Sumatran Earthquake and Tsunami

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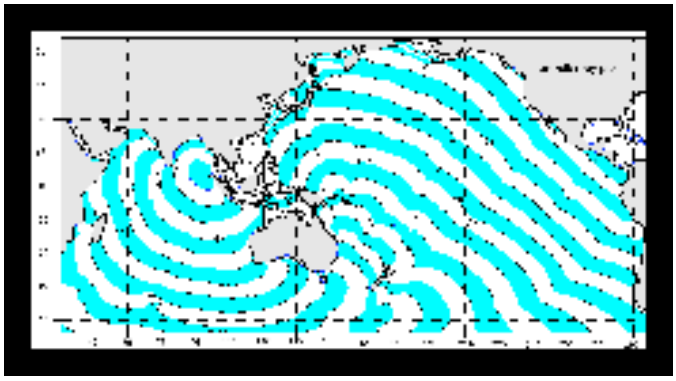

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Sumatran Earthquake

By Kevin McCue and Cvetan Sinadinovski

A great earthquake occurred at 00:58:49 (UTC) on Sunday, December 26, 2004 off the northwest coast of Sumatra, Indonesia.

Magnitude: 9.0

Date-Time: Sunday, December 26, 2004 at 00:58:49 (UTC) or

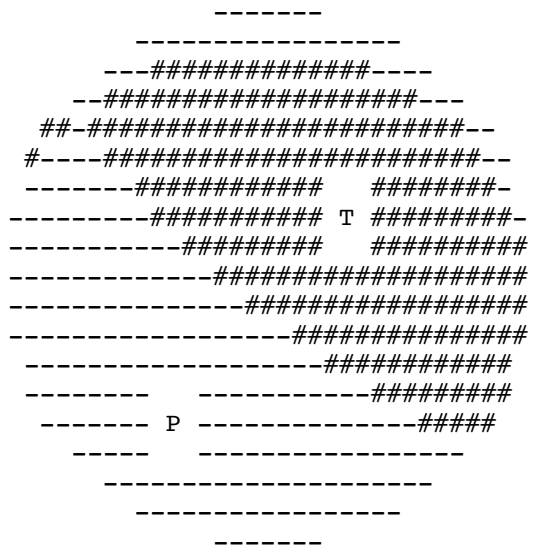
Sunday, December 26, 2004 at 7:58:49 AM local time at epicentre.

Epicentre: 3.244°N, 95.825°E, Depth: 10 km

255 km SSE of Banda Aceh, Sumatra, Indonesia, 315km W of Medan, Sumatra, Indonesia, 1260 km SSW of Bangkok and 1590 km NW of Jakarta.

Focal Mechanism:

	Strike	*Dip*	*Slip*
NP1	274	13	55
NP2	130	79	98



The following is extracted from Newspapers and the USGS website at http://earthquake.usgs.gov/

The earthquake and tsunami killed at least 220,000, 173,900 of them in Indonesia. The tsunami killed at least 29,800 people in Sri Lanka, 10,700 in India, 5300 in Thailand, 80 in Maldives, 68 in Malaysia, 90 in Myanmar, 150 in Somalia, 10 in Tanzania 2 in Bangladesh and 1 in Kenya and 3 in the Seychelles. The tsunami also struck Cocos Island (where its amplitude was measured at 0.5m – the atoll rise to just 3 m above sea level), Kenya, Madagascar, Mauritius, Reunion, Seychelles and the south-west coast of Australia. It was recorded in New Zealand and along the west coast of South and North America.

The earthquake was felt (VIII) at Banda Aceh and (V) at Medan, Sumatra. It was also felt in Bangladesh, India, Malaysia, Maldives, Myanmar, Singapore, Sri Lanka and Thailand.

This is the fourth largest earthquake in the world since 1900 and the largest since the 1964 Prince William Sound, Alaska earthquake.

The devastating megathrust earthquake of 26 December 2004 occurred on the interface of the Australian/Indian and Eurasian plates where the Australian/Indian plate subducts beneath the overriding Eurasian plate. The Australian/Indian plate begins its descent into the mantle at the ocean trench, west of the earthquake's epicentre.

