



Australian Government
Geoscience Australia

TEACHERS NOTES AND STUDENT ACTIVITIES
RECORD NO. 2011/27

Tsunami





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SECOND EDITION RECORD NO. 2011/27

GEOSCIENCE AUSTRALIA

ABOUT THE BOOKLET

This booklet is intended to provide information for both Science and Geography teachers to support their work with pupils in both upper primary and secondary settings. Teachers should evaluate the student activities to ensure they are of appropriate difficulty for their cohort of students. If you have any further comments or feedback, please email us: education@ga.gov.au.

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WHAT IS A TSUNAMI?

Tsunami (pron: 'soo-nar-me') is a Japanese word; 'tsu' meaning harbour and 'nami' meaning wave. The phenomenon is usually associated with earthquakes, landslides or volcanic eruptions occurring in, or adjacent to, the ocean which results in the sudden movement of the **water column**. Until recently tsunamis were called tidal waves, even though the event has nothing to do with tides.

Before one can understand the remarkable characteristics of a tsunami, it is first important to understand the characteristics of a wave. All waves are characterised by their **length, height, amplitude** (half the wave height), **velocity** (rate of forward motion of the wave peak) and **period or frequency** (the interval of time between successive wave peaks passing the same point). The highest point of the wave is the wave peak or crest, with the lowest point of the wave being the **wave trough** (figure 1). The relationships among these properties vary depending on the nature of the mechanism creating the wave, the intensity of this generating mechanism and the environment in which the wave exists.

The characteristics of a wave

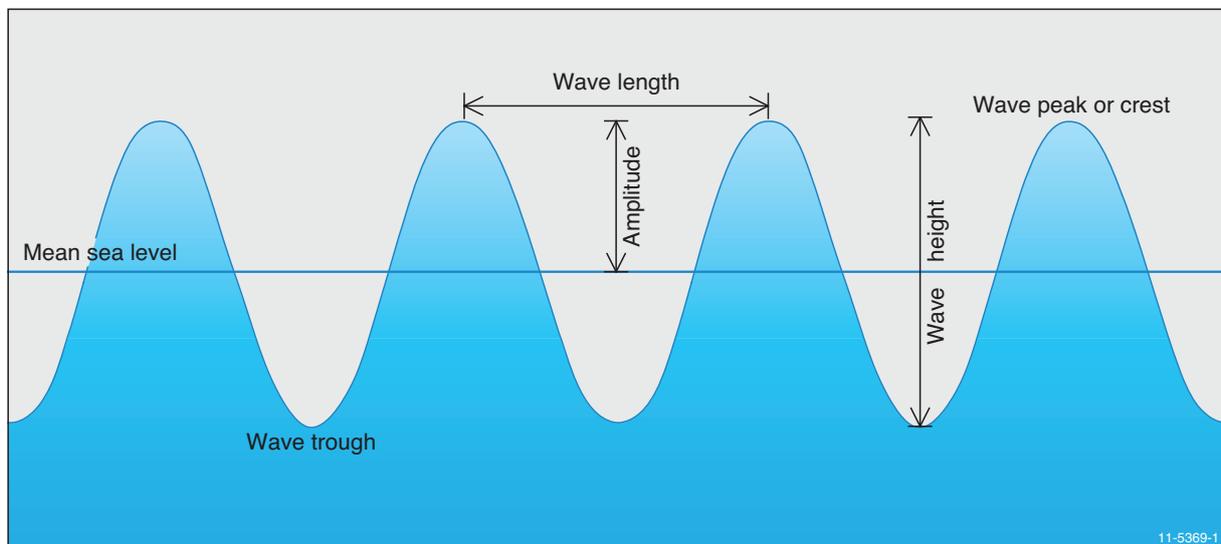


Figure 1: The characteristic features of waves represented here is the wave trough and wave peak or crest, the wave height and its amplitude, and the wave length.

Tsunami waves have an extremely long wave length and wave period. The wave length in the open ocean is up to 100 to 150 kilometres (figure 2b). In the deep ocean, tsunamis can travel between 640 and 960 kilometres per hour, approximately the speed of a Boeing 747 (Jumbo Jet). The wave period in a tsunami can be anywhere from 5 to 90 minutes. At the coast, a tsunami may appear as a breaking wave, a fast-moving tide or a barely noticeable ripple. The first sign of a tsunami can be either a rise or fall in the water level, depending on whether a wave crest or trough is first to arrive at the coast.

A **tsunami-generated wave** is different from a **wind-generated surface wave** on the ocean (figure 2a and b). The passage of a tsunami involves the movement of water from the surface to the seafloor which means its speed is controlled by water depth. Consequently, as the wave approaches land and reaches increasingly shallow water it slows. However, the **tsunami** which is still in deeper water is moving slightly faster and catches up, resulting in the wave bunching up and becoming much higher. A tsunami is often a series of waves and the first may not necessarily be the largest.

Differences between tsunami-generated and wind-generated waves

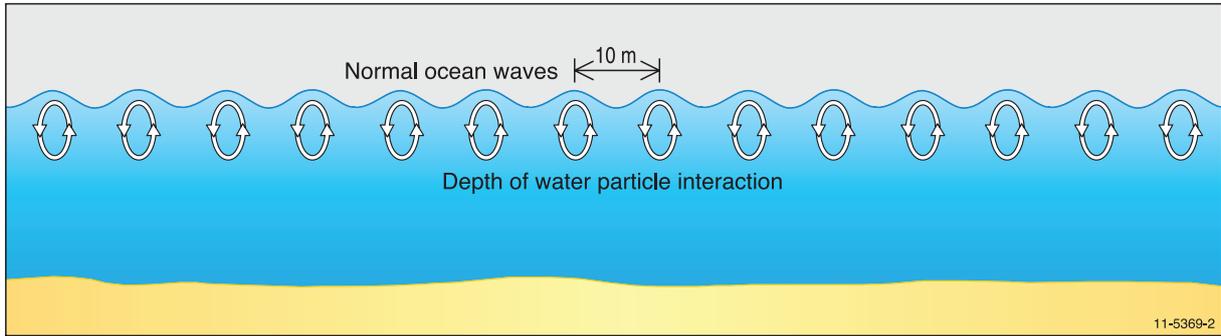


Figure 2a: Wind-generated surface waves in the deep ocean. A wind generated wave usually has a wave length of a few metres and a wave height that diminishes easily due to the low energy force from wind.

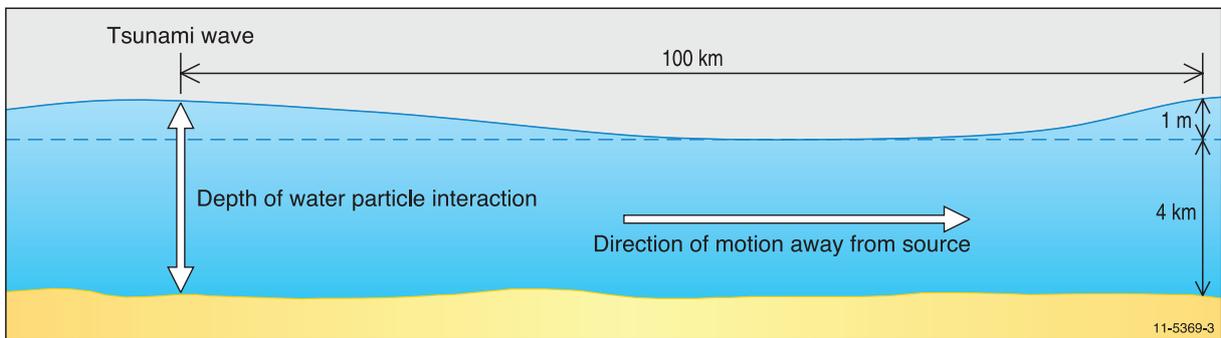


Figure 2b: Tsunami-generated waves in the deep ocean. A tsunami can be generated by tectonic, volcanic, meteorite or landslide occurrences that result in a sudden disturbance in the water column. The energy that is then generated fills the entire water column from the ocean floor to the surface, resulting in wave lengths of up to 100 to 150 kilometres. (Wave lengths and heights are indicative only).

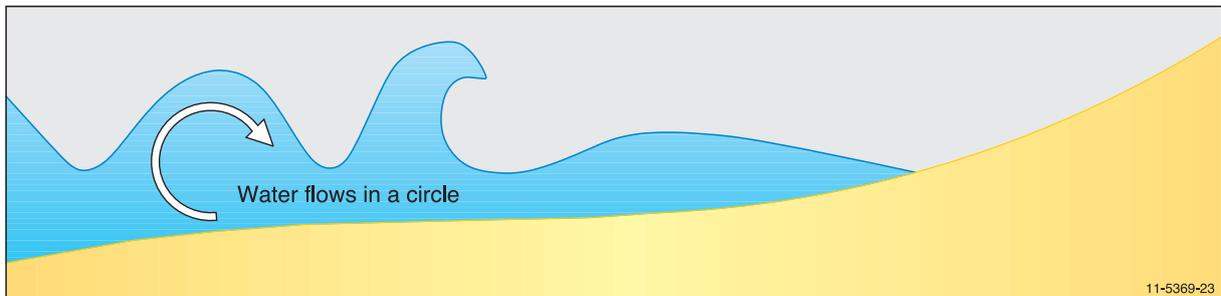


Figure 2c: Wind-generated surface waves near the coast. A wind-generated wave flows in a circular motion and will advance and recede on the coastline without flooding higher areas.

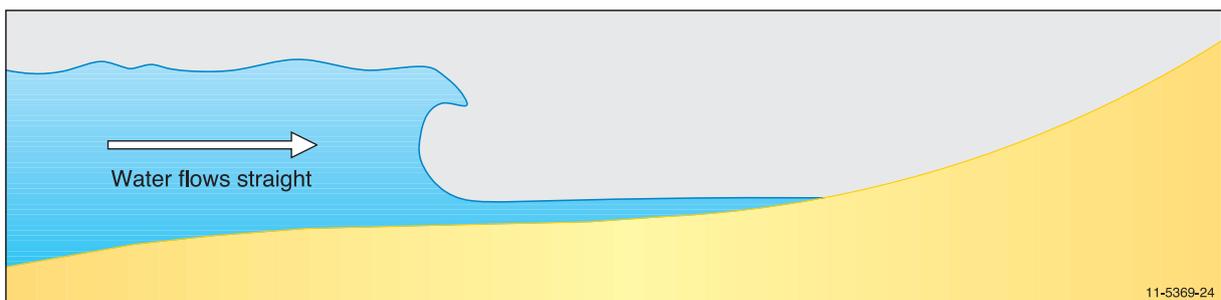


Figure 2d: Tsunami-generated surface waves near the coast. A tsunami-generated wave flows straight and will quickly advance over the land as a wall of water.

WHAT CAUSES TSUNAMIS?

Tsunamis are waves generated by sudden movement of the ocean due to earthquakes, landslides on the sea floor, land slumping into the ocean, large volcanic eruptions or a meteorite impact in the ocean.

