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SECOND EDITION

GEOGRAPHY

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DYNAMIC LEARNING

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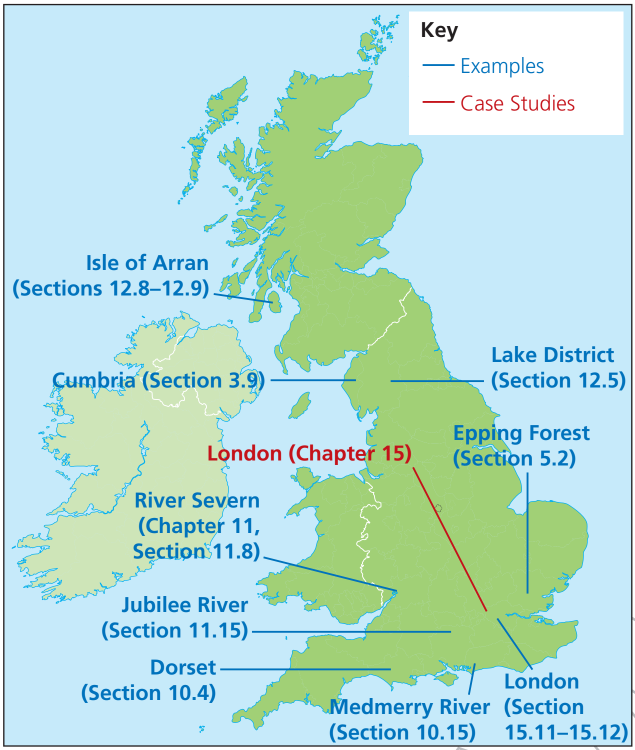
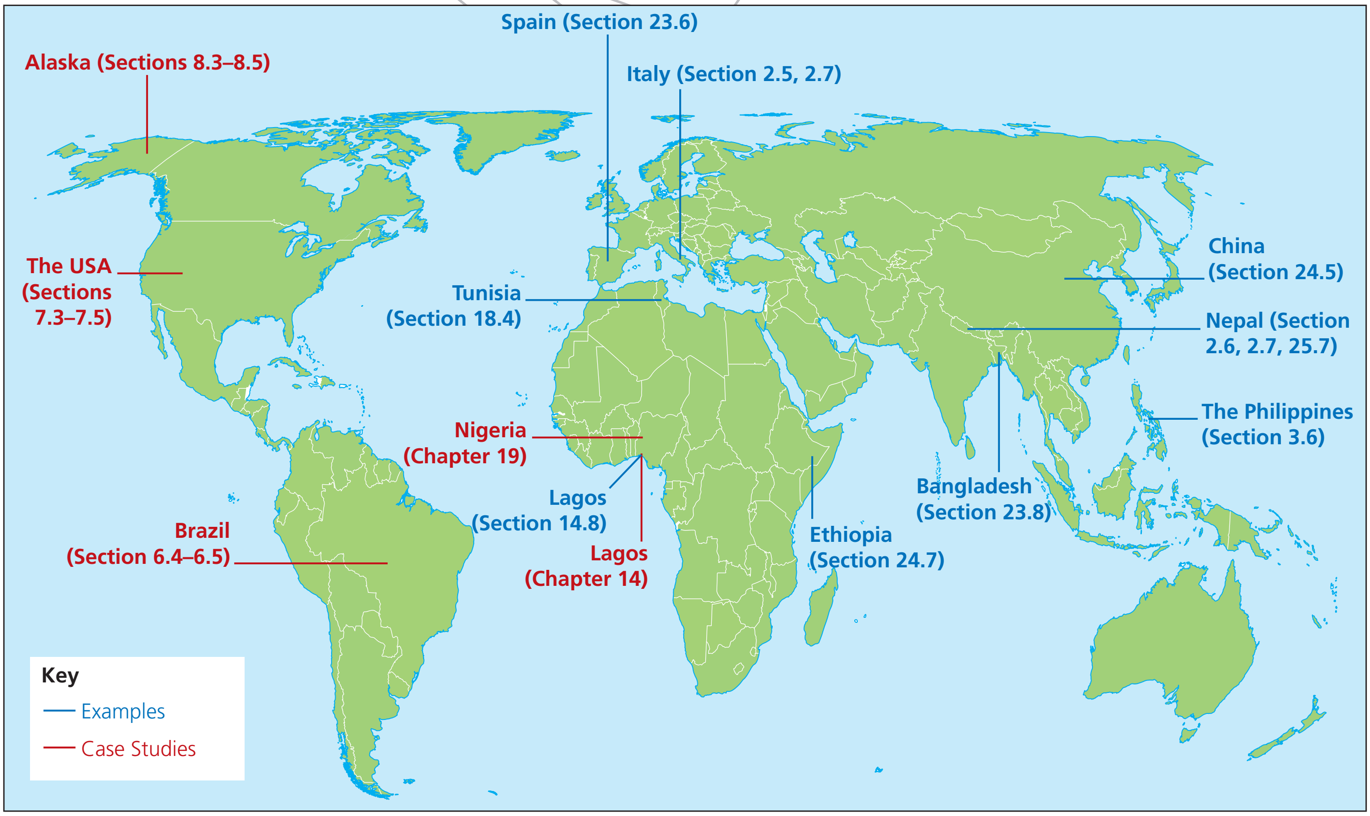


Case studies and examples across the world used in this book



1 Natural hazards

KEY LEARNING

- What natural hazards are
- Different types of natural hazard
- Factors that affect hazard risk

Defining natural hazards

What is a natural hazard?

Natural events have always occurred on our dynamic Earth. Without people, natural events would be just that, events – there would be no natural 'hazards'. Yet in a world with a rapidly growing population, and with technological developments leading to faster travel and quicker communication, it is difficult to ignore that humans are becoming increasingly vulnerable to **natural hazards**. Natural hazards pose potential risk of damage to property, and loss of life. The more humans that come into contact with natural events, the more the potential risk of natural hazards increases.

How are different types of natural hazard classified?

Natural hazards are most commonly classified by their physical processes, that is, what caused the hazard to occur. These processes include:

- **tectonic hazards**, such as **earthquakes** or tsunamis, which involve movement of tectonic plates in the Earth's crust
- **atmospheric hazards**, such as tropical storms
- **geomorphological hazards**, such as flooding, which occur on the Earth's surface
- **biological hazards**, such as forest fires, which involve living organisms.

However, these categories are closely linked. For example, tsunamis are a tectonic hazard, but can also be caused by a **landslide** (a geomorphological hazard) displacing a large body of water. Some natural hazards are caused by human influence rather than a natural process. For example, forest fires in California in 2014 were recorded as being caused by arson and falling power lines rather than naturally occurring events.

Where do natural hazards occur?

Some regions around the world are more vulnerable to natural hazards than others. The different colours of the countries in Figure 1.4 show the likelihood of a natural disaster occurring, based on historical data.

The year 2018 was a bad one for natural hazards. There were volcanic eruptions in Indonesia and Guatemala, earthquakes and tsunamis in Indonesia, flooding across East Africa and wildfires in California. Some of the biggest natural hazards that occurred around the world in 2018 are located on the map in Figure 1.4.

▲ Figure 1.1 Avalanche, Italy, 2017

▲ Figure 1.2 Flooding, York, 2015

What factors affect hazard risk?

The frequency and magnitude (strength) of natural hazards are increasing due to human influences such as the enhanced greenhouse effect (which increases the risk of more **extreme weather** such as drought) and **deforestation** (which increases the risk of hazards such as flooding). The main factors that affect **hazard risk** are:

- Wealth – a risk tends to decrease with increased wealth, as people can afford to prepare for and respond to natural hazards.
- Population growth – by 2024, 8 billion people are expected to populate the planet, which inevitably increases hazard risk as there are more people to interact with natural events.

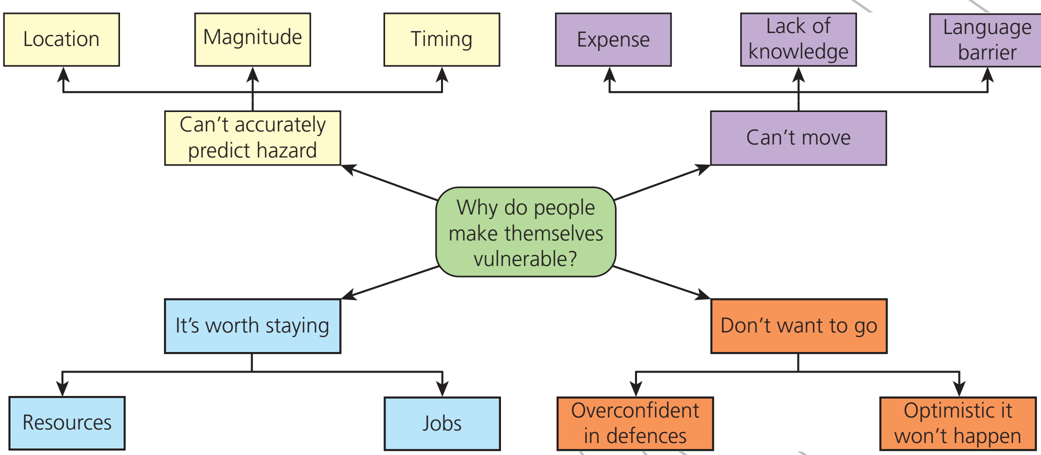


Figure 1.3 Why people live near hazardous areas

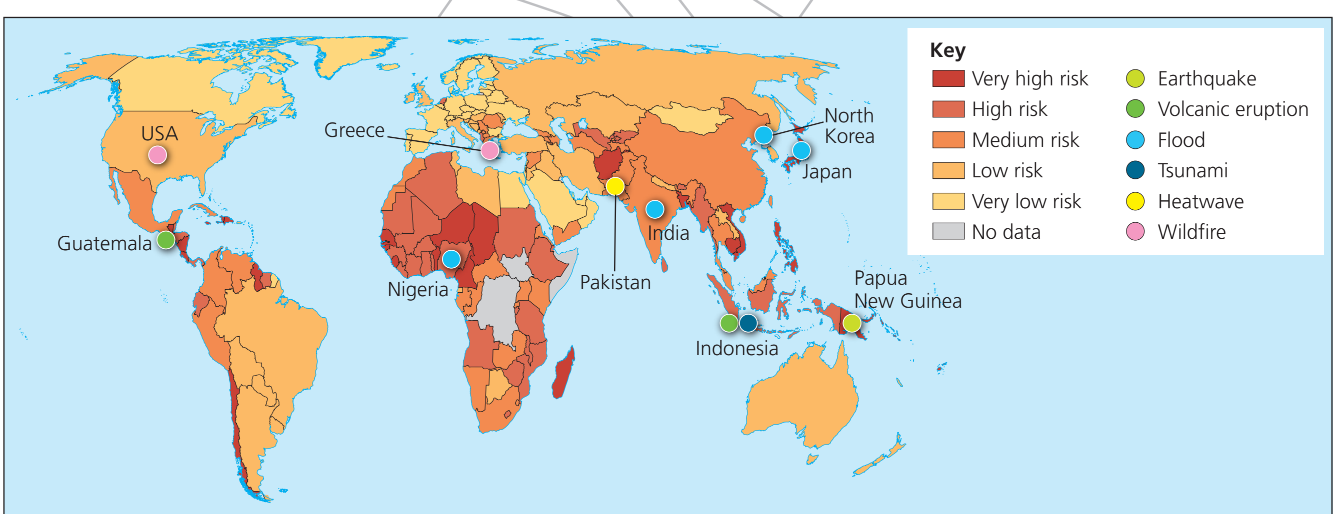


Figure 1.4 World natural hazard risk and biggest natural disasters in 2018

Activities

1. Distinguish between a natural hazard and a natural event.
2. Categorise the following natural hazards into tectonic, atmospheric, geomorphological or biological: earthquakes, volcanic eruptions, flooding, landslides, tornados, avalanches, forest fires; hurricanes, typhoons or cyclones.
3. Explain why some hazards are more difficult to categorise than others.
4. Describe the pattern of natural hazard risk in Figure 1.4.
5. Use Figure 1.3 to explain why people can make themselves more vulnerable to natural hazards.
6. Suggest how humans could have caused the hazards in Figure 1.1 and Figure 1.2.