In the region of the earthquake, the Australian/Indian plate moves toward the northeast at a rate of about 60mm/year relative to the Eurasian plate. This results in oblique convergence at the trench. The oblique motion is partitioned into thrust-faulting, with slip directed perpendicular to the trench, and strike-slip faulting, which occurs several hundred kilometers to the east of the trench and involves slip parallel to the trench. The December 26 earthquake was the result of thrust-faulting as you can see from the mechanism above.

The last great magnitude 8 earthquake on the onshore strike-slip Sumatran Fault was on 17 May 1892 with 3.5 to 4m of right-lateral movement.

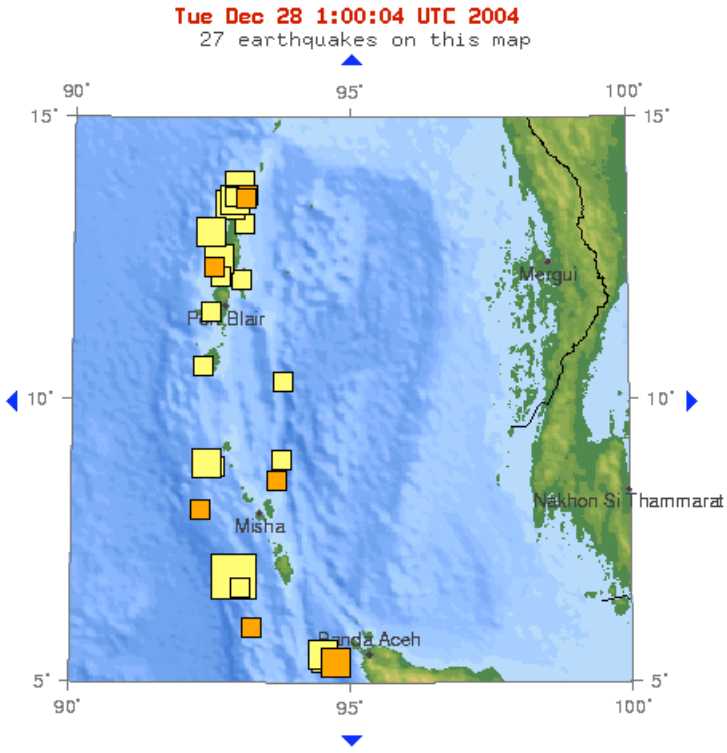
Preliminary locations of larger aftershocks following the megathrust earthquake show that approximately 1100 km of the plate boundary slipped during the earthquake, giving a rupture duration of about 6 minutes. From the size of the earthquake, it is likely that the average displacement on the fault plane was about fifteen meters. The sea floor overlying the thrust fault would have been uplifted by several meters as a result of the earthquake.

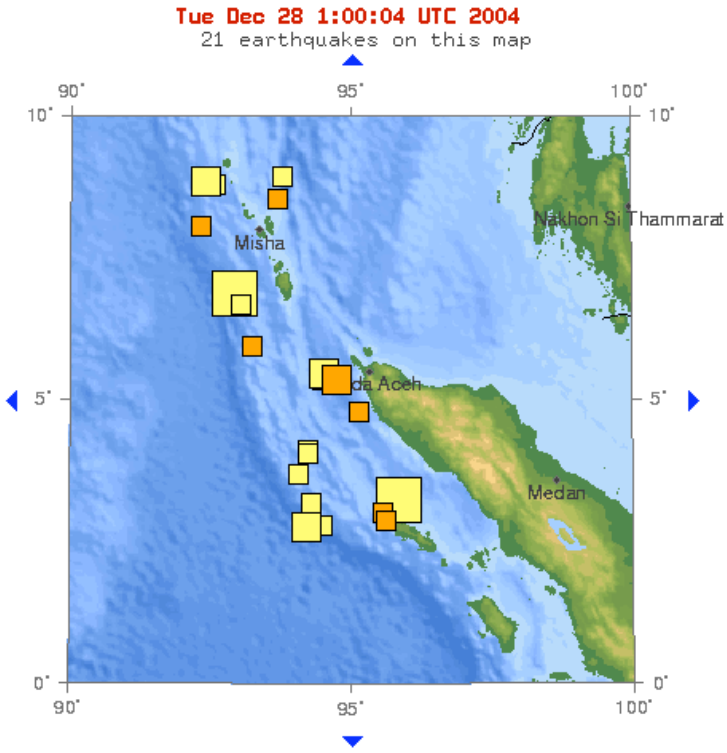
The world's largest recorded earthquakes have all been megathrust events, occurring where one tectonic plate subducts beneath another. These include: the magnitude 9.5 1960 Chile earthquake, the magnitude 9.2 1964 Prince William Sound, Alaska, earthquake, the magnitude 9.1 1957 Andreanof Islands, Alaska, earthquake, and the magnitude 9.0 1952 Kamchatka earthquake. As with the recent event, megathrust earthquakes often generate large tsunamis that cause damage over a much wider area than is directly affected by ground shaking near the earthquake's rupture.

