The Asian Tsunami, 2004

Tony Waltham

Abstract. Displacement on the convergent plate boundary off the coast of Sumatra, late in 2004, created an earthquake of Magnitude 9.3. Uplift of the seabed generated a tsunami that swept the coasts of Sumatra, Sri Lanka and elsewhere round the Indian Ocean. Though the death toll and destruction were catastrophic, the value of any future warning system may be open to debate.

The tectonic event off the coast of Sumatra, very late in 2004, could be dismissed as a normal feature of a convergent plate boundary. Or it could be described as a very large earthquake, an unusual tsunami and a massive disaster (Fig. 1). Both views are correct. This is one geological event that everyone has heard about; it has had a significant impact on popular perceptions of earthquakes and tsunamis, and has already increased understanding in seismological science.

The earthquake

In the broad picture, the earthquake was due to fault displacement within the convergent boundary zone between the India oceanic plate and the Eurasia continental plate. The India plate is almost locked into the Eurasia plate where the Indian continental slab grinds into the Himalayas, but its movement increases towards the east. There it is subducted under the continental margin at Sumatra at a rate of about 60 mm per year, though this is locally oblique, in a direction about 45° to the plate boundary (Fig. 2). The plate boundary is marked by the Sunda Trench, with water more than 5000 m deep, where the main thrust fault dips at about 11° from its floor to lie beneath the continental shelf of Sumatra. Subduction of the oceanic plate is also marked by the line of 35 volcanoes along Sumatra and two more in the Andaman Islands.

The situation on the over-riding plate is complicated by the Burma microplate that lies between the Sunda Trench and a divergent boundary of only modest current activity beneath the Andaman Sea. East of this the Sunda plate is effectively the southern tip of the Eurasia plate, the two separated by a boundary of minimal movement.

Centuries of continuing subduction of the Indian plate (since any previous large earthquake in this sector) had dragged the Burma microplate downwards and also placed it in considerable compression. Strain energy steadily accumulated across the fault until, inevitably, it overcame the frictional resistance - early on December 26 when the rocks sheared along the fault plane. The initial failure was at a depth of about 30 km, beneath the shelf about 50 km off the coast of Sumatra, and the peak displacement along the fault plane was just over 20 m. This movement propagated outwards, and within about three minutes most of the southern half of the Burma microplate (as far as the Nicobar Islands) had moved by at least 10 m, with smaller displacements that extended and declined further north. Abrupt fault-plane displacement of 10 m or more extended across an area that was more than 400 km north-south and around 100 km wide. The direction of the fault movement (and therefore the tsunami impulse) was at 90° to the orientation of the plate boundary; this was about 45° from the direction of oblique plate subduction in this sector.

This huge extent of rock fracture accounted for the exceptionally high magnitude of 9.3. The very large stress accumulation, and therefore the very large earthquake, may have been in part due to constraint of the plate's oblique deformation within the curvature of the plate boundary. This could be a feature of the change of the Indian plate margin from convergent along the Sunda Trench to conservative strike-slip northwards through Myanmar. Stress may also have been increased by the epicentre's position just across the Sunda Trench from its junction with the poorly defined oceanic boundary between the India and Australia plates.

Figure 1. The tsunami advancing on Khao Lak beach, Thailand, with a wave front that towers about 5 m above the single person in view. These images were recovered from the digital camera of a Canadian couple, John and Jackie Knill, who both died in the event; they have been made available by courtesy of the family.

Earthquake magnitude

As an absolute scale of an earthquake's strength, the familiar Richter scale of earthquake magnitude has been superceded. Richter's scale is derived from wave amplitudes recorded on seismographs, but is not very precise, especially for large earthquakes. The newer Moment Magnitude scale is the measure of total energy released by an earthquake.

Seismic moment (M_O) relates to the fundamental parameters of the faulting process, as it is the product of the shear strength of the faulted rock, the area of the fault and the average displacement on the fault. Moment Magnitude (M_W) is then calculated as a logarithmic function of seismic moment, with constants introduced to give values that are close to Richter magnitudes (ML).

The Sumatran event is described as Magnitude 9.3, meaning the Moment Magnitude and not the Richter Magnitude. Magnitudes remain distinct from Intensity (either Mercalli or MSK), which reflects earthquake damage at an individual site, and therefore decreases away from the epicentre.

Tsunami magnitude is a log scale related to wave height and distsnce from source, which may or may not include a constant that makes it close to the earthquake magnitude.