2 Tectonic hazards

KEY LEARNING

- The Earth's structure
- How tectonic plates move
- The location of earthquakes and volcanoes
- The relationship between earthquakes, volcanoes and plate margins

Earthquakes and the distribution of volcanoes

What is the Earth's structure?

The Earth's internal structure is divided into layers (see Figure 2.1). At the centre is the **core**, which is mainly made of iron and nickel, is extremely hot and under a lot of pressure. The inner core is solid; the outer core is liquid. The **mantle** surrounds the core, is beneath the Earth's crust and is made of solid material that can flow very slowly. The upper portion of the mantle is a weak layer called the asthenosphere, which can deform like plastic. The outermost layer of the Earth is the solid **crust**, and there are two main types of crust: **oceanic** and **continental**.

Oceanic crust is:

- thinner and more dense (5–10 km)
- formed of basaltic rock
- sinks when it meets continental plates
- usually less than 200 million years old.

Continental crust is:

- thicker (20–200 km)
- composed mainly of granite rock
- up to 3.8 billion years old.

The crust and upper mantle together form a rigid shell at the surface of the Earth called the **lithosphere**. The lithosphere is broken into several major fragments, called **tectonic plates**, which move very slowly over the upper mantle. The movement of plates can be tracked from space using GPS.

Where two plates meet it is known as a **plate margin**. There are three types of plate margin, which describe the different ways that the plates are moving: **constructive**, **destructive** and **conservative plate margins** (see Sections 2.2 to 2.4). The interaction between the different tectonic plates and the mantle beneath leads to the triggering of **earthquakes** and volcanic activity.

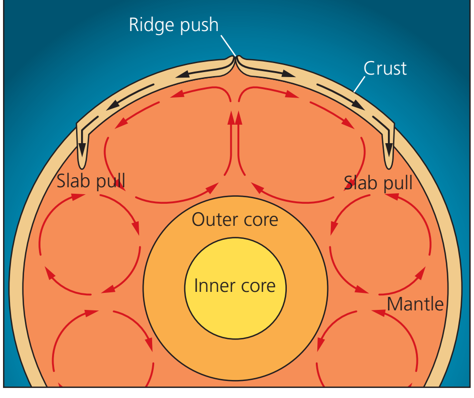


Figure 2.1 The layers of the Earth showing ridge push and slab pull

How do tectonic plates move?

What exactly makes tectonic plates move is still being explored by scientists.

Convection

One theory is called convection. The core's temperature is around 6,000 °C. This causes magma (molten rock) to rise in the mantle. As it rises further from the core, it cools and sinks back towards the core. The convection currents flowing in the mantle carry the plates with them. Only limited evidence of convection currents has so far been found.

Ridge push and slab pull

A more recent explanation is called **ridge push** and **slab pull** (see Figure 2.1). At constructive margins, **ocean ridges** form high above the ocean floor. Beneath ocean ridges the mantle melts; the molten magma rises as the plates move apart, and cools down to form new plate material. As the lithosphere cools, it becomes denser and starts to slide down, away from the ridge, which causes plates to move away from each other. This is called ridge push. Additionally, at destructive margins the denser plate sinks back into the mantle under the influence of gravity, which pulls the rest of the plate along behind it. This is called slab pull.

Where are earthquakes and volcanoes located?

Earthquakes and **volcanoes** are not randomly distributed over the Earth's surface. Figure 2.3 shows the distribution of earthquakes and volcanoes. The pattern matches where plate margins are located (see Figure 2.2). Earthquakes are found at all three types of plate margins, whereas volcanoes are found at two, constructive and destructive (see Sections 2.2 to 2.4.)

Earthquakes and volcanoes are found both on land and in the sea.

For example, there is a chain of volcanoes and earthquakes which runs along the west coast of North and South America. The large band of volcanoes and earthquakes which circles the Pacific Ocean is known as the Ring of Fire.

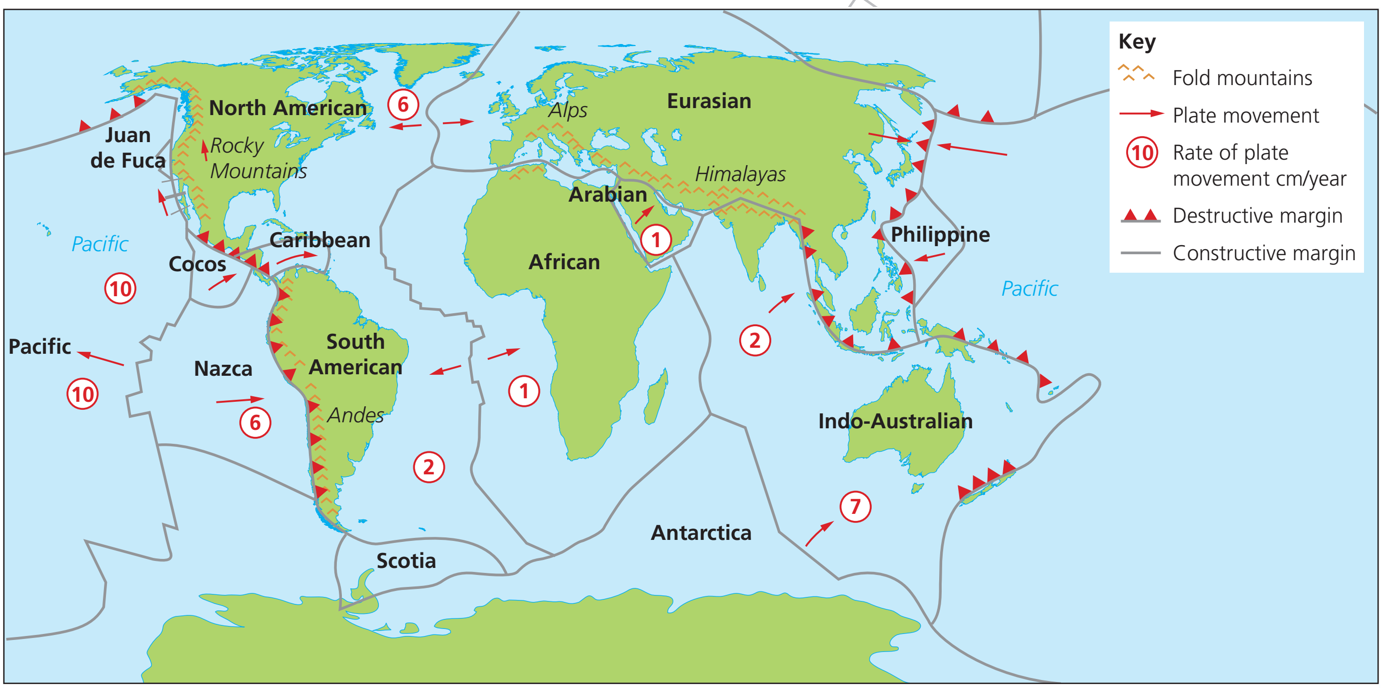


Figure 2.2 World map of major tectonic plates and plate margins

Not every earthquake and volcano lies along a plate margin. Some also occur in the middle of plates. These are known at 'hot spots', where the Earth's crust is thought to be particularly thin. For example, Hawaii has formed due to volcanic eruptions at a hot spot that is located far from the edge of the Pacific Plate.

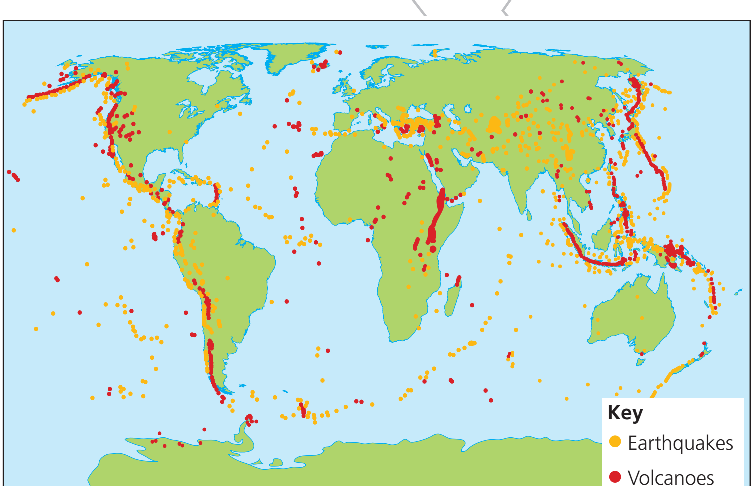


Figure 2.3 Tectonic hazards around the world

Activities

1 Define what a tectonic plate is.
2 Contrast the characteristics of continental and oceanic crust.
3 Describe the global distribution of earthquakes.
4 Describe the global distribution of volcanoes.
5 Do you agree with these statements? Explain your answer.
   a) 'Earthquakes and volcanoes occur together.'
   b) 'Earthquakes and volcanoes occur away from each other.'
   c) 'Earthquakes and volcanoes occur along plate margins.'
   d) 'Earthquakes and volcanoes occur away from plate margins.'
6 Using Figure 2.1, explain how tectonic plates move.
7 Explain what hot spots are.

KEY LEARNING

- How plates at constructive margins move
- Why earthquakes and volcanoes are found at constructive plate margins

Constructive plate margins

How do plates move at constructive margins?

Constructive plate margins occur when tectonic plates move apart from each other. Most tectonic plates move a few centimetres a year. This may not sound much, but over time this has meant that whole continents have moved position. As shown in Figure 2.2 in Section 2.1, the Eurasian Plate and North American Plate form a constructive plate margin: they are moving away from each other at a rate of six centimetres per year.

Why are earthquakes and volcanoes found at constructive plate margins?

1 At constructive margins, the upper part of the mantle melts and the hot molten magma rises. The East Pacific Rise, on the other hand, is a faster moving constructive plate margin. It separates the Pacific Plate from the North American Plate and Nazca Plate at a rate of about ten centimetres per year.

2 As the tectonic plates are moved away from each other, this releases pressure and therefore molten magma rises between. It cools down to form solid rock. As the rock cools, it becomes denser and sinks, causing the tectonic plates to move further (see ridge push on page 4).

3 Much of the magma never reaches the surface but it is buoyant enough to push up the crust at constructive margins to form ridge and rift features. In a few places the magma erupts on to the surface, producing a basic lava that is runny and spreads out before solidifying. Over many eruptions, a volcano that typically is low, has a wide base and gentle slopes, known as a **shield volcano**, is formed.