Another subduction zone occurs further south along the same trench system and seaward of the Indonesian archipelago north of Australia, through Java, Timor to the western end of Papua province. A magnitude 8 earthquake occurred off the island of Sumba on 19 August 1977 generating a destructive tsunami through the archipelago and causing minor damage in northwestern Australia. A magnitude 7.8 earthquake on 2 June 1994 also killed more than 2250 people in southeast Java and again caused minor damage in northwestern Australia. This area is the main potential risk of producing a megathrust event that could seriously threaten coastal communities and oil fields of northwest Australia.

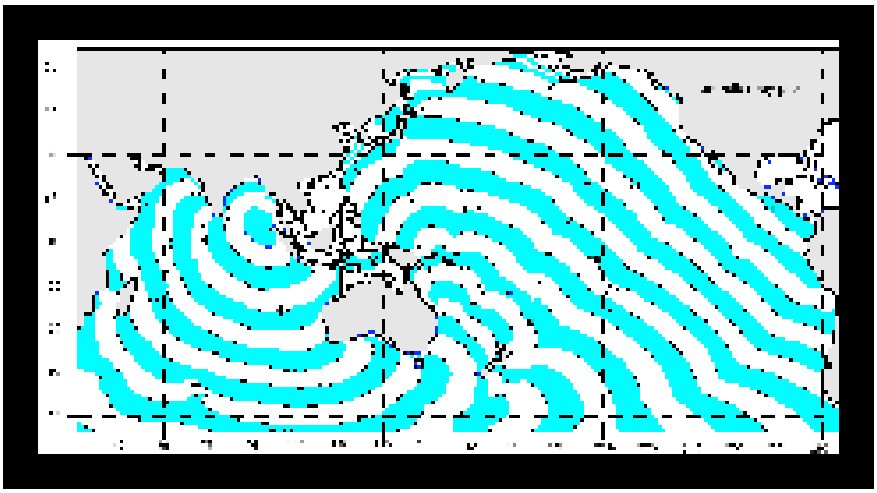
Below are mapped the mainshock and aftershocks in the following 2 days. There were 31 earthquakes with magnitudes between 5.5 and 7.3 in the 48-hour period after the main event, and it seems that seismicity migrated northward from the mainshock.

Major earthquakes occurred off Sumatra in 1833 and 1861, but there are no written records of any effects in Australia.





The figure below shows how the tsunami propagated through the Indian Ocean and south of Australia into the Pacific Ocean, possibly the first tsunami known to have been recorded worldwide.



There are few reports of infrastructure damaged by either the earthquake or tsunami apart from roads and a section of railway washed away in Sri Lanka. Here is one report of an engineered building which seems to have survived the tsunami.