The causes of tsunami-generated waves

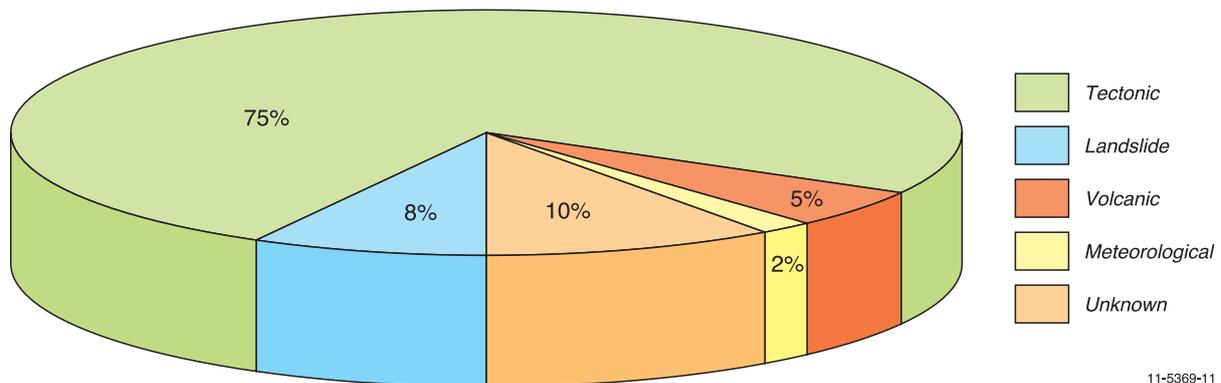


Figure 3: Most oceanic tsunamis (up to 75 per cent of all recorded cases) are generated by shallow-focus earthquakes capable of transferring sufficient energy to the overlying water column. The remainder are the result of landslide (8 per cent), volcanic (5 per cent) and meteorite (Meteorological) impact (2 per cent). Up to 10 per cent of all the recorded run-ups still have unidentified sources (adapted from the Institute of Computational Mathematics and Mathematical Geophysics Tsunami Laboratory website).

A) Earthquakes

The most common cause of a tsunami is an undersea earthquake that results in a sudden rise or fall of a section of the Earth's crust under or near the ocean. Typically tsunamis are generated by earthquakes that occur along subduction zones. A subduction zone is an area on the earth where two tectonic plates meet and move towards one another, with one sliding down underneath the other into the Earth at rates typically measured in centimetres per year.

A tsunami-generating earthquake may create a rapid vertical motion of a tectonic plate that can displace the overlying water column, creating a rise or fall in the level of the ocean above (figures 4a, b and c). This rise or fall in sea level is the initial impulse that generates tsunami waves. Fault movement that is horizontal causes little or no displacement of water and therefore such earthquakes do not generate tsunamis.

Earthquake-generated tsunami on a subduction zone

The vertical displacement of the seafloor, caused by the earthquake, creates a rise and fall in the level of the ocean

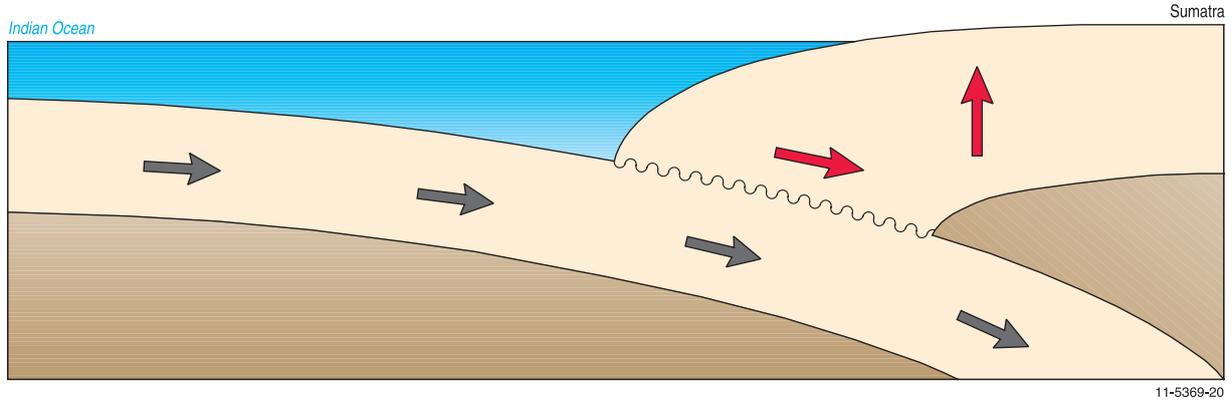


Figure 4a: Prior to earthquake. Subduction zone earthquakes cause the most common source of destructive tsunamis. They are generated when the lower subducting plate drags the upper plate down causing it to bend.

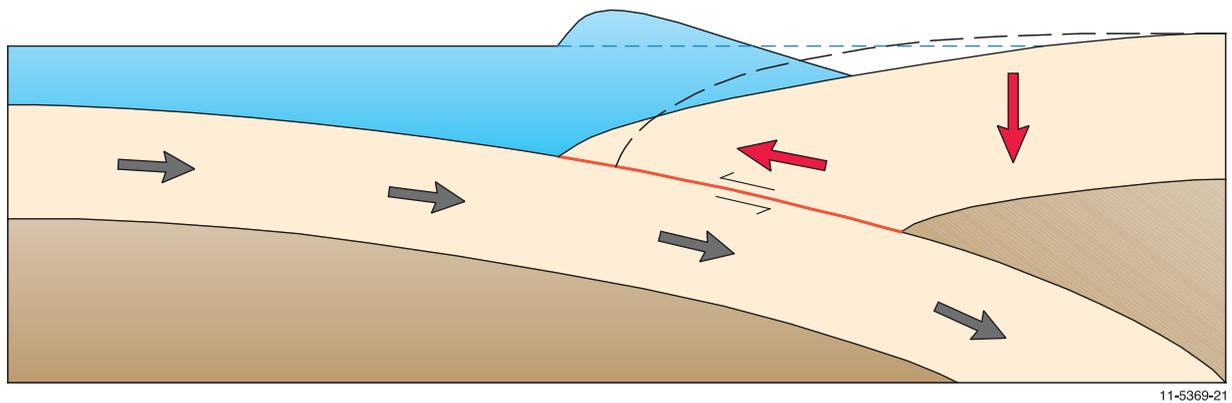


Figure 4b: At time of earthquake. Release of stress on the plate boundary causes the upper plate to rebound to its initial, unflexed position, displacing upwards the column of water above. The arrows (shown on the upper plate) in the above pictures indicate the direction in which the upper plate is deformed due to drag and release of the lower plate.

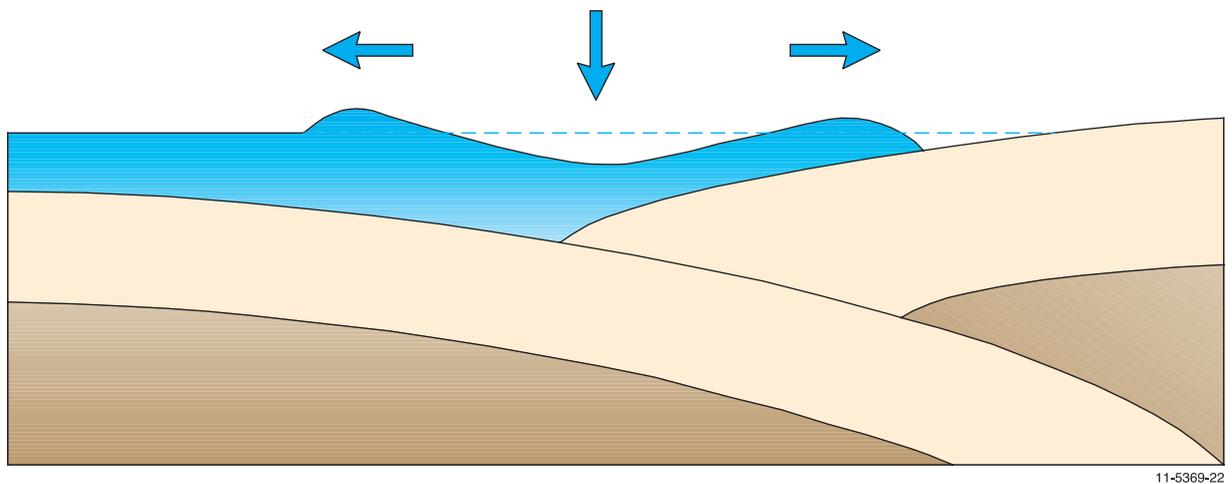


Figure 4c: 10 minutes after earthquake. The displaced sea surface propagates outward as a tsunami.

Case study: 2004 Indian Ocean tsunami

On the morning of Sunday 26 December 2004 a massive magnitude 9.2 earthquake occurred off the west coast of northern Sumatra in Indonesia. The earthquake started approximately 250 kilometres south-southwest of Banda Aceh and ruptured the entire section of the Sunda Arc between Sumatra and the Nicobar and Andaman Islands over 1000 kilometres to the north. The resulting tsunami affected countries right across the Indian Ocean Basin.

The earthquake generated a powerful high tsunami which moved through the Indian Ocean region at more than 500 kilometres per hour. The maximum measured tsunami run-up was over 40m in height. The tsunami waves caused widespread death and injuries and devastated coastal areas, destroying towns, homes, infrastructure and the livelihoods for thousands of displaced people. The worst affected countries included India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka, Seychelles, Thailand and Somalia. Other countries that absorbed some of the brunt of the tsunami were Bangladesh, Kenya and Australia. This tsunami has been claimed as one of the most devastating natural disasters in recent history.

B) Landslides

A landslide that occurs under the sea, or on land that moves from above sea level into the ocean, can disturb the overlying water and generate a tsunami (figure 5). Landslides are produced when slopes or deposits of sediment become unstable and the material fails because of the influence of gravity.

Submarine landslide-generated tsunami

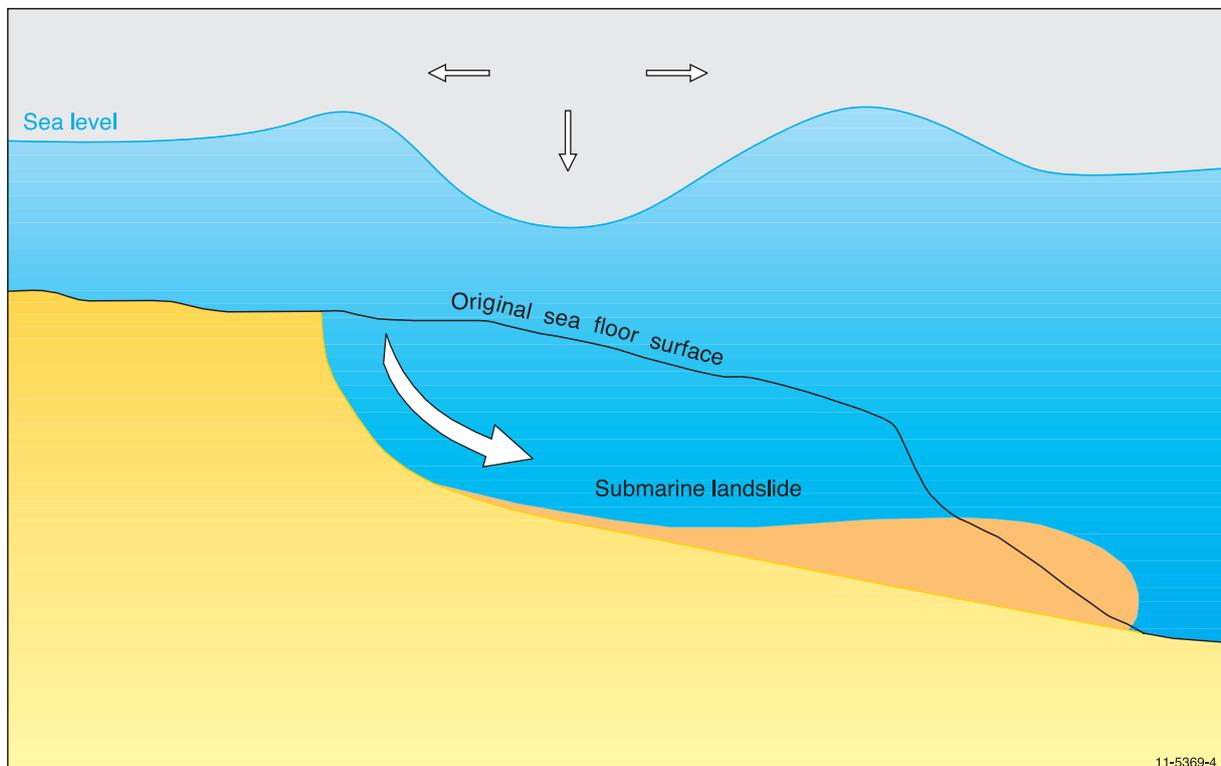


Figure 5: Submarine landslide-generated tsunami. The mass movement of rock material displaces the surrounding water column.