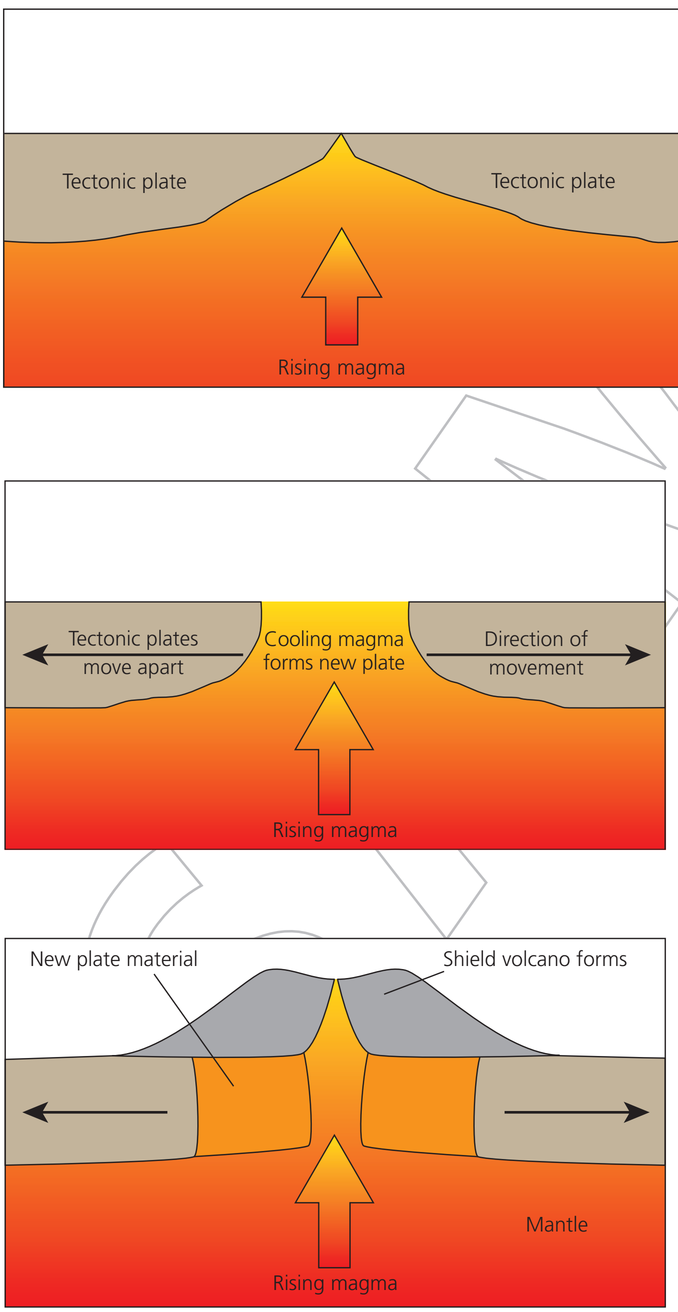


Figure 2.4 Constructive plate margins

The Mid-Atlantic Ridge is located along a constructive plate margin. The North American plate is moving away from the Eurasian plate (Figure 2.5). The magma has risen and caused uplifting of the Earth's crust, forming the ridge as a range of underwater mountains.

Iceland is the world's largest volcanic island situated on the Mid-Atlantic Ridge. Magma has risen to form underwater volcanoes, which have grown above sea level to form this volcanic island. The Westman Islands are 15 islands all created by volcanic activity originating on the seabed (Figure 2.5).

Rift valleys are steep-sided valleys that form at constructive plate margins. The strain of the tectonic plates moving away from each other is splitting Iceland in two, causing cracks or faults to form on either side. As the sides of the rift move and stretch apart, sections drop down to form rift valleys.

Iceland's Thingvellir National Park has a visitor centre with a path leading to the Almannagjá fault where a stretch of the plate margin can be viewed (Figure 2.6). Hundreds of small earthquakes occur in Iceland on a weekly basis.

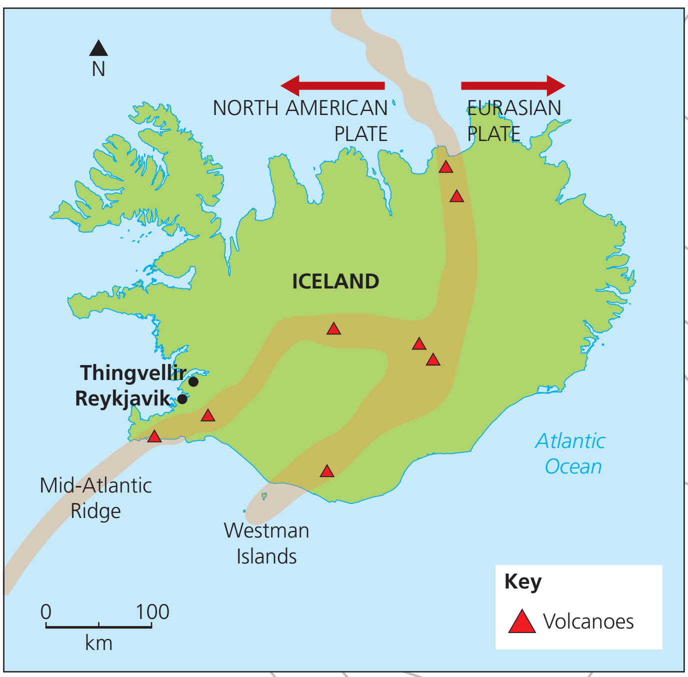


Figure 2.5 Map of Iceland

Figure 2.6 Mid-Atlantic Ridge, Thingvellir, Iceland

Activities

1. Describe the direction in which plates move at constructive plate margins.
2. Use Figure 2.2 in Section 2.1 (page 5) to identify the plate names at two different constructive plate margins.
3. Are earthquakes experienced at constructive plate margins? Explain your answer.
4. What evidence can you find on the map (Figure 2.5) and the photograph (Figure 2.6) that Iceland lies on a constructive plate margin?
5. Explain why there are so many volcanoes located in Iceland.

Geographical skills

Draw a sketch of Figure 2.6 and label human and physical features.

KEY LEARNING

- How plates at destructive margins move
- Why earthquakes and volcanoes are found at destructive plate margins

Destructive plate margins

How do plates move at destructive margins?

Destructive plate margins occur when tectonic plates move towards each other and collide. The effect this has depends on the type of plate:

- If two continental plates collide, they are both buoyant and so cannot sink into the mantle. As a result, compression forces the plates to collide and form mountains.
- If an oceanic and a continental plate collide, the denser oceanic plate is **subducted** and sinks under the continental plate, into the Earth's mantle, where it is recycled, causing earthquakes, fold mountains and volcanoes.

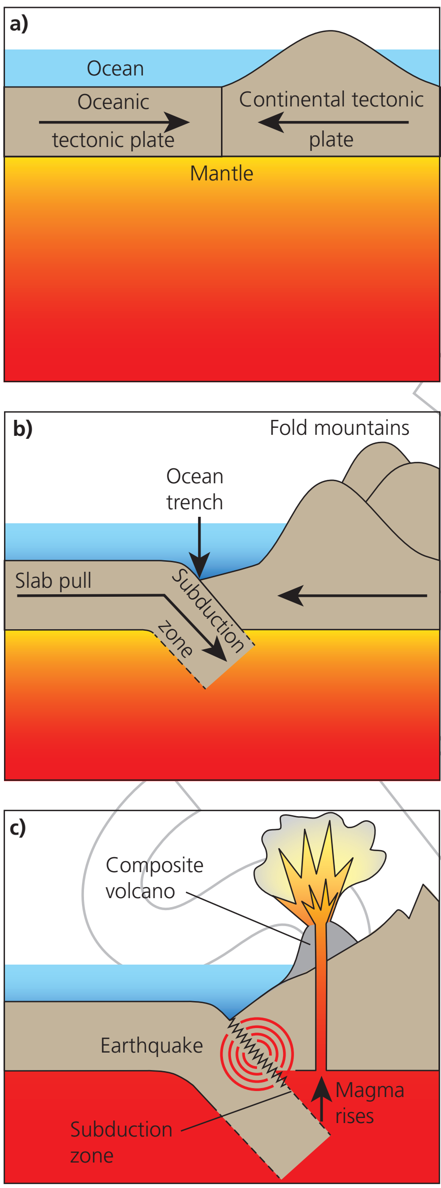


Figure 2.7 Destructive plate margins

Why are earthquakes and volcanoes found at destructive plate margins?

The pressure and strain of an oceanic and continental plate moving towards each other can cause the Earth's crust to crumple and form fold mountains. As the plates converge, pressure builds up. The rocks eventually fracture, causing an earthquake, which can be very destructive (see Figure 2.7a).

The denser oceanic plate subducts down into the mantle under the influence of gravity. The plate is denser than the surrounding mantle so pulls the rest of the plate along behind it, driving further movement of the tectonic plate. At the surface, this creates a deep ocean trench (see Figure 2.7b).

As the oceanic plate sinks deeper into the mantle, it causes part of the mantle to melt. Hot magma rises up through the overlying mantle and lithosphere, and some can eventually erupt at the surface, producing a linear belt of volcanoes. The magma becomes increasingly viscous (sticky) as it rises, producing **composite volcanoes** which are steep-sided, erupt a variety of materials such as sticky acidic lava and ash, and have violent eruptions (see Figure 2.7c).

Japan's volcanoes

Japan is prone to earthquakes and volcanic eruptions. It has 118 **active volcanoes** currently erupting or showing signs of eruption (ten per cent of the global total), more than almost anywhere else in the world. Japan's band of volcanoes form part of the Ring of Fire (see page 5) surrounding the Pacific Ocean. There are so many because Japan lies on the margin of four plates: the Eurasian, North American, Pacific and Philippine (see Figure 2.2 in Section 2.1). The Pacific plate subducts beneath the North American plate and the Philippine plate, which then subducts beneath the Eurasian plate. Many parts of Japan have experienced earthquakes due to the pressure built up in the plates as they move at this destructive plate margin.

Also formed at the destructive plate margin of the Pacific and Philippine plates is an ocean trench, known as the Mariana Trench. It is 10,994 metres deep – deeper than the tallest mountain, Mount Everest (8,848 metres). The Mariana Trench is the deepest known part of the Earth's oceans.

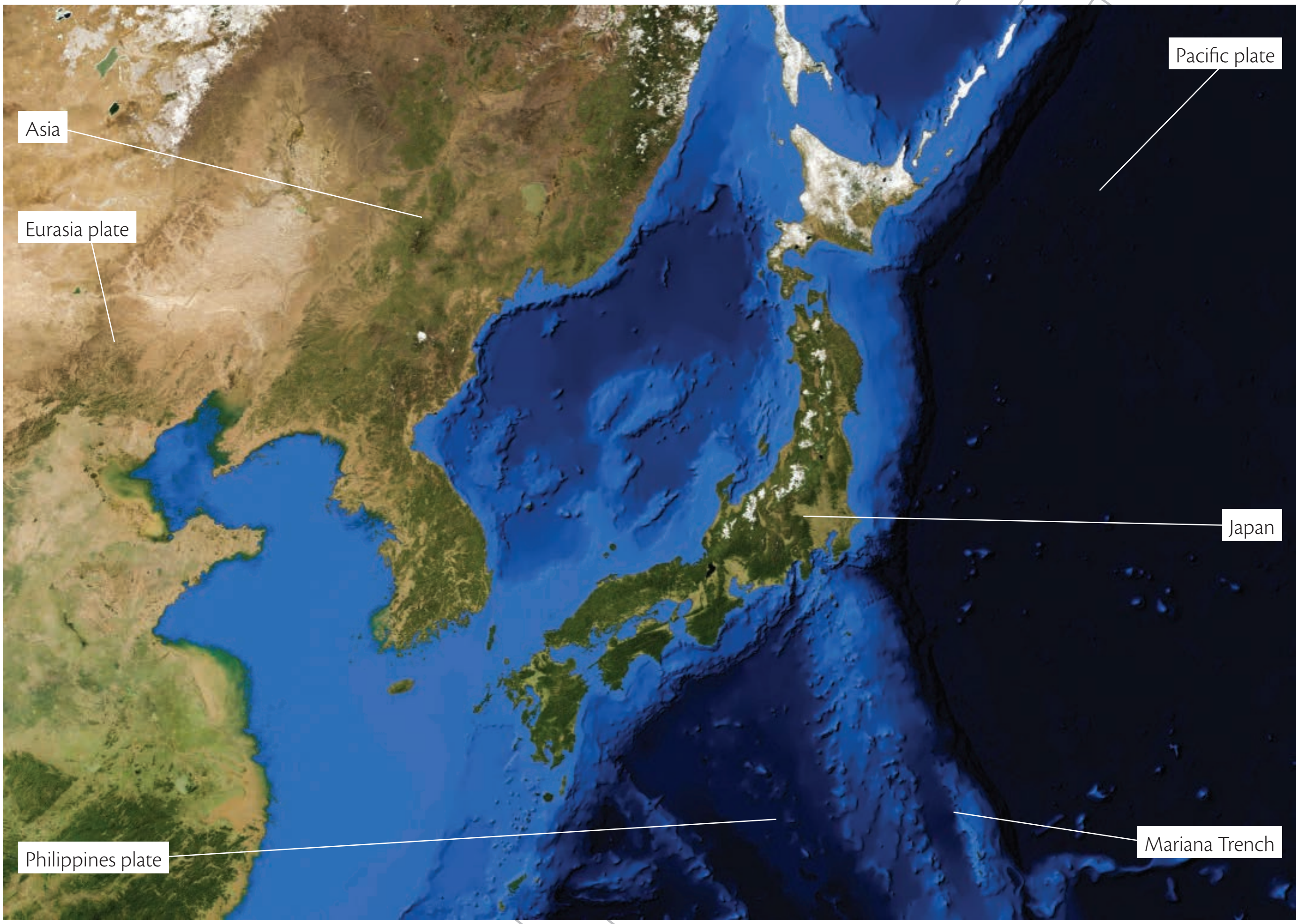


Figure 2.8 Satellite image of Japan. The darker the blue, the greater the ocean's depth

Activities

1. Describe the direction in which plates move at destructive plate margins.
2. Use Figure 2.2 in Section 2.1 to determine which of the following are destructive plate margins:
   - Eurasian and Philippine plates
   - Nazca and Pacific plates
   - Nazca and South American plates
   - North American and Eurasian plates.
3. What landforms are found at destructive plate margins?
4. Explain how earthquakes and volcanoes are formed at destructive plate margins.