Because it was under the sea, the earthquake had little direct impact on built structures. The nearest large town was Banda Aceh, on the northern tip of Sumatra, where the intensity reached VIII on the Mercalli scale. This was expressed in modest (but not total) damage to brick and concrete structures, along with various side effects - all of which were lost within the immediately subsequent tsunami destruction. Most timber buildings probably survived the earthquake very well, but were the most easily lost to the tsunami.

Even though damage intensity was low, this was a very major earthquake. An event of this magnitude is close to the theoretical maximum (which is based on the amount of stress that can accumulate in rocks before their shear strength is exceeded), and is due to the very large area activated on the fault plane. The Sumatra event ranks as the world's second largest since 1900 (Table 1); magnitudes of earlier events can only be roughly estimated. It is noticeable that the other earthquakes greater than Magnitude 9 have all been around the Pacific margin.

Within the following two weeks, there were more than a dozen aftershocks with magnitudes of 6-7, and an eventual total of around 600 smaller aftershocks. All were caused by stress redistribution within the Burma microplate, mainly north of the epicentre and reaching as far as the Andaman Islands. This continued slow slip extended the fault's rupture zone until it was 1200 km long. A full month after the main event, a distinctly separate swarm of aftershocks developed along a 20 km zone east of the Nicobar Islands (Fig. 2). This was due to movement of the Burma microplate against the Sunda plate, expressed in strike-slip displacements on the boundary fault.

Another earthquake, of Magnitude 8.7, followed on March 28, 2005, with its epicentre further south on the same plate boundary (Fig. 2). Though this was a major earthquake in its own right, it was effectively a large aftershock, as it was almost certainly triggered by stress changes during and after the December event. It caused significant destruction on the islands of Nias and Simeulue and on smaller islands between them, and some hundreds of people died. Though it created nearly 1 m of uplift on Simeulue and a similar amount of subsidence on one of the smaller islands, it developed only a very modest tsunami that reached a height of about 400 mm on the Sumatran coast.

Residual ground movement

The fault displacement of around 20 m was largely accounted for by relaxation of the Burma microplate as it moved outwards and upwards along the thrust plane over the Indian plate, which was relatively immobile in the short term (Fig. 3). With the fault plane dipping at 11°, this created the 4 m of seabed uplift that very effectively created the tsunami. This pattern of plate relaxation matches that first recognised after Alaska's earthquake of similar style in 1964, where large zones of both uplift and subsidence were measured in and around Prince William Sound. Modelling of ground displacements on the basis of the 2004 seismic data indicates a bowl of tectonic subsidence more than 1 m deep over the relaxed ground above the deeper part of the thrust fault and behind the frontal zone of uplift.

Reported observations after the event have confirmed the theoretical pattern of ground movement, though accurate survey data is not yet available. Simeulue, the most northerly island off the Sumatra coast (Fig. 2), was on the axis of rotation. Its west coast was elevated by about 1.5 m, exposing large areas of coral reef, while its east coast subsided by about 0.5 m, leaving land areas permanently flooded. The bowl of subsidence extended to the Aceh coast, parts of which declined by about 0.4 m. The zone of uplift extended west of the island, so was largely beneath the sea. Reports of large areas of newly exposed reef on the western sides of some of the Nicobar Islands, with flooded land on their east sides, indicate a similar pattern of residual ground movement. It appears that the zones of uplift and subsidence extended the full 1000 km between Simeulue and the Nicobars - accounting for the great size of the resultant tsunami.

earthquake location	year	M
Southern Chile	1960	9.5
Sumatra, Indonesia	2004	9.3
Southern Alaska, USA	1964	9.2
Aleutians, Alaska, USA	1957	9.1
Kamchatka, Russia	1952	9.0