Large portions of islands which make up the Hawaiian island chain have, in recent geological time, slumped into the Pacific Ocean. Some scientists believe that these events caused massive tsunamis, which may have reached the east coast of Australia.

Case study: Papua New Guinea

On the 17 July 1998 a magnitude 7.0 earthquake occurred off the north coast of Papua New Guinea. This was 20 to 30 kilometres offshore from the village of Aitape. The ground and homes shook so violently that people could hardly stand and water tanks collapsed. Within approximately 10 minutes the earthquake had created a deadly local tsunami. Three tsunami waves were generated and reached heights of up to 7 to 12 metres. This completely destroyed the coastal villages of Arop and Warapu and also severely damaged Sissano and Malol. The disaster killed approximately 3000 people, and motivated many villagers to leave the area and never return. There is some confusion about how an earthquake that was relatively small in magnitude could have generated such a destructive tsunami. It has been hypothesized that the earthquake triggered an undersea landslide which created the enormity of the tsunami.

C) Volcanic activity

Tsunamis associated with volcanoes are less common than those from earthquakes, but can still be just as destructive. Of the casualties that occur from volcanic eruptions, usually about one-quarter result from volcano-generated tsunami.

There are three main volcanic processes that cause a tsunami:

- i. Submarine volcanic explosions occur when the cool seawater comes in contact with hot magma. It can react violently and produce steam explosions (figure 6).

Volcano-generated tsunami from hot lava

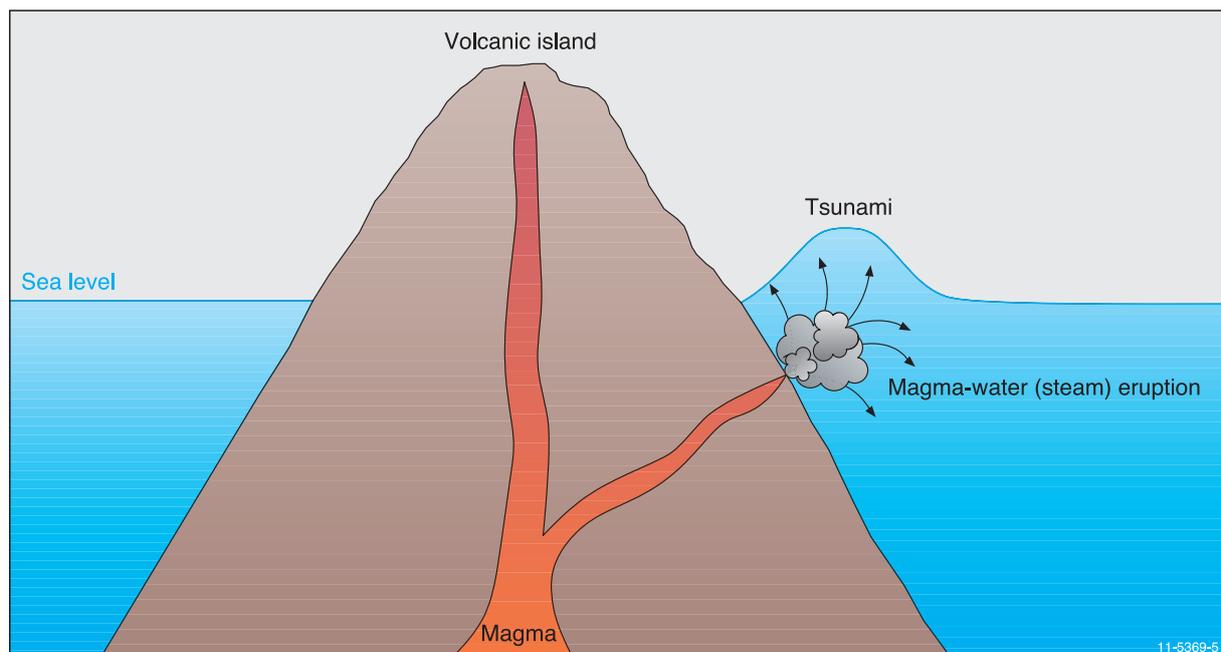


Figure 6: Volcano generated tsunami resulting from the explosive interaction between hot magma and cold water during submarine eruptions.

- ii. Gravitational (or earthquake-related) collapse of volcanic material on the flanks of a volcano can generate a landslide which displaces the surrounding water column and leads to the generation of a tsunami (figure 7).

Volcano-generated tsunami from gravitational collapse

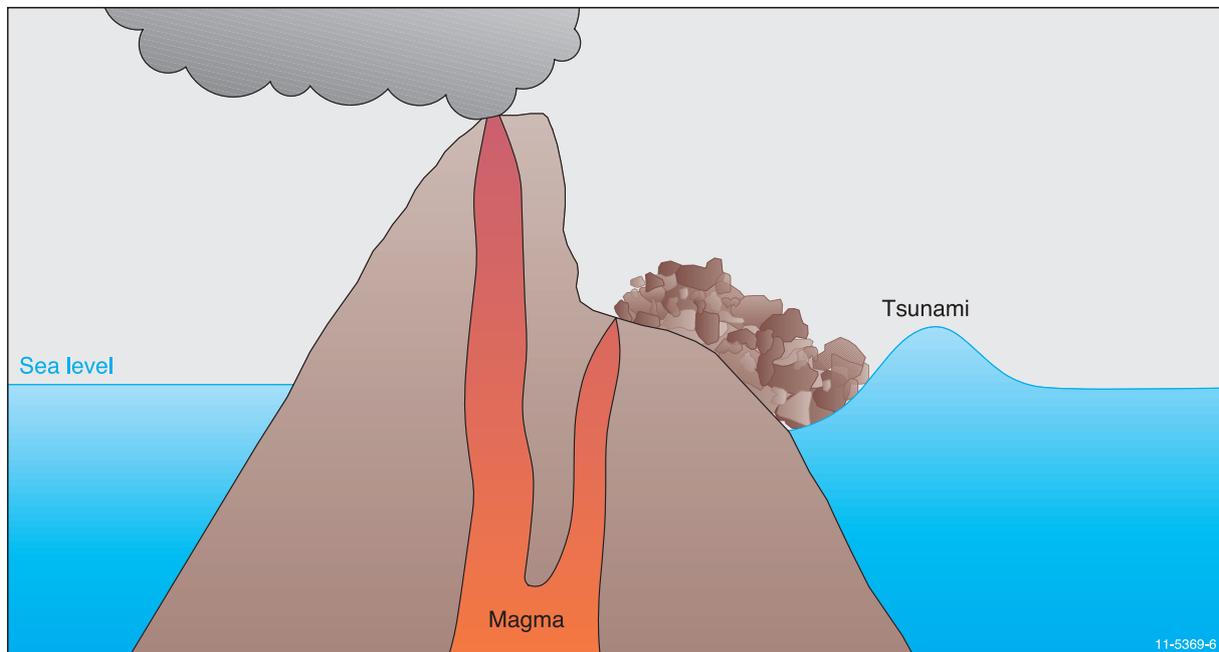


Figure 7: Volcano generated tsunami resulting from gravitational collapse of volcanic material on the flanks of a volcano causing a landslide.

Case study: Krakatau, Indonesia

The island of Krakatau (also known as Krakatoa) is situated in the Indonesian archipelago, between Java and Sumatra. The massive volcanic eruption that occurred on Krakatau on 27 August 1883 was the culmination of three months of smaller eruptions.

On 26 August a series of eruptions created tsunamis 1 to 2 metres high. As the eruptions became more severe, so did the tsunamis. On the morning of 27 August, an eruption caused a tsunami that was 10 metres high. This was followed by another explosion sending ash to a height of 25 000 metres, and an explosion that could be heard 2000 kilometres away – it was even heard in central Australia. At one point the tsunamis generated waves that reached heights of 40 metres and tossed coral reef blocks weighing approximately 100 tonnes onto the shore. A boat was carried 9 metres above sea level, 3 kilometres inland. The tsunami travelled across the Pacific and Indian Oceans and was even recorded in the Atlantic. In Australia, a 6 metre tsunami was observed along the northwest coast of Western Australia. The tsunami waves destroyed hundreds of coastal towns and villages on the islands of Java and Sumatra.

The official death toll was 36 417, however many bodies were washed out to sea and never found.

- iii. Collapse of a caldera can occur when the magma beneath a volcano withdraws back deeper into the earth. The sudden subsidence displaces water causing a tsunami (figure 8a, b).

Volcano-generated tsunami resulting from caldera collapse

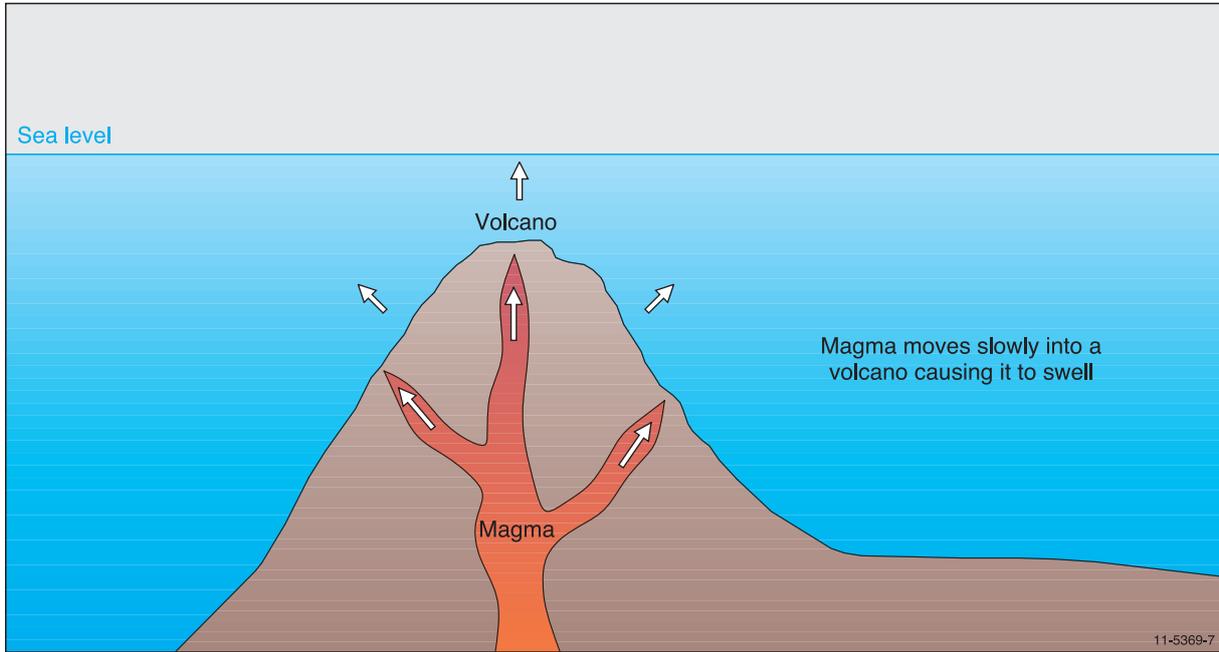


Figure 8a: Volcano builds up over time on the seafloor.