Kalpakkam's nuclear plant in India closed by tsunami

(extracted from a report by J Sri Raman, a freelance journalist in Chennai)

Chennai, India, a coastal city in southeast India has just survived the tsunami and a nuclear threat. The enormous waves which hit Chennai last Sunday, did not only destroy fishermen's hamlets and flood out thousands of other homes and lives. The tsunamis also inundated a part of the nuclear plant located in the outskirts of the city and close to the sea.

Nuclear authorities denied there was damage or radioactive leaks but ruled out a full report for two reasons; secrecy that surrounds any nuclear plant and the threat of radioactive leaks. They did, however acknowledge havoc in the entire Kalpakkam area, home to a sizeable fishing community that also houses employees of the nuclear complex. The day after the disaster, at least 60 lives were reported lost in the employees' township and some 250 in the rest of the area. The toll, unofficially much higher, has continued to mount.

No official concern was voiced over the complex, which comprises two pressurized heavy water reactors and a test reactor, a reprocessing plant and an under-construction prototype fast breeder reactor or PFBR. The authorities claimed that, while one of the heavy water reactors had been closed for re-tubing before the tsunamis, the other was shut down the moment an inordinate amount of seawater was detected entering the pump-house for the coolant unit. (The second reactor was re-started seven days later.)

Nothing has been said officially about the reprocessing plant and its central waste management facility. No reassurance has been forthcoming about the most critical components of the complex. The complex has lost scores of scientific and technical personnel, ranging from a design engineer of the test reactor washed away while praying in a church mass, to others carried away by monster waves from the ~500 houses destroyed in the sprawling township. One female worker may have met her death inside the complex. Two male workers, posted at the waste discharge point at the seafront jetty, are reported missing.

R. Ramesh says that land subsidence in coastal areas should be expected as an inevitable consequence of tsunamis – and underscores the fact that the fast breeder reactor's site is just three to 5.6 meters above the sea level.

Prior to construction of the fast breeder reactor, the 1991 law restricting environmentally-sensitive constructions in the coastal zone was amended to exempt nuclear plants. Kalpakkam is only one of the many nuclear installations in India's coastal environment.

Massive quake hits off Tasmanian coast
(Macquarie Earthquake on Christmas Eve - 2 days before Sumatran earthquake)

Extract of report by The Age on Christmas Eve 2004

Based on interview with Cvetan Sinadinovski of Geoscience Australia

December 24, 2004 - 5:34PM

The world's biggest earthquake in almost four years rumbled beneath a vast stretch of ocean between Australia and Antarctica on Friday but gave southern Tasmania little more than a gentle shake.

The quake, which at its epicentre measured 8.1 on the Richter Scale, hit at the Macquarie Rise in the Pacific Ocean at 1.59am (AEDT), seismologists said.

Its impact was felt about 900km to the north-west, on the Tasmanian coast, but apparently not 400km to the south on remote Macquarie Island, where Australian scientists slept through it.

Geoscience Australia seismologist Cvetan Sinadinovski said buildings in Tasmania shook for up to 15 seconds, but no injuries were reported.

And there was little danger of significant structural damage to buildings from a quake so far out to sea.

"If it happened underneath a population centre in Australia, this would probably have destroyed a whole city," Dr Sinadinovski said.

"In terms of size, this could have been more than 30 times stronger than the Newcastle event (earthquake) of 1989."

While inter-plate tremors are recorded every one or two years at the Macquarie Rise, where the Indo-Australian and Pacific plates meet, Friday's quake was the most significant in at least 80 years.

Globally, it was the strongest since June 2001, when more than 120 people were killed when an earthquake measuring 8.4 on the Richter scale struck less than 200km off the coast of Peru.

A Tasmanian police spokesman said emergency services received a handful of calls after 2am, with people reporting shaking houses, swinging light fittings and a sound "like a washing machine mid-cycle".

The quake also woke people on the south island of New Zealand, but not the 22 Australians and 800,000 king penguins on Macquarie Island, a Tasmanian outpost 1,500km south-east of the island state and 1,300km north of the Antarctic continent.

Australian Antarctic Division (AAD) director Tony Press said staff phoned the Macquarie Island base to check immediately after learning of the quake on Friday morning.

