



TSUNAMIS

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The Indian Ocean and Japanese tragedies

Few Britons had heard of tsunamis before Boxing Day 2004 when the Indian tectonic plate forced its way under the Asian plate off the coast of Sumatra after decades of increasing pressure. An area of ocean floor 100 kilometres (km) wide and 1000 km long, 5 times the area of Wales, buckled. The Asian plate rose 3 metres in places and moved horizontally by up to 20 metres. There were large underwater landslides. The judder or 'quake' was finally graded at 9.0 on the Richter scale, the largest in the world for 40 years*. Much of the enormous energy released was transferred through a series of waves or tsunamis which sped across the Indian Ocean. The citizens of Banda Aceh at the NW end of Indonesia barely 20 minutes away had little chance. Warning systems might have saved lives elsewhere, particularly in Sri Lanka where the tsunami took about 2 hours to arrive and even further away in Somalia where unlike Kenya (where warnings were given) many hundreds of lives were lost. Warnings might also have helped in the tourist centre of Phuket, Thailand, some 90 minutes distant.

The total loss of life was thought to be about 230,000, higher than the 2 previous great tsunami disasters: at Lisbon in 1755 and Messina, Italy, in 1908 where fatalities were each estimated to be 50 -100,000. Some 5 million people were displaced; there was huge destruction of property; vital wells were filled with sea water, and there were many harrowing stories of children orphaned and families decimated.

The tsunami which hit the east coast of Japan on 11th March 2011, again arising from a grade 9.0 earthquake, might have been considered less severe - the final death toll will be 'only' about 25,000 - had the tsunami not overtopped the tsunami defences and knocked out the grid and standby power supplies to the Fukushima nuclear power station. The defences had been designed for a wave 5.7 metres in height, not the 14 metres which arrived. No life was lost from the radiation released but great damage was done to the Japanese economy.

What is a tsunami?

Throw a rock into a pond, observe the splash and watch the ripples radiate to the pond's edge and back, reducing in height all the time. Note that the bigger the rock and the faster it enters the water, the greater will be the splash and the height of the ripples.

Tsunamis demonstrate these features at a massive scale with the crucial difference that their size causes the physical laws of wave movement to be played out in a potentially devastating way.

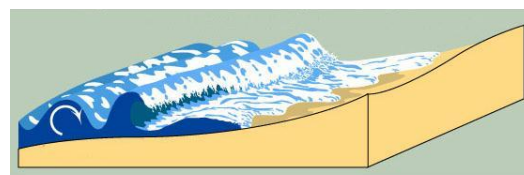
What are 'waves'?

Consider the 'Mexican' waves seen commonly at cricket grounds. A flowing movement runs round the ground yet the spectators merely stand up and sit down. Ocean water similarly moves up and down (or, more strictly, rotates clockwise in the direction of motion) and in doing so *transfers* energy through the water from the initial impulse (in the Pacific and Indian Oceans, the earthquakes) to something which can not move - land.

The height and length of the wave depends on the energy imparted to the water. Tsunamis arise from such huge movements that the wave length - the distance from crest to crest - can exceed 100 km. The speed of tsunamis is usually limited by the depth of water. At a water depth of 4000 metres a tsunami would travel at about 710 km/h** (450 mph) and have a wave length of 213 km. There would be 20 minutes between crests.

This great speed inevitably means that warning times

Top: Normal wave breaks onto shore. Energy dissipates quickly



Bottom: Tsunami wave crest is so long the wave breaks but keeps on coming



will be limited. On 5th May 1960 an earthquake off the south central coast of Chile recording 9.5 on the Richter scale caused a tsunami that killed several hundred Japanese 10,000 miles away. The same tsunami took 14.8 hours to reach the wave at the shore was still 10.7 metres in height. The wave 'trough' was timed arriving 10-15 minutes later.

How a tsunami develops

An earthquake or other initial impulse can physically lift or lower the sea causing it to 'bounce' up and down as it attempts to regain its normal level. It is this that creates

* An excellent and more detailed report can be found in *Geology Today* Vol. 21 No. 1 (Blackwell Publishing Ltd)

** For tsunamis, wave velocity, $V = \sqrt{gd}$,

the square root of the water depth d (metres) times g , the acceleration due to gravity. (9.8 metres/sec/sec)

An ALDES Briefing Note

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This note has been written for ALDES by Richard Balmer and David Nowell. It should be factually correct but any opinions are the authors' alone. If you see errors or have comments contact Richard Balmer at richardbalmer162@btinternet.com

the waves. Given an open, unobstructed, flat bottomed ocean the waves would spread out in a circular pattern with the height of the wave decreasing pro-rata to the distance. Eye witness accounts of the Indian Ocean tsunami all said the sea withdrew before the first wave arrived. This means that the first visible sign of the tsunami was a wave 'trough' rather than a crest. Most people mentioned only 2 waves, with the second the larger, but several smaller ones would also have come.

