

Tsunami threat to coastal areas of Sabah, East Malaysia

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Abstract: A study of the regional tectonic setting and a review of historical data on earthquakes and tsunami indicate that there is no threat from local tsunami to the coastal areas of west Sabah fronted by the South China Sea. Distant tsunami, generated by earthquakes along a subduction zone marked by the Manila Trench at the northeast end of the South China Sea, also do not pose a threat to the coastal areas of west Sabah in view of the wide continental shelf that will lead to insignificant run-ups (<0.5 m). There is also no threat of local tsunami to the coastal areas of northeast Sabah fronted by the Sulu Sea, though distant tsunami generated by large magnitude ($M_s > 7.0$) earthquakes with shallow foci (<33 km depth) along the subduction zone marked by the Negros Trench at the north end of the Sea may reach these coastal areas. The wide continental shelf fronting the northern and central sectors of northeast Sabah will, however, result in insignificant run-ups (<0.5 m) of these distant tsunami, though the narrower continental shelf off the east Dent Peninsula may result in locally significant run-ups (>0.5 m). Tsunami that have occurred in the Sulu Sea, however, have so far only been of a local significance. There is also no threat of local tsunami to the coastal areas of east Sabah fronted by the Sulawesi Sea, though distant tsunami generated by earthquakes along subduction zones marked by the Cotabato and North Sulawesi trenches along the north and south edges of the Sea, respectively, may reach these coastal areas. The relatively wide continental shelf along most coastal areas of east Sabah will, however, result in insignificant run-ups (<0.5 m) of these distant tsunami, though the narrow continental shelf fronting the coastal areas of the Dent and Semporna Peninsulas may lead to locally significant run-ups (>0.5 m high). Tsunami that have occurred in the Sulawesi Sea, however, have so far only been of a local significance and have been generated by large magnitude ($M_s > 7.0$) earthquakes with shallow foci (<33 km depth) along the subduction zones marked by the Cotobato and North Sulawesi Trenches.

Abstrak: Kajian kedudukan tektonik serantau serta rekod sejarah gempabumi dan tsunami menunjukkan bahawa kawasan pantai barat Sabah yang dikelilingi oleh Laut Cina Selatan tidak menghadapi ancaman tsunami tempatan. Tsunami jarak jauh yang dijanakan oleh gempabumi di zon subduksi yang ditandakan oleh Parit Lautan Manila di hujung timur laut Laut Cina Selatan juga tidak menunjukkan sebarang ancaman kepada kawasan pantai barat Sabah berikutan kewujudan pentas benua yang lebar mengakibatkan paras limpahan yang rendah (<0.5 m). Tsunami tempatan tidak memberi ancaman terhadap kawasan pantai timur laut Sabah yang dikelilingi oleh Laut Sulu walaupun tsunami jarak jauh yang dijanakan oleh gempa bumi bermagnitud tinggi ($M_s > 7.0$) dengan fokus yang cetek (<33 km kedalaman) di sepanjang zon subduksi yang ditandakan oleh Parit Lautan Negros di hujung utara Laut Sulu berkemungkinan sampai ke pantai kawasan ini. Pentas benua yang sangat lebar di bahagian utara dan tengah kawasan pantai timur laut Sabah mengakibatkan limpahan air yang rendah (<0.5 m), manakala pentas benua yang lebih sempit di timur Semenanjung Dent pula berupaya mengakibatkan paras limpahan tempatan yang lebih tinggi (>0.5 m). Walaubagaimanapun, tsunami yang telah berlaku di Laut Sulu hanya memberi kesan secara tempatan sahaja. Kawasan pantai timur negeri Sabah yang dikelilingi oleh Laut Sulawesi juga tidak menghadapi ancaman tsunami tempatan, tetapi boleh dipengaruhi oleh tsunami jarak jauh yang dijanakan oleh gempabumi di sepanjang zon-zon subduksi yang ditandakan oleh Parit Lautan Cotabato dan Sulawesi Utara yang terletak di hujung utara dan selatan Lautan Sulawesi. Pentas benua yang lebar di hadapan kebanyakan kawasan pantai timur negeri sabah hanya mengakibatkan paras limpahan yang rendah sahaja (<0.5 m), manakala di hadapan Semenanjung Dent dan Semporna, paras limpahan tempatan yang lebih tinggi (>0.5 m) boleh terjadi berikutan pentas benua yang lebih sempit di sini. Walaubagaimanapun, tsunami yang telah berlaku di Laut Sulawesi hanya memberi kesan tempatan sahaja. Tsunami tersebut yang telah dijanakan oleh gempabumi bermagnitud besar ($M_s > 7.0$) dengan fokus yang cetek (<33 km kedalaman), telah berlaku di sepanjang zon-zon subduksi yang ditandakan oleh Parit Lautan Cotabato dan Sulawesi Utara.