Table 1. *The world's largest earthquakes since 1900; M = Moment Magnitude.*

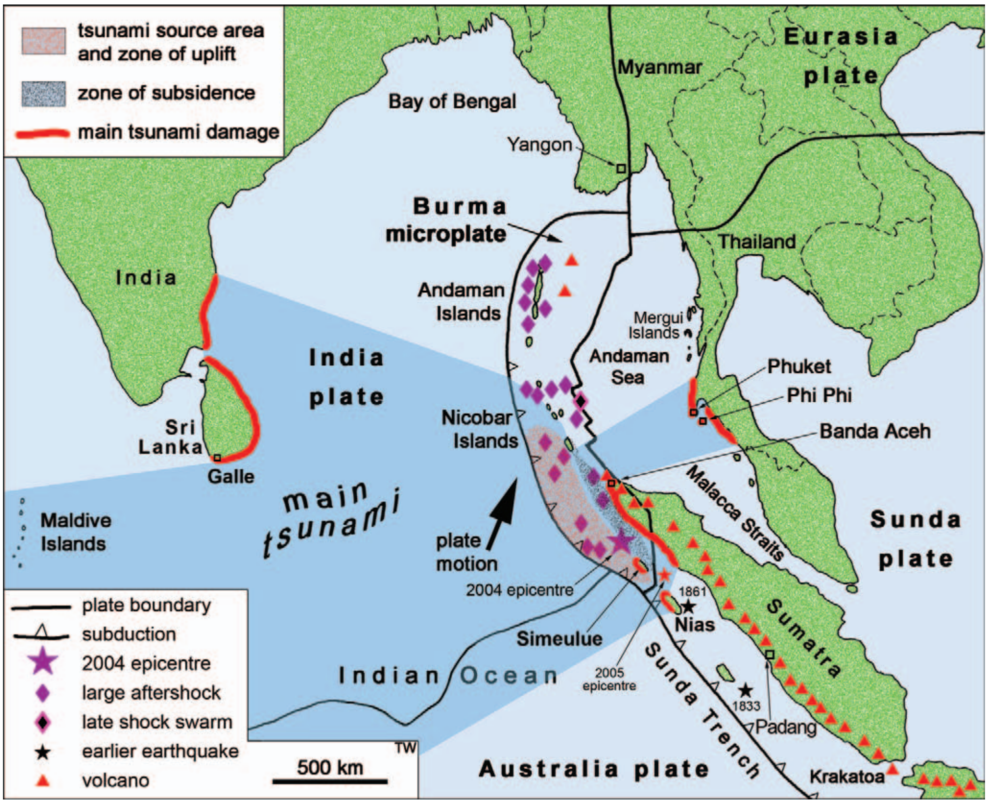

Figure 2. *Locations of features of the 2004 earthquake and tsunami; the zones of subsidence and uplift are approximate, based on available observations and measurements; the areas swept by the main tsunamis have diffuse margins where wave heights decreased laterally.*