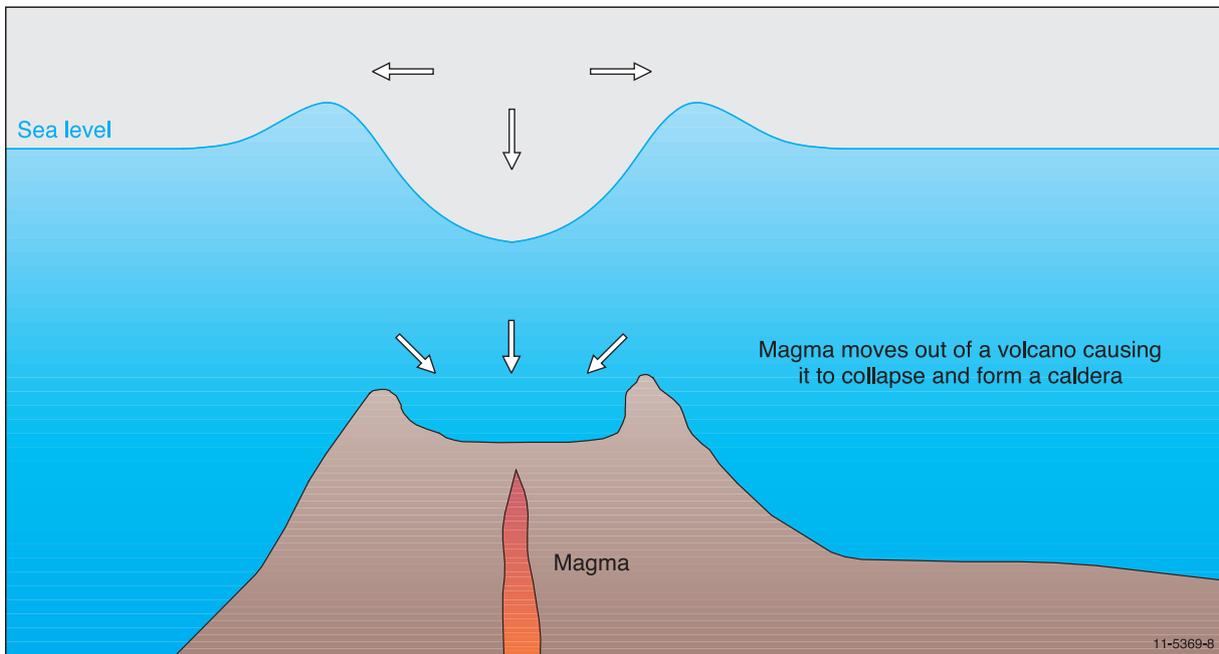


Figure 8b: Collapse of the volcano into the underlying, emptied magma chamber produces a caldera causing displacement of the water column and generation of a tsunami.

D) Meteorites and asteroids

As two-thirds of the earth is covered by water, it is likely that when an asteroid or a meteorite actually hits the Earth it will land in the ocean. This would be devastating for coastal areas because of the tsunami that would be generated. Nevertheless, if the asteroid or meteorite happened to collide with the land this would produce a dust cloud, which could possibly block out the sun for months.

Impact craters on Earth

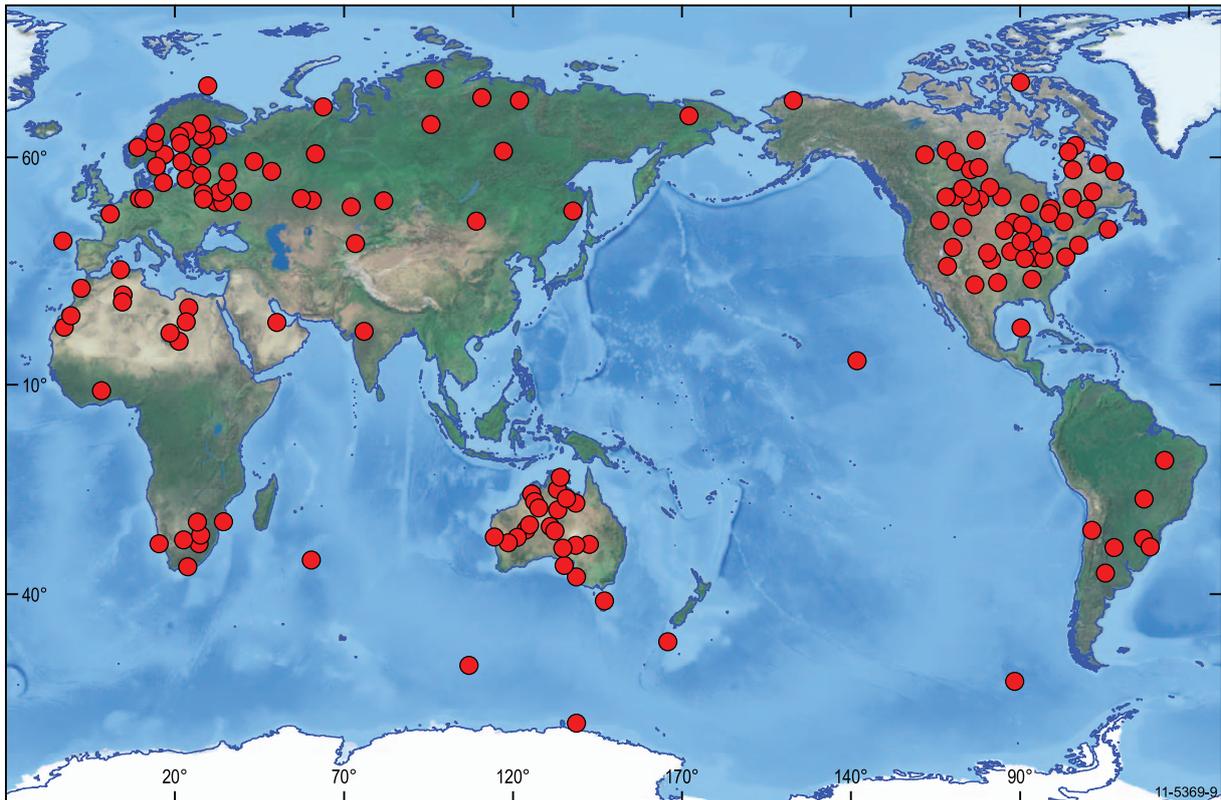


Figure 9: Location of the 185 known impact craters on Earth. Many others are undetectable on the sea floor.

Case study: Chicxulub meteorite

At the end of the Cretaceous period, 65 million years ago, the 10 kilometre-wide Chicxulub ('chick-shoe-loob') meteorite slammed into the area that now forms the Yucatan Peninsula on the northern coast of Mexico. A huge 180 kilometre-wide crater was formed when massive quantities of dust and rock were blasted into the atmosphere by the impact. Vast vapour clouds also billowed out as water turned instantly to vapour. In addition, the shock waves generated by the meteorite would have travelled out from the site of impact, creating massive tsunamis in nearby oceans. Huge numbers of living creatures were devastated by the effects of the meteorite's impact and associated tsunamis. In fact, scientists estimate that more than half of the Earth's plant and animal species (including the dinosaurs) became extinct at this time.

WHERE DO TSUNAMIS OCCUR?

Most tsunamis occur in the Pacific Ocean because the Pacific basin is surrounded by the most tectonically active zones. The edges of tectonic plates interact to form seismically active belts along with active (often explosive) volcanoes. This is often referred to as the Pacific Ring of Fire.

Tsunamis also occur in the Mediterranean Sea and Indian and Atlantic oceans. One of the most devastating tsunamis on record occurred as a result of the 'Great Lisbon Earthquake' of 1755.

Case study: Lisbon, Portugal

On 1 November 1755, an earthquake that reportedly lasted for 5 to 8 minutes¹, and would have measured approximately 8.8 in magnitude, occurred near Lisbon, Portugal. Almost immediately after the earthquake a tsunami was generated. Waves destroyed coastal towns in Spain, north Africa and as far away as Barbados in the Caribbean. The greatest devastation was in Lisbon where between 30 000 and 50 000 people were killed.

Historical tsunami sources

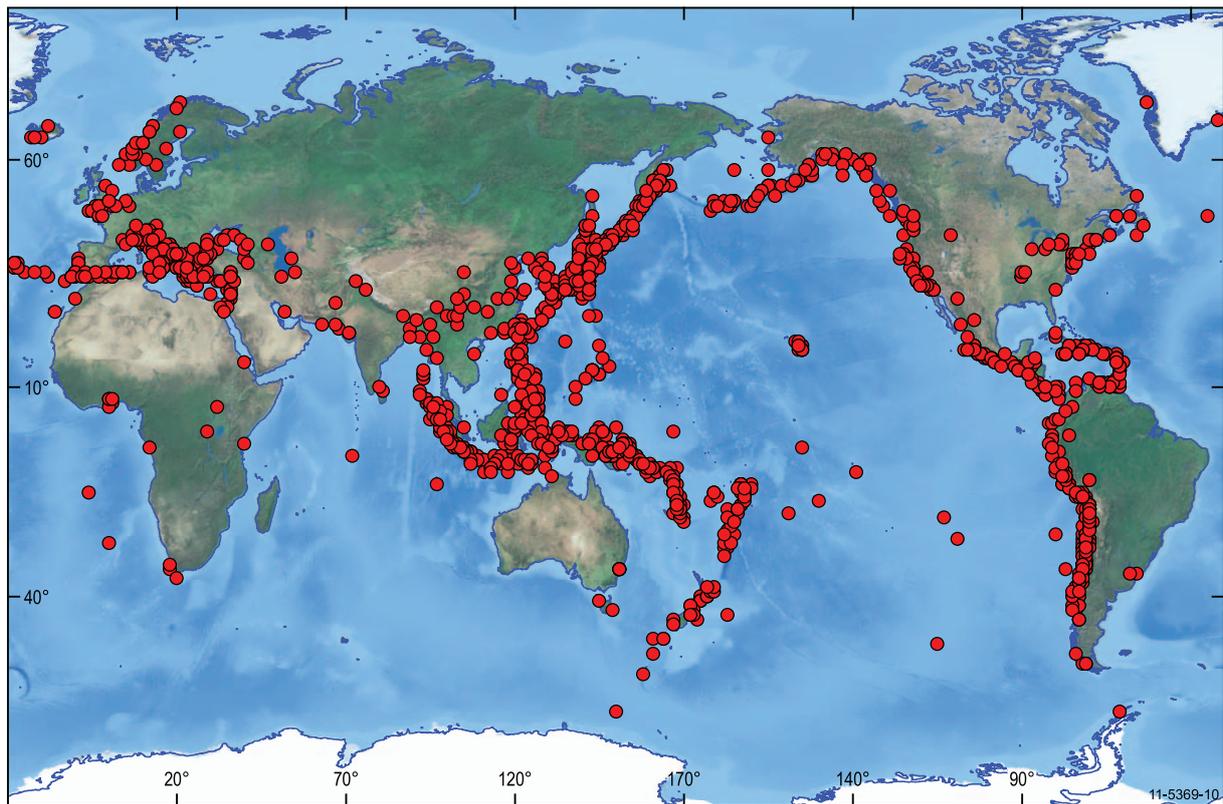


Figure 10: Location of known tsunami sources in the world. Dots on continents may be associated with lakes or rivers.

