have occurred in the Bay of Bengal on April 2, 1762, caused by an earthquake in Bangladesh – Myanmar border region. The epicenter is believed to be 40 km SE of Chittagong, or 61 km N of Cox's Bazaar, or 257 km SE of Dhaka, Bangladesh. The shock caused severe damage at Chittagong and other areas on the eastern seaboard of the Bay of Bengal. The Arakan coast was elevated for more than 160 km. The quake also caused a tsunami in the Bay of Bengal. The water in the Hoogly River in Kolkata rose by two meters. The rise in the water level at Dhaka was so sudden that hundreds of boats capsized and many people were drowned. This is the earliest well-documented tsunami in the Bay of Bengal (Mathur, 1998).

1819 June 16, India, Kutch, Mw 7.8. Severe earthquake with large changes in the elevation of the land. The town of Sindri (26.6N 71.9E) and adjoining country were inundated by a tremendous rush from the ocean, and all submerged, the ground sinking apparently by about 5m (Macmurdo,1821)

An earthquake on 11th November 1842 near the northern end of Bay of Bengal caused a tsunami by which waters of the distributaries of the Ganges Delta were agitated. Boats were tossed about as if by waves in a squall of wind.

1845 June 19, India, Kutch. “The sea rolled up the Koree (Kori creek, 23.6N 68.37E) (the east) mouth of the Indus overflowing the country as far westward as the Goongra river, northward to the vicinity of Veyre, and eastward to the Sindree Lake,” (Nelson,1846)

On October 31, 1847 the small island of Kondul (7°13’N 93°42’E) near Little Nicobar was inundated (Heck, 1947; Berninghausen, 1966) by an earthquake whose Mw, magnitude could have been >7.5 (Bilham et al. 2005).

Mihir Guha (http://www.freejournal.net), former Director General of the India Meteorological Department, informed that a tsunami struck Sunderbans (Bangladesh) in May 1874, killing several hundred thousand people. It was result of an earthquake in Bhola district. Earthquake and tsunami both played havoc in vast areas of Sunderbans, 24-Prganas, Midnapore, Barishal, Khulna and Bhola. Even Kolkata felt its impact. It was the same year that the meteorological center in Alipore was set up. However, no written record of such an earthquake or tsunami is available.

Other minor tsunamis of height up to 2m hit the east coast of India in 1842 and 1861 (from Sumatra), 1881 (from Car Nicobar), 1883 (Krakatau), 1907 (Sumatra) and 1941 (Andaman). The 1881 Andaman earthquake of Mw7.9 caused 1.2-m high tsunami. Indonesian earthquake of 1907 registered about a meter high tsunami in India. Madras Port Trust recorded a 2m high tsunami due to the eruption of the Krakatau volcano in Indonesia on 27 Aug 1883. Andaman earthquake of Mw7.7 in 1941 registered a 1.5m high tsunami. Some of these tsunamis are described below:

An earthquake of magnitude Mw 7.9 occurred at Car Nicobar Island on 31 Dec. 1881. A tsunami was generated by this earthquake in the Bay of Bengal. Though the run-ups and waves heights were not large, its effects were observed in the Andaman & Nicobar Islands and were recorded on the east coast of India. A meter high wave was recorded at Port Blair on South Andaman Island (Berninghausen, 1966). In the Nicobar Islands, the waves were less than 75 cm high. On the east coast of India, the tsunami first arrived at Nagapatinam at around 10:15 am local time (LT) with a 1.2m high waves. Tidal gauges at other locations recorded minor variations from normal tidal changes. The tsunami then struck the rest of the Tamil Nadu coast, first hitting Chennai and then progressing north toward Vishakhapatnam in Andhra Pradesh at 10:43 LT. Waves arrived at False Point on the Mahanadi delta in Orissa at 11:15 LT and at Pamban in the Gulf of Mannar at 11:32 LT. Waves less than 0.3 metres high were recorded later in the day in West Bengal by tidal gauges at Dublat at the mouth of the Hoogly river at 13:00 LT and then in Diamond Harbour at 15:10 LT (Ortiz and Bilham, 2003). Waves attributed to this tsunami were also observed at Batticaloa and Trincomalee on the east coast of Sri Lanka (Berninghausen, 1966). No tsunami was reported from tidal gauges in Myanmar (Ortiz and Bilham, 2003).

A tsunami was noticed at Dublet (mouth of Hoogly River) near Kolkata due to earthquake in the western part of the Bay of Bengal in 1884 (Murty et al. 1999) that reached up to Port Blair.