INTRODUCTION

Tsunami are large waves of extremely long wavelength and period that are generated by violent, impulsive undersea disturbances near the coast or in the ocean; the most destructive usually being generated by earthquakes with shallow foci in regions of the earth where there is subduction along tectonic plate boundaries. When the plates move past each other, they can tilt or displace large areas of the ocean floor, thus disturbing the ocean's surface

and generating tsunami. Not all earthquakes, however, generate tsunami for it is usually those with a Richter magnitude exceeding 7.5 that have produced destructive tsunami (ITIC, 2007). Displacements of the ocean floor by volcanic eruptions and landslides can also generate tsunami that can be very destructive locally, though their energy is rapidly dissipated as the waves travel across the ocean (Pararas-Carayannis, 1985).

Tsunami arrive at a coastline as a series of successive crests (high water levels) and troughs (low water levels)

- usually occurring 10 to 45 minutes apart. As they enter the shallow waters of coastlines, bays, or harbours, their speed and wavelength decreases, though their heights are considerably increased. Depending on the water depth and coastal configuration furthermore, the waves may also undergo extensive refraction. Tsunami waves may thus smash into the shore like a wall of water or move in as a fast moving flood or tide - carrying everything on their path. Either way, the waves become a significant threat to life and property. If the tsunami arrive at high tide or if there are concurrent storm waves, the effects will be cumulative and the inundation and destruction even greater. The maximum height a tsunami reaches on shore is called the run-up and is the vertical distance between the maximum height reached by the water on shore and the mean sea level surface. Tsunami run-up at the point of impact will depend on how the energy is focused, the travel path of the tsunami waves, the coastal configuration, and the offshore topography (ITIC, 2007).

There is very little that can be done to prevent the occurrence of tsunami, though their impacts, especially loss of life and property, can be considerably reduced through proper planning. In this respect, qualitative evaluations of the potential threat of tsunami to coastal areas are very useful as they serve as a base on which tsunami warning and evacuation systems can be developed. In this paper, the potential threat of tsunami to the coastal areas of Sabah is discussed and is based on a study of its tectonic setting as well as a review of historical data on tsunami and earthquakes. The coastal configuration as well as the near-shore, and off-shore, bathymetry are also considered in order to identify areas where there may be significant run-ups (>0.5 m high) in the event of a tsunami.

REGIONAL TECTONIC SETTING

Sabah occupies a central position in the area of the

junction between the Eurasian, Indo-Australian, Pacific and Philippines tectonic plates; the overall configuration consisting of the Pacific Plate moving west towards the Eurasian Plate as the Indo-Australian Plate moves northwards (Fig. 1). A mosaic of smaller plates, some of them forming marginal seas, characterizes the area; the evolution of which is still far from being understood, though several models have been proposed (Hall, 2002). Sabah is located on the eastern side of the South China Sea basin, which is one of the marginal seas. The South China Sea covers an area of some 3.5 million km² and extends northeastwards from the 3° South latitude between south Sumatra and Kalimantan to the Strait of Taiwan. Its southwest half is covered by shallow sea (<100 m deep), whilst its northeast half is much deeper (>3,700 m deep). Oceanic crust with magnetic lineaments is found in the centre of the South China Sea basin; the oldest and most recent anomalies being dated at 32 Ma and 17 Ma respectively. An east-west trending, extinct spreading ridge is present in the northeast end of the basin, whilst an older, northeast-southwest trending ridge is found in its' central part. The remaining part of the South China Sea basin has been interpreted to consist of attenuated continental crust, which in the vicinity of Sabah is called the Northwest Sabah Platform (Hazebroek and Tan, 1993). Some 200 km off the west coast of Sabah is found the Northwest Borneo Trough (2,700 to 2,900 m deep) which extends northeastwards into the Palawan Trough. On the west side of these Troughs is found the Reed Bank submarine plateau and Dangerous Grounds dominated by atolls, reefs and shoals of Neogene age (Schluter *et al.*, 1996).

Off northeast Sabah is the Sulu Sea, which is characterized by several northeast-southwest trending tectonic elements including the Northwest Sulu Basin (water depth up to 2,222 m), the Cagayan Ridge and the Southeast Sulu Basin (water depth exceeding 4,815 m) (Schluter *et al.*, 1996). These northeast-southwest trending



Figure 1: Plate tectonic setting of Sabah (from Figure 1 of Hall, 2002).

terraces are cut by a series of northwest-southeast trending strike-slip faults. A prominent northwest-southeast trending strike slip fault separates the Cagayan Ridge from northeast Sabah and probably extends into the major fault just south of Balabac Island, known as the Strait Balabac Fault. The Sulu Sea forms a near perfect circle with an average depth of over 4,400 meters, though at its southeast edge, the Sulu Archipelago raises the sea floor to a depth of 100 metres. To the west of the Sulu Sea and separating it from the South China Sea is a chain of northeast-southwest trending islands; Palawan Island being the largest.