Geographical skills

Draw an annotated sketch map of Figure 2.8. Annotate the image to show where you would expect earthquakes, volcanoes and mountains to be formed – explain why.

✪ KEY LEARNING

- How plates at conservative margins move
- Why earthquakes are found at conservative plate margins

Conservative plate margins

How do plates move at conservative margins?

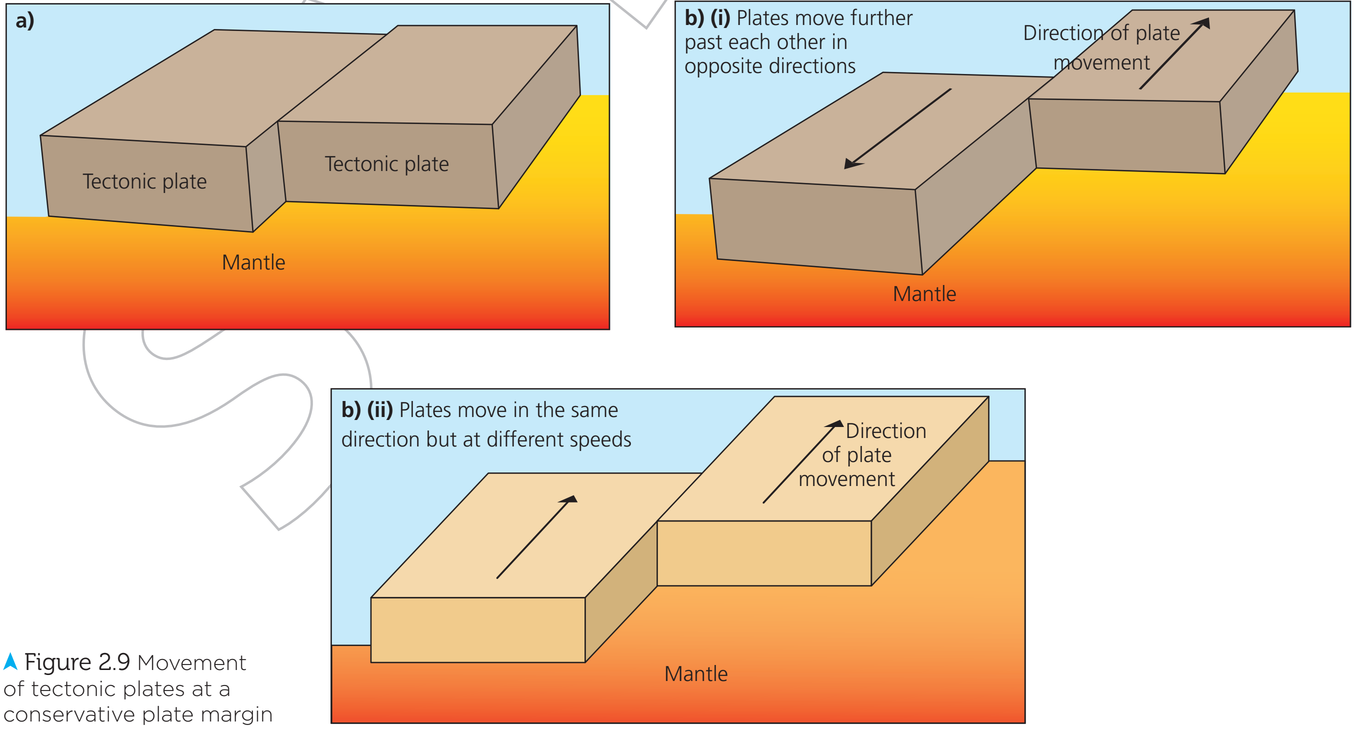
A conservative plate margin occurs when tectonic plates move parallel to each other. The two plates can move side by side, either in the same direction but at different speeds, or simply in the opposite direction to one another (see Figure 2.9).

Why are earthquakes found at conservative plate margins?

One theory is that pressure might build up at the margin of the tectonic plates as they are pulled along behind a plate being subducted elsewhere. As the plates move past each other, friction causes them to become stuck. Pressure builds up and up until eventually the rock fractures and pressure is released, sending out huge amounts of energy, causing an earthquake. However, volcanoes are not formed at conservative plate margins. Magma cannot rise to fill a gap as there is no gap created between the tectonic plates, and therefore there is no new land formed. Neither is there any land destroyed, because there is no tectonic plate subducted into the mantle.

The San Andreas Fault stretches 800 kilometres through the state of California in the USA. It is found along the margin between the North American plate and the Pacific plate. These tectonic plates are sliding past each other in roughly the same northwest direction, but at different speeds (see Figure 2.10). The North American plate moves at approximately 6 centimetres per year, whereas the Pacific plate moves at approximately 10 centimetres per year. Fifteen to twenty million years ago, Los Angeles would have been south of where San Diego is now. If the plates continue to move at the same speed, in 20 million years' time, Hollywood in Los Angeles will be adjacent to the Golden Gate Bridge in San Francisco.

California experiences thousands of small earthquakes every year. One of the biggest earthquakes to hit California was in San Francisco in 1906. Scientists have estimated that the 1906 San Francisco earthquake measured a magnitude of 8.3 on the **Richter scale**. (The largest earthquake ever recorded was in Chile, in 1960, which measured 9.5.) Approximately 700 people died and the damage caused was estimated to cost over US$500 million.



▲ Figure 2.9 Movement of tectonic plates at a conservative plate margin

The US Geological Survey have run computer models to predict the next major earthquake on the San Andreas Fault. They report that there is most likely to be an earthquake similar to the 1906 San Francisco earthquake at intervals of about 200 years. There is only a small chance (about 2 per cent) that an earthquake like this would happen within the next 30 years.

Figure 2.10 Map showing the San Andreas Fault, California, USA

Figure 2.11 The San Andreas Fault

Activities

1 Use Figure 2.2 in section 2.1 to identify a different conservative plate margin from the San Andreas Fault.

2 a) Are the following statements about conservative margins true or false?
   i) Two tectonic plates move away from each other.
   ii) Two tectonic plates move parallel past each other.
   iii) Two tectonic plates move towards each other.
   iv) Earthquakes are found at conservative margins.
   v) Volcanoes are found at conservative margins
   b) Explain your answer for each statement.

3 Describe and explain the similarities between the photographs in Figure 2.5 in Section 2.2 and Figure 2.11 on this page.

4 Complete the following summary table about the three types of plate margins.

Margin type	Type of plates (oceanic or continental or either)	Direction of plate movement	Earthquakes (tick or cross)	Volcanoes (tick or cross)
Constructive				
Destructive				
Conservative				

Geographical skills

The Richter scale is logarithmic. This means each increase of one on the scale means the power is increased by 10, not 1. So a magnitude 6 earthquake is 10 times more powerful than a magnitude 5 earthquake.

Calculate how much more powerful a magnitude 8 earthquake is than a magnitude 4 earthquake.

Example

KEY LEARNING

- Primary and secondary effects of an earthquake
- How people responded to the Amatrice earthquake

Earthquake in Amatrice, Italy (2016)

What were the effects of the earthquake?

On 24 August 2016, an earthquake measuring a magnitude of 6.2 on the Richter scale struck central Italy. The earthquake's epicentre was halfway between the towns of Amatrice and Norcia, at a shallow depth of 5.1 km.

Amatrice is a town in the Apennine Mountains in central Italy, approximately 30 miles north of L'Aquila, which also experienced a major earthquake in 2009 (see Figure 2.12). The Amatrice earthquake was felt as far as 100 miles away, in Rome. Amatrice experienced a range of impacts which affected the wealth of the area and of the community (**economic impacts**), the lives of members of the community (**social impacts**) and the **landscape** (**environmental impacts**).

Primary effects

As a direct result of the earthquake, 299 people were killed, 400 were injured and 4454 were made homeless. It struck at 3.36 a.m., so most people were asleep in buildings which collapsed, with no time to evacuate:

- Towns and villages in the regions of Umbria, Lazio and Marche suffered most damage.
- Around 293 historic buildings were damaged or destroyed, including the fourteenth-century Basilica of St. Benedict in Norcia, and the Church of Sant'Agostino and the Basilica of San Francesco in Amatrice.
- Over half the buildings were destroyed in Amatrice, 80 per cent of the historic old town, despite their reinforcements.
- Amatrice's Romolo Capranica school completely collapsed (considered a substandard construction).
- Even though the government had allocated €1 billion for building improvements to be made following the 2009 L'Aquila earthquake, many properties did not meet seismic building standards (across Italy, this is true of around 70 per cent of buildings).
- The earthquake struck during the summer holiday season, so the population was much higher than normal. The death toll included tourists celebrating an annual food festival.
- Overall, the EU estimated the total damage at €21.9 billion.

Figure 2.12 Amatrice in the region of Lazio, Italy

Secondary effects

Some effects of the earthquake occurred later and indirectly as a result of the initial earthquake itself. These are some of the **secondary effects**:

- The centre of Amatrice town was cordoned off due to the unsafe buildings. Parts of the centre were made 'red zones', reducing business, tourism and income.
- Farmers struggled to earn a living as 90 per cent of sheep, goats and cattle barns (and their milking systems) were destroyed.
- Landslides blocked roads and reduced access to the area.
- Residents suffered psychological damage, especially as they know they live in the most seismically active area in Europe.
- The press reported individuals were arrested for looting properties in Amatrice.

What were the responses to the earthquake?

Immediate responses

There were a range of **immediate responses**. For those made homeless, 10,000 were accommodated in 58 tent camps. Converted sports halls and hotels on the Adriatic coast provided shelter for 4000. Additionally:

- Rescue workers, including the Italian Red Cross, 5000 soldiers and Alpine guides, arrived within an hour, searching for survivors and providing food and tents. Twelve helicopters and 70 dog teams were involved in the rescue effort.
- Patients at Amatrice hospital were transferred to a nearby hospital in Rieti as Amatrice hospital was severely damaged. A temporary hospital was set up. The national blood donation service appealed for new donors to ensure demand was met.
- Facebook set up their safety check feature for people in the area to let friends and family know they were safe. The Italian Red Cross requested locals remove wi-fi passwords so rescue teams could communicate more easily.
- Italian Prime Minister Matteo Renzi announced €50 million for the emergency response, for reconstruction work to begin immediately and taxes for residents to be cancelled.
- British chef Jamie Oliver pledged donations for every plate of Amatrice's famous Amatriciana pasta served in his restaurants. All proceeds from visits to museums and archaeologist sites on 28 August throughout Italy went to a fund to help rebuild the historic sites damaged in the earthquake.

However, rescue efforts were hampered due to blocked roads, a damaged bridge, the mountainous terrain and over 2000 aftershocks which caused even more damage.