June 26, 1941 Andaman earthquake had a moment magnitude Mw 7.7 and was located at 12.1^{o} N and 92.5^{o} E (Bilham et al., 2005). A tsunami was triggered by this earthquake in the Bay of Bengal. Height of the tsunami was reported to be of the order of 0.75 to 1.25 meters. At the time no tidal gauge was in operation. Mathematical calculations suggest that the height could be of the order of 1m. This tsunami was witnessed along the eastern coast of India. It is believed that nearly 5,000 people were killed by the tsunami on the east coast of India. Local newspapers are believed to have mistaken the deaths and damage to a storm surge, however, a search of meteorological records does not show any storm surge on that day on the Coromandel Coast (Murty, 1984). National dailies like the Times of India, which reported the quake's shaking effects, did not mention any deaths, either as a result of a storm surge or a tsunami.

The deadliest tsunami prior to 2004 in South Asia was in November 1945, which originated off the Makran coast of Pakistan in the Arabian Sea and caused deaths as far as Mumbai. More than 4000 people were killed on the Makran Coast by both the earthquake and the tsunami. The earthquake was also characterized by the eruption of a mud volcano, a few kilometers off the Makran Coast, which are common features in Western Pakistan and Myanmar. It led to the formation of a four small islands. A large volume of gas that erupted from one of the islands, sent flames leaping "hundreds of meters" into the sky (Mathur, 1988). The most significant aspect of this earthquake was the tsunamis that it triggered. The tsunami reached a height of 17m in some Makran ports and caused great damage to the entire coastal region. A good number of people were washed away. The tsunami was also recorded at Muscat and Gwadar. The tsunami had a height of 11.0 - 11.5 m in Kutch, Gujarat (Pendse, 1945). At 8:15am, it was observed on Salsette Island i.e Mumbai (Newspaper archives, Mumbai). It was recorded in Bombay Harbour, Versova (Andheri), Haji Ali (Mahalaxmi), Juhu (Ville Parle) and Danda (Khar). At Versova (Andheri, Mumbai), 5 persons who were fishing were washed away. At Haji Ali (Mahalaxmi, Mumbai), 6 persons were swept into the sea. At Danda and Juhu, several fishing boats were torn off their moorings. The tsunami did not do any damage to Bombay Harbour. Most persons who witnessed the tsunami said that it rose like the tide coming in, but much more rapidly. The height of the tsunami in Mumbai was 2m. A total of 15 persons were washed away in Mumbai.

Mw 7.7, 1983 earthquake in Chagos Archipelago, was one of the strongest earthquakes ever recorded in the Indian Ocean. It occurred at 17:46pm UTC. The earthquake caused some damage (NEIC) to buildings and piers on Diego Garcia. Diego Garcia is part of the Chagos Archipelago. The 1983 earthquake spawned a tsunami in the region. In the lagoon, on Diego Garcia, there was a 1.5-meter rise in wave height and there was some significant wave damage near the southeastern tip of the island. A 40 cm wave was also recorded at Victoria, Seychelles. There was a large zone of discolored seawater observed 60 - 70 km NNW of Diego Garcia. Moment-tensor solution indicated normal faulting along an E-W plane at a depth of 10km with source duration of 34 sec.

CONCLUSIONS

The catalog prepared for tsunamis in the Indian Ocean includes about ninety tsunamis. Eighty percent of the tsunamis in the Indian Ocean are from Sunda arc region where on an average tsunamis are generated once in three years. In rest of the Indian Ocean tsunamis can be generated once in ten years or so. The Makran accretion zone of southern Pakistan has produced some tsunamis. The 28 Nov. 1945 (Mw 8.0) earthquake generated the last major tsunami in the Arabian Sea. Indus Delta and may be the Coasts of Kutch and Saurashtra are also potential zones for great earthquakes and tsunami. Tsunami was generated by an earthquake in 1762 in Myanmar and in 1874 by an earthquake near Bangladesh. The Chagos ridge has given rise to a local tsunami due to a normal earthquake of Mw 7.7 on 30 Nov. 1983 near Diego Garcia.

This work was carried out under CSIR Emeritus Scientist Scheme.

REFERENCES

Bendick, R, and R. Bilham, (1999). A Search for Buckling of the SW Indian Coast related to Himalayan Collision, in Macfarlane, A., Sorkhabi, R. B., and Quade, J., eds., Himalaya and Tibet: Mountain Roots to Mountain Tops: Geol Soc Amer. Special paper 328. 313-322.