Off east Sabah is the Suluwasi (or Celebes) Sea, which is bounded to the south by the north arm of Sulawesi, the island of Mindano to the northeast and the Sulu Islands to the northwest. This Basin is currently separated from the West Philippine Sea Basin to the northeast by a complex series of plate boundaries which include the Sanghie Arc, the Halamera and Philippine Trenches as well as the islands of the Philippine Archipelago. However, tectonic plate reconstructions indicate that these two basins were formerly connected (Nichols and Hall, 1999). The Celebes Sea is in the form of a huge basin with a total area of some 280,000 km² and is mostly a deep, flat (4,600 to 5,200 m deep) plain with steep sides; the deepest part being some 6,200 m just southwest of Mindanao. The Sea opens southwest through the Makassar Strait into the Java Sea. The border between the Celebes and Sulu Seas is the Sibutu-Basilan Ridge (Sulu Volcanic Arc) where strong ocean currents, deep sea trenches and sea mounts, combined with active volcanic islands, result in complex oceanographic features.

EARTHQUAKE RELATED EVENTS IN SABAH

Earth tremors (ground shaking) have been reported from time to time in Sabah, though systematic compilation of these reports only started in 1964. A brief summary (in chronological order) of these reports is shown in Table 1 and extends on previous compilations by Lim (1985, 1986) and Raj (1996). From Table 1, it can be seen that the earth tremors are associated with earthquakes whose foci are located not only on-shore, and near-shore, Sabah, but also some distance away in neighbouring countries. It is also to be noted that although there are no reports of tsunami or abnormal tides associated with the earth tremors, there have been other effects. For instance, Fitch (1958) reported that during the Mindanao earthquake of 21 September 1897, “islands appeared in the sea near Labuan and Balambangan Island, due to the escape of mud and inflammable gases from depth. Minor, local earth tremors were also said to have occurred from time to time in association with revival of the activity of mud volcanoes on the islands off Sandakan Peninsula”.

Instrumental seismicity records of the general area (from the National Earthquake Information Centre of the United States Geological Survey) show the distribution of

Table 1: Summary on reports of earth tremors in Sabah (1897 - present)