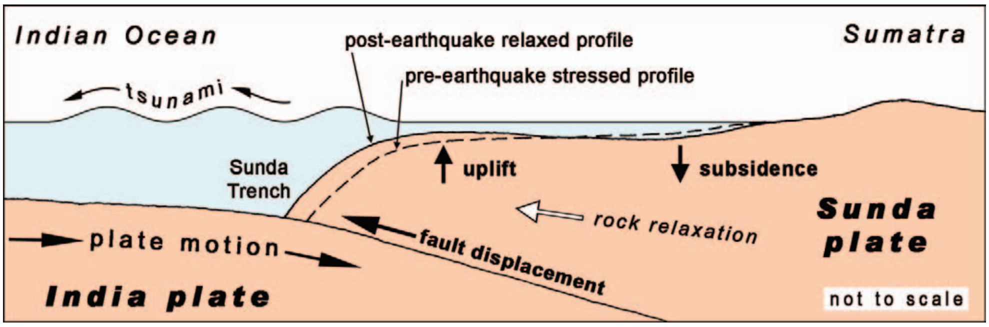

Figure 3. *Schematic cross section through the earthquake zone; not to scale.*

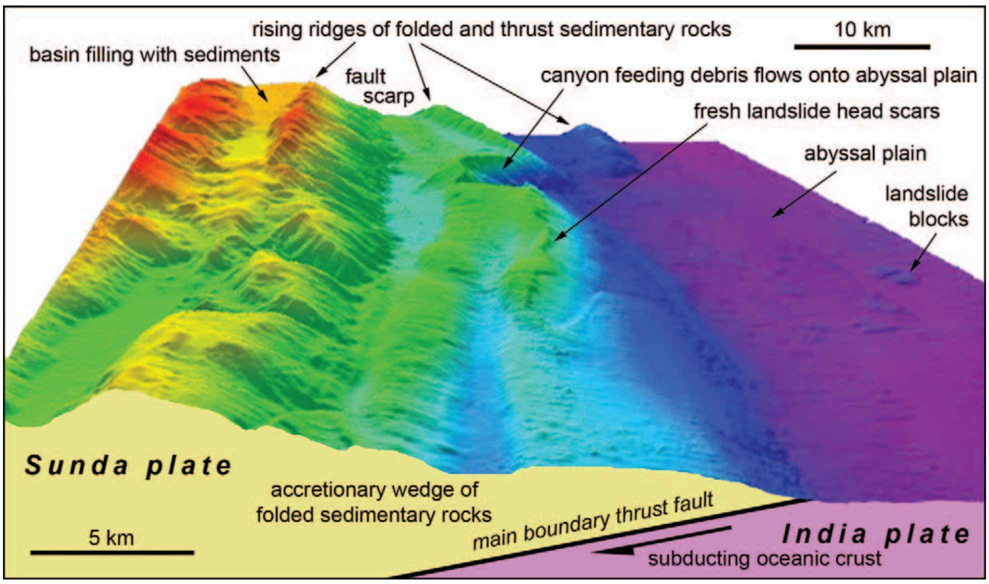

Figure 4. *Seabed topography off the Sumatran coast, just west of the earthquake epicentre, looking southwest along the plate boundary; bar scales relate to the near and far ends of this very oblique perspective view; seabed colours show their depth, from red at about 1 km to purple at about 6 km; there is no vertical exaggeration. (Source survey by MHS Scott, by courtesy of the Royal Navy and U.K. Hydrographic Office.)*

The marine survey conducted soon after the earthquake event could not detect the few metres of seabed uplift, but it did provide some spectacular images of the plate boundary, where the continental slope rises from the abyssal plain on the inbound oceanic plate (Fig. 4). Ridges up to 1500 m high and parallel to the fault scarps are interpreted as rising fold structures, with or without thrusts, within the wedge of sedimentary rock that is accreted to the front of the over-riding plate. Massive underwater landslides are also recognisable. Older slides have degraded into bowls at the head of canyons that fed debris flows onto the abyssal plain, while younger landslides are identified by their clean and un-eroded head scars. Some frontal ridges could be either folds or massive, old landslide blocks. Without resurvey before and after the earthquake, it is not clear how much movement or reactivation of all or parts of these slides and folds occurred during the 2004 event. Any sub-sea landslides of these sizes could contribute to the tsunami growth, in the same way that seabed uplift may be due to rising fold structures or a broader relaxation expansion of the continental plate edge.

The tsunami

Incorrectly known as a tidal wave, and oddly known by the Japanese word for a harbour wave, a tsunami is quite simply a very large wave that has been pushed by some large-scale rock movement. The largest tsunamis are created by abrupt seabed displacements of fault blocks, though they can also be created by volcanic explosions, or landslides under or into water.

Seafloor displacement pushes the water into a single large wave, which is then followed by oscillations as the water returns to equilibrium. The cyclic disturbance of the water means that, in far-travelled wave trains, the first wave is not usually the largest, because the second or third waves have resonated to greater heights; in 2004, this was recorded at most coastal arrivals. It also accounts for the frequently observed retreat of the sea in advance of the first positive wave, as water is sucked back into the growing wave; the frontal negative wave can also be enhanced by any seabed subsidence, as observed in the eastbound tsunami in 2004. Though waves radiate out in all directions, a tsunami wave is noticeably directional, with its greatest size being in the direction of fault displacement – westbound in the 2004 event.

Tsunamis are pressure waves developed through the entire depth profile of the water; they are unlike the rotational movements in surface waves created by wind. They therefore travel fastest when unimpeded across the open ocean, at speeds up to 800 km/hour, but are much slower where restrained by drag over the seabed in shallow water. A tsunami does weaken with distance from its source due to lateral dissipation of energy as the wave radiates over an enlarging front, though the long wavelength means that amelioration is much less than that of normal storm waves.

Felt in Britain and the East Midlands

Sumatra's massive earthquake was recorded on instruments all round the world. The seismograph at Melton Mowbray detected the first P-waves 25 minutes after the event, and the larger surface waves arrived around 2 a.m. local time, an hour after the event but still before the tsunami hit the Sri Lankan and Thai coasts.

Disturbance from the tsunami spread into every ocean of the world. After traversing the entire Indian Ocean and then the full length of the Atlantic, it arrived on Britain's shores about 37 hours after the event. It was barely recognisable on the tide gauge at Newlyn, in Cornwall, as its waves were less than 100 mm high and arrived almost on the crest of a storm surge that was significantly greater.