Berninghausen, W. H., (1966). Tsunamis and Seismic Seiches reported from regions adjacent to the Indian Ocean, Bull. Seism. Soc. Am., 56 (1), 69-74.

Bilham, R, R. Engdahl, N.Feld, and S.P. Sayabala (2005). Partial and complete rupture of the Indo-Andaman plate boundary 1847-2004, Seism. Res. Lett., 76 (3), 299-311.

George Pararas-Carayannis (2003). Near and Far-Field Effects of Tsunamis Generated By the Paroxysmal Eruptions, Explosions, Caldera Collapses and Massive Slope Failures of The Krakatau Volcano in Indonesia on August 26-27, 1883, Science of Tsunami Hazards, 21 (4), 191-222.

Heck, N.H. (1947). List of seismic sea waves, Bull.Seism. Soc. Am., 37, 269-286.

Lisitzin, E. (1974). Sea Level Changes, Elsevier Oceanographic Series, No.8, New York, 273pp.

Macmurdo, Captain (1821). Account of the earthquake which occurred in India in June 1819, Edinburgh Phil.J. 4, 106-109.

Mathur, S.M., (1998). "Physical Geology of India", National Book Trust of India, New Delhi.

Murty, T. S., A. Bapat & Vinayak Prasad (1999). Tsunamis on the coastlines of India, Science of Tsunami Hazards, 17 (3), 167-172.

Murty, T.S. (1984). Storm surges- meteorological ocean tides, Bull. Fisheries Research Board of Canada, Ottawa.

Nelson, Captain (1846). Notice of an earthquake and a probable subsidence of the land in the district of Cutch, near the mouth of Koree, or the eastern branch of the Indus in June 1845, Geol.Soc. London, Quart. J.,2, 103.

Newcomb, K.R. and McCann, W.R. (1987). Seismic history and tectonics of the Sunda Arc, JGR, 92 (B1), 421-439.

Ortiz, M., and Bilham, R. (2003). Source Area and Rupture Parametres of the 31 December 1881 Mw=7.9 Car Nicobar Earthquake estimated from tsunamis recorded in the Bay of Bengal, J. Geophys. Res- Solid Earth, 108(4), ESE 11, 1-16.

Pendse, C. G. (1945). The Mekran earthquake of the 28th November 1945, India Met. Deptt. Scientific Notes, 10, 141-145.

Table 1

List of Tsunamis in Sumatra-Java region

N	Year	Location	Long.	Lat.	Mag	Ca	Pro	I	Max Run up (run ups)	Ref.
1	416.09.10	Java-S	120	-10		6	2			NOAA/NESDIS
2	1681.12.11	Sumatra				1	4			Newcomb& Mccann
3	1768.06.22	Bali Sea	115	-7	Ms 7.5	1	4			NOAA/NESDIS
3	1770	Sw. Sumatra	102	-5	Ms 7	1	3	0.5	(1)	NGDC/NOAA
4	1797.02.10	Sw. Sumatra	99	-1	Ms 8	1	4	3.0	(1)	Berninghausen
5	1799	Se. Sumatra	104.75	-2.983		1	2			Berninghausen
6	1815.04.10	Java-Flores Sea	118	-8.2		6	4			NOAA/NESDIS
7	1815.11.22	Bali Sea	115.2	-8	Ms 7	3	3			NOAA/NESDIS
8	1816.04.29	Penang Island	100.25	5.383		1	2		(1)	NGDC/NOAA
9	1818.03.18	Bengkulu, Sumatra	102.267	-3.77	Ms 7	3	3	1.5	(1)	Berninghausen
10	1818.11.08	Bali Sea	117	-7	Ms 8.5	1	2			NOAA/NESDIS
11	1820.12.29	Flores Sea	119	-7	Ms 7.5	1	4			NOAA/NESDIS
12	1823.09.09	Java	108.5	-6.5	Ms 6.8	1	2			NOAA/NESDIS
13	1833.01.29	Bengkulu, Sumatra								Berninghausen (1966)
14	1833.11.24	Sw. Sumatra	102.2	-3.5	Mw 8.7	1	4	2.5	(3)	NGDC/NOAA, Newcomb & McCann (1987)
15	Sep. 1837	Banda Ache	96	5.5	Ms 7.2	4	2	0.5	(1)	NGDC/NOAA
16	1843.01.05	Sw. Sumatra	98	1.5	Ms 7.2	1	4	3.0	(3)	Berninghausen (1966), Heck1947
17	1843.01.06	Sw. Sumatra	97.33	1.05						Berninghausen (1966)m Heck1947
18	1852.11.11	Sibolga, Sumatra	98.8	1.7	Ms 6.8	1	1		(1)	NGDC/NOAA
19	1856.07.25	Java-Flores Sea	116	-8.5		1	2			NOAA/NESDIS
20	1857.05.13	Bali Sea	115.5	-8	Ms 7	1	4		(2)	NOAA/NESDIS
21	1859.10.20	S. Java Sea	111	-9		1	2		(1)	Berninghausen (1966)
22	1861.02.16	Sw. Sumatra	97.5	-1	Ms 8.5	1	4	3.0	(9)	Berninghausen (1966)
23	1861.03.09	Sw. Sumatra	99.37	0.3	Ms 7	1	4	2.0	(4)	NGDC/NOAA
24	1861.04.26	Sw. Sumatra	97.5	1	Ms 7	1	4	1.5	(1)	NGDC/NOAA
25	1861.06.05	Java,	107.3	-6.3			2			NOAA/NESDIS
26	1861.06.17	Sw. Sumatra	97.5	1	Ms 6.8	1	3			NOAA/NESDIS