Source: Adapted from National Oceanographic and Atmospheric Administration, National Geophysical Data Center (NOAA NDGC) tsunami database.

¹ The rupture time for the 2004 Indian Ocean tsunami was around 10 minutes

WHEN TSUNAMIS REACH THE LAND

The **generation** of a tsunami, usually due to an earthquake in deep water, produces movement of water which is dispersed in all directions away from its source (known as **propagation**). As the tsunami approaches land its wave length and wave height changes. This is because the speed at which a tsunami travels is related to the depth of the water. When the tsunami is approaching land, the water depth decreases and the tsunami speed slows down due to friction. As it slows its wave height increases. The front of the wave slows first and the effect is like a car pile-up on a freeway, with the rear of the wave catching up with the front. The tsunami continues to increase in wave height due to this bunching effect. This effect is called **shoaling** and typically occurs in water less than 100 metres deep. You cannot feel a tsunami onboard a ship in the deep ocean as the wave height is small (say less than 50 centimetres) and the wavelength is long (say 100 kilometres). As it nears land, the height may increase to several metres, however the tsunami may also create barely noticeable ripples. Though tsunamis 30 to 40 metres high have occurred usually all of the waves are much smaller.

The four phases of a tsunami as it approaches the shore

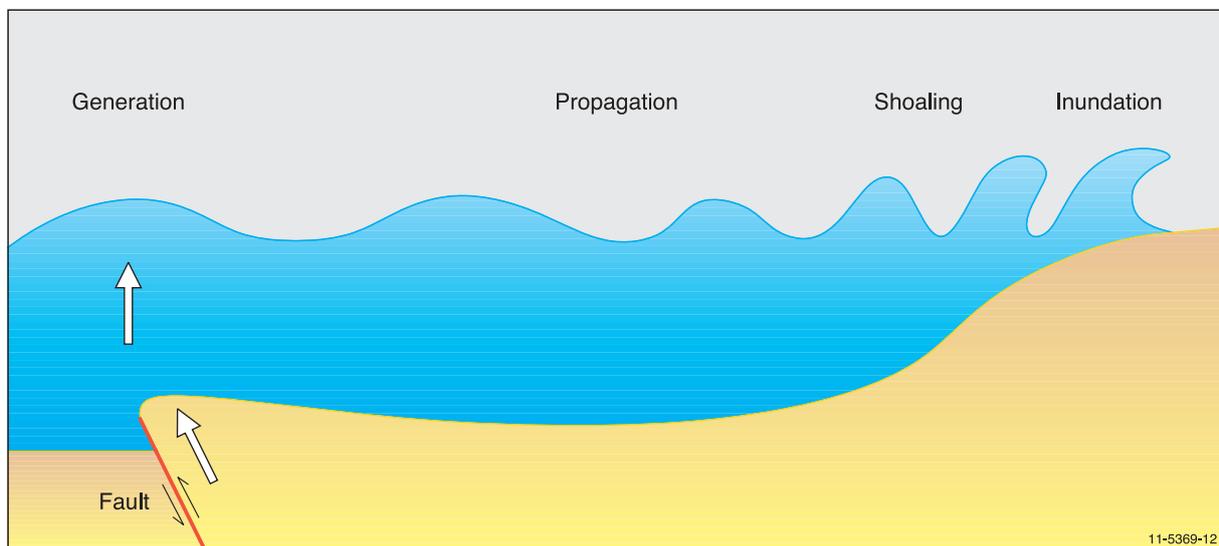


Figure 11: The phases of a tsunami as it approaches the shore: generation in the deep water, propagation towards the shore, shoaling as the water depth decreases and inundation of the land. (Note: diagram above is not true to scale)

When tsunamis reach the land, the size of the wave and extent of destruction depends on the shape of the coastline and the depth and slope of the sea floor (bathymetry). Areas most at risk are funnel-shaped bays and harbours, such as Hilo Harbour, Hawaii.

The effects of a tsunami can be further exacerbated by the Seiche effect. The Seiche effect is the ‘sloshing’ of water in a basin. The time over which the water continues to oscillate depends on the physical size and shape of the basin so that, for example, the Seiche period for bathtubs may be 2 to 3 seconds, for a swimming pool 8 to 12 seconds. For natural harbours or bays it can vary from a few minutes to a few hours.

Waves may also be focussed onto particular parts of the coast by submarine canyons or valleys, so the amplitude varies in a complex way along a coast.

One of the characteristics used in describing the tsunami flooding on to land (**inundation**) is “**run-up**”. Run-up is the highest point on the land that the tsunami reached. This point is measured as a height above **sea level**. Another characteristic is the **maximum horizontal extent of flooding**. This tells us how far inland the tsunami reached (figure 12). The run-up and maximum distance inland are often used to describe the impact of tsunamis.

Characteristics of tsunami inundation

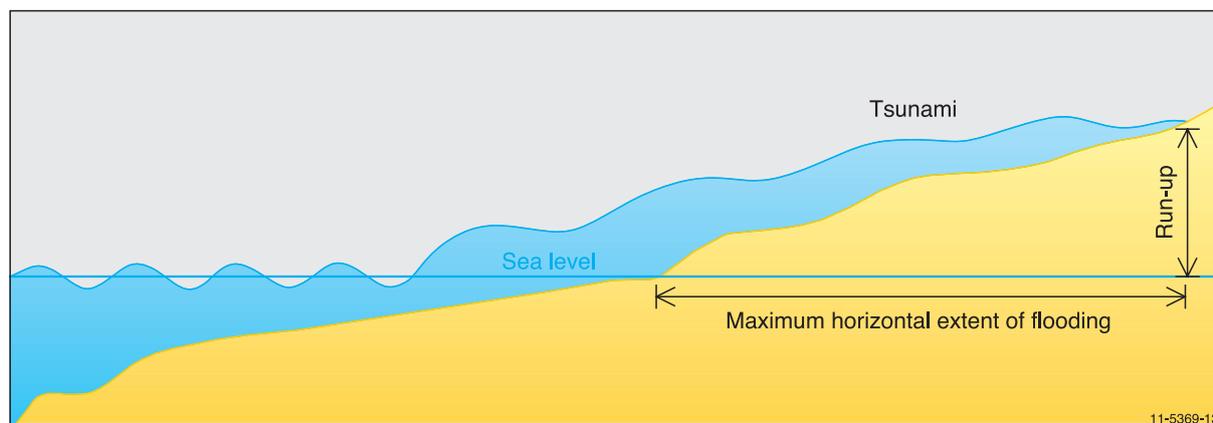


Figure 12: The characteristics of tsunami inundation. The ‘run up’ is the highest point on the land reached by the tsunami. The maximum horizontal extent of the flooding calculates how far inland the tsunami reached.

Calculating the velocity, wave height and destructive force of a tsunami for any stretch of coastline is complicated by several factors. For example, the shape of the sea floor can produce effects that are unlikely to be predicted by simple equations. Harbours and headlands also cause the waves to reflect, diffract, refract, and even change their direction. Tsunamis have also been known to ‘bend’ around islands, eventually engulfing the coast on what was supposed to have been the protected side. Other factors include the effect of backwash from one wave on to the waves that follow, and the exact nature of the disturbance that generated the tsunami in the first place.

Smaller tsunamis that may not cause inundation may still pose as a threat to people or boats in the water. This is a result of potentially strong or unusual currents and oscillating water levels near shore.

To accurately assess tsunami risk, scientists need information on:

- the likely occurrence and location of a tsunami-generating event,
- the expected magnitude of the event,
- the shape of the sea floor, and
- the topography of the affected coastal area.

All this information is rarely available, complicating the identification of potentially vulnerable areas. Nevertheless, as more information on recent, historical and pre-historical tsunamis is collected, the identification of vulnerable regions using computer modelling should become more accurate. Since the 2004 Indian Ocean Tsunami, there has been a large increase in the number of groups worldwide that conduct detailed computer modelling of the tsunami source, propagation through deep water and inundation of the land. These modelling results are used by emergency managers to develop evacuation routes and can be used as an input to town planning. For example, the model outputs can inform which areas may require restricted development, or the building of walls to protect dwellings from inundation.

See activity: Run-Up on Llewellyn.

TSUNAMIS IN AUSTRALIA

The first accurately recorded tsunami that affected Australia occurred in Tasmania in 1858, and since then around 50 tsunami events have been recorded (Dominey-Howes 2007). Where information on the tsunami source is known, nearly all were generated by earthquakes. The one exception is the 1883 tsunami observed in Western Australia which was generated by the eruption of Krakatau in Indonesia.

The largest historical run-up observed was in northwest Western Australia, with a run-up height of 8 metres recorded at Steep Point in 2006. This tsunami was generated by a subduction zone earthquake near Indonesia that generated a tsunami that was recorded along most of the coast of Western Australia, although it did not cause significant inundation. It appears that the shape of the sea floor acted to focus the tsunami's energy there. Several campers were lucky to escape after the tsunami flooded their campsite, and washed their four-wheel drive 10 metres along the beach. Fish, starfish, corals and sea urchins were deposited on roads and dunes well above the high tide level. Fortunately for Australia, most of the tsunamis that reach our shores are small, however, they can still create dangerous rips and currents near beaches. If there has been a tsunami warning, please follow the advice of your local emergency service and stay away from the beach.

See activity: Time and tide.

WARNING SYSTEMS

The Joint Australian Tsunami Warning Centre (JATWC) is operated by the Bureau of Meteorology (The Bureau) and Geoscience Australia. Based in Melbourne and Canberra, the JATWC has been established so that Australia has an independent capability to detect, monitor, verify and warn the community of a tsunami in our region and possible threats to Australian coastal locations and offshore islands.

The Bureau and Geoscience Australia have built on their combined scientific and technical expertise including seismic and sea level monitoring and warning systems to provide a 24 hour tsunami monitoring and analysis capacity for Australia. Previously, Australia relied on the Pacific Tsunami Warning Centre (PTWC) and the Japan Meteorological Agency (JMA) for limited tsunami information to interpret and feed into the Australian Tsunami Alert System (ATAS).

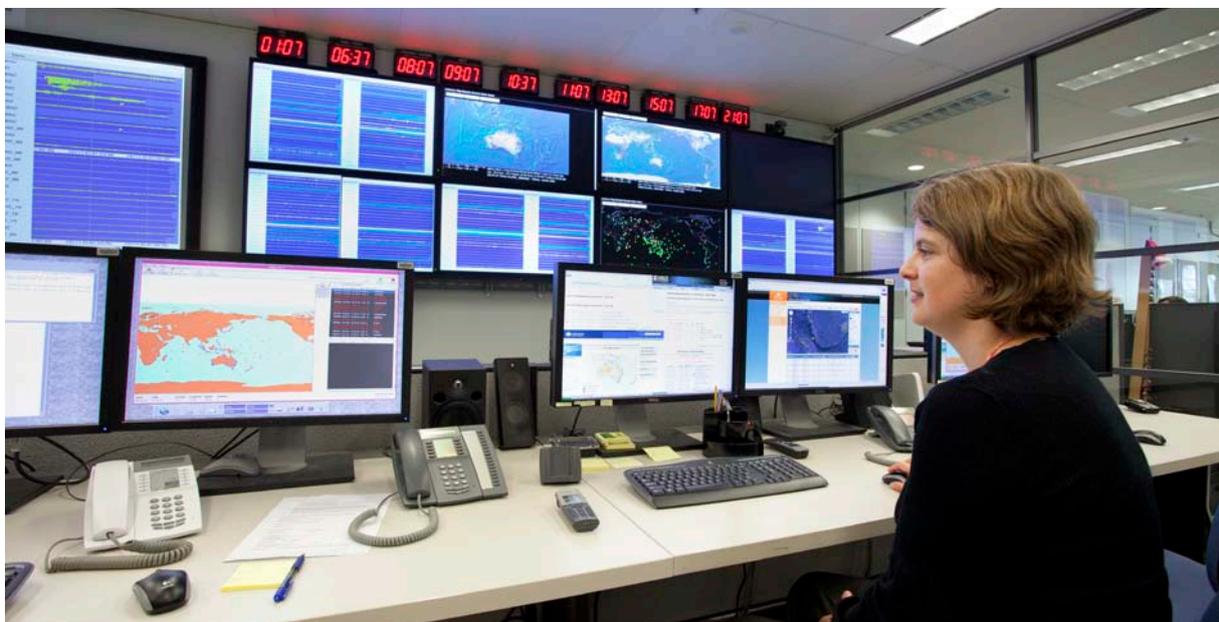


Figure 13: Joint Australian Tsunami Warning Centre at Geoscience Australia.

