The Earth in our hands

- how geoscientists serve and protect the public

6 TSUNAMIS

What is a tsunami*?

A tsunami is a sea wave triggered by a sudden movement on the seabed or at the surface. Such movement might be due to an earthquake, volcanic eruption, submarine landslide, or asteroid impact. Events like this trigger wave motion in the overlying water. If the shape and slope of the seafloor are unfavourable, the resulting wave hitting coastlines may reach gigantic proportions. Tsunamis are particularly dangerous because coastal areas tend to be densely populated.

Tsunamis may cause immense damage to low-lying coastlines. There may be great loss of life in the so-called "inundation" or "run-up" zone. In the 1990s, even with major improvements in education and global warning systems, more than 4000 people were killed by tsunamis and entire coastal communities have been wiped out.

Since 1990, 82 tsunamis have been reported, mostly from the Pacific Rim, where the world's largest earthquakes and most volcanoes occur. A quarter of the deaths that can be attributed to volcanoes during the last 250 years were actually caused by their associated tsunamis. Although there are no active volcanoes in the UK and there is limited earthquake activity, it is at potential risk from tsunamis caused by submarine landslides (see *The cost*, below).

A major submarine slope failure in the N. Atlantic could give rise to a tsunami large enough to flood major cities on the coast of America or Europe. An asteroid impact anywhere in the Atlantic would have a similar effect. The tsunami produced by the Eltanin Asteroid impact (2.16 million years ago off the southern tip of South America) spread over the entire Pacific Ocean and the southern Atlantic, reaching the coastlines of North and South America, Australasia, Japan and Asia, and South Africa within 24 hours.

Tsunamis have played an important role in human history. A tsunami is thought to be associated with the legend of Atlantis; around 1628 BC, the eruption of the Aegean island of Thera (Santorini) produced a 30m-high tsunami that probably hastened the demise of the Minoan civilisation on Crete. The 1883 eruption of Krakatoa in the Sunda Strait (Indonesia), triggered tsunamis that killed more than 36,000 people.

["Tsunami" is Japanese for "long wave in a harbour". Tsunamis are not the same thing as "tidal waves", though the terms are sometimes used interchangeably. Tidal waves are caused by tides rushing up narrowing coastal inlets, like the famous Severn Bore in the UK. Sometimes "tsunami" is used as a plural, without the "s".]*

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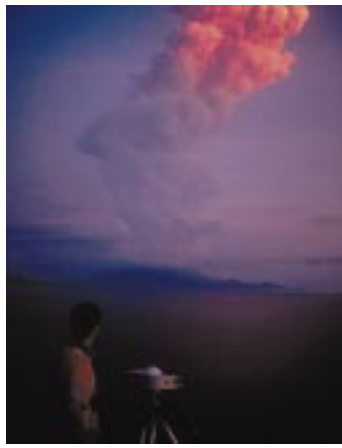

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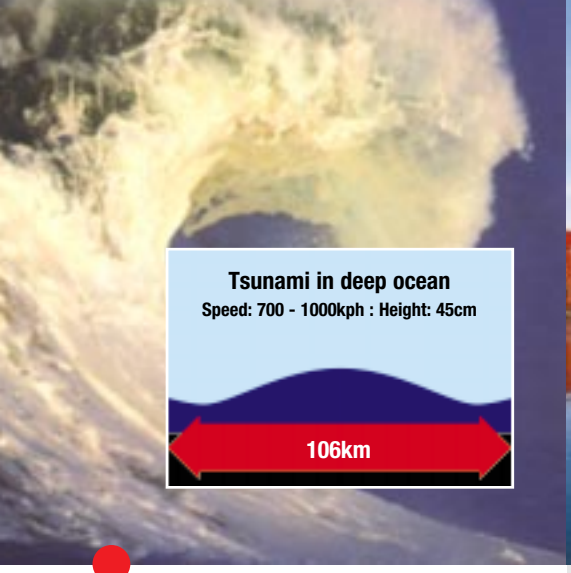
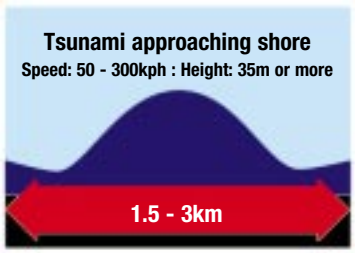


The where, when and how of tsunamis

Tsunamis can be thought of as very large versions of the ripples caused by a single stone dropping into a pond. Tsunami events may likewise consist of many separate wave fronts - though each up to a hundred kilometres apart and perhaps thousands of kilometres long. The speed of tsunamis depends on the depth of the water through which they travel. In deep water they can travel as fast as 1000km per hour, though at this point they may be only a few centimetres high. They are invisible from the air and would not be felt on board a ship. For this reason tsunamis cause few deaths in open sea.