27	1861.09.25	Sw. Sumatra	100	-1.5	Ms 6.5	1	3	1.5	(1)	Berninghausen (1966)
28	1864	Sumatra								Berninghausen
29	1883.08.26	Krakatau	105.423	-6.10		6	3	1.0	(8)	Berninghausen
30	1883.08.27	Krakatau (Volcano)	105.25	-6.06		6	4	4.5	35 (67)	Berninghausen
31	Feb. 1884	Krakatau	105.423	-6.10		1	2			Murty et al. (1999)
32	1885.07.29	Ajerbangis	99.383	0.2	Ms 6.8	1	2			NGDC/NOAA
33	1889.08.16	Java, Indones.	106	-6	Ms 6	1	3	1.0		NGDC/NOAA
34	1892.05.17	Malay Peninsula	99.5	2.5	Ms 7.5	1	3		4 (4)	NGDC/NOAA
35	1896.10.10	Sw. Sumatra	102.5	-3.5	Ms 6.8	1	2		1 (1)	NGDC/NOAA
36	1904.07.04	Sumatra								
37	1907.01.04	Sw. Sumatra	94.5	2	Ms 7.6	1	4	2.0	2.8 (7)	NGDC/NOAA / Newcomb &McCann
38	1908.02.06	Sw. Sumatra	100	-5	Ms 7.5	1	4	1.0	1.4 (1)	NGDC/NOAA
39	1909.06.03	Sumatra	101	-2	Ms 7.7	1	2	1.0	1.4	NGDC/NOAA
40	1914.06.25	W. Coast Of S. Sumatra	102.5	-4.5	Ms 8.1	1	0			NGDC/NOAA
41	1917.01.21	Bali Sea	115.4	-8	Ms 6.5	1	3		2	NGDC/NOAA
42	1921.09.11	S. Java Sea	111	-11	Ms 7.5	1	4		0.2	NGDC/NOAA / Newcomb &McCann
43	1922.07.08	Lhoknga, Ache	95.233	5.467		1	1			NGDC/NOAA
44	1926.06.28	Sw. Sumatra	99.5	-1.5	Ms 6.7	1	0			NGDC/NOAA
45	1928.03.26	Krakatau	105.423	-6.102		6	1			NGDC/NOAA
46	1930.03.17	Java-S.	105.4	-6.1		6	1			NGDC/NOAA
47	1930.06.19	Java-S.	105.3	-5.6	Ms 6	1	3		0.7	NGDC/NOAA
48	1930.07.19	S. Java Sea	114.3	-9.3	Ms 6.5	1	2		0.1	NGDC/NOAA
49	1931.09.25	Sw. Sumatra	102.7	-5	Ms 7.5	1	3		31.4	NGDC/NOAA
50	1935.12.28	Sw. Sumatra	98.25	.001	Ms 8.1	1	1			NGDC/NOAA
51	1936.08.23	Malay Peninsula	95	6	Ms 7.3	1	2			NGDC/NOAA
52	1948.06.02	Malay Peninsula	94	5.5	Ms 6.5	1	2		0.7	NGDC/NOAA
53	1949.05.09	Malay Peninsula	95	5	Ms 6.7	1	2			NGDC/NOAA
54	1955.05.17	Malay Peninsula	94	6.5	Ms 7.2	1	2			NGDC/NOAA
55	1957.09.26	S. Java Sea	107.3	-8.2	Ms 5.5	1	3		0.7	NGDC/NOAA
56	1958.04.22	Sw. Sumatra	104	-4.5	Ms 6.5	1	2		1	NGDC/NOAA
57	1963.12.16	Java	105.4	-6.2	6.5	1	2		0.7	NGDC/NOAA
58	1964.04.02	Off Nw Coast Of Indon.	95.7	5.9	Ms 7.0	8	3		0.7	NOAA/NESDIS
59	1964.04.02	Malay	95.7	5.9	Ms 7.0	1	3		**2**	NOAA/NESDIS