Ships at sea would have barely noticed the tsunami. Though raised perhaps a metre above normal levels, the distance from crest to trough was so long the sea would still have appeared flat. Given warning, it is in fact safer for ships afloat to head out to sea than seek land.

Near land the sea grows shallow. The reasons why some lengths of coastline in the Indian Ocean fared worse than others are complex. The profile of the sea bed varies so the incoming tsunami was concentrated in some parts and deflected in others. The worst possible situation occurs where the sea bed runs down steadily. The physical laws of wave motion dictate that as the depth reduces the speed of the tsunami must slow down. Though energy is dissipated through friction at the sea floor, the wave compensates for the reduced speed by *increasing in height*. A normal wave on a beach eventually reaches a point where it is too high for the depth of water left and begins to break and run forward like a bore. Many Indian Ocean eye witnesses spoke of a wave 10 metres high - the height of a 2-storey house - and this is likely to be correct.

Unlike a normal wave whose energy dissipates within seconds (see figure over), a tsunami has a 'crest' which is *several kilometres long*. Effectively the *whole sea* near a coastline can rise by 10 metres *in a few seconds*. If the land is flat, the water simply pours overland sweeping anything weak before it. A tsunami is not technically a 'tidal' wave but seems like one.

Coastlines can escape where the ocean bed falls away rapidly. The Maldives are coral atolls. The tsunami waves maintained their speed right up to the shore and though destructive, did not gain the height which made them so devastating in Sri Lanka.

Causes of tsunamis

The most common cause is an earthquake which lifts (or lowers) the ocean floor or triggers a landslide either under water or from land. In 1958 an earthquake induced a landslide into the almost enclosed Litka Bay, Alaska, which caused water to 'splash' to a height of 525 metres! In 1929 an earthquake caused an underwater slip off Newfoundland killing 29 Canadians. The tsunami was recorded as far away as Portugal even though the quake only recorded 7.2 on the Richter Scale. Underwater volcanic eruptions can trigger tsunamis. As volcanoes as well as earthquakes tend to arise near the edges of the planet's tectonic

plates it is not surprising the majority of tsunamis emerge there. The Pacific rim has had over 80% of recorded global events.

What can be done?

The natural forces involved are too great to prevent earthquakes occurring, volcanoes erupting etc. Geologists can only investigate, monitor and warn. Defences are expensive and political leaders can mostly only install good communications and educate populations, principally to seek high ground or upper floors of robust buildings. The simplest of warning messages was developed after the 1998 tsunami in Papua New Guinea. It was: *IN BIG EARTHQUAKE RUN FOR HILLS*.

The Pacific Ocean has 2 warning systems. The larger is the Tsunami Warning System (TWS) supported by 26 countries. Surveys of ocean depth and vulnerable coastlines and estuaries have been undertaken and communications links from monitoring scientists to official bodies *and the media* put in place and practiced. Sensors have been installed to detect earthquakes (whose shock waves can travel 20 or more times faster than a tsunami) but, because earthquakes do not necessarily trigger tsunamis, deep tidal gauges are needed as well. All this costs money to set up and maintain. The Indian Ocean countries turned down a similar scheme in 2003 but one was finally completed in December 2010.

Should we have concerns in the UK?

Few large earthquakes occur near the UK but the Benfield Greig Hazard Research Centre at University College London have highlighted concerns about a potential landslide at La Palma in the Canary Islands. The next eruption of the Cumbre Vieja volcano might cause 500 billion tonnes of rock (twice the volume of the Isle of Wight) to hurtle into the Atlantic at over 200 mph. The resulting tsunami would take 8 hours to reach the US eastern seaboard and could back up into the English Channel. Cumbre Vieja last erupted in 1971. In the past the intervals between eruptions have varied from 20 to 200 years. Though an eruption is 'due', the volcano is quiescent at present. Other geologists say no similar event has occurred in the geological record relating to the Canaries although an underwater slip 8,000 years ago at Storegga off Norway generated a tsunami that left distinct 'wash over' sediments along 600 km of the North Sea coast of Britain.

A separate worry concerns asteroids. Asteroids a quarter of a mile across arrive on average only once every 80,000 years but they would be travelling at 50,000 mph and have the energy of 1000 Bikini Atoll H-bombs! If they landed in ocean a 'crater' 3 miles wide would create a tsunami 180 metres high at 10 miles, 13 metres high at 100 miles and a metre high at 1000 miles which would still be high enough to cause a 10 metre high surge at coastlines. The UK is beginning to look out for these things now, but there is no way to stop them.

The earth is not a risk free place.