As a tsunami nears the coast, however, the leading waves begin to travel more slowly in the shallower water. In water 20m deep, the first waves to arrive will have slowed to a mere 50km per hour. Later waves then begin to catch up, piling up water and creating a high, destructive, wave. Thus, a wave that was only 45cm high in deep water may become 35m tall as it reaches land.

Some examples of tsunami events from around the globe

An earthquake of magnitude 7.5, between 3 and 8km offshore and in water 50m deep, caused a tsunami that hit the coast of Costa Rica in 1991. The sea first retreated by a distance of 75m, before rushing back, completely destroying all buildings on the shoreline.

On 17 July 1998, following a magnitude 7.0 earthquake, a tsunami hit the northern coast of Papua New Guinea killing more than 2500 people and leaving thousands more missing. The waves reached over 15m high, destroying three villages and severely damaging four more.

At the time geologists believed it unlikely that the earthquake alone had generated the tsunami. Further investigation revealed that a giant mass of sediment had slipped to the bottom of the continental slope in an earthquake-triggered “slump” (underwater landslide).

The chances of a similar event occurring in the Atlantic are lower because the Atlantic does not experience many large earthquakes. However, this is no cause for complacency. In 1929 (November 18) a tsunami was triggered by a slump that was itself triggered by a 7.2 earthquake off the coast of Grand Banks, Newfoundland. The disaster caused $400,000 of damage, and 29 people were killed. The tsunami was registered in South Carolina (US) and even across the Atlantic in Portugal.

Geological faults discovered recently lying at up to 200m below the ocean north of Cape Hatteras (North Carolina) threaten disaster to US East Coast. These faults traverse the edge of the continental shelf, where the sea floor begins to drop away to great depth. If a sediment pile here were to collapse downslope after an earthquake along these faults, the resulting tsunami would take only 20 minutes to reach the coast of Virginia and North Carolina.

Slumps like this have occurred in the past off the Norwegian coast, and caused tsunamis that have struck the UK (see below).

Steep-sided volcanic islands or coastal volcanoes are often unstable and prone to collapse. Such scenarios exist in the Canary Islands (Atlantic Ocean), Etna (Mediterranean), Reunion (Indian Ocean), and Hawaii (Pacific Ocean).

In 1949 the west flank of the Cumbre Vieja volcano on the coast of La Palma (Canary Islands) began to slide towards the sea. Since then, a block of rock 200 cubic kilometres in volume has become detached. This is moving seawards at about 1cm per year. Towering 6km above the ocean floor, this mass will one day fall into the Atlantic.

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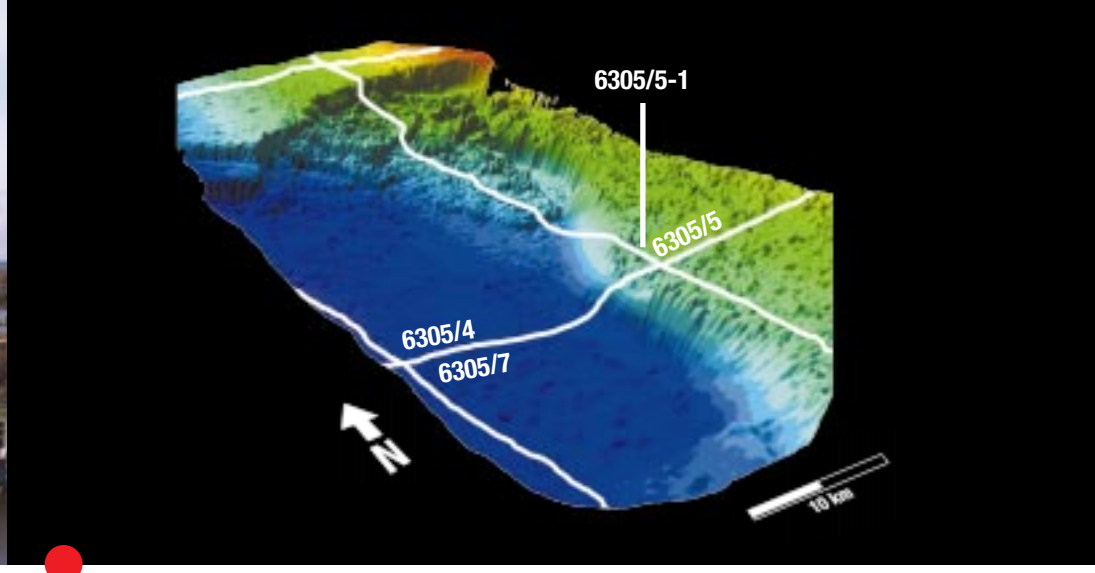

Pictured above: A 3D image of the Storegga slide.

The resulting tsunami could, initially, be over 600m high and would have a global effect. It would reach the Caribbean islands and the US east coast within eight hours, leaving no time to evacuate all the population. It is likely that the low-lying Caribbean islands would be totally submerged by the wave.