Date	Details
21 Sept 1897	Sandakan: Two tremors felt after mid-day. Town clock stopped. Kinabatangan, Labuk, Sugut, Kudat & Labuan: Tremors felt. Epicentre: South of Mindano where considerable loss of life. Mag. 8.7.
5 Apr 1902	Tawau area: Severe earth tremor felt at about 8.00 p.m.
10 Apr 1902	Sandakan: Quivering vibration felt on S.S. Labuan whilst anchored.
1 Oct 1902	Sandakan, Kudat, Sugut area & Labuan: Tremors reported. South of Klias Peninsula: Seabed upheaved to form new island.
2 May 1903	Tawau: Mild earthquake felt in the evening.
31 Dec 1908	Sebatik coal depot: Tremor felt at 9.05 a.m. S.S. Victoria heeled over.
15 May 1909	Tawau area: Tremor felt with some damage to crockery. Silimponon Coalfield: Coal dumps collapsed and blocked tram lines
27 July 1911	Ranau area: Weak earthquake felt. Reported to be 3rd within 6 years.
6 June 1912	Timbang Batu, Marudu Bay: Earthquake felt at 5.35 p.m. Booming sound.
24 Feb 1913	Lahad Datu district: Tremor felt about 4.00 a.m. No damage recorded.
10 Feb 1916	Timbang Batu area: Earthquake felt at 8.15 p.m.
19 Apr 1923	Tawau - Cowie Harbour: Earth tremor lasting 20 sec felt at 11.15 a.m. Epicentre: South of Tarakan in Kalimantan. Mag. 7.
11 Aug 1923	Lahad Datu: Earthquake lasting 30 sec felt at 8.50 a.m. Epicentre: South Sulawesi Sea. Mag. 6.5.
25 Jan 1928	Bengkoka Peninsula: Earthquake shocks felt at about 1.00 a.m.
27 Mar 1932	Pingan-Pingan, Marudu Bay: Strong tremor lasting several seconds.
17 Oct 1932	Keningau: Two earthquake shocks felt at 4.45 p.m. and 5.50 p.m.
4 Dec 1932	Sandakan: Slight, distinct earth tremor lasting 30sec felt after 4.00 p.m. Epicentre: South Sulawesi Sea. Mag. 6.25.
2 June 1951	Kudat: Strong tremor at 2.50 p.m. Cracks in road & sea wall. Epicentre: 10 km NW of Kudat. Mag. 5.75.
28 June 1964	Bakapit (24 km E of Lahad Datu): Earth tremors felt in the evening.
24 Jan 1965	Bakapit area: Earth tremors felt in the afternoon.
15 Feb 1965	Bakapit area: Tremors felt at 6.50 p.m., 6.59 p.m., 7.11 p.m. & 7.23 p.m.
3 Mar 1965	Bakapit area: Earth tremor of intensity III felt at 8.45 p.m.
18 Oct 1965	Ranau area: Mamut Base Camp - weak tremor felt at 7.07 a.m.
19 May 1966	Kota Kinabalu, Papar, Penampang, Tuaran, Tambunan & Ranau: Tremor at 1.26 a.m. Epicentre: SW Ranau - 48 km depth. Mag. 5.4
27 Jan 1968	Tambisan, Ganduman & Segama: Intermittent tremors, 27 Jan - 8 Feb.
5 June 1968	Lahad Datu: Slight tremor felt at 2.50 a.m.
11 Oct 1968	Tawau: Slight tremor reported.
28 Oct 1969	Tawau: Slight tremor felt at 12.55 p.m.
25 May 1976	Sandakan: Weak tremor at 10.05 a.m. Minor cracks in 3 buildings.
5 June 1976	Tawau area: Earth tremor of intensity III felt
15 July 1976	Tawau area: Four slight tremors felt.
25 July 1976	Tawau, Semporna, Lahad Datu, Kunak & Sandakan: Tremors at 10.05 p.m. Epicentre: Near Lahad Datu. Mag. 5.3
26 July 1976	Tawau, Semporna, Lahad Datu, Kunak & Sandakan: Tremor at 11.26 am. Lahad Datu: Police complex & houses damaged. Mud cone activated. Tawau: Cracks in General Hospital & Resident's Office. Epicentre: Darvel Bay at 29 km depth. Mag. 5.6 Main shock followed by earthquake swarm - total of some 215 events
25 Dec 1981	Tawau: Earth tremor lasting some 30 sec at 8.30 a.m. No damage. Epicentre: Darvel Bay at 39 km depth. Mag. 5.4.
30 July 1983	Lahad Datu area: Two tremors at 9.00 a.m. & 11.00 a.m.
26 May 1991	Ranau area: Strong foreshock at 3.02 p.m. followed by 3 strong shocks. Epicentres around Ranau. Foreshock & main shocks felt all over West Sabah, including Tenom, Papar, Beaufort, Tambunan & Kota Kinabalu.
3 Nov 1994	Kota Kinabalu: Earth tremor felt at about 11.30 a.m.
17 Nov 2002	Ranau: Tremor felt in several parts at 6.09 p.m.
3 Feb 2005	Ranau: Tremor reported at 1.54 a.m.
5 Feb 2005	Kota Kinabalu, Tawau & several coastal areas: Tremors reported. Priority tsunami alert issued to East Coast at 8.56 p.m.; called off at 1.00 a.m.
24 May 2005	Sandakan, Beluaran & Lahad Datu Districts: Tremors felt about 3.58 a.m.
21 Jan 2007	East Coast: Tsunami alert issued at 9.40 p.m.; called off at 11.30 p.m.

earthquake foci more clearly; the majority of epicenters in Sabah being located on-shore or off-shore the Dent and Semporna Peninsulas (Fig. 2). The epicentres here demarcate a broad zone that extends into the Sulu Volcanic Arc; the foci being mostly shallow (<33 km depth) and closely related to major northeast and northwest trending faults (Lim, 1986). Seismicity here is considered to result from reactivated fault movements associated with a present-day tensional crustal setting.

Epicentres in central and north Sabah demarcate an approximately north-northeast trending belt and are centered around Ranau town where they appear to be

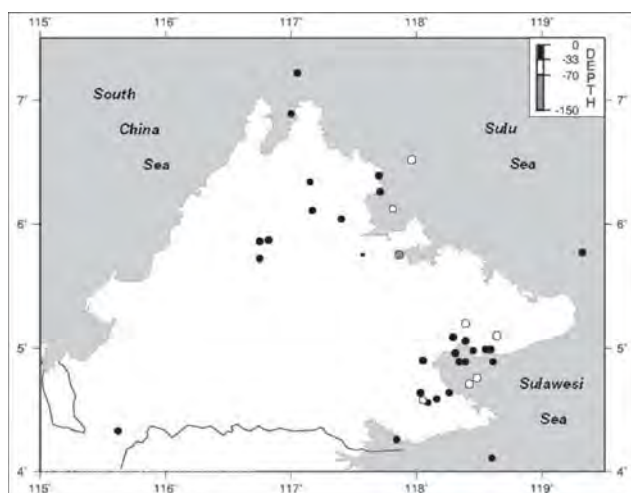


Figure 2: Epicentres of earthquakes in Sabah (1973 - Present) (from USGS/NEIC Data Base; <http://neic.usgs.gov/neis/epic>).