Figure 2.13 Aftermath of the earthquake in Amatrice, Italy, 2016

Long-term responses

There were several **long-term responses**:

- Students attended classes in neighbouring schools while 12 classrooms in prefabricated buildings were constructed in Amatrice so children could return to school there.
- A €42 million government initiative called 'Italian Homes' sought to rebuild villages with buildings of the same character, but now earthquake-proof. Tax incentives allow 65 per cent of total renovation costs to be used as tax breaks to help reduce the cost of rebuilding. However, this was not enough to ensure a significant increase in buildings that are safe. Prime Minister Matteo Renzi stated it was 'absurd' to think Italy could build completely earthquake-proof buildings. The Italian press criticised the government over building regulations, especially as some recently renovated buildings had also collapsed.
- Six months after the earthquake, the Italian government promised to move people from temporary camps into lightweight wooden houses.
- A year later, 2.4 million tons of rubble and debris remained in affected areas.

Activities

1. Use Figure 2.12 to describe the location of Amatrice.
2. Define the primary and secondary effects of an earthquake.
3. a) Give three examples of primary effects likely in any earthquake around the world.
   b) Give three examples of secondary effects likely in any earthquake around the world.
4. Complete the table of effects for this earthquake.

Economic	Environmental	Social

5. Explain how four of the responses described would help to manage the effects.
6. Justify why both immediate and long-term responses were needed.

Example

KEY LEARNING

- Primary and secondary effects of the earthquake
- How people responded to the Gorkha earthquake

Earthquake in Gorkha, Nepal (2015)

What were the effects of the earthquake?

On Saturday 25 April 2015, at 11.56 a.m. (local time), a 7.8 magnitude earthquake struck the Gorkha district in Nepal (Figure 2.14). The earthquake's epicentre was in Barpak, 80 kilometres northwest of the capital, Kathmandu.

Figure 2.14 Nepal, Asia

Primary effects

The immediate **primary effects** included:

- A total of 8,841 dead, over 16,800 injured and 1 million made homeless.
- Historic buildings and temples in Kathmandu, including the iconic Dharahara Tower (Figure 2.16), a UNESCO World Heritage Site, in which 200 people were estimated to be trapped, were destroyed; there were no compulsory building standards in Nepal, so many modern buildings also collapsed.
- The destruction of 26 hospitals and 50 per cent of schools. (Save the Children estimated 29,000 more people would have been killed if the earthquake had struck during school hours, rather than on a Saturday.)
- A reduced supply of water, food and electricity.
- 352 aftershocks, including a second earthquake on 12 May 2015 measuring 7.3 magnitude.

Secondary effects

The earthquake triggered an avalanche on Mount Everest. It swept through Everest Base Camp, which is used by international climbing expeditions. Out of the 19 who died, several were tourists and the rest were members of an ethnic group in Nepal called Sherpas. Sherpas work as porters, guides and cooks. They are aware of the dangers of Mount Everest, but tourism can provide them with an income to help lift them out of poverty.

In 2014, the World Travel and Tourism Council reported that tourism was 8.9 per cent of Nepal's GDP and provided 1.1 million jobs. It was expected to increase by 5.8 per cent in 2015, but until Nepal has recovered from the earthquake, tourism, employment and income will shrink.

The earthquake happened just before the monsoon season, when rice is planted. Rice is Nepal's staple diet, and two-thirds of the population depend on farming. Rice seed stored in homes was ruined in the rubble, causing food shortages and income loss.

What were the responses to the earthquake?

Immediate responses

Nepal requested international help. The UK's Distasters Emergency Committee (DEC) raised US$126 million by September 2015 to provide emergency aid and start rebuilding the worst-hit areas.

Temporary shelters were set up. The Red Cross provided tents for 225,000 people. The United Nations (UN) health agency and the World Health Organization (WHO) distributed medical supplies to the worst-affected districts. This was important as the monsoon season had arrived early, increasing the risk of **waterborne diseases**.

Nepal's mountainous terrain and inadequate roads made it difficult for aid to reach remote villages. 315,000 people were cut off by road and 75,000 were additionally unreachable by air. Sherpas were used to hike relief supplies to remote areas. Facebook launched a safety feature so people could indicate they were 'safe'. Several companies did not charge for telephone calls.

Long-term responses

Nepal's government (along with the UN, EU, World Bank, Japan International Cooperation Agency and Asian Development Bank) carried out a Post-Disaster Needs Assessment. It reported that 23 areas required rebuilding, such as housing, schools, roads, monuments and agriculture. Eight months after the earthquake, the Office for the Coordination of Humanitarian Affairs (OCHA) reported that US$274 million of aid had been committed to the recovery efforts.

The Durbar Square heritage sites were reopened in June 2015 in time to encourage tourists back for the tourism season. Mount Everest was reopened for tourists by August 2015 after some stretches of trail were re-routed. By February 2016, the Tourism Ministry extended the climbing permits that had been purchased in 2015 to be valid until 2017, so that climbers would return and attempt Everest again.

A recovery phase started six months later by the Food and Agriculture Organization of the United Nations (FAO). To expand crop production and growing seasons, individuals were trained how to maintain and repair **irrigation** channels damaged by landslides in the earthquake.

However, by November 2018, a community perception report (funded by UK Aid) stated that 34 per cent of people affected by the earthquake were still living in temporary shelters or in homes that were unrepaired.

> Nepal's recovery needs are US$6.7 billion, roughly a third of the economy. Early estimates suggest that an additional three per cent of the population has been pushed into poverty as a direct result of the earthquakes. This translates into as many as one million more poor people.

Figure 2.15 Post-Disaster Needs Assessment *(Source: Worldbank.org press-release 23/06/2015)*

Figure 2.16 Dharahara (Bhimsen) Tower, Kathmandu, before and after the earthquake

Figure 2.17 Tents set up near Kathmandu airport, Nepal

Activities

1. Use Figure 2.14 to describe the location of Nepal.
2. Draw a sketch of the photos in Figure 2.16 or Figure 2.17 that shows the effects of the earthquake. Annotate the effects.
3. Identify the economic, environmental and social effects for the Gorkha earthquake.
4. Why do you think the tents in Figure 2.16 were set up near Kathmandu airport?
5. Explain three immediate and three long-term responses to the Gorkha earthquake.
6. Research other 'before and after' images of the earthquake. Describe the differences.

Example

KEY LEARNING

- How the effects and responses compare
- Why effects and responses are different

Comparing the Italy and Nepal earthquakes

Do effects and responses to earthquakes differ?

Earthquakes occur whether the country is a high-income country (HIC), newly emerging economy (NEE) or a low-income country (LIC). Tectonic events do not discriminate by wealth. However, the effects of an earthquake differ due to the ability to predict, protect against and prepare for the hazard. Equally, a country's ability to manage the effects and devastation can be affected by its level of wealth and resources.

How do Italy's and Nepal's earthquakes compare?

	Italy	Nepal
Income level	High income	Low income
GDP	US$1.832 trillion (2015)	US$21.41 billion (2015)
GNI per capita	US$32,910 (2015)	US$780 (2015)
Magnitude	6.2 magnitude	7.8 magnitude
Time of day	3.36 a.m. (local time)	11.56 a.m. (local time)
Deaths	299	8,841 (19 on Mount Everest)
Homeless	4,454	1 million
Hospitals damaged	Amatrice Hospital	26 hospitals
Sites damaged	Basilica of St. Benedict, Norcia. The Basilica of San Francesco, Amatrice. Amatrice's Romolo Capranica school.	World Heritage sites, for example Dharahara Tower, the Patan and Bhaktapur Durbar Square.
Cost of damage	US$19.7 billion	US$5.15 billion
Amount of aid	US$1.3 billion from EU	US$274 million from EU

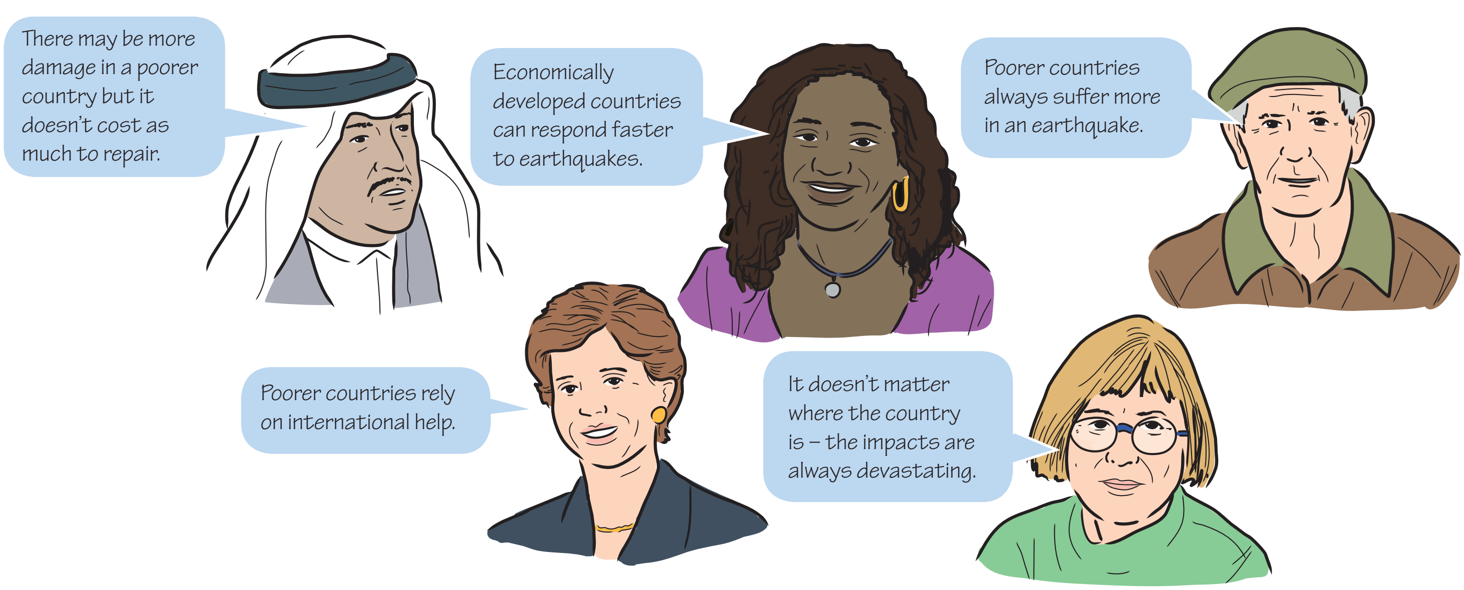


Figure 2.18 Attitudes to earthquakes in HICs and LICs

Why do effects and responses differ?

Earthquakes never occur in exactly the same circumstances. Figure 2.19 shows some factors that are responsible for the different effects and responses in different countries. Many are influenced by the wealth of the country concerned.

Depth of focus
The shallower the focus the more energy to cause damage.

Population density
The more people the more potential risk of injuries and fatalities.

Building density
The more buildings the greater the likelihood some will collapse.

Plate margin
Some plate margins are more destructive than others.

Distance from epicentre
The closer to the epicentre the greater the magnitude will be.

Magnitude
The stronger the earthquake the greater the impact.

Medical facilities
The more medical resources the easier it is for victims to get treatment.

Transport infrastructure
The better the transport network the quicker it is to evacuate victims and for aid to arrive.

Monitoring and predicting
More resources available to monitor and predict earthquakes should reduce the risks.

Time and day of the week
If buildings and roads collapse when they are empty there are fewer casualties.

Time of year
Climate in different seasons can make impacts and responses harder (e.g. monsoon).

Construction standards
Buildings with strict building regulations have less chance of collapsing.

Type of event
Secondary effects, e.g. tsunamis, avalanches and landslides, cause further devastation.

Resources and finance
The more resources and money available the quicker it is to rebuild homes and businesses.

Earthquake-prone areas
Planning, preparation and protection is more likely in areas that expect earthquakes.

Emergency services
More skilled emergency services, armies and volunteers reduce casualties.

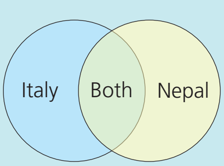
Training
More training so the public and emergency services know what to do to reduces casualties.

Corruption
Corrupt governments and organisations divert aid and supplies away from areas that need it most.