In the open ocean, a tsunami may be only 300 mm high (and unnoticeable to shipping), but it can pile up into a massive wave as it approaches land. This is due to the wavelength of 100 km or more, with the front of the wave slowing down in shallow water, while the rear catches it up. The effect is compounded as the wave crest overtakes the dragging wave base to create a towering breaker, and a wave further gains height where it is compressed into a tapering inlet. When the front of such a long wave steepens on approach to land, the profile becomes that of a great plateau. Its advance creates not a quick rise and fall of the water (as on a normal surfer's wave), but a sharp rise, followed by the water keeping on coming for 10 minutes or more. It is the sheer volume of water sweeping over a low coastline that causes the massive damage on land.

The 2004 tsunami was generated between Sumatra and the Nicobar Islands where the southern half of the Burma microplate was uplifted over the thrust fault (Fig. 2). It appears that the deeply buried fault at the earthquake epicentre was no more effective at tsunami creation that the zone at shallower depths into which movement propagated northwards. The huge area of uplift accounted for the great size of the tsunami, and the direction of fault movement launched the main tsunami crest on a compass bearing of 250° westwards towards the open ocean. Once started, the wave motion keeps on going, and the 2004 tsunami was recorded right across the world.

This was a very big tsunami. There are few reliable yardsticks for comparison of tsunami events because the wave impact on coastlines varies so much with respect to orientation, shape and profile. Wave heights reached on the nearest coast in the 2004 event appear to have had a general crest at about 15 m, excluding some very small tapering inlets where wash certainly went much higher. The tsunami from the eruption of Krakatoa in 1883 is commonly credited with wave heights of 30 m, and there have been some very high tsunamis impacting the coasts of Japan in historical times, but the 2004 event does appear to lie in the top handful of the world's earthquake tsunamis.

This excludes localised events such as the landslide-created wave in Lituya Bay, Alaska, that achieved a run-up to around 500 m above sea level in 1958. Nobody died at Lituya Bay, because nobody was there, but if tsunamis are judged by the numbers of people they kill, then the 2004 event that emanated from Sumatra was the world's worst.

Tsunami impact in the source area

On all unprotected, low-lying coasts the impact of the tsunami was the same. It swirled inland as a relentless flood of seawater; it developed bores a few metres high in river channels, inlets and valleys, but elsewhere it was a smoother rise of water level. Even though it lacked the drama of towering waves except on a few exposed beaches, the water swept relentlessly inland until checked by higher ground. The effect was rapid flooding, and the surges moved faster than a man could run. Water velocities were up to 30 kph, so high that people had little chance of swimming to safety, and structural damage was widespread. The soft sediments of coastal plains were easily scoured, and the backwash of the retreating tsunami scoured huge volumes of sand and mud to leave the ground surface below sea level. Added to this was the tectonic subsidence of about 0.5 m; swathes of coastal Sumatra were transformed from low land to shallow sea.

The city of Banda Aceh, in northern Sumatra, was the nearest to the earthquake epicentre. Many of its smaller buildings collapsed, but the effects were eclipsed 15 minutes later when the tsunami arrived. Wave heights reached 10-15m on many parts of the western coast of Aceh province, creating massive damage as the sea swept kilometres inland. Large ships were thrown up on shore, and harbour walls were smashed and undermined. Houses, bridges, trees and crops were stripped from low-lying areas as far as 3 km or more inland, bays and inlets were enlarged by scour, but hills between escaped unscathed (see the back cover for 'before' and 'after' images of Gleebruk on the Aceh coast; from NASA Earth Observatory).

Within 30 minutes the tsunami had hit the Nicobar and Andaman Islands. Wave heights reached over 5 m, and many people died on the low-lying islands, but the impact was minimised by the steep profiles of the volcanic islands within the chain.

Off the coast of Sumatra, the villagers of Lewah, on the island of Simeulue (Fig. 2), had experienced shaking from the earthquake so strong that for two minutes nobody could stay standing. But they then ran to the adjacent hills, so nobody died when the tsunami arrived soon after. On Nias, the next island south, the north-coast town of Lahewa was hit by a series of tsunami waves; of these, the third arrived as a surge nearly 2 m high over 5 hours after the earthquake. These appear to have been reflected waves, as was the one that swept up the east coast of Nias from the south nearly 8 hours after the earthquake.