The JATWC boasts world class scientific technology with the expressed aim of providing the longest lead time of any potential tsunami threat. The major objective of the JATWC is to provide Australian emergency managers with a minimum of 90 minutes warning of a likely tsunami impact generated from subduction zone earthquakes. The JATWC is a long-term investment in effective emergency management and has the real potential to save lives and infrastructure.

The JATWC is the core component of the Australian Tsunami Warning System (ATWS). Other contributors to the ATWS include the Attorney-General's Department through its role in public education and support for state emergency service organisations who respond to tsunami warnings by arranging evacuations. The Australian Agency for International Development (AusAID) are also part of the ATWS and support disaster risk reduction programs in neighbouring countries in the Asia-Pacific region.

Geoscience Australia receives real-time data from over 50 seismic stations in Australia, and more than 250 international seismic stations. The agency upgraded and expanded the existing network of seismic stations in Australia and overseas as part of an ATWS program to extend Australia's sources of seismic data.

To be considered as a possible tsunami-generating earthquake three factors have to be checked:

1. did the earthquake occur beneath the ocean (or very close to the shore)?
2. was the magnitude above 6.5?
3. was the depth less than 100 kilometres?



Figure 14: Geoscience Australia ATWS seismic station located in Coen, North Queensland.

After an earthquake is detected, the relevant seismic data is analysed by specially designed automatic systems that form part of the 24 hour operations centre. Once alerted by the system the Duty Seismologists at Geoscience Australia determine the potential for the detected earthquake to cause a tsunami by further analysing the seismic information.

The JATWC also receives data from The Bureau's sea level observations. Highly sensitive instruments provide real-time sea level observations that can verify whether an earthquake has generated a tsunami as well as monitoring its path. The data is provided by sea-level stations along coasts and deep-ocean tsunami detection buoys. Utilising the sea level data and scientific modelling, specially trained staff at The Bureau then issue a warning based on the model. The warning provides an estimate of the time of arrival of the first tsunami wave and threat level.

The threat levels are:

1. No threat

An undersea earthquake has been detected, however it has not generated a tsunami, or the tsunami poses no threat to Australia and its offshore territories.

2. Marine threat

Warning of potentially dangerous waves, strong ocean currents in the marine environment and the possibility of only some localised overflow onto the immediate foreshore.

3. Land threat

Warning for low-lying coastal areas of major land inundation, flooding, dangerous waves and strong ocean currents.

The Bureau issues advice and warnings of any identified tsunami threat to emergency management agencies, harbour masters, the media and the public using procedures similar to those used for warnings of other severe weather or hazardous events.

The JATWC is now leading the world by providing warnings that identify not only affected coastal regions, but also whether the tsunami threat is to land or marine areas.

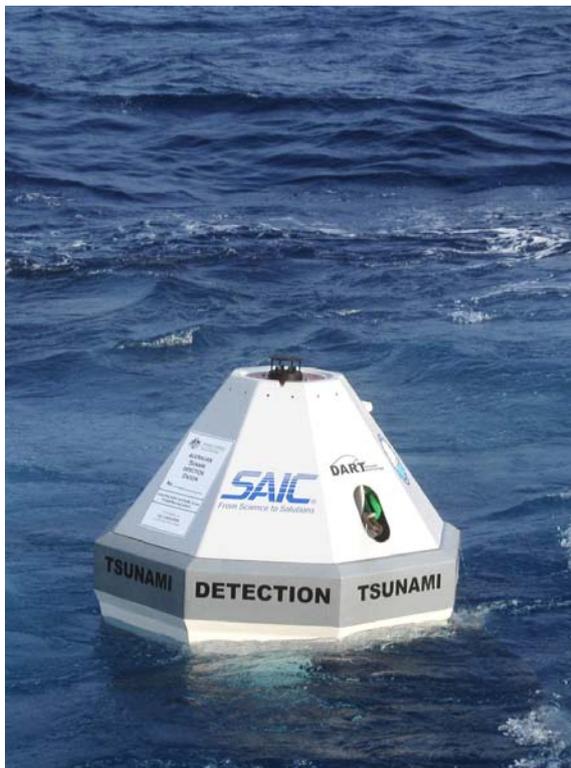


Figure 15: The next generation Easy-to-Deploy (ETD) Deep-ocean Assessment and Reporting of Tsunami (DART(R)) buoy system.

Source: Science Applications International Corporation (SAIC) website <<http://media.saic.com>>

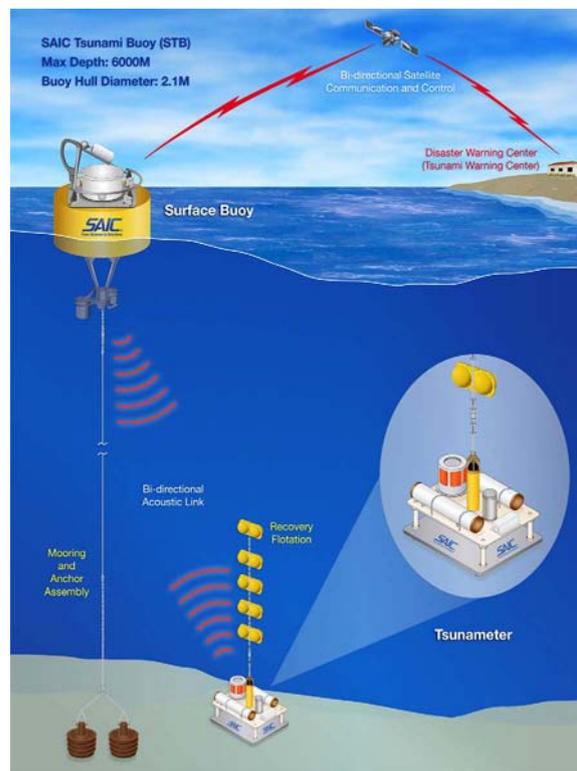


Figure 16: The tsunameter and surface buoy work together to verify potential tsunami activity.

Source: Science Applications International Corporation (SAIC) website <<http://media.saic.com>>

REFERENCES

Dominey-Howes, D., 2007. Geological and historical records of tsunami in Australia. *Marine Geology*, 239 (1-2), 99-123.

USEFUL WEBSITES

Australian Academy of Science: www.science.org.au (search tsunami)

Bureau of Meteorology, Joint Tsunami Warning Centre: <http://www.bom.gov.au/tsunami/index.shtml>

Intergovernmental Oceanographic Commission: <http://ioc-unesco.org/>

Institute of Computational Mathematics and Mathematical Geophysics: http://tsun.sccc.ru/tsun_hp.htm

National Oceanographic and Atmospheric Administration, National Geophysical Data Center:
<http://www.ngdc.noaa.gov/hazards>

Stop Disasters! A disaster simulation game from the UN/ISDR:
<http://www.stopdisastersgame.org/en/home.html>

University of Washington - Earth & Space Sciences: www.geophys.washington.edu

GEOSCIENCE AUSTRALIA SOURCES

Tsunami research at Geoscience Australia:
<http://www.ga.gov.au/hazards/tsunami.html>

Cummins, P & Leonard, M. 2005. The Boxing Day tsunami 2004—a repeat of 1833. *AusGeo News Issue 77* (March). Geoscience Australia, Canberra. Available at: <http://www.ga.gov.au/ausgeonews/ausgeonews200503/>

Sexton J, Nielson O, Burbidge D & Dhu T. 2009. Scientific expertise and emergency management. *AusGeo News 93* (March). Geoscience Australia, Canberra. Available at: <http://www.ga.gov.au/ausgeonews/ausgeonews200903/emergency.jsp>

Jaksa D. 2009. Tsunami warning system fully operational. *AusGeo News 96* (December). Geoscience Australia, Canberra. Available at: <http://www.ga.gov.au/ausgeonews/ausgeonews200912/tws.jsp>

**Have you visited Geoscience Australia's website?
www.ga.gov.au/education**

GLOSSARY

Caldera: Large volcanic crater created by explosion or internal collapse of a volcanic cone.

Inundation: The horizontal extent of flooding from the sea.

Lithosphere: Rigid outer part of the Earth consisting of the crust and upper mantle.

Seismic Data: Seismic data is the trace of seismic waves as recorded by a seismograph. The trace consists of amplitude measurements over time which can be used by seismologists to locate and estimate the size of seismic events such as earthquakes or blasts. Also referred to as waveform data.

Shoaling: The influence of the seafloor on wave behaviour, which reduces wave speed and wave length and increases the wave height.

Subduction zone: An area on the Earth where two tectonic plates meet and move towards one another (converge), with one sliding underneath the other (subducting) at rates typically measured in centimetres per year.

Tectonic plates: Segments of the Earth's lithosphere that move relative to one another, each at a different speed or direction. This movement causes changes in the positions of the continents, volcanic activity, earthquakes, mountain building, and formation and destruction of oceanic crust.

Tsunami-(generated wave): Giant oceanic waves generated by an earthquake, landslide, meteorite/asteroids, or a volcanic eruption below sea level.

Water column: The volume of water between the sea bed and the sea surface

Wave amplitude: This is quoted as half the wave height. It should be recognised that tsunami waves are typically not symmetrical.

Wave height: The vertical distance between the trough and the crest of a wave.

Wavelength: The mean horizontal distance between successive crests or troughs of a wave pattern.

Wave period: The time taken for a one wavelength to pass a given point.

Wave run-up: The maximum vertical height above mean sea (or other reference) level reached by the uprush of a tsunami across a beach or up a structure. In some cases it may be measured at the horizontal inundation limit, but in cases where the tsunami overtops coastal dunes or washes up over sea cliffs, it may be measured at these points if they are higher than the elevation at the horizontal inundation limit.

Wind-generated wave: Waves formed by the action of wind blowing over the sea surface that are characterised by a range of heights, periods and wave lengths.

Tsunami

STUDENT ACTIVITIES

RUN-UP ON LLEWELLYN

Recommended age: Upper primary to secondary

The Tsunami Warning Centre (TWC) in Bay Town on Llewellyn Island is keeping a close watch on a small volcanic island off the coast called McNamara Island. For the past month a large slope on the island's eastern side has become very unstable. Sara Sertori, head of the Centre, has asked you to be in charge of the evacuation plans for each of the towns on Llewellyn Island if a landslide on McNamara Island causes a tsunami. TWC operates four tsunami recording stations (A, B, C and D on map) which provide information on the arrival times and heights of tsunamis.

In the past, volcanic eruptions and landslides on McNamara Island have caused tsunamis around the coastline of Llewellyn Island. These have caused catastrophic damage to some of the towns.

The map of Llewellyn Island shows heights above sea level using contour lines.