▲ Figure 2.19 Factors affecting the impact and responses to an earthquake

➜ Activities

1 Draw a large Venn diagram, as shown, to categorise which effects and responses are similar and which are different in the earthquakes in Italy and Nepal. You will need to use the information in Sections 2.5 and 2.6. Colour-code the effects and responses.



2 Sort the reasons for varying impacts in Figure 2.19 into two categories: those influenced by wealth and those not influenced by wealth.

3 Suggest other ways that the impacts in Figure 2.19 could be categorised.

4 Use Figure 2.19 to explain reasons for the differences in:
   a) effects in Italy and Nepal
   b) responses in Italy and Nepal.

5 Decide if you agree or disagree with the statements in Figure 2.18 and give reasons for your answers.

6 Are earthquakes more devastating in high-income countries (HICs) or low-income countries (LICs)? Justify your answer.

KEY LEARNING

- Where people live in relation to earthquakes and volcanoes
- Why people live in areas at risk of tectonic hazards

Risking it

Do people live in areas prone to volcanic eruptions and earthquakes?

Despite all the dangers, millions of people still live in hazard-prone areas. As the world's population rises, more people will live in volcanic and earthquake-prone areas. Figure 2.20 shows that large cities, with over 1 million inhabitants, can be found in the same locations (and within close proximity) to earthquakes. Approximately eight per cent of the 7.7 billion people who live in the world live near volcanoes, and 50 per cent of the 330 million people in the USA are living at risk of earthquakes.

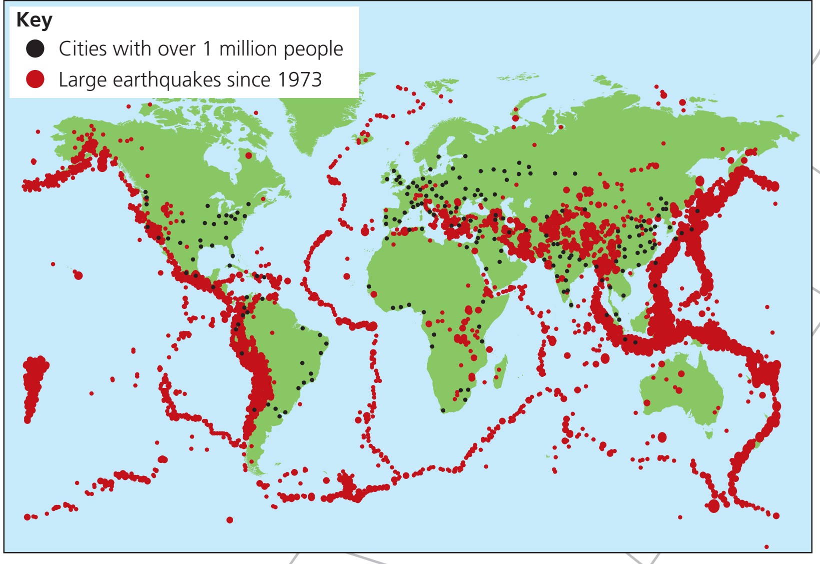


Figure 2.20 Cities with over 1 million inhabitants and earthquakes

Why do people continue to live in hazardous areas?

Geothermal energy

In volcanically active areas, **geothermal energy** is a major source of electrical power: steam is heated by hot magma in permeable rock, then boreholes are drilled into the rock to harness the super-heated steam to turn turbines at power stations. It is renewable energy – it will not run out, and it will reduce greenhouse gases and the likely effects of **climate change**.

Hellisheidarvirkjun (or Hellisheidi) power plant is the largest geothermal power station in Iceland and the second largest in the world. It provides electricity and hot water for the capital, Reykjavik. Geothermal energy produces approximately 30 per cent of Iceland's total electricity.

Figure 2.21 Hellisheidarvirkjun geothermal power plant, Iceland

Farming

Lava and ash erupting from volcanoes kill livestock and destroy crops and vegetation. After thousands of years, weathering of this lava releases minerals and leaves behind extremely fertile soil, rich in nutrients. Land can be farmed productively in these areas to provide a source of food and income. Volcanic soils are found on less than one per cent of the Earth's surface, but support 10 per cent of the world's population.

Mining

Settlements develop where valuable minerals are found, as jobs are created in the mining industry. It is not just dormant and extinct volcanoes that are mined, but also active volcanoes.

Kawah Ijen is an active volcano in East Java, Indonesia. Its crater is one of the biggest sulphuric lakes in the world. Sulphur is sold, for example, to bleach sugar, make matches, medicines and fertiliser. However, mining in active volcanoes is dangerous:

- Miners can afford little protective clothing.
- Hydrogen sulphide and sulphur dioxide gases burn their eyes and throats and cause respiratory diseases.
- In the last 40 years, 74 miners have died from the fumes.
- Loads of sulphur weighing 100 kilograms are carried up and down the rocky and slippery mountain paths.

Nevertheless, miners can earn an average of $6 per day (more than on a coffee plantation), so miners continue to live and work in dangerous areas.

Figure 2.22 A cartoon showing how people may be persuaded to move away from hazardous areas. The speech bubble says, 'Hey – great news! I've finally decided to sell you my house on the island!'

Tourism

Tourists visit volcanoes for the spectacular and unique views, relaxing hot springs, adventure and, for thrill seekers, the sense of danger. More than 100 million people visit volcanic sites every year. The revenue they generate benefits the locals and the countries they are in.

Family, friends and feelings

People do not wish to leave because their friends and family are there. It is often cheaper and easier to stay, especially when the risks may not be perceived as dangerous enough or residents are in denial that a disaster may occur.

Figure 2.23 Mining sulphur at Kawah Ijen crater, Indonesia

Activities

1. How does the map in Figure 2.20 demonstrate that people are at risk from earthquakes?
2. Why would a farmer consider the benefits of living near a volcano different in the short term rather than in the long term?
3. Draw a sketch of the photograph in Figure 2.23. Annotate it with the following labels:
   crater, lake, sulphur, hydrogen sulphide and sulphur dioxide gases, little protective clothing, hand–carried loads of sulphur, rocky paths.
4. Describe three benefits of living near a volcano.
5. Explain why it may have taken time for the character in Figure 2.22 to make that decision.

KEY LEARNING

- How the risks of earthquakes can be reduced
- How the risks of volcanic eruptions can be reduced

Risk management

Can the risks of earthquakes be reduced?

Prediction, **monitoring**, **protection**, and **planning** all aim to reduce the damage that earthquakes and volcanic eruptions cause to people and property.

Monitoring and prediction

It is possible to predict the general locations where earthquakes are most likely to happen, as they occur along plate margins. However, it is extremely difficult to predict their time, date and exact location. The following show some ways that technology is used to try to monitor and predict tectonic hazards:

- **Seismologists** use radon detection devices to measure radon gas in the soil and **groundwater**, which escapes from cracks in the Earth's surface.
- Sensitive seismometers are used to measure tremors or **foreshocks** before the main earthquakes.
- Earthquake locations and their times are mapped to spot patterns and predict when the next earthquake will occur.
- Smart phones have GPS (Global Positioning System) receivers and accelerators built in. They can detect movements in the ground, which are analysed to potentially warn others further away.
- Animals are believed to act strangely when an earthquake is impending.

Protection

Buildings made of brick or buildings with no reinforcement collapse easily during an earthquake. Designing buildings and strengthening roads and bridges to withstand earthquakes provides protection. This is also called **mitigation**. Figure 2.24 shows features of earthquake-resistant designs.

Unfortunately, earthquake-resistant buildings and **infrastructure** are extremely expensive, so it is usually not possible to adapt existing buildings. The aim of earthquake-resistant buildings is to ensure that people are not injured or killed – so although this might be achieved, the building may still need to be repaired or even rebuilt after an earthquake.

Planning

Planning and preparing what to do during and after an earthquake helps the authorities, emergency services and individuals to act quickly and calmly, so there is less chaos and fewer injuries and deaths:

- Furniture and objects can be fastened down so they are prevented from toppling over.
- Residents can learn how to turn off the main gas, electricity and water supplies to their properties.
- Preparing emergency aid supplies, how they would be distributed and where evacuation centres will be saves lives, as food, water, medicine and shelter are accessed faster.
- On 1 September each year, the Japanese practise earthquake drills on a national training day. This marks the anniversary of the Tokyo earthquake in 1923, which killed 156,000 people.
- The American Red Cross provides an earthquake safety checklist to help people plan and prepare for earthquakes in their homes, at work and in schools.

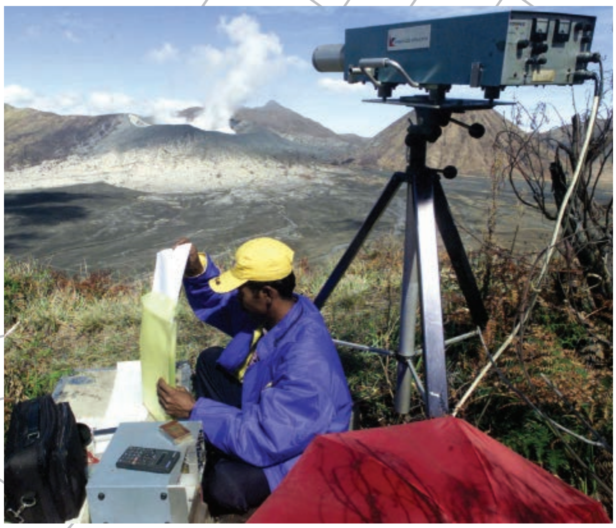
➤ Figure 2.24 Earthquake-resistant building design

Can the risks of volcanic eruptions be reduced?

Monitoring and prediction

It is easier to predict volcanic eruptions than earthquakes. Volcanoes usually give advance warning signals that they are going to erupt. However, the exact time and day of the eruption is still difficult to predict.

- Satellites (GPS) and tiltmeters monitor ground deformation (changes in the volcano's surface).
- Seismometers measure small earthquakes and tremors.
- Thermal heat sensors detect changes in the temperature of the volcano's surface.
- Gas-trapping bottles and satellites measure radon and sulphur gases released.
- Scientists measure the temperature of water in streams and rivers to see if it has increased.



▲ Figure 2.25 Monitoring volcanic activity

Planning

An evacuation plan is one of the most effective methods of protection against an eruption. Authorities and emergency services need to prepare emergency shelter, food supplies and form evacuation strategies. Exclusion zones can be designated so that no one is allowed to enter where people are considered vulnerable and in danger. Additionally, residents can be educated about preventing unnecessary injury and loss of life. They can practise advice to cover their eyes, nose and mouth to prevent being irritated by gas fumes. If residents are not evacuated, they are taught to seek shelter or go indoors to avoid the dangers of falling ash and rock.

Protection

Protecting against a volcanic eruption is extremely difficult. Buildings cannot be designed to withstand the lava flows, **lahars** or weight of debris and ash falling on roofs, especially if this mixes with water. Therefore, people need to **evacuate** their homes to a safe location under the instruction of the authorities.

➜ Activities

1 Define the terms prediction, protection, planning and monitoring.

2 True or false? (a) Earthquakes can be predicted. (b) Volcanoes can be predicted. Explain your answers.

3 Use Figure 2.24 to describe how each feature in the earthquake-resistant building reduces injury and loss of life.

4 Describe how the risks of living in an earthquake-prone area may be lessened by (a) individuals and (b) governments.

5 Devise your own earthquake safety checklist and explain your reason for each item.

6 Copy and complete the information in the following table.

Monitoring and predicting a volcanic eruption		
Changes a volcanologist would observe	Equipment used to monitor volcano	Explain why the changes mean a volcanic eruption is imminent

7 Suggest what the man in Figure 2.25 is doing.

8 'Predicting tectonic hazards is a waste of time.' To what extent do you agree with this statement?

9 Why are prediction, protection and planning each important factors in reducing the risks of a tectonic hazard?

10 Suggest why monitoring, prediction, protection and planning may differ in different parts of the world.

KEY LEARNING

- The features of global atmospheric circulation
- How global pressure and surface winds influence precipitation

Global atmospheric circulation

What are the features of global atmospheric circulation?

