Why did the 28 March 2005 Sumatra earthquake of M_w 8.7 generate only a minor tsunami?

The tsunami run-up is generally twice the vertical movement of the ocean floor[1] and its power depends upon the rupture area. The 2004 Sumatra–Andaman earthquake of magnitude 9.3 generated 30 m-high tsunami when upward slip of the ocean floor was up to 15 m along a 1300 km long and 160 to 240 km wide rupture (Figure 1)[2]. In contrast, magnitude 8.7 Nias earthquake of 28 March 2005 had upward movement of only 2 m of seafloor in an adjacent area of 300 km × 100 km and hence could generate only 4 m-high tsunami[3]. Focal depth of both the earthquakes was the same around 30 km and mechanism of both the earthquakes was the same: pure thrusting of the Laurasian plate towards southwest along a NW striking and low-dipping plane over the subducting block of the India–Australia plate[4].

The power of the tsunami is affected by landslides in the ocean floor induced by earthquakes. A landslide caused by Papua New Guinea earthquake of magnitude 7.1 generated a 17 m high tsunami. In February 2005, a Royal Navy ship detected large landslides over the rupture zone of the 2004 earthquake. The earthquake had created large thrust ridges, about 1500 m high, which collapsed in places to produce large landslides, several kilometres across. The force of displaced water was such that blocks of rocks, massing millions of tons apiece, were dragged as much as 10 km. An oceanic trench several kilometres wide, was also formed. There is no report of any landslide associated with the 2005 earthquake, and may be because of this the 2005 tsunami was only locally damaging.

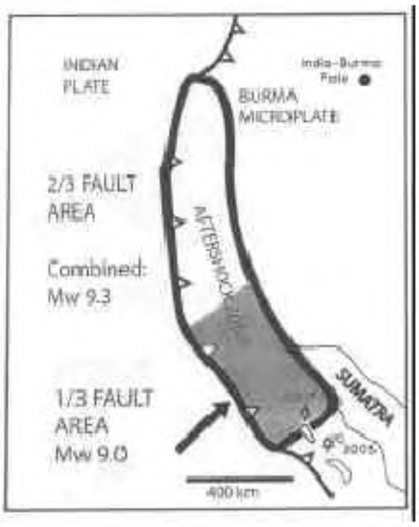

Figure 1. The entire 1300 km long aftershock zone estimated to be the rupture zone by analysis of normal mode data. The dark 400 km segment had a fast slip and the northern 900 km segment had slow slip. Convergence between India and Burma is oblique and there is no convergence north of the aftershock zone (after Stein and Okal[2]). SE of 2004 epicentre is the island of Simeulue and SE of 2005 epicentre is island of Nias.

Rupture zone of the 2005 Sumatra earthquake was SE of the rupture of 2004 earthquake over which lie the islands of Simeulue and Nias. Synolakis and Arcas modelled a rather strong tsunami, if these islands were removed from their model[5]. The reason given by them is that over the islands there is no water and around them less water to be displaced. However, the 1861 great earthquake and 1907 major earthquake in the same area generated strong tsunamis. Moreover, the rupture that covered the entire belt of Andaman–Nicobar islands during the 2004 earthquake played a key role in the generation of tsunami as modelled by Satake[6]. Large tsunami amplitudes in Sri Lanka and India resulted from rupture on the northern, north-trending segment because tsunami amplitudes are largest perpendicular to the fault. Hence, presence of islands in the rupture zone may not be the prime reason for a weak 2005 tsunami.

Nevertheless, it did cause a locally damaging 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 3–4 m wave struck the islands of Banyak and Simeulue and 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 (10–22 cm), the Maldives (10 cm), and Sri Lanka (25–30 cm).

Moment magnitude is calculated from seismic moment, which in turn is proportional to the rupture area and slip. From centroid moment tensor analysis of surface waves of periods below 300 s or rupture modelling from *P*-wave train of 10–80 s, a rupture length of 400 km and magnitude 9.0 was estimated for the 2004 Sumatra earthquake. In these analyses, the later phases could not be modelled, as the original source duration was much longer. From the study of normal mode vibrations of the earth (periods over 300 s), magnitude is estimated to be 9.3 and rupture 1300 km. These estimates are three times larger than the earlier estimates. The southern 400 km rupture was a fast slip and the northern 900 km rupture was a slow slip. Rupture in Andaman–Nicobar Islands seems to have developed less energy in frequencies > 5 Hz, as the buildings (usually of 1 or 2 storey) are damaged by intensity VII or less, which is unusual in rupture zone of *M* 9.3 earthquake. Propagation of rupture up to Andaman–Nicobar Islands for the 2004 earthquake was visualized, as it was known that the tsunami had reached there within a few minutes of the earthquake shaking[7].