"We grabbed hold of a couple of people having breakfast this morning and they didn't know anything about it," he said.

AAD chief scientist Michael Stoddardt said there was nothing to suggest wildlife had suffered because of the quake.

Dr Sinadinovski said it could have produced a localised tsunami or unusual tidal activity had the plate displacement been vertical, rather than horizontal.

"We can assume this size of earthquake could rupture tens of kilometres and have a displacement of a couple of metres (of water) for sure," he said.

An aftershock registering 6.1 hit at 6.50am, with more likely to follow, he said.

"Theoretically we should expect more mid-five or mid-six events over the next few days," he added.

Macquarie Earthquake and a 20 cm tall Tsunami

Message forwarded by Hugh Cowan to AEES on Christmas Eve 2004

GNS MEDIA RELEASE, 24 DECEMBER 2004

LARGEST EARTHQUAKE OF 2004 WORLDWIDE, OFFSHORE SOUTHERN NEW ZEALAND

A great earthquake that occurred under the sea 740 km southwest of Invercargill this morning was the largest worldwide so far this year.

The magnitude 8.1 earthquake struck at 3.58am and was felt over much of the lower half of the South Island, Geological and Nuclear Sciences Ltd (GNS) said. Public reports filed through the GeoNet Project website (www.geonet.org.nz) indicated long rolling motions typical of large, distant quakes but fortunately no damage.

Aftershocks are expected to occur during the next few weeks, but because of their distance from land, it is unlikely they would be felt strongly, said seismologist Dr Ken Gledhill. A tsunami of 20 cm was recorded by NIWA in Foveaux Strait at 6:00 am, three hours after the earthquake. An earthquake of this size could generate a damaging tsunami, but movement associated with this quake involved little upheaval of the seafloor.

Unlike the magnitude 7.3 earthquake that occurred south of New Zealand on November 23, this mornings quake occurred some distance away from the boundary between the Australian and Pacific tectonic plates, known as the Macquarie Ridge.

The Macquarie Ridge is known to be a seismically active area and a similar great quake of magnitude 8.2 occurred nearby in May 1989. The surprising thing about today's quake is that it occurred in an area where faults have been identified but previously considered inactive. "Despite its distance from land and minimal impact on society, the size and location of this event make it scientifically important", Dr Gledhill said.

Links between the two Great Earthquakes ?

By Gary Gibson

The Macquarie Ridge earthquake was of magnitude Mw 8.1, the world's largest for 2004 until superceded less than three days (about 58 hours) later. It was in the Southern Ocean about 400 km north of Macquarie Is and about 700 km southeast of Hobart. It was on the opposite side of the Australian plate.

The news media carried reports that the Asian earthquake may have been triggered by the “Tasmanian” event. However, the stress change in the surrounding area following a large earthquake drops off very quickly with distance, and is negligible (less than stress changes due to weather patterns or tides) beyond a thousand kilometres.

Although this is what the equations give, I do remember Lord Kelvin's age of the Earth based on heat flow. He considered the heat flow from the earth, the temperatures at formation and at the current time. Using the equations of physics, the earth could not have been older than about 25 million years! Unfortunately he did not take into account radioactive heating within rocks.

So perhaps there is some other relationship between the earthquakes. Many seismologists in Russia and China have models that incorporate space-time relationships between earthquakes, and some progress has been made on pattern recognition. I feel sure that earthquakes tend to cluster in time and space beyond the obvious clustering of foreshocks, mainshocks and aftershocks.

Beyond doubt though, is that the Aceh earthquake would have happened eventually, and the longer it delayed occurring, the larger it would be. The convergence between the Australian-Indian plate, and the Eurasian plate is about 60 mm per year, and a significant proportion of this will be associated with the maximum credible earthquake. Assuming that the slip on this earthquake is about 15 metres, the recurrence interval of such events will be longer than 15000/60 = 250 years, modified by a factor depending on the movement associated with smaller events.

Why does the sea level usually fall before a tsunami arrives?