		Peninsula								
60	1967.04.12	Malay Peninsula	97.3	5.5	Ms 7.5	1	3	**1.5**		NGDC/NOAA
61	1977.08.19	Sunda Islands	118.4	-11	Ms 8	1	4			NOAA/NESDIS
62	1982.02.24	Java Trench	97.7	4.37	Ms 5.4	1	4			NGDC/NOAA
63	1984	Off West Coast Of Sumatra	97.955	0.18	7.2					Engdahl et al. (1998)
64	1985.04.13	Bali Island, Indonesia	114.2	-9.2	Ms 6.2	1	2			NGDC/NOAA
65	1994.02.15	Southern Sumatra	104.3	-5	Ms 7.0	1				NGDC/NOAA
66	1994.06.02	Java, Indonesia	112.8	-10.5	Ms 7.2	1	4		**13** (15)	NGDC/NOAA
67	2000.06.04	Off West Coast of Sumatra	102.09	-4.72	Ms 7.8				(1)	USGS/NEIC(PDE)
68	2000.06.18	South Indian Ocean	97.45	-13.8	Ms 7.8	1	4		**0.3**	NOAA/NESDIS
69	2004.12.26	Off West Coast Of Sumatra	95.947	3.307	Mw 9.3	1	4	**3.0**	**24** (302)	NGDC/NOAA
70	2005.03.28	Off West Coast Of Sumatra	97.013	2.074	Mw 8.7	1	4		**4** (2)	NOAA/NESDIS
71	2005.04.10	Kepulauanmentavia	99.607	-1.64	Ms 6.7	1	4		**1** (1)	NOAA/NESDIS

I is tsunami intensity, max. run up is in meters, reported number of runups are given within brackets. The data are taken from National Geophysical Data Center (NGDC); National Oceanic and Atmospheric Administration (NOAA) and National Environmental Satellite, Data, and Information Service (NESDIS). A "-1" is used as a flag (missing) value in some fields. The cause and probability of the tsunamis are shown by “Ca.” and “Pro.” respectively. The cause and probability of the tsunamis are given by following codes.

Cause Code:

Cause code indicates the cause or source of the tsunamis.
Valid values: **1 to 12**
1 = earthquake
2 = questionable earthquake
3 = earthquake and landslide
4 = earthquake and volcano
5 = earthquake, volcano and landslide
6 = volcano
7 = volcano and earthquake
8 = volcano and landslide
9 = volcano, earthquake, and landslide
10 = landslide
11 = meteorological
12 = explosion

Event Probability:

Probability of actual tsunami occurrence is indicated by a numerical rating of the validity of the reports of that event:

Valid values: 0 to 4
4 = definite tsunami
3 = probable tsunami
2 = questionable tsunami
1 = very doubtful tsunami
0 = erroneous entry

Tsunami Magnitude:

Tsunami magnitude, Mt is defined in terms of tsunami-wave amplitude by Iida et al. (1967) as:

$Mt = \log_2 Hmax$

Some other formulae are also in use.

Tsunami Intensity:

Tsunami intensity scales have been suggested based on its effect and damage caused by it. There are many formulae for intensity based on tsunami runups. Tsunami intensity is defined by Soloviev and Go (1974) as

$I = \log_2 (2^{1/2} * h)$

where "h" is the maximum run up height of the wave.