The Indian Ocean tsunami

The tsunami crossed the Bay of Bengal in just two hours, to launch its major impact on the unprotected coasts of southeast India and eastern and southern Sri Lanka. A sequence of three waves reached heights of 5-10 m where the tsunami swept up onto open sand beaches and washed inland across very low gradients. Some coastal towns were just seriously flooded (Fig. 5), but many villages on the exposed west coasts of Sri Lanka and India were simply wiped off the map. Basic wooden buildings that faced tropical beaches were fine for anything except a tsunami wave when water rose just a few metres to destroy everything. In many villages, only the fishermen survived because they were out on their boats in deep water, where the tsunami passed unnoticed beneath them.

The worst single tragedy overtook a crowded train on the coastal line to Galle, in southern Sri Lanka. The first tsunami wave derailed the train and caused few casualties, but left its passengers stranded and exposed to the full force of a second, larger wave. This swept in 3 m deep onto the overturned carriages; only 20 people survived out of 1500 on the train.

The southwestern sector of the tsunami swept past Sri Lanka, but then lost much of its energy as it spread out into the western Indian Ocean. It caused major flooding on the low-lying Maldives and Seychelles, but had less remaining power by the time it reached the African coast. Fortunately, there were few people living along the Somalian sector which received the greatest impact.

Disaster-prone Bangladesh escaped lightly from this one. The tsunami had little northward component, and then lost energy in crossing the huge deltaic apron of sediment within the north end of the Bay of Bengal, before meeting a braided coastline with only a low population; just two children died when a small boat was capsized by the reduced tsunami wave.

Figure 5. *Tsunami water sweeps the streets of a small town on the south coast of Sri Lanka (photo: NBC).*

Figure 6. Damage to a car left beside a Phuket beach show why so many people died when they were swept into the debris-laden tsunami inrush (photo: Liz Price).

The Andaman Sea tsunami

The rebound effect of wave surges meant that the tsunami's second greatest development was eastwards, through the deeper channel south of the Nicobar Islands, and on towards Thailand. The shallower water in the Straits of Malacca meant that it travelled more slowly than in the ocean, and it took two hours to reach the unprotected Thai coast around Phuket, where wave heights were generally around 3 m. Some beach profiles created breaking waves that were over 5 m high (Fig. 1), and tree damage around some tapering inlets on the rocky sections of coast showed that the tsunami washed up to about 25 m high.

Unfortunately, the tsunami hit Phuket and the coast just to the north on the crest of a high tide and in mid-morning, by which time the beaches and towns were crowded with holidaymakers. Many people on the beaches could escape to high ground when they saw the abnormally large waves approaching; the second wave (15 minutes after the first) was the largest, and some people even took warning from the sea's retreat just prior to arrival of the first wave (there was a frontal trough to the tsunami wave chain in this direction). But there was less warning in the towns; when debris-laden seawater swept through 1-2 m deep, and fast enough to wash all the cars out of the streets, people caught at ground level had to be lucky to survive (Fig. 6). The upper floors of modern hotels were safe, as most concrete buildings survived, but wooden buildings were wrecked (Fig. 7). The wave impact varied greatly from beach to beach, being greatest where the beach had a gentle profile or faced directly to the west.

The tsunami lost only some of its power as it swept into Phang Nga Bay, and the island of Phi Phi had its sea-level town washed away while the limestone hills remained uninhabited and unscathed. South of Phi Phi, the tsunami hit Ko Mook while a group of 80 tourists were swimming through the sea-level Emerald Cave into the hong (a doline lagoon inside the limestone island); two died in the water surge through the cave, while the rest survived by climbing onto rock ledges.

Towards the northeast, the official death toll in Myanmar was only 90, but reports from that country are unreliable due to the military censorship. The tsunami may have lost energy in the shallows of the Andaman Sea, but it must have had significant impact on the Mergui Islands and mainland coast of southern Myanmar; the fate of many of the Moken sea gypsies who live round the islands may never be known. There are also reports of hundreds of people drowned when villages of shanty houses were destroyed along the coast west of Yangon.

Figure 7. Concrete buildings survived in Phuket, Thailand, but the ground floors of frailer structures were washed out by the swirling tsunami waters (photo: Liz Price).

Figure 8. A seaview bar in Phuket re-opens while still bearing a reminder of the tsunami (photo: Liz Price).

The aftermath

By March 2005, the death toll of the earthquake and tsunami had risen to around 290,000, and nearly all of these died in the tsunami as opposed to in the preceding earthquake. With many people still listed as missing, and many bodies carried out to sea, the final toll may be close to 300,000.