Engineering work can create slopes that may become unstable and fail - causing tsunamis. On the evening of 3 November 1994 in Skagway, Alaska, construction of a railroad dock extension is thought to have overloaded the sediments on which it was built. About 1 million cubic metres of rubble and sediment slid into the fjord. The resulting tsunami, up to 12 m high, surged across the harbour. In addition to the $20 million loss and one death on the dock itself, around two million dollars' worth of damage was caused to small boats and a ferry terminal (unoccupied at the time).

Another example occurred at Nice Airport, France, in 1979. Here, a much larger submarine landslide was triggered by collapse of an airport runway extension under construction. A tsunami up to 3m high caused damage along 30km of the French Riviera, and several deaths.

The cost: UK under threat?

Tsunamis usually cause the greatest damage near their source. This was true in Papua New Guinea (1998), Indonesia (1992, 1995) where thousands were killed, and Nicaragua (1992) where around 100 people died.

However, between 1946 and 1960 four tsunamis occurred whose effects were Pacific-wide. The 1960 Chilean earthquake (8.6 on the Richter scale) was the largest earthquake of the 20th Century. On the coast, closest to the epicentre, tsunami waves measuring 25m high arrived within 10 to 15 minutes, killing at least two hundred people, sinking all the boats, and flooding half a kilometre inland.

The total number of lives lost from the tsunami along the coast Peru-Chile coast is not known, but estimates range between 330 to 2000. The tsunami took only 15 hours to travel 6800km to Hawaii. There 60 people died. Another eight hours later, waves 6m high hit the coast of Japan and killed 180.

There are few reports of tsunamis in historical records in the UK, but the geological record shows that such events occurred in the more distant past. Geoscientists are monitoring areas (e.g. off the coast of Norway) likely to generate submarine landslides, or "slumps".

A slump here about 7200 years ago - possibly triggered by an earthquake - gave rise to a tsunami that inundated the Moray Firth and east coast of Scotland. There is evidence that the Storegga Slide, for example (picture), has moved as many as three times in the past. Were such a tsunami to happen today it would have a disastrous effect on such cities as Inverness, Aberdeen and Edinburgh.

Many deep-water sediments off Norway are rich in methane hydrate. This substance, normally solid, is easily disturbed - for example, by shaking or heating. Earthquakes - or global warming - may cause the hydrate to give off methane gas and trigger slumping.

Much of the UK's east coast, facing Norway's unstable offshore slopes, is low-lying. Many major eastern ports lie on estuaries where the "funnel effect" could further increase tsunamis' destructive effects. Houses, factories and vital infrastructure could be devastated. Land and fresh-water aquifers flooded by salt-water could be contaminated for many years and agriculture in fertile lowlands affected.

For this reason, geoscientists are monitoring and mapping slumped masses such as the Storegga, Andoya and Traenadjupet slides (NE Norwegian-Greenland sea). Their maps will help in interpreting the likely effects of future slides.

We cannot prevent tsunamis but we can recognise the potential hazard and prepare accordingly.

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About these briefings

The Earth is a dynamic planet. It is active and productive, offering humanity enormous opportunities. However, living on it also presents us with many dangers; some of our own making.

In our interaction with the Earth, geoscientists are in the front line. They seek and find the raw materials we use for agriculture, roads, buildings, energy, water supply and all the industries that provide wealth and health.

Geoscientists help society understand natural hazards and mitigate their effects. Such dangers include floods, landslips, volcanic eruptions and earthquakes.

Geoscientists also help to minimise hazards we have created (or made worse) by our activities. These include subsidence, and the disposal of waste.

With their unique understanding of the immensely long time spans over which Earth processes operate, geoscientists help communities world-wide to learn how to use the planet's resources safely, wisely, and sustainably.

This series of Briefings is dedicated to bringing this role to public attention.

Further information

http://www.nerc-bas.ac.uk/tsunami/
The Tsunami Initiative links insurance and science. It aims to improve the competitiveness of the UK insurance industry by using UK science to improve risk assessment.

http://www.geolsoc.org.uk
The Geological Society of London - enter "tsunami" in the search box

http://www.disasterrelief.org
Enter "tsunami" in the search box

http://www.wcatwc.gov
US West Coast and Alaska Tsunami Warning Center

http://www.usgs.gov
US Geological Survey - enter "tsunami" in the search box

http://www.bgrc.com
The Benfield Greig Hazard Research Centre

http://www.geophys.washington.edu/tsunami/
Tsunami! provides general information about tsunamis

http://www.storegga.no/museum/tsunami.htm
Norwegian site with information, images and information about the Storegga slide - with an animation of its associated tsunami

http://www.brunel.ac.uk/depts/geo/iainsub/studwebpage/best/Storegga.html
Brunel University pages by John Best on the Storegga Slide

Van Rose, S. Catastrophes - *Time's trail of destruction. Earthwise*, Issue 14. 1999 (British Geological Survey)

McGuire, *W. Apocalypse: a natural history of disasters.* Cassell 1999; ISBN 0-304-35209-8

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