Table 2

List of Tsunamis that Affected Indian Region and Vicinity

S. N.	Date	Location	Long.	Lat.	Eq. Mag	Cau	Pro	I	Max Run up (run ups)	Ref.
1	326 B.C.	Indus delta /Kutch region				1	4			Lisitzin (1974)
2	About 500 AD	Poompuhar, Tamilnadu (probably due to Krakatau eruption)	79.52	11.12			4			Wikipedia
3	900 AD	Nagapattinam, Tamilnadu (may be from Sunda-Andaman arc)	79.53	10.46			4			Kalaki Krishnamurty
4	1008	Iranian Coast	60	25		1	4			Murty et al. (1999)
5	1762.04.12	Bay of Bengal (Bangladesh)	92	22		1	4		**>2** (1)	Mathur (1988)
6	1819.06.16	Kutch	26.6	71.9	Mw 7.8	1	3			Macmurdo
7	1842.11.11	N.Bay of Bengal	90	21.5		1	4		(3)	Oldham (1883)
8	1845.06.19	Kutch	23.6	68.37		1	3			Nelson
9	1847.10.31	Little Nicobar Island	93.667	7.333	Mw 7.5-7.9	1	3			Berninghausen (1966), Heck,1947
10	1868.08.19	Andaman Islands	92.73	11.67		1	4		**4**	NGDC/NOAA
11	1874	Sunderbans (Bangladesh)	89	22		1	2			Mihir Guha, Free Journal
12	1881.12.31	W. of Car Nicobar	92.43	8.52	Mw 7.9	1	4		**1.2**	Berninghausen (1966), Ortiz and Bilham (2003)
13	Jan. 1882	Sri Lanka (may be from Indonesia)	81.14 E	8.34		1	3			Berninghausen (1966)
14	1883.08.27	Krakatau (Volcanic Eruption)	105.25	-6.06		6	4	4.5	**2**	Berninghausen (1966)

15	1884	W. of Bay Of Bengal								Murty et al. (1999)
16	1935.05.31	Andaman-Nicobar			Mw 7.5	1	4		(1)	NGDC/NOAA
17	1935.11.25	Andaman-Nicobar	94	5.5	Ms 6.5	1	2			NGDC/NOAA
18	1941.06.26	Andaman Islands	92.5	12.1	Mw 7.7	1	4		**1.25**	Bilham et al. 2005
19	1945.11.27	Makran Coast	63.5	25.2	Mw 8.0	1	4		**17**	Murty et al. (1999)
20	1983.11.30	Chagos ridge	72.11	-6.85	Mw 7.7	1	4		**1.5** (2)	NGDC/NOAA
21	2004.12.26	Off west coast of Sumatra and Andaman-Nicobar	95.947	3.307	Mw 9.3	3	4	3.0	**30**	NGDC/NOAA