Global atmospheric circulation helps to explain the location of world climate zones (see Figure 3.1) and the distribution of weather hazards. In Chapter 5, you will also learn how the Earth's climate zones govern the pattern of **global ecosystems**.

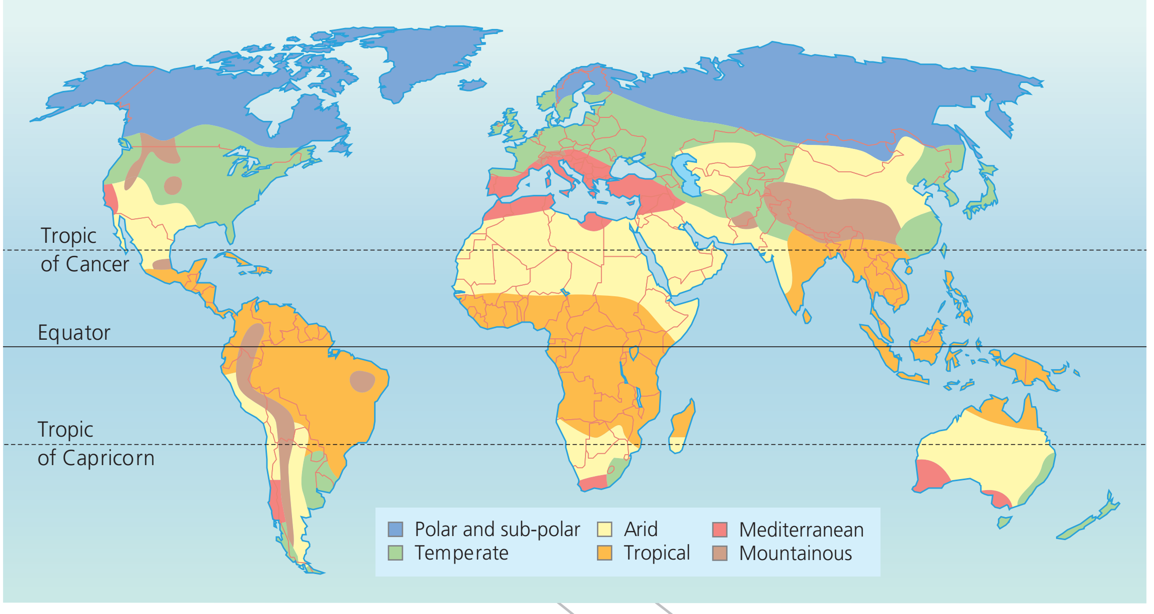


Figure 3.1 World climate zones

The most important influence on worldwide variations in climate is **latitude**. Because of the curved surface of the Earth, the Equator receives much higher **insolation** than the **polar** latitudes. The parallel rays of the Sun are spread thinly when they strike the Earth's surface at high latitudes, whereas at low latitudes sunlight is more highly concentrated (Figure 3.2).

As a result, air at the Equator is heated strongly. It becomes less dense and rises to a high altitude. This creates a global climate zone of low pressure: the equatorial zone. After rising, the air spreads out and begins to flow towards the North and South Poles.

Meanwhile, the low insolation received at polar latitudes results in colder, dense air and high pressure. As the air sinks towards ground level, it spreads out and flows towards the Equator.

Taken together, the low pressure belt at the Equator and the high pressure belt at the Poles provide the basis for a simple **convection cell** to operate. Global atmospheric circulation, however, is a little more complicated.

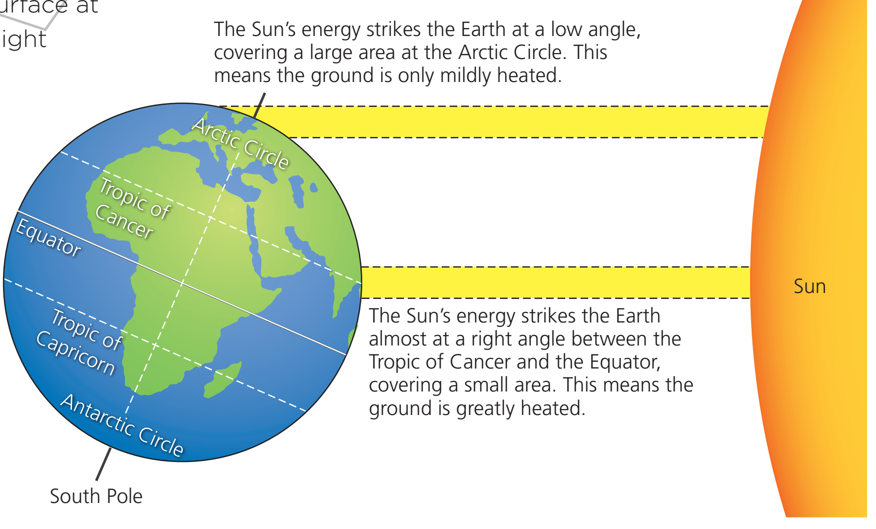


Figure 3.2 Solar heating of the Earth varies with latitude (showing the position of the Earth on 21 June, the Summer Solstice)

There are three convection cells, not just one, as Figure 3.3 illustrates. As well as pressure belts at the Poles, there are areas of high pressure at the Tropics of Cancer and Capricorn. As the air sinks towards the ground, it warms up. The result is high pressure and hot, dry desert conditions. This circulation of air between the Tropics and the Equator is called the Hadley cell.

Global circulation involves three cells because the Earth rotates on its axis, generating strong, high-altitude winds which wrap around the planet like belts. These winds flow towards the east, as the Earth spins, and interact with the convection cells. Figure 3.3 shows two particularly strong high-altitude currents of air called **jet streams**.

The exact position of the jet streams and convection cells changes with the seasons, which take place because the Earth is tilted on its axis. Each year, as the planet journeys around the Sun, insolation rises and falls at each latitude. In high polar latitudes, the Sun does not even rise during the winter. In southern Europe, temperatures rise steeply in summer before falling in winter.

Activities

1 Study Figure 3.1.
   a) Identify the climate zone which the UK belongs to.
   b) Identify all the different climate zones found in (i) the USA and (ii) Russia. (Use an atlas or online map to show you the countrys' borders.)

2 a) State what is meant by insolation.
   b) Using Figure 3.2, explain one reason why the Equator receives higher insolation than polar latitudes.

3 a) State what is meant by an arid climate.
   b) Explain why arid conditions exist in (i) parts of the tropics and (ii) some polar regions.

How do global pressure and surface winds influence precipitation?

Global pressure and surface wind patterns influence **precipitation** in several important ways:

- Rainfall is high and constant throughout the year near the Equator. As hot air rises, it cools slightly. Water vapour is converted into droplets of rain.
- The low-pressure zone around the Equator is called the intertropical convergence zone (ITCZ). Air rises and triggers bursts of torrential rain. Sometimes, the ITCZ grows a 'wave' of low pressure which extends further than usual. Tropical storms develop along these waves. Once they gain energy, they can travel even further away from the Equator (pages 24–25).
- Rainfall is often higher in coastal areas in Western Europe due to the movement of the Polar jet stream over the Atlantic. Rain-bearing weather systems called depressions (also known as **cyclones**) follow the Polar jet stream, often bringing stormy conditions to the UK's west coast (see page 38).
- Rainfall is often low around the Tropics of Capricorn and Cancer. Dry air descends there as part of the Hadley cell, resulting in **arid** conditions.
- Precipitation is also very low in polar regions and falls mostly as snow, as cold air cannot hold much water vapour.

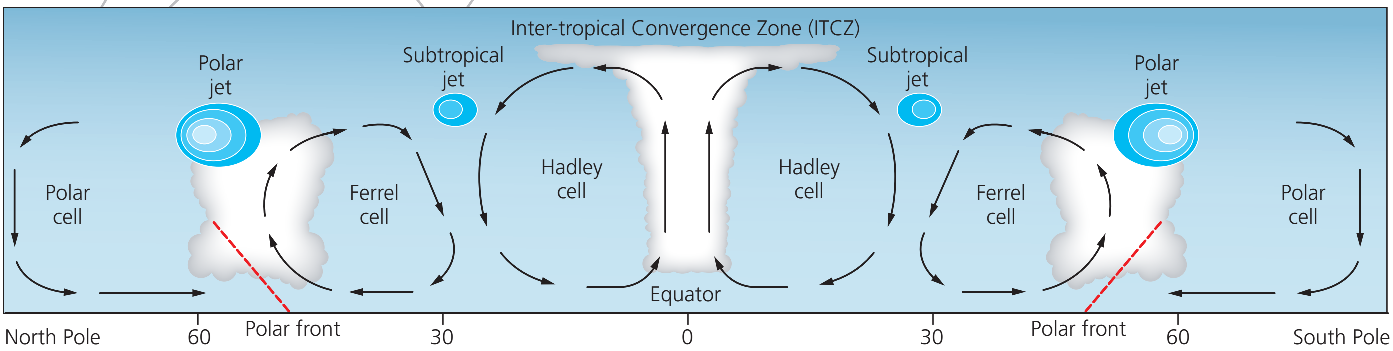


Figure 3.3 The three global convection cells and the position of the high-altitude jet streams

KEY LEARNING

- Tropical storms and why they occur
- Why tropical storms are distributed where they are
- How tropical storms relate to global atmospheric circulation

The global distribution of tropical storms

What are tropical storms?

Tropical storms are a natural hazard. A tropical storm occurs when tropical warm air rises to create an area of intense low pressure, much lower than the depressions experienced in the UK. As the warm, moist air reaches high altitudes, powerful winds spiral around the calm central point, creating the 'eye of the storm', and the warm air cools and condenses into heavy rainfall and thunderstorms.

Between 1995 and 2015, tropical storms killed the most people of all weather related disasters. Storms were also the weather-related hazard associated with the largest economic losses between 2015 and 2019. The devastation caused by tropical storms is clear to see in Figure 3.4.

What are tropical storms called?

Tropical storms have different names depending on the location in the world (see Figure 3.5). Their location is their only difference. They are known as:

- **hurricanes** in the Atlantic and Eastern Pacific Oceans (such as Hurricane Irma, 2017)
- **typhoons** in the west of the North Pacific Ocean (such as Typhoon Haiyan, 2013)
- **cyclones** in the Indian and South Pacific Oceans (such as Cyclone Idai, 2019).

Each tropical storm has its own unique international name. These names are predetermined by the World Meteorological Organization. They are alphabetical and alternate in gender. For example, the 2022 name list starts with Alex, Bonnie, Colin, Danielle, Earl, Fiona and so on. Tropical storms are more recognisable and engaging for the public when given names rather than co-ordinates. Names repeat every six years unless a large loss of life or cost in damage would make it insensitive to repeat them.

Figure 3.4 Destruction near Beira, Mozambique after Cyclone Idai in 2019

Why are tropical storms distributed where they are?

The 80–100 tropical storms that take place every year are caused by particular conditions. Tropical storms occur in the tropics (mainly where the intertropical convergence zone (ITCZ) lies) – broadly south of the Tropic of Cancer and north of the Tropic of Capricorn.

The distribution of tropical storms is dependent on a number of conditions.

- Low latitude areas, between 5° and 30° north and south of the Equator. Here, a higher insolation means temperatures are higher than at the poles (see Section 3.1).
- Sea temperatures above 27°C, at a depth of approximately 60–70 metres. This provides the heat and moisture that causes the warm air to rise rapidly in this low-pressure region. Latent heat is then released, which powers the tropical storm. The warmest seasons are between summer and autumn when it is most typical for tropical storms to develop. The seasons vary depending on their location (see Figure 3.5).
- A low wind shear (wind which remains constant and does not vary with height). This means the tropical storm clouds can rise to high levels without being torn apart.
- The Coriolis effect (see Section 3.3) is not strong enough along the Equator for tropical storms to spin.