Researchers from NOAA Laboratory of Satellite Altimetry (LSA) detected the 2004 Indian Ocean tsunami in profiles of sea level along the flight paths of four satellites by comparing the sea level seen on 26 December 2004 with the sea-level measurements a few days/weeks earlier. The height went down over time as the wave spread over the ocean and the energy expended on shore. At 2 h after the quake, it was 60 cm. By 3h 15 min, it dropped to 40 cm. By 8 h 50 min, it had spread over most of the Indian Ocean and was quite small – 5 to 10 cm – about the limit of the satellite resolution. After all the elapsed time, it was still large enough to bounce back to a height of 25 cm. LSA obtained the satellite data several hours after the tsunami.

Figure 2 shows the possible tsunamigenic earthquake source zones along Andaman–Sumatra trench, Makran subduction zone in Pakistan and possibly Kutch–Saurashtra region. The southernmost Myanmar earthquake of 1762 and Bangladesh earthquake of 1874 generated strong tsunamis and hence, there is a possibility of tsunamis from these zones. The earthquakes in these regions have thrust faulting, which is conducive to generation of tsunamis. The normal component motion due to the major earthquakes along the Carlsberg ridge and Chagos ridge can generate local tsunamis as an earthquake of *M* 7.8 on 20 November 1983 (epicentre east of Carlsberg ridge) caused

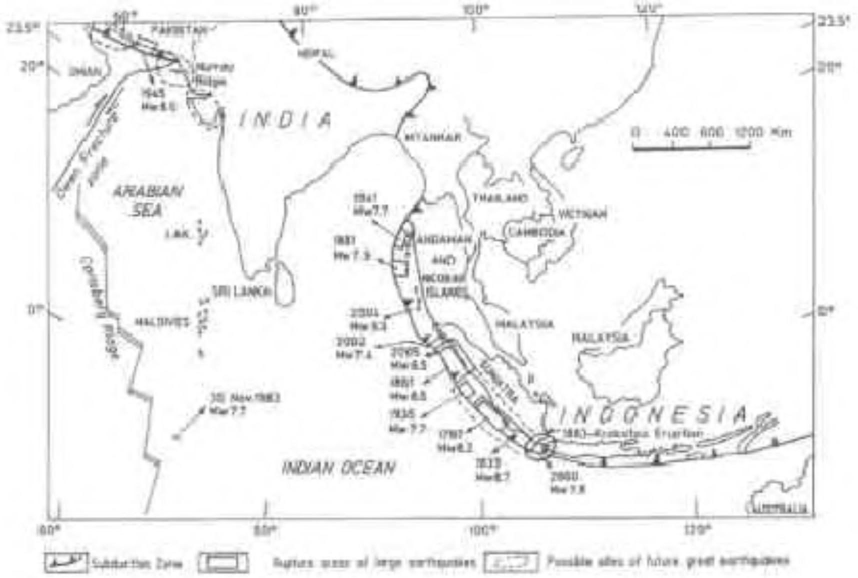

Figure 2. Source zones of earthquakes which can generate tsunamis in coming decades in the Indian Ocean: southern Sumatra subduction zone, Makran coast and possibly Kutch–Saurashtra coast. Possibilities also exist in the coastal regions of southernmost Myanmar and Bangladesh.

a local tsunami that damaged Diego Garcia. Mid portion of the Makran subduction zone gave rise to the 1945 great earthquake and a devastating tsunami, while the adjacent segments on the two sides are potential zones. Hence, west coast region needs to have preparedness measures. Along the Andaman–Sumatra trench convergence rate is 15–20 mm/yr, giving return periods of 400 yr for *M* 8.5 earthquakes, with a slip of around 8 m. However, some great earthquakes have occurred more frequently: *M* 8.5 earthquake of 2005 occurred at the rupture zone of *M* 8.7 earthquake of 1861 and rupture zone of the 1833 *M* 8.7 earthquake encompassed the 1797 *M* 8.2 earthquake rupture zone. Though smaller tsunamigenic earthquakes of magnitude 7.5 to 8.0 have occurred more frequently, but at intervals of over a few decades, like 1907 and 1935, major earthquakes occurred near the 1861 source zone. From these considerations the probability of a severe tsunami hitting India within a couple of decades from Andaman–northern Sumatra region appears to be low, which has already produced 2004 and 2005 great earthquakes. The southern Sumatra segment is a potential zone for a great earthquake. However, India does not lie perpendicular to the fault in this part of the trench. Hence, damage due to tsunami may not be substantial in India and Sri Lanka.

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