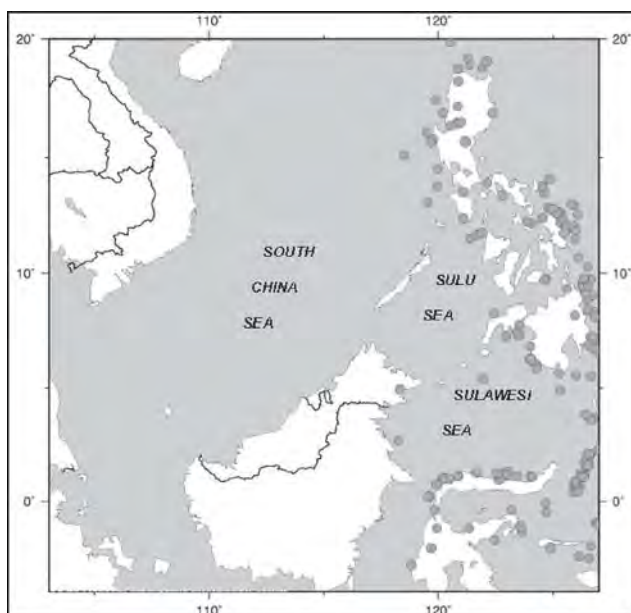


Figure 3: Epicentres of earthquakes ($M_s > 6.0$) with shallow foci (< 33 km depth) in areas surrounding Sabah (1973 - Present) (from USGS/NEIC Data Base; <http://neic.usgs.gov/neis/epic>).

related to northeast trending fractures (Lim, 1985, Lim and Godwin, 1992). The earthquake foci here are mostly shallow (< 33 km depth) and considered to result from reactivated fault movements associated with continued uplift of the area in a tensional crustal setting. Epicentres in the Labuk Bay area appear to be related to major north to northeast trending faults (Lim, 1985) and are also considered to result from reactivated fault movements associated with a tensional crustal setting.

Moderate to large magnitude earthquakes ($M_s > 6.0$) with shallow foci (< 33 km depth) in the general area furthermore, show a distinct distribution that correlates well with a number of tectonic plate boundaries and active, major faults (Fig. 3). The linear belt of epicentres off-shore north Sulawesi point to a southward dipping subduction boundary marked by the North Sulawesi

Trench, whilst epicentres to the west of north Sulawesi mark the left-lateral, Palu-Koro strike slip fault. Epicentres on the eastern edge of the Sulawesi Sea mark a complex boundary of several, approximately north-south trending, thrust and subduction zones marked by the Sanghie Thrust as well as Halmahara and Phillipines Trenches.

The linear belt of epicentres of moderate to large magnitude earthquakes ($M_s > 6.0$) with shallow foci (< 33 km depth) off-shore west and south Mindanao Island indicate a northeastward dipping subduction zone marked by the Cotobato Trench. Towards the northeast end of the Sulu Sea furthermore, the linear zone of epicentres of moderate to large magnitude earthquakes ($M_s > 6.0$) with shallow foci (< 33 km depth) point to a northeastward dipping subduction zone marked by the Negros Trench.

No moderate to large magnitude ($M_s > 6.0$) earthquakes with shallow or deep foci have been recorded in the South China Sea close to Sabah, though there have been a handful of low magnitude events. No distinct trend is shown by these epicentres which appear to mark earthquakes associated with normal faulting (Raj, 1996). At the northeast end of the South China Sea, a north-south trending zone of epicentres of moderate to large magnitude earthquakes ($M_s > 6.0$) with shallow foci (< 33 km depth) off-shore west Luzon Island point to an eastward dipping subduction zone marked by the Manila Trench.

TSUNAMI IN NEIGHBOURING AREAS

Records of the Tsunami Event Database at the National Geophysical Data Center of the National Oceanic and Atmospheric Administration (NOAA) show that there have been some 239 tsunami events in Indonesia up to the end of February 2007, whilst there were a total of 100 such events for the Philippines (NGDC, 2007). In the case of the Philippines furthermore, there were some 10 tsunami events reported for the Sulu Sea which fronts the coastal areas of northeast Sabah and only some 7 events for the South China Sea which fronts the coastal areas of west Sabah (Table 2). In the case of the Sulawesi Sea, which fronts the coastal areas of east Sabah, there were some 7 tsunami events reported in the Philippines and some 22 tsunami events reported in Indonesia (Table 3).