By Peter G. Baines and John D. Fenton at University of Melbourne

It is a common experience that, in coastal regions that suffer the impact of tsunamis, the sea level initially falls, and remains suppressed for a period of up to many minutes, prior to the arrival of the tsunami waves that do all the damage. Why does this occur? There does not appear to be a common explanation in the literature, and we offer the most likely explanation here.

In general, there are three main ways in which tsunamis are generated. The first is by a submarine avalanche, which occurred on the north coast of New Guinea on the 17th July, 1998. The second is by the sudden volcanic eruption of submerged volcanoes, which occurred with Krakatoa on the 27th August 1883, and the third is by submarine earthquakes, as occurred in the recent Boxing Day earthquake in 2004. For the last two types, the nett effect of the geophysical disturbance is to cause a depression of the ocean floor. In some regions the sea floor may rise (as in the Boxing Day earthquake), but on the largest length scales the sea floor may be expected to fall. In the cases that cause tsunamis, this effect is sufficiently rapid to cause the sea surface to fall with it. The propagation of tsunami waves is largely governed by the shallow water-long wave equation for non-dispersive waves. For such waves, the propagating wave has the shape of the initial disturbance. Hence, a sudden initial depression of the sea floor will cause a corresponding depression of the sea surface. For a very long depression with no variation along it, all movement transverse to it, this causes two waves of half the initial amplitude to propagate away in opposite directions, carrying the shape of the depression of the sea floor. The shape of this disturbance will evolve as it propagates across the ocean, because the longer wave components propagate faster than the shorter components. If the longest components are waves of depression, these will lead the slower smaller scale components, and arrive at the coastal environment sooner. The further away from the source of the disturbance the longer the difference in arrival times will be, and there are records of the initial depression varying from a few seconds up to three quarters of an hour. As waves of elevation propagate up a continental shelf and slope, the propagation speed decreases because of the decreasing depth, and the waves tend to steepen and perhaps form solitary-like waves. But there is no dynamical process by which it may cause a region of suppressed sea level ahead of it.

Hence, it appears that the reason why the suppressed sea level occurs before the arrival of a tsunami is that there is a nett decrease of the sea floor and sea surface by the source disturbance on the longest length scales, and that, given sufficient time, this becomes the leading part of the wave disturbance due to wave dispersion. The main damage at coastal sites occurs when the back end of this depression arrives, steepening and increasing in amplitude as it propagates onshore.

Ground Shaking Felt in SE Asia

by Kusnowidjaja Megawati, the University of Hong Kong

An M_w 9.0 mega-thrust earthquake occurred on December 26, 2004 just off the west coast of Sumatra, near the Province of Aceh in Indonesia. The earthquake happened on the interface of the India and Burma plates. The Earthquake Research Institute (ERI), the University of Tokyo has published the detailed rupture model obtained using the inversion analysis of the recorded ground motions (http://www.eri.u-tokyo.ac.jp/sanchu/Seismo_Note/2004/EIC161ea.html). The result shows that the total duration of the source rupture was about 400 seconds (for comparison, the source duration of an M_w 7.0 is typically 15 – 20 seconds), and the rupture plane covered an area of 1000 km by 240 km. The average displacement on the fault plane was about 15 metres.

The distribution of the aftershocks obtained from the USGS shows that the rupture plane extended from the Simeuleue island, off the west coast of Sumatra, to the Nicobar and Andaman islands in the northwest. Since the epicentre was located beneath the Simeuleue island, the rupture may have initiated beneath the island and propagated toward the northeast. That probably explains why the ground shaking in Banda Aceh (R = 250 km, MMI VI-VII, estimated PGA = 70 - 100 cm/s^2, estimated PGV = 8 cm/s) was stronger than that in the cities located southeast of the epicentre, such as Medan (R =300 km, MMI IV-V). Note that R indicates the epicentral distance.

The source rupture also shows that the largest slips occurred around 175 km and 650 km northwest of the epicentre, farther away from Singapore, Kuala Lumpur and Penang. This may be the reason why the tremor was hardly felt in Kuala Lumpur (R = 650 km) and Singapore (R = 900 km). With only about 10 people reportedly felt the tremor in Singapore (according to the Strait Times), the PGA on rock sites was estimated to be smaller than 1 gal.