With so many people washed away by the tsunami, the immediate desperate task for so many survivors was to find missing relatives. Then, reunited or not, survival became the major task. Drinkable water was a rare commodity, food was nearly non-existent, and only the warm weather made the lack of shelter just tolerable. There was concern that the many dead bodies and vast amounts of debris constituted a major health hazard, but there was no significant outbreak of disease after the event. Estimates gave half a million people injured, a million homeless and five million without access to basic services; the subsequent international aid effort was unprecedented.

Rebuilding and protection

Repairs to water supplies, roads, bridges and hospitals were immediate tasks for the state agencies. Rebuilding of houses and homes largely falls to the struggling survivors, and therefore has a certain delay, which could give time for better planning. There would be clear benefits in rebuilding some of the towns and villages on higher ground, where topography permits. Elsewhere, coral reefs, coastal mangrove forests and sand dunes could protect future development; positive conservation or even their re-establishment would be worthwhile, as shown by some protected sites in 2004. Beach hotels and fishing villages may be increasingly recognised as undesirable, though tourism is vital to the economy of many coastal regions (Fig. 8).

Press criticisms of inadequate building standards were not justified; the simple wooden houses in most regions were perfectly satisfactory for anything except the exceptional. Especially without the luxury of a Western economy, it is unreal to design structures to withstand events that occur only at intervals of hundreds of years. Most concrete structures survived the tsunami. But the villages of Sumatra had few of these other than the mosques - which remained after the event like giant tombstones amid oceans of debris. Where a town has to be rebuilt on low ground, a scatter of concrete buildings three storeys high could offer valuable refuges in any future tsunami; large tourist hotels could be a real benefit in this respect.

Predictions and warnings

The more significant aftermath debate is over the scope for predicting or warning of a tsunami. Sadly, prediction is impossible; the causative earthquakes cannot yet be predicted. Furthermore, not all undersea earthquakes produce tsunamis, and an event can only be recognised on tide gauges once it has started. So the alternative is a warning system. The Pacific Ocean has 90% of the world's tsunamis, and already has an international tsunami warning system in place. Offshore earthquakes are detected, and signs of tsunamis are then monitored. Tsunamis can only be seen in shallow coastal waters, but automated tide gauges and seabed pressure gauges record the passing of low and long tsunami waves in open water. Serial warnings are then issued, though how a tsunami affects a distant coast varies with local conditions.

No such system exists for the Indian Ocean. Proposals for one had been discussed by the relevant coastal nations prior to the 2004 event, but had been shelved or dismissed as not worthwhile. Even with hindsight, this appears to have been a reasonable decision. There have been very few tsunamis in the Indian Ocean. The Sumatran coast suffered destructive tsunamis in 1797, 1833, 1843 and 1861 (besides the Krakatoa event in 1883), but there was none in the 20th century.

However a United Nations meeting on Disaster Reduction, coincidentally held in January 2005 in Kobe, Japan, did resolve to establish an Indian Ocean tsunami warning system by mid-2006. Plans for effective response, including education programmes in tsunami-awareness, would take another few years, and there are even plans for a global system by 2007. Kobe's budget for this was $30M, but how this was to be raised was not answered, and India has since estimated a budget of $27M just for its input. There must be serious questions about the benefits of such a programme; it appears that emotions and politics could have overtaken reality at Kobe.

Even if a system is in place, warning times could be minimal. Scientists at the Pacific Tsunami Warning Centre in Hawaii knew of the 2004 earthquake within minutes of it happening. But it was a few hours before they knew its size and could assess the tsunami hazard. By then, 80% of the tsunami casualties were already dead. And they could find nobody to warn of the danger, other than the US base on Diego Garcia. They did manage to contact Kenya, where some coastal evacuation was then organised, so that only one person died when the reduced tsunami hit the coast eight hours after the earthquake.

A well-established Indian Ocean system would not have had enough time to give any useful warning on Sumatra, where the majority of the casualties occurred. Towns in Sri Lanka and Thailand could have been warned, but time would have been very tight. And warning a coastal villager, who is too poor to buy batteries for his transistor radio, is seriously difficult. Tsunamis take 10-20 hours to cross the Pacific Ocean. A future tsunami further south along the Sumatran coast will hit the city of Padang within 10-20 minutes. No high-tech system will provide enough warning before a 2 km run-up (as seen this time in Aceh), devastates a Padang city much larger than when it was heavily damaged by a tsunami in 1833.