Tsunami reported in the Philippines for the South China Sea are associated with earthquakes along the subduction boundary marked by the Manila Trench, whilst those reported in the Sulu Sea are associated with earthquakes along the subduction boundary marked by the Negros Trench. The earthquakes that have generated these tsunami have been of large magnitudes ($M_s > 6.8$ to 8.3), though there were two of smaller magnitude (M_s 6.4 and 6.5). Limited data furthermore, indicates that these earthquakes had mostly shallow foci (< 33 km depth) (Table 2).

Tsunami reported in the Philippines for the Sulawesi Sea are associated with earthquakes along the subduction boundary marked by the Cotobato Trench off-shore south

Mindanao Island; these earthquakes being of large magnitudes ($M_s > 6.8$ to 8.6) and having shallow foci (<33 km depth) (Table 2). Tsunami reported in Indonesia for the Sulawesi Sea are associated with earthquakes along the subduction boundary marked by the North Sulawesi Trench; these earthquakes being of large magnitudes ($M_s > 7.0$ to 8.6), except for two of lower magnitude (M_s 6.7 and 6.7). Limited data furthermore, indicates that these earthquakes had shallow foci (<33 km depth) (Table 3).

One of the outstanding discrepancies in the two sets of tsunami events in the Sulu and Sulawesi Seas for the Philippines and Indonesia (Tables 2 and 3) is the absence of any correlation between them. Tsunami events that have occurred in the Sulu and Sulawesi Seas thus appear to have been strictly 'local' ones with devastation only in their immediately adjacent coastal areas. Tsunami in the Sulawesi Sea have thus only either impacted the coastal areas of the Philippines, or of Indonesia, and have apparently not crossed the Sulawesi Sea to have significant run-ups in coastal areas on the other side.

The local nature of these tsunami is underscored by the September 1968 Newsletter of the International Tsunami Information Center (ITIC) which states that «A strong earthquake shook Central Sulawesi Island, Indonesia at 0207 on August 10, 1968. The Indonesian Bureau of Natural Disasters announced that huge tsunami waves were generated that swept the coastal areas in the Donggala district of the Island. Two hundred people were killed and numerous houses were destroyed especially in the coastal village of Tambu. The island of Tuguan off the North Celebes Island coast with several hundreds of inhabitants was engulfed by large tsunami waves and partly subsided». No reports of unusual wave activity were, however, reported in the coastal areas of Mindanao Island on the other end of the Sulawesi Sea.

In the September 1976 Newsletter of the International Tsunami Information Center (ITIC) furthermore, it was reported that «Mindanao, the southernmost and largest of the Philippine Islands, was rocked by an earthquake of magnitude 8.0 on the Richter Scale, during the early morning hours of August 17, local time (1610 UTC Aug. 16). This earthquake generated a devastating tsunami in the Celebes Sea that caused havoc and destruction along coastal; communities of the Moro Gulf in Mindanao and neighbouring Sulu Islands. More than 8,000 people were killed or are missing, making this the worst earthquake and tsunami disaster in the history of the Philippines». The Newsletter also reported that Honolulu Observatory posted a tsunami watch following the earthquake, though this was cancelled when the Observatory determined there would be no Pacific-wide tsunami. «Apparently, most of the tsunami energy was trapped in the Celebes Sea which is bounded by numerous islands and shoals. No unusual wave activity furthermore, affected the Sulawesi and Kalimantan (Borneo) coasts of Indonesia according to the Indonesian Hydrographic Office.

DISCUSSION

South China Sea

In view of the tectonic setting as well as available historical data, there is little likelihood of there occurring earthquakes in the South China Sea close to the coastal areas of west Sabah that can generate tsunami. As such, there is no threat of local tsunami to these coastal areas. At the northeast end of the South China Sea, however, tsunami may be generated by earthquakes along the eastward dipping subduction zone marked by the Manila Trench. Earthquakes along this subduction zone could possibly generate tsunami, though much of their energy would have been dissipated by the time they neared the west coast of Sabah. The west coast of Sabah is furthermore, fronted by a wide continental shelf; the 100 m bathymetric contour being located some 30 km and more off-shore. Negligible run-ups can thus be expected even if distant tsunami reach the coastal areas of west Sabah. Tsunami generated in the adjoining Sulu Sea will also not cross over into the South China Sea in view of the shallow sea and several islands in the Palawan Island chain.