As reported by the newspapers in Indonesia, Singapore and Malaysia, the ground tremors did not cause widespread major structural damage. Most of the damage was due to the tsunami.

Data on Tsunami

Message from Paula Dunbar of National Geophysical Data Centre
forwarded by Col Lynam to AEES on 31 December 2004

From "A Tentative List of Tsunamis in the Marginal Seas of the North Indian Ocean", T.S. Murty and M. Rafiq, Natural Hazards 4: 81-83, 1991.

June 26, 1941 at 12.5N 92.5E magnitude 8.1 11:52 UTC
Tsunami on the east coast of India and tsunami in the Arabian Sea
5000 people killed (I am assuming only from the tsunami)

Nov 27, 1945 14.12 N 62.36 E, magnitude 8.3
Tsunami in the Arabian Sea, several people killed
1.98 m runup in Bombay
1.37 m runup in Karachi
13.0 m runup Ormara
13.0 m runup Pasni
Maximum amplitude 15.24 (but no designation of where this runup occurred just that this was the max. amplitude)

From "Tsunamis and Seismic Seiches Reported from Regions Adjacent to the Indian Ocean", Wm. H. Berninghausen, Bulletin of the Seismological Society of America, Vol. 56, no. 1, p. 69-74, Feb 1966.

The abstract states:
"References have been made in the past to the absence of tsunamis and seismic seiches in the Indian Ocean. However, a survey of available literature indicates that at least 27 such waves have been reported. most of these were reported from the coastal regions of the seismically active Indonesian Arc, whereas progressively fewer such waves were reported from the coastal regions adjacent to the Bay of Bengal, Arabian Sea, and the south eastern coast of Africa and the western coast of Australia."

From Table 3: Makran coast Tsunami of Nov 28, 1945
Karwar - 14 deg 48 min N, 74 deg 08 min E,
Wave flooded creeks and inlets
Bombay - 18 deg 54 min, 72 deg 50 min E, estimated wave height 6.5 feet
Waves caused some loss of life; boats were smashed at their moorings
Karachi - 24 deg 52 min N, 67 deg 03 min E , estimated wave height 4.5 feet
Wave caused damage in the Karachi harbor and loss of life and property along the adjacent coast
Ormara - 25 deg 12 min N, 64 deg 38 min E, estimated wave height 40-50 feet
Waves caused serious loss of life and property
Pasni - 25 deg 15 min N, 63 deg 28 min E, estimated wave height 40-50 feet
Waves caused serious loss of life and property
Victoria, Mahe Island, Seychelles - 44 deg 37 min S, 55 deg 27 min E, estimated wave height 1 foot
Waves noted on the tide gauge.

Links to images and movies

Based on information provided by Hubert Chanson at University of Queensland and forwarded by Prof John Fenton at University of Melbourne

- Tsunami propagation predictions by the NOAA
  Video Quicktime : ftp://ftp.pmel.noaa.gov/tsunami/sumatra/indo2004.mov

- The preliminary report by the USGS Earthquake Hazards Program
  http://earthquake.usgs.gov/eqinthenews/2004/usslav/

- NASA Earth Observatory
  http://earthobservatory.nasa.gov/
  http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3

- Some digital movies
  [V1] http://www.chafee.net/TR/tsunami/tsunamiphuket.wmv
  [V2] http://www.chafee.net/TR/tsunami/penang.wmv
  [V3] http://www.chafee.net/TR/tsunami/zeebeving.avi

- Photographs of the limited runup at the Reunion island
  http://m-r.li/mon_image.php?f=radoub.jpg
  http://m-r.li/mon_image.php?f=plage.jpg

- Some photographs
  http://in.news.yahoo.com/23/

  For technical information:
  http://www.uq.edu.au/~e2hchans/photo.html#Tsunami
  [Click PROCEED at ITS-Advisory webpage & Enable cookies in your browser]