1. **Using a red pen mark a run-up height of 15 metres on the map.**
2. **Which towns on Llewellyn Island would need to be evacuated if a tsunami of this magnitude was approaching the island?**

3. **Knowing that you may only have a few minutes to warn people living in these towns, how could you prepare residents for a possible future evacuation and what methods could you use to warn them that a tsunami was on its way?**

The speed with which these tsunamis travel from McNamara Island can be calculated using the following formula:

$$\text{Average speed} = \frac{\text{Total distance (km)}}{\text{Time taken (hrs)}}$$

The last tsunami in this region occurred five years ago and was caused by a similar landslide on the side of McNamara Island. The site of the landslide is marked on the map with a Z.

4. The table below shows the arrival times of the tsunami at three tsunami recording stations closest to McNamara Island. Complete the table by:
- Measuring the distance from the landslide (Z) to each station.
 - Calculating the speed the tsunami travelled to each station using the formula above.

Remember to convert the times recorded into hours! For example: 9 minutes/ 60 minutes = 0.15 hours.

Recording station	Distance (km)	Arrival time after landslide	Tsunami speed (km/h)
A		9 minutes	
B		12 minutes	
C		15 minutes	

5. What is the average speed this tsunami travelled? (Add the tsunami speed for stations A, B, & C, then divide by three). _____ km/h

6. The speed for this same tsunami calculated by data from the recording station (D) near Lewisvale was 575 kilometres/hour. Is this slower or faster than the average speed of the tsunami calculated for stations A, B & C? _____

7. The fishing fleet, which uses Bay Town as a port, was out at sea 20 kilometres south east of McNamara Island when a large tsunami reached them. What evidence would the fishermen detect to indicate that a tsunami reached them? What about boats in the harbour?

Llewellyn Island



A-D Tsunami recording stations

Note: In order for this activity to work, this sheet must be printed at 100% scale (ie. not fit to page)

2004 INDIAN OCEAN TSUNAMI

Recommended age: Upper primary to secondary

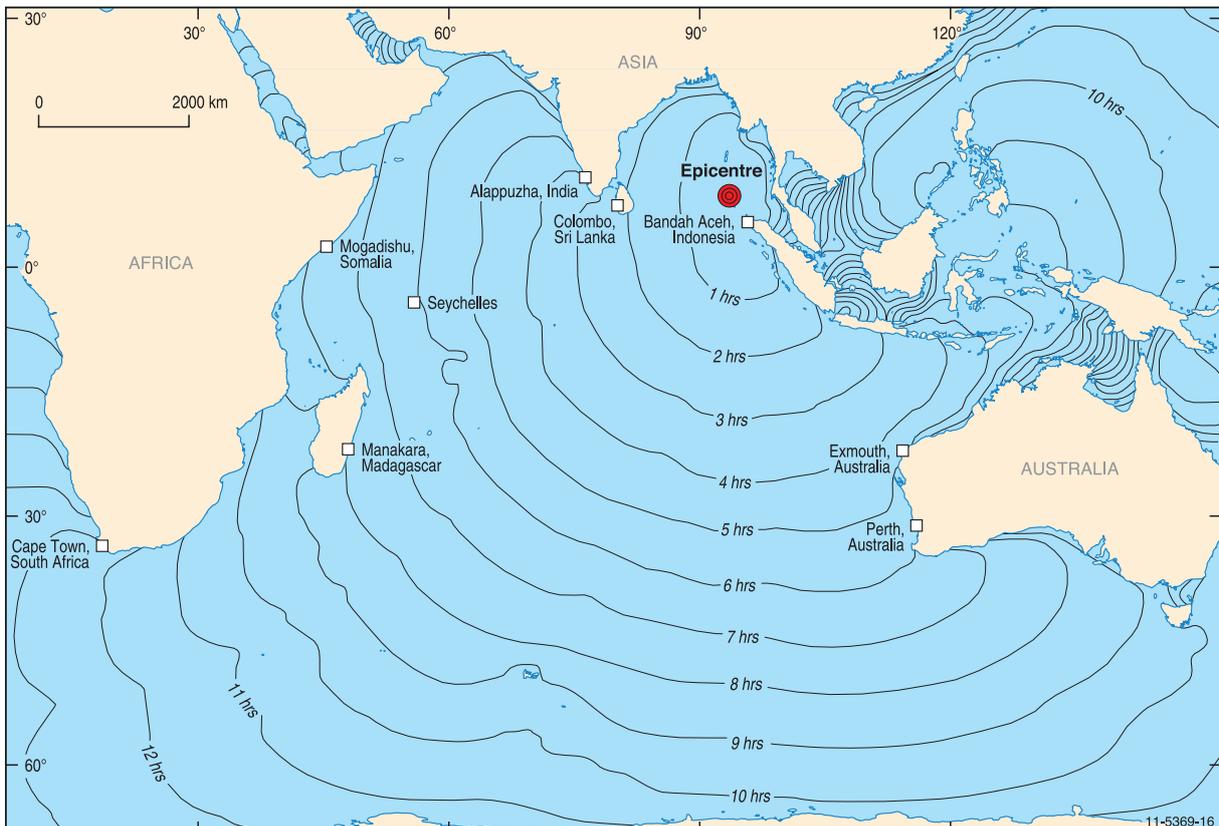
NEWS FLASH

A massive magnitude 9.2 earthquake occurred on Sunday 26 December 2004 at 12:48am off the west coast of northern Sumatra in Indonesia. A 10 metre high tsunami can be expected with an earthquake of this magnitude.

The following is a travel time chart for this tsunami. The lines indicate how far the tsunami travelled each hour. The distance between each line represents 60 minutes. Using the tsunami travel time chart work out how long the tsunami will take to reach the following cities.

Cities	Travel time (hours)
Bandah Aceh, Indonesia	
Alappuzha, India	
Colombo, Sri Lanka	
Mogadishu, Somalia	
Exmouth, Australia	
Perth, Australia	
Cape Town, South Africa	
Seychelles	

Estimated tsunami travel times (in hours)



TIME AND TIDE

Recommended age: Secondary

Close observation and comparison of the tide charts is usually the only indication the National Tidal Facility has that a tsunami has reached the Australian coastline. On average, a tsunami reaches our shores once every two years but most are too small to be noticed.

On the next page is the tide chart record for Vardon Harbour. It is a 24-hour tidal record for Wednesday 27 July and Thursday 28 July. The sea level, in metres, has been recorded every 15 minutes.

Plot the information from the tide chart on to the graph. Once you have plotted the tide information, answer the questions below.

1. Over a 24-hour period the Harbour usually experiences two high tides and two low tides.

- i. At what time is the first low tide? _____
- ii. What time would you expect the next low tide? _____
- iii. At what time is high tide? _____

2. How many waves are in the tsunami 'wave train'? _____

3. What is the duration of the tsunami? _____ hours

**4. How long after the first tsunami wave did the 'highest wave' arrive at the coast?
_____ hours**

5. Would a tsunami of this size have been destructive for Vardon Harbour? Give reasons.

6a. Draw on the graph a dashed line to show the expected water level if there was no tsunami. How high was each of the tsunami waves compared to the expected water level?

Wave 1 _____ metres

Wave 2 _____ metres

Wave 3 _____ metres

6b. This tsunami occurred during low tide. Predict the tide level for each wave if the first wave arrived at 1200 during high tide:

Wave 1 _____ metres

Wave 2 _____ metres

Wave 3 _____ metres

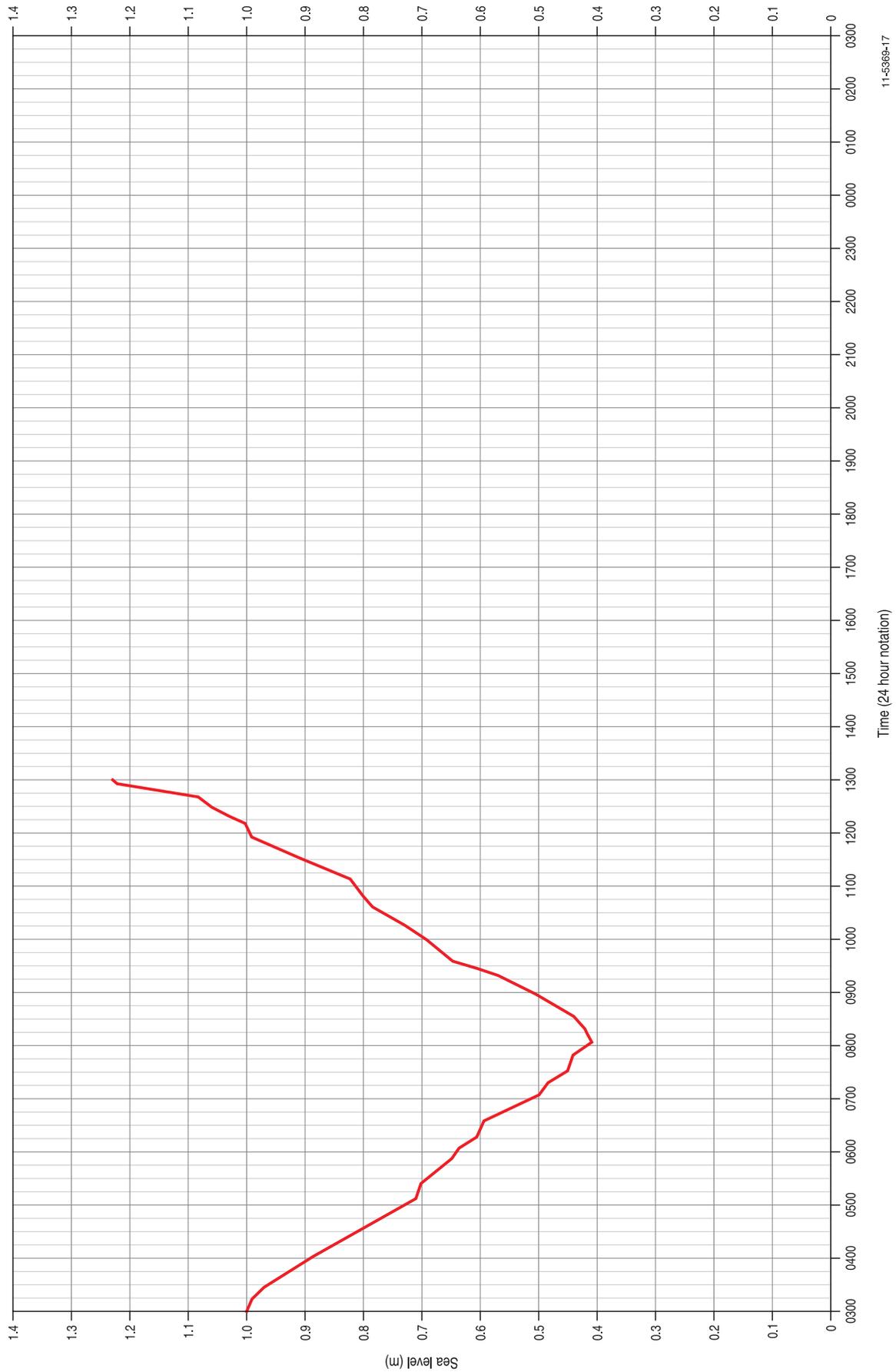
6c. Describe the problems that could have resulted, in and around the harbour, if the tsunami had occurred during high tide.