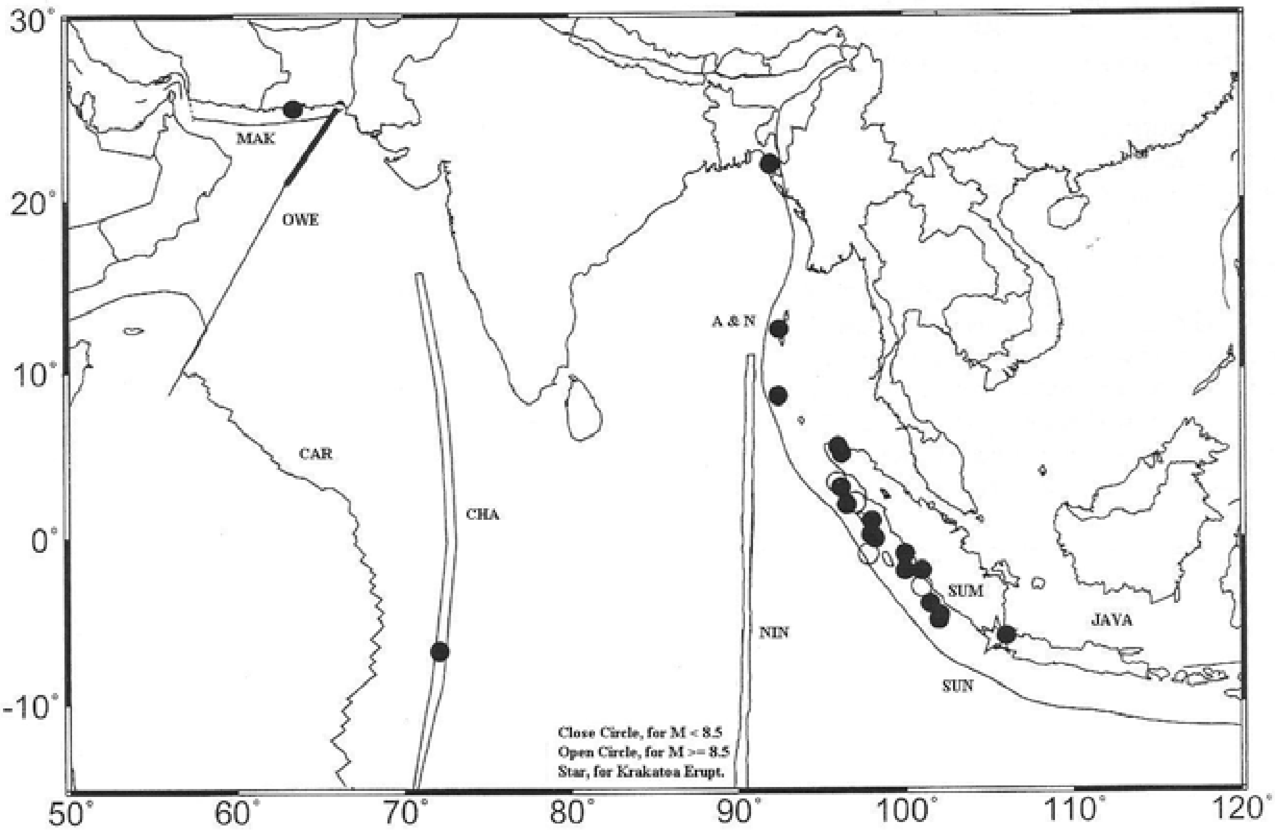

Fig.1. Locations of tsunamis in the Indian Ocean.

MAK - Makran Accretion Zone, OWE – Owen Fracture Zone, CAR – Carlsberg Ridge, CHA – Chagos Archipelago, A & N – Andaman & Nicobar Islands, SUM – Sumatra, NIN – Ninety East Ridge, SUN – Sunda Subduction Zone and JAVA- Java.