Realistic warning may be garnered from local sources better than from an expensive international system. While human bodies littered the tsunami debris in both Sumatra and Sri Lanka, there were very few other large animals. No elephants died in Sri Lanka. They and many other animals can detect low-frequency ground and air vibrations (generated by an earthquake or an approaching tsunami). A seismic signal is a type of acoustic vibration. If it is greatly magnified, it can be heard by man; but its low-amplitude, low-frequency can be heard by animals, and their natural senses tell them to move away from danger. It was widely noted that animals moved inland to safety before the tsunami struck. Aboriginal peoples, who live on isolated islands in the Nicobars, suffered minimal casualties; there is no evidence that they have any sixth sense, but they noted changes in bird calls, and then just followed their animals up onto high ground – before the tsunami arrived.

Perhaps tsunami-awareness programmes could be more cost-effective than high-tech science. Knowing about the almost ubiquitous sea retreat ahead of a tsunami, and watching the animals, really does work, even on coasts adjacent to an offshore earthquake epicentre. And the money saved could be spent on some tsunami-proof concrete buildings.

In context

The 2004 Asian earthquake tsunami was a major disaster; and was by far the world's worst tsunami event. The only two earthquakes that may have been more disastrous were both in China, with data that is old or perhaps unreliable (one in 1556 with 830,000 dead, and one in 1976 with a toll widely reported as 655,000). Disease and flooding have taken greater tolls, but there is something dramatic and immediate about earthquakes and tsunamis. However, one of the reasons for the high number of deaths in the 2004 tsunami was quite simply the vast numbers of people now crowded onto planet Earth, and few areas are more crowded than the shores of the Indian Ocean. Each major event tends to be worse than the last one.

It is perhaps relevant to look at the numbers of people that die as a proportion of the contemporary world population (Table 2). It then appears that, awful and tragic though it was, the 2004 tsunami was overshadowed by the great earthquake in China. It was also quite minor in comparison to the effects of influenza and the plague. It was trivial in comparison to malaria, which may have killed half of all the people that have ever lived. And its death toll is matched about every 10 days by those who die of starvation, mostly in Africa.

A British tsunami?

The chances of a tsunami hitting Britain are very low indeed, but are not zero. An earthquake-induced event is very unlikely, mainly because the Atlantic Ocean has only a short section of convergent boundary, with minimal activity, flanking the Caribbean Antilles. In 1755, the seabed earthquake, off the Portugal coast, created massive tsunami damage in Lisbon and elsewhere on the nearby European and African shores. The tsunami reached the coast of Britain as a wave train that lasted nearly 5 hours, with the third and fourth waves each about 3 m high at Newlyn, Cornwall, but the overall impact was little more than that of a storm surge on a spring high tide. There was also the probable tsunami in the Bristol Channel in 1607 (see *Geobrowser* on page 74 in this issue of the *Mercian*).

The greater threat comes from landslide-induced tsunamis. The gigantic slide of seabed sediments at Storegga, in the northern North Sea, created a tsunami that swept the coasts of Scotland and Northumbria about 8000 years ago (*Mercian*, v15, p5; David Smith, 2005, *Geology Today*, v21, pp64-68). Threat of an Atlantic tsunami from a future collapse of the Cumbre Vieja volcano in the Canary Islands is recognised, but this does rely on a rapid large-scale failure; the alternative of slow sliding or small multiple failures will have much less impact. More seabed debris flows are being recognised (*Mercian*, v15, p4), so the tsunami hazard does exist, but the risk is reduced by the extreme rarity of these events.

The one benefit of a great tragedy is that it unifies people in fighting a common cause. After the 2004 tsunami, armed opponents overcame their differences, and everyone helped the injured and bereaved. But the ceasefires lasted only days. Then, the Indonesian army and the Aceh rebels resumed killing each other, some high caste Indians refused precious water to low caste villagers, and fighting resumed in Sri Lanka's 20-year war with the Tamil Tigers – which has killed nearly double the tsunami toll. These facts should all be significant to any over-reaction towards creating an expensive tsunami warning system in a part of the world that has far greater problems to resolve.

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Dr Tony Waltham
11 Selby Road, Nottingham NG2 7BP
tony@geophotos.co.uk

event	date	deaths	world population	proportion of mankind killed
tsunami, Indian Ocean	2004	>290,000	6000M	0.0048 %
earthquake, Shanxi, China	1556	830,000	500M	0.17 %
influenza, worldwide	1918-19	21,000,000	2000M	1 %
plague, Black Death	14th C	75,000,000	400M	20 %

Table 2. *Natural disasters of the world, in context.*