Sulu Sea

As with the west coast, the tectonic setting and available historical data indicate that there is little likelihood of there occurring earthquakes in the Sulu Sea close to the coastal areas of northeast Sabah that can generate tsunami. As such, there is no threat of local tsunami to these coastal areas. The tectonic setting and available historical data, however, show that tsunami will continue to be generated in the Sulu Sea by earthquakes along the subduction zone marked by the Negros Trench. These tsunami are more likely to be of local significance and not really pose any serious threat to the coastal areas of northeast Sabah. The northeast coast of Sabah, however, has a continental shelf of variable width; the 100 m bathymetric contour located some 50 km and more off-shore the northern and central sectors, but some 5 to 20 km off-shore the southern sector (eastern Dent Peninsula). Negligible run-ups can thus be expected along the northern and central sectors of the northeast coast of Sabah if distant tsunami reach the coast here. The narrow continental shelf along the southern sector will, however, have less of a dissipating impact on distant tsunami and may lead to locally significant run-ups (>0.5 m high). The coastal areas of the eastern Dent Peninsula may therefore, be considered to be at some risk from distant tsunami generated within the Sulu Sea. Earthquakes generating such tsunami along the subduction zone marked by the Negros Trench would have to be of large magnitudes ($M_s > 7.5$) and have shallow foci (<33 km depth). It is to be noted that tsunami generated in the Sulawesi Sea will not cross over into the Sulu Sea in view of the shallow sea and islands along the Sulu Volcanic Arc.

Table 2: Tsunami events in coastal areas of the Philippines fronted by the Sulu, Sulawesi and South China Seas (NGDC Tsunami Data Base, 2007).

Year	Mo	Dy	Hr	Mn	Runups	Location Earthquake	Epi centre		Dpth (km)	Ms	Mw
							Lat.	Long.			
1675	3				0	Negros Trench	13.400	121.100			
1869	8	16			0	Negros Trench	12.300	123.100		7.0	
1889	5	25	18	23	0	Negros Trench	13.500	121.000		6.8	
1889	5	26			0	Negros Trench	13.500	121.000		6.8	
1915	11	19			0	Negros Trench	10.000	119.500	33	6.4	
1925	5	5			0	Negros Trench	9.300	122.700	33	6.8	
1928	6	15	6	13	0	Negros Trench	12.400	120.900	33	7.0	
1939	5	7			0	Negros Trench	13.500	121.200	150	6.5	
1948	1	24	17	46	2	Negros Trench	10.500	122.000		8.3	
1948	1	25			0	Negros Trench	10.600	122.000	33	8.2	
1897	9	21	5	15	0	Cotobato Trench	7.100	122.000		8.6	
1897	10	19	7	15	0	Cotobato Trench	6.500	122.000			
1976	8	16	16	11	12	Cotobato Trench	6.300	124.000	33	7.8	8.1
1976	8	17			0	Cotobato Trench	7.900	123.400		6.8	
1978	6	14	12	32	0	Cotobato Trench	8.200	122.400	24	6.9	
2000	1	26	0	0	4	Cotobato Trench	5.100	120.150	0		
2002	3	5	21	16	3	Cotobato Trench	6.030	124.250	31	7.2	7.5
1749	8	12	9		0	Manila Trench	13.600	121.100			
1770	12				0	Manila Trench	14.200	121.000			
1824	10	26			0	Manila Trench	14.200	121.000			
1828	11	9	9	18	0	Manila Trench	14.200	121.000			
1852	9	16	10	30	0	Manila Trench	14.000	120.500		7.5	
1924	6	2			1	Manila Trench	16.200	119.700			
1934	2	14	3	59	2	Manila Trench	17.600	119.000	3.3	7.6	

Sulawesi Sea

As with the west and northeast coasts, the tectonic setting and available historical data indicate that there is little likelihood of there occurring earthquakes in the Sulawesi Sea close to the coastal areas of east Sabah that can generate tsunamis. As such, there is no threat of local tsunamis to these coastal areas. The tectonic setting and historical data, however, indicate that that tsunami will continue to be generated in the Sulawesi Sea by earthquakes along the subduction zones marked by the Cotobato and North Sulawesi Trenches. These tsunamis are most likely to be of a local significance and thus not really pose a serious threat to the coastal areas of east Sabah. The east coast of Sabah furthermore, has a continental shelf of variable width; the 100 m bathymetric contour located some 5 to 15 km off-shore the Dent and Semporna Peninsulas, but some 20 to 25 km off-shore Tawau and more than 60 km off-shore Darvel Bay. The narrow continental shelf off-shore the Dent and Semporna Peninsulas will have a limited dissipating impact and locally significant run-ups (>0.5 m high) may result during the approach of distant tsunamis. The wider continental shelf along the other coastal stretches will, however, result in a greater dissipation impact and negligible run-ups (<0.5 m high) from distant tsunamis are thus anticipated along the Darvel Bay and Tawau coasts. Earthquakes generating such tsunamis along the subduction zones marked by the Cotobato and North Sulawesi Trenches would have to be of large magnitudes ($M_s > 7.5$) and have shallow foci (<33 km depth). It is to be noted that tsunamis generated in the Sulu Sea will also not cross over into the Sulawesi

Sea in view of the shallow sea and islands along the Sulu Volcanic Arc.