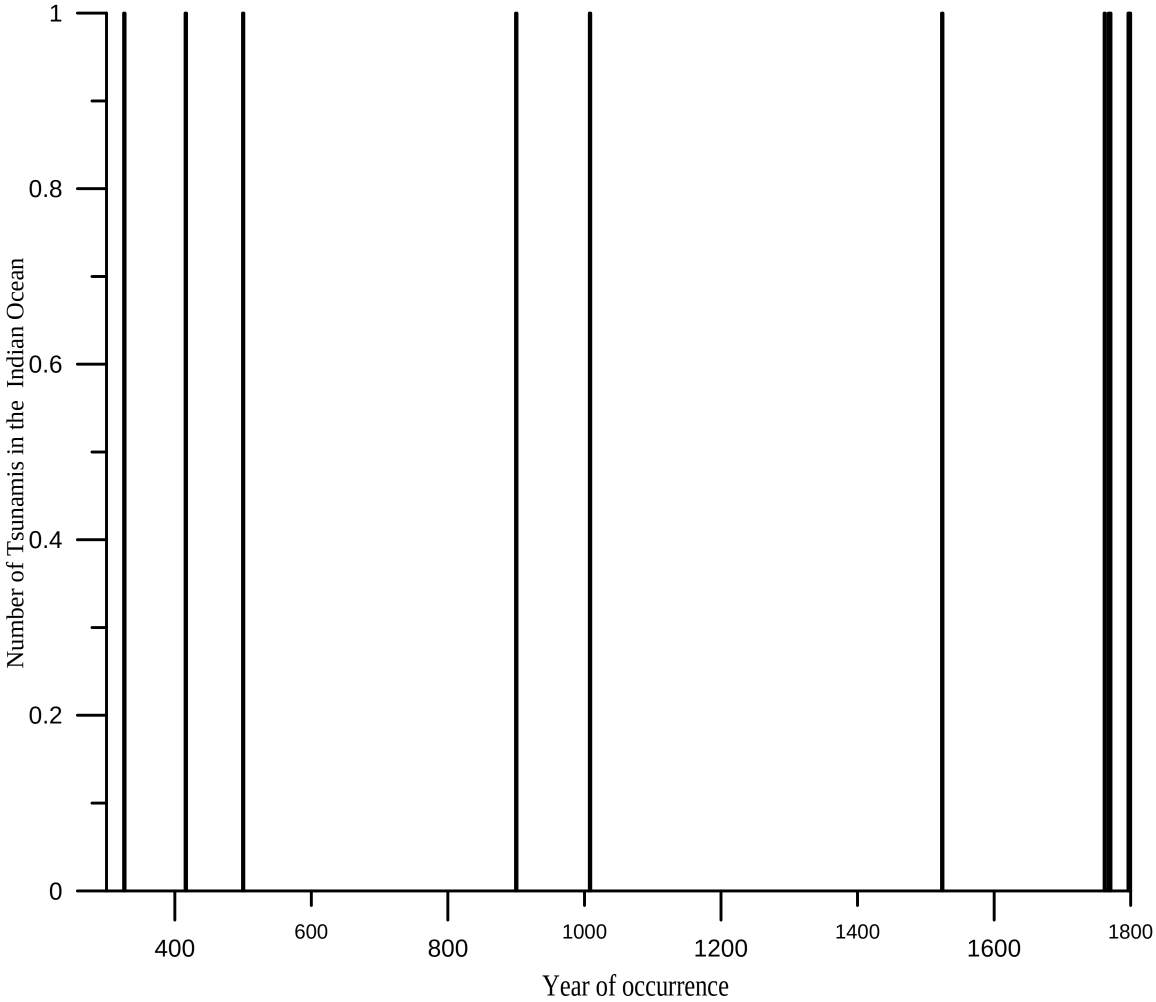

Fig. 2a. No. of Tsunamis in the Indian Ocean vs. Years of occurrences, Prior to 1800.

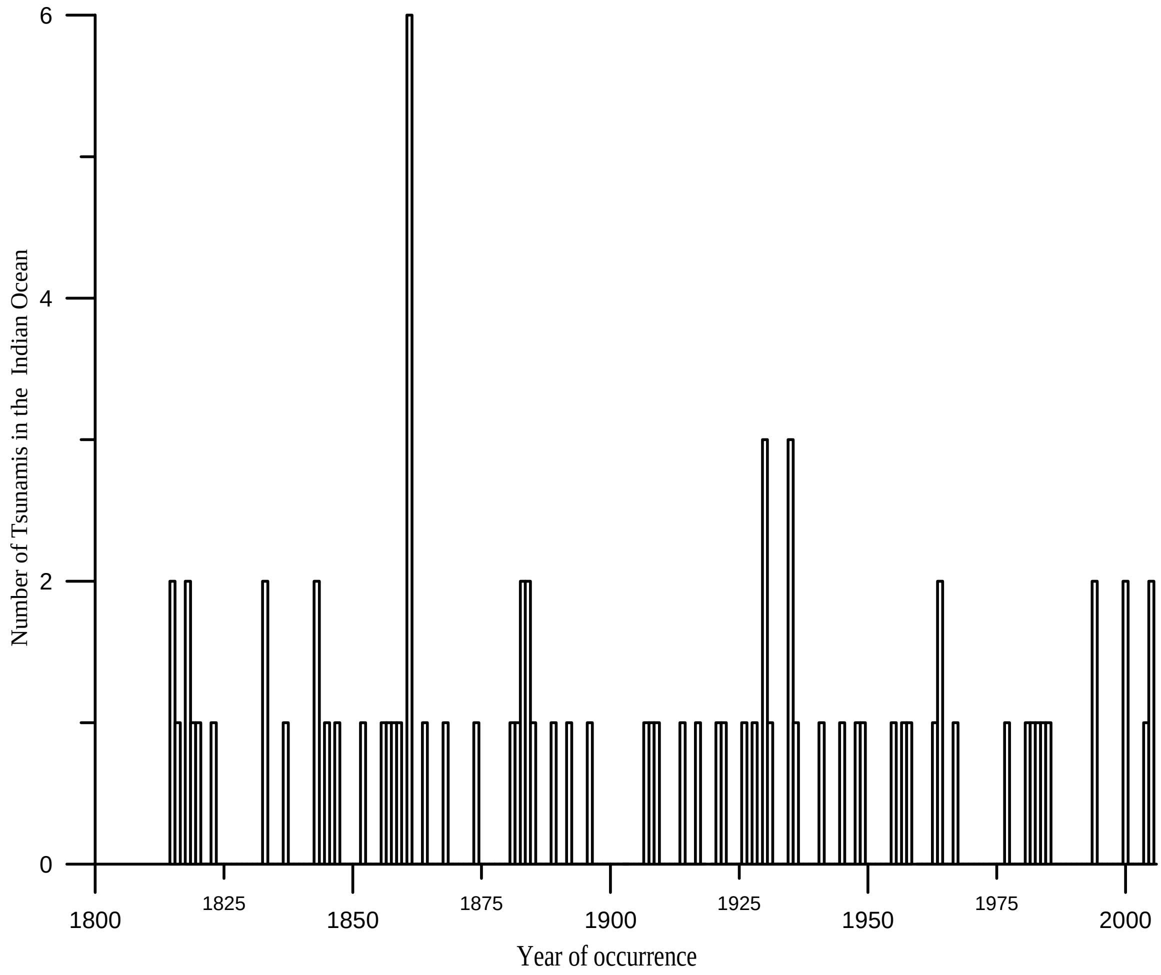

Fig. 2b. No. of Tsunamis in the Indian Ocean vs. Years of occurrences, 1800 Onward to Present.