Tide chart recordings for Vardon Harbour: Wednesday 27 July & Thursday 28 July

Please note: Time is in 24 hour notation (eg 7.00pm = 19.00)

Wednesday, 27 July & Thursday, 28 July					
Time	Sea level (m)	Time	Sea level (m)	Time	Sea level (m)
03.00	1.00	11.00	0.82	19.00	0.80
03.15	0.97	11.15	0.88	19.15	0.35
03.30	0.93	11.30	0.93	19.30	1.00
03.45	0.90	11.45	0.99	19.45	0.95
04.00	0.86	12.00	1.00	20.00	0.92
04.15	0.82	12.15	1.05	20.15	0.41
04.30	0.79	12.30	1.08	20.30	0.43
04.45	0.75	12.45	1.22	20.45	0.47
05.00	0.71	13.00	1.25	21.00	0.52
05.15	0.70	13.15	1.29	21.15	0.55
05.30	0.68	13.30	1.31	21.30	0.58
05.45	0.65	13.45	1.31	21.45	0.60
06.00	0.63	14.00	1.29	22.00	0.63
06.15	0.60	14.15	1.25	22.15	0.67
06.30	0.59	14.30	1.22	22.30	0.69
06.45	0.55	14.45	1.18	22.45	0.71
07.00	0.50	15.00	1.13	23.00	0.75
07.15	0.48	15.15	1.00	23.15	0.79
07.30	0.45	15.30	0.97	23.30	0.82
07.45	0.44	15.45	0.94	23.45	0.86
08.00	0.41	16.00	0.91	00.00	0.90
08.15	0.42	16.15	0.87	00.15	0.93
08.30	0.44	16.30	0.82	00.30	0.97
08.45	0.48	16.45	0.78	00.45	1.00
09.00	0.52	17.00	0.72	01.00	1.03
09.15	0.57	17.15	0.90	01.15	1.07
09.30	0.64	17.30	0.90	01.30	1.10
09.45	0.67	17.45	0.70	01.45	1.10
10.00	0.70	18.00	0.40	02.00	1.15
10.15	0.74	18.15	0.45	02.15	1.20
10.30	0.78	18.30	0.90	02.30	1.25
10.45	0.80	18.45	0.95	02.45	1.27

Graph of tide chart for Varon Harbour (27th & 29th July)



Tsunami

ANSWER SHEETS

RUN-UP ON LLEWELLYN

Recommended age: Upper primary to secondary

The Tsunami Warning Centre (TWC) in Bay Town on Llewellyn Island is keeping a close watch on a small volcanic island off the coast called McNamara Island. For the past month a large slope on the island's eastern side has become very unstable. Sara Sertori, head of the Centre, has asked you to be in charge of the evacuation plans for each of the towns on Llewellyn Island if a landslide on McNamara Island causes a tsunami. TWC operates four tsunami recording stations (A, B, C and D on map) which provide information on the arrival times and heights of tsunamis.

In the past, volcanic eruptions and landslides on McNamara Island have caused tsunamis around the coastline of Llewellyn Island. These have caused catastrophic damage to some of the towns.

The map of Llewellyn Island shows heights above sea level using contour lines.

1. Using a red pen mark a run-up height of 15 metres on the map.
2. Which towns on Llewellyn Island would need to be evacuated if a tsunami of this magnitude was approaching the island?

Trewinville, Baytown, Lewisvale.

Although Lewisvale is in the lee of the island, it is still possible that the wave may still refract around the island. Visit: <http://www.soundwaves.usgs.g/2009/12> for more information and a case study on the Samoa Tsunami, September 29, 2009.

3. Knowing that you may only have a few minutes to warn people living in these towns, how could you prepare residents for a possible future evacuation and what methods could you use to warn them that a tsunami was on its way?
 - a. **Having an evacuation plan in place so residents know the safe areas to go.**
 - b. **Use sirens on beaches and low lying areas.**
-

The speed with which these tsunamis travel from McNamara Island can be calculated using the following formula:

$$\text{Average speed} = \frac{\text{Total distance (km)}}{\text{Time taken (h)}}$$

The last tsunami in this region occurred five years ago and was caused by a similar landslide on the side of McNamara Island. The site of the landslide is marked on the map with a Z.

4. The table below shows the arrival times of the tsunami at three tsunami recording stations closest to McNamara Island. Complete the table by:
 - a. Measuring the distance from the landslide (Z) to each station.
 - b. Calculating the speed the tsunami travelled to each station using the formula above.

Remember to convert the times recorded into hours! For example: 9 minutes/ 60 minutes = 0.15 hours.

Recording station	Distance (km)	Arrival time after landslide	Tsunami speed
A	$(10.3\text{cm} \div 4\text{cm}) \times 50 = 128.75$	9 minutes 0.15h	858.3
B	$(11.7\text{cm} \div 4\text{cm}) \times 50 = 146.25$	12 minutes 0.2h	731.25
C	$(13.2\text{cm} \div 4\text{cm}) \times 50 = 165$	15 minutes 0.25h	660

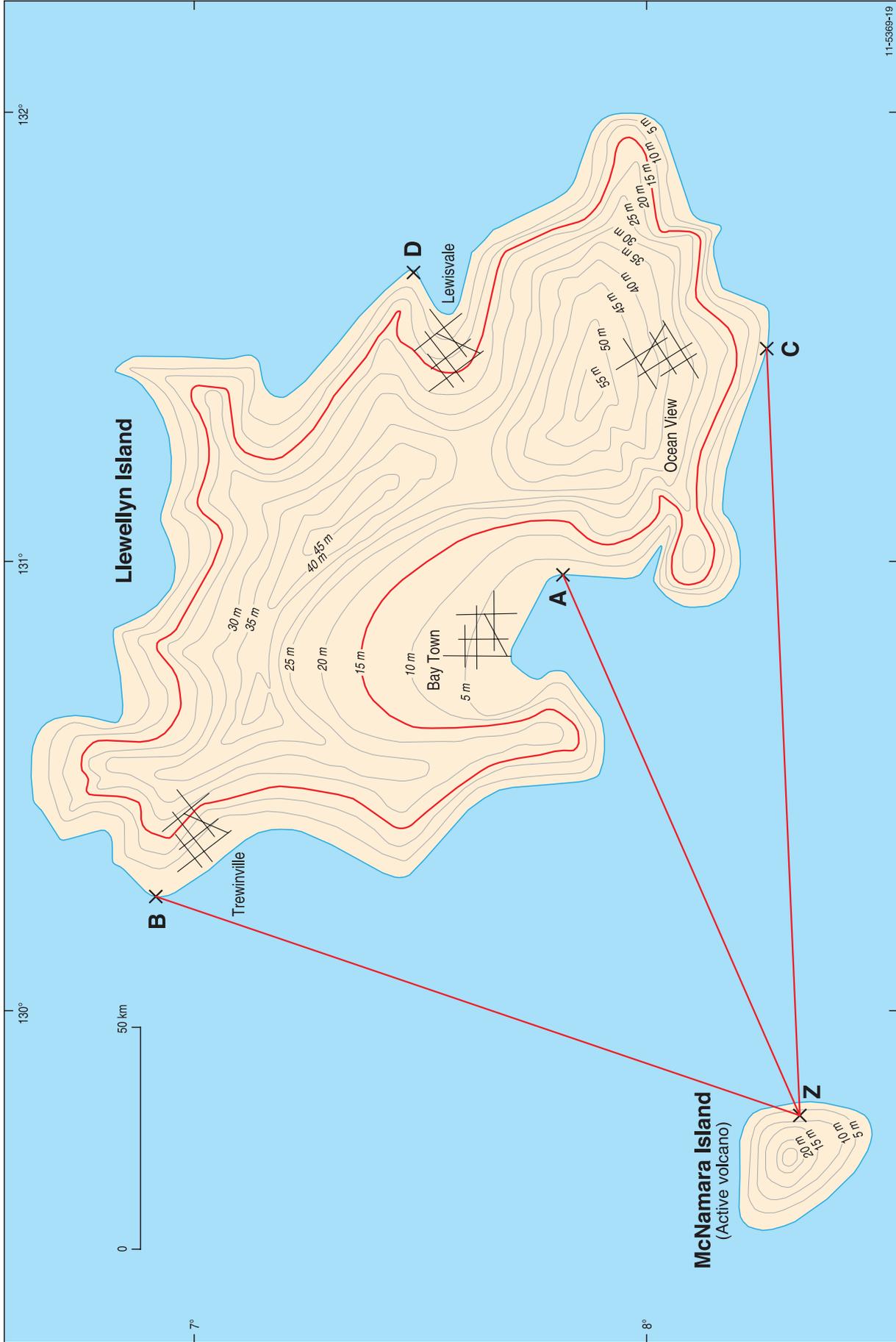
Note: These answers are based on The Llewellyn Island map being printed at 100%.

5. What is the average speed this tsunami travelled? (Add the tsunami speed for stations A, B, & C, then divide by three). 750 km/hr

6. The speed for this same tsunami calculated by data from the recording station (D) near Lewisvale was 575 kilometres/hour. Is this slower or faster than the average speed of the tsunami calculated for stations A, B & C? Slower
7. The fishing fleet, which uses Bay Town as a port, was out at sea 20 kilometres south east of McNamara Island when a large tsunami reached them. What evidence would the fishermen detect to indicate that a tsunami reached them? What about boats in the harbour?

The fishermen out at sea are unlikely to detect any evidence of a tsunami. The wavelength is too large and the change in wave height too small for a boat to feel a noticeable change which would indicate a tsunami. Boats in the harbour would experience unpredictable changes in water level and dangerous currents and turbulence.

Llewellyn Island



A-D Tsunami recording stations

Note: In order for this activity to work, this sheet must be printed at 100% scale (ie. not fit to page)

2004 INDIAN OCEAN TSUNAMI

Recommended age: Upper primary to secondary

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Alappuzha, India	
Colombo, Sri Lanka	
Mogadishu, Somalia	
Exmouth, Australia	
Perth, Australia	
Cape Town, South Africa	
Seychelles	

TIME AND TIDE

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Close observation and comparison of the tide charts is usually the only indication the National Tidal Facility has that a tsunami has reached the Australian coastline. On average, a tsunami reaches our shores once every two years but most are too small to be noticed.

On the next page is the tide chart record for Vardon Harbour. It is a 24-hour tidal record for Wednesday 27 July and Thursday 28 July. The sea level, in metres, has been recorded every 15 minutes.

Plot the information from the tide chart on to the graph. Once you have plotted the tide information, answer the questions below.

1. Over a 24-hour period the Harbour usually experiences two high tides and two low tides.

- i. At what time is the first low tide? 0800
- ii. What time would you expect the next low tide? 2000–2100
- iii. At what time is high tide? 1330–1345

2. How many waves are in the tsunami 'wave train'? 3

3. What is the duration of the tsunami? ~3 hours

4. How long after the first tsunami wave did the 'highest wave' arrive at the coast?
~2 hours

5. Would a tsunami of this size have been destructive for Vardon Harbour? Give reasons.

No, it occurred during a low tide and even the largest wave wasn't higher than a high tide peak.

Unusual currents may still have caused some damage or injury, however.

6a. Draw on the graph a dashed line to show the expected water level if there was no tsunami. How high was each of the tsunami waves compared to the expected water level?

Wave 1 ~0.20 metres

Wave 2 ~0.45 metres

Wave 3 ~0.55 metres

6b. This tsunami occurred during low tide. Predict the tide levels for each wave if the first wave arrived at 1200 during high tide:

Wave 1 ~1.2 metres

Wave 2 ~1.75 metres

Wave 3 ~1.80 metres

6c. Describe the problems that could have resulted, in and around the harbour, if the tsunami had occurred during high tide.

Changed currents, sloshing water, boats disturbed and may run aground. Inundation of low-lying areas, debris and people in water, damage to buildings and infrastructure.

Graph of tide chart for Varon Harbour (27th & 29th July)