CONCLUSION

It is concluded that there is no threat from local tsunamis to the coastal areas of west Sabah facing the South China Sea. Distant tsunamis, generated by earthquakes along a subduction zone marked by the Manila Trench at the northeast end of the South China Sea, also do not pose a threat to these coastal areas in view of the wide continental shelf that will lead to insignificant run-ups (<0.5 m).

It is also concluded that there is no threat of local tsunamis to the coastal areas of northeast Sabah facing the Sulu Sea, though distant tsunamis generated by large magnitude ($M_s > 7.0$) earthquakes with shallow foci (<33 km depth) along the subduction zone marked by the Negros Trench at the north end of the Sea may reach these coastal areas. The wide continental shelf fronting the northern and central sectors of northeast Sabah will, however, result in insignificant run-ups (<0.5 m) of these distant tsunamis, though the narrower continental shelf off the east Dent Peninsula may result in locally significant run-ups (>0.5 m). Tsunamis that have occurred in the Sulu Sea so far, have only been of a local significance, even though they have been generated by large magnitude (up to M_s 8.3) earthquakes.

It is finally concluded that there is no threat of local tsunamis to the coastal areas of east Sabah facing the Sulawesi Sea, though distant tsunamis generated by

Table 3: Tsunami events in coastal areas of Indonesia fronted by the Sulawesi Sea (NGDC Tsunami Data Base, 2007)

Year	Mo	Dy	Hr	Mn	Runups	Location Earthquake	Epicentre		Dpth (km)	Ms
							Lat.	Long.		
1673	8	12			1	N. Sulawesi Trench	.800	127.300		
1845	2	8			0	N. Sulawesi Trench	2.600	122.600		7.0
1846	1	25			0	N. Sulawesi Trench	2.000	126.500		7.2
1856	3	2			1	N. Sulawesi Trench	3.700	125.600		
1857	11	17			1	N. Sulawesi Trench	1.000	125.000		
1857	11	18			0	N. Sulawesi Trench				
1858	11	13			1	N. Sulawesi Trench	1.000	126.000		7.4
1858	12	13			0	N. Sulawesi Trench				
1859	6	28			1	N. Sulawesi Trench	1.000	126.500		7.0
1859	7	29			1	N. Sulawesi Trench		125.500		7.2
1871	3	2			0	N. Sulawesi Trench	2.300	125.400		
1871	3	2			2	N. Sulawesi Trench	2.300	125.400		
1889	9	6			2	N. Sulawesi Trench	3.100	125.600		8.0
1889	9	8			0	N. Sulawesi Trench				
1889	9	9			0	N. Sulawesi Trench				
1892	6	7			0	N. Sulawesi Trench	3.700	125.600		
1910	12	18			0	N. Sulawesi Trench	4.000	127.000	33	6.7
1918	7	18			0	N. Sulawesi Trench	3.100	125.500		
1936	4	1	2	9	1	N. Sulawesi Trench	4.500	126.500	60	7.7
1939	12	22	21		1	N. Sulawesi Trench		123.000	150	8.6
1968	8	10	2	7	11	N. Sulawesi Trench	1.400	126.200	33	7.3
1991	6	20	0	0	0	N. Sulawesi Trench	1.900	122.800	0	6.2
1996	1	1	8	5	12	N. Sulawesi Trench	.700	119.900	24	7.6
1996	12	14	0	0	0	N. Sulawesi Trench	.600	119.900	39	7.0

earthquakes along subduction zones marked by the Cotabato and North Sulawesi Trenches along the north and south edges of the Sulawesi Sea, respectively, may reach these coastal areas. The relatively wide continental shelf along most coastal areas of east Sabah will, however, result in insignificant run-ups (<0.5 m) of these distant tsunami, though the narrow continental shelf fronting the coastal areas of the Dent and Semporna Peninsulas may lead to locally significant run-ups (>0.5 m high). Tsunami that have occurred in the Sulawesi Sea have so far only been of a local significance, even though they have been generated by large magnitude (up to M_s 8.6) earthquakes with shallow foci (<33 km depth) along the subduction zones marked by the Cotabato and North Sulawesi Trenches.

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