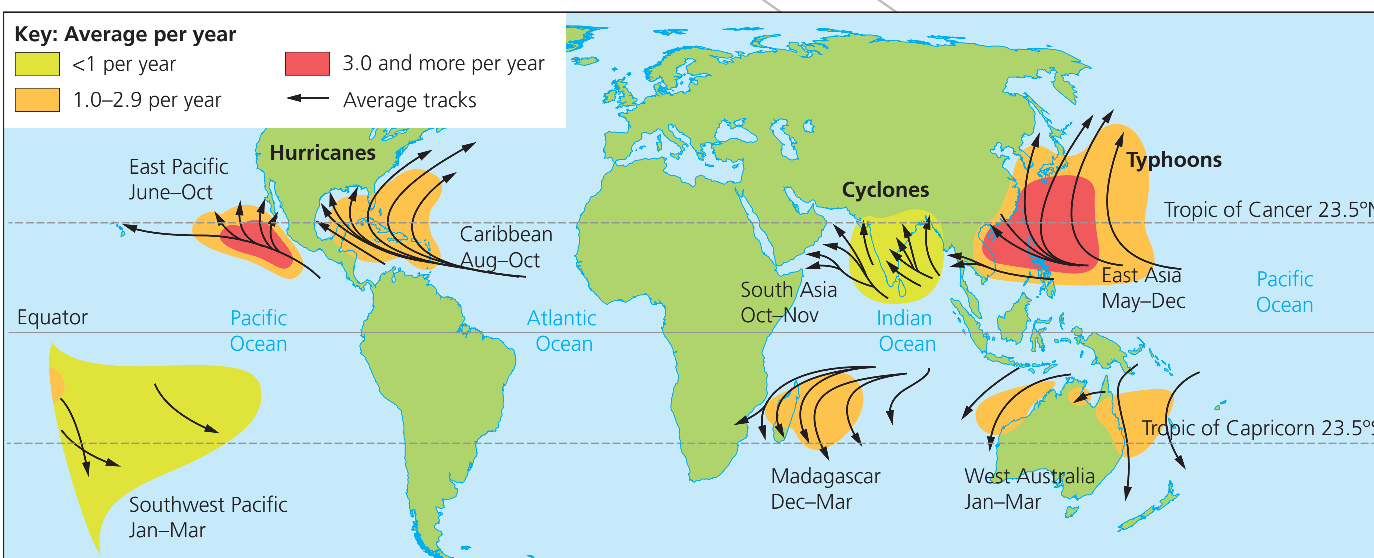


Figure 3.5 The global distribution of tropical storms

Activities

1. Define the term tropical storm.
2. Why is the tropical storm in Figure 3.4 called a cyclone? (Hint: find Vanuatu in an atlas.)
3. Describe the global pattern of tropical storms in Figure 3.5.
4. Explain why the following conditions are needed for a tropical storm to form:
   a) temperature above 27 °C
   b) not along the Equator
   c) low wind shear
   d) over the ocean.
5. Use Figure 3.5 to locate the regions where you would expect people to be most vulnerable to tropical storms.
6. Research a recent tropical storm. Identify evidence which demonstrates that tropical storms are natural hazards that pose risk of damage to property and life.

KEY LEARNING

- How tropical storms form
- The structure and features of tropical storms

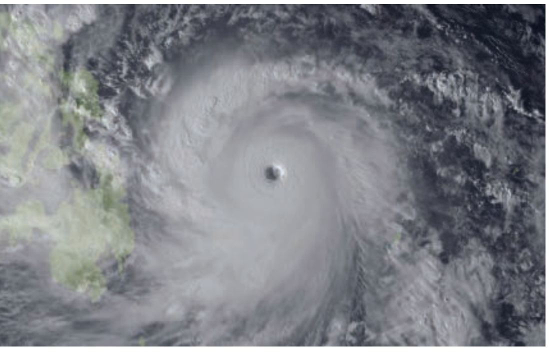


Figure 3.6 Satellite image of a tropical storm (Typhoon Haiyan, 2013)

In a spin

How does a tropical storm form?

Tropical storm formation follows a particular sequence:

1. Air is heated above the surface of warm tropical oceans. The warm air rises rapidly under the low-pressure conditions.
2. The rising air draws up more air and large volumes of moisture from the ocean, causing strong winds.
3. The **Coriolis effect** causes the air to spin upwards around a calm central eye of the storm.
4. As the air rises, it cools and condenses to form large, towering cumulonimbus clouds, which generate torrential rainfall. The heat given off when the air cools powers the tropical storm.
5. Cold air sinks in the eye, therefore there is no cloud, so it is drier and much calmer.
6. The tropical storm travels across the ocean in the **prevailing wind**.
7. When the tropical storm meets land it is no longer fuelled by the source of moisture and heat from the ocean, so it loses power and weakens.

A At the start of a tropical storm, the temperature and air pressure fall. Air rises and clouds begin to form. It becomes windy.	B As the tropical storm continues, the air pressure falls more rapidly, wind increases, cumulonimbus cloud forms and there is heavy rainfall.	C There is a period of calm with no wind or rain at the eye of the storm. The Sun appears, so it gets warmer. Air pressure is very low.	D Wind and heavy rainfall increase dramatically again, the temperature drops and air pressure begins to rise.	E As the tropical storm ends, the air pressure and temperature rise. Wind and rainfall subside.

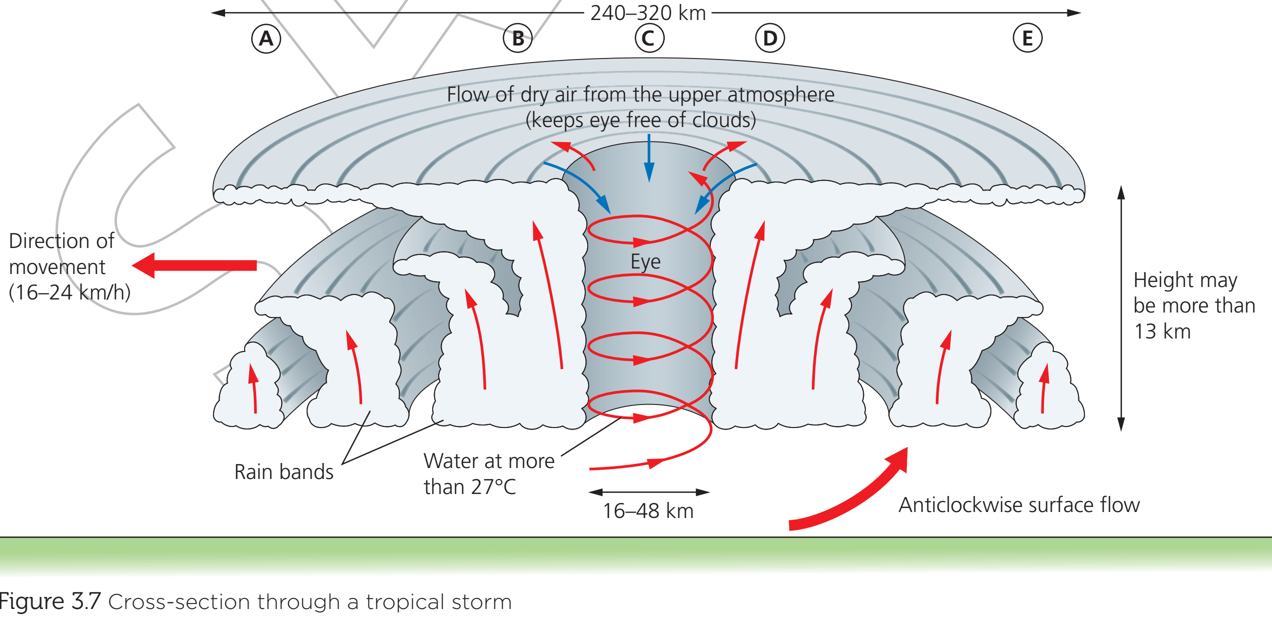


Figure 3.7 Cross-section through a tropical storm

What are the structure and features of a tropical storm?

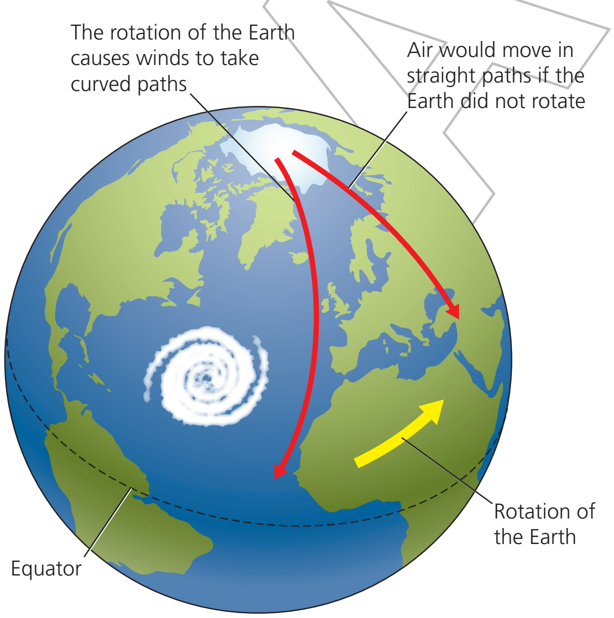
Figure 3.7 shows a cross-section of the structure of a tropical storm. The satellite image in Figure 3.6 shows the swirling wind and cloud around the central circular eye of the storm where there is no cloud.

Why does a tropical storm spin?

The Coriolis effect bends and spins the warm rising air. The spinning can be seen in satellite images (such as in Figure 3.6 on page 26). Hurricanes in the northern hemisphere bend to the right, which causes the clouds to swirl anticlockwise, whereas cyclones in the southern hemisphere swirl in a clockwise direction.

What direction do tropical storms travel?

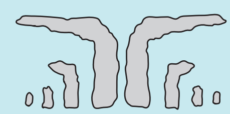
Tropical storms travel from east to west due to the direction in which the Earth spins. When they hit land, they lose the energy source from the sea that powered them. As they pass over land, friction also slows them down. As they lose energy they change direction. This exact direction and speed is unknown. However, tropical storms in the northern hemisphere track north and tropical storms in the southern hemisphere track south (Figure 3.5 on page 25). An average tropical storm has a lifespan of approximately one to two weeks.



▲ Figure 3.8 The Coriolis effect

➔ Activities

1 Draw a sequence of at least three diagrams, with captions, to show the formation of a tropical storm.
2 What is the eye of the storm?
3 Using the satellite image on page 26, state which hemisphere the tropical storm is in and how you reached your answer.
4 Sketch a larger version of the cross-section of a tropical storm in Figure 3.7. Annotate it with the sequence of weather conditions that would be experienced. (Include information about wind, rain, clouds, temperature and air pressure.)



5 Write a short paragraph to explain what causes tropical storms to spin.
6 What happens to a tropical storm when it reaches land? Explain why.

What is the Coriolis effect?

Winds blow from areas of high pressure to areas of low pressure. They do not blow in straight lines across the Earth but are affected by the Coriolis effect. As the Earth rotates it causes the wind to bend. This is because the Earth has a curvature, with the Equator far wider than the poles. Therefore the Earth has to spin faster at the Equator. This difference in speed means that wind bends as it blows across the Earth. This is known as the Coriolis effect.

KEY LEARNING

- How climate change might affect tropical storms

Climate change and tropical storms

How might climate change affect tropical storms?

Climate change (see Chapter 4) will alter the conditions that cause tropical storms to form.

Higher storm surges

As the temperature increases, sea levels will rise due to **thermal expansion**. The impact of rising sea levels will mean **storm surges** are expected to become higher.

Increased heavy rainfall

A warmer atmosphere will mean the air can hold more moisture so heavy rainfall is expected to increase. Historic amounts of rainfall of over 1524 millimetres were recorded in south-eastern Texas during Hurricane Harvey in 2017 (see Figure 3.10).

More destructive flooding

As heavy rainfall is expected to increase, this will mean there is likely to be increased flooding during tropical storms, which will be more destructive.

The number and intensity of tropical storms varies greatly from year to year. This makes it more challenging for scientists to detect trends in the future frequency and intensity of tropical storms due to climate change. Since the 1970s, satellite technology has made it possible to track tropical storm frequency and intensity more consistently. Longer-term trends are more complicated, although scientists use hurricane models to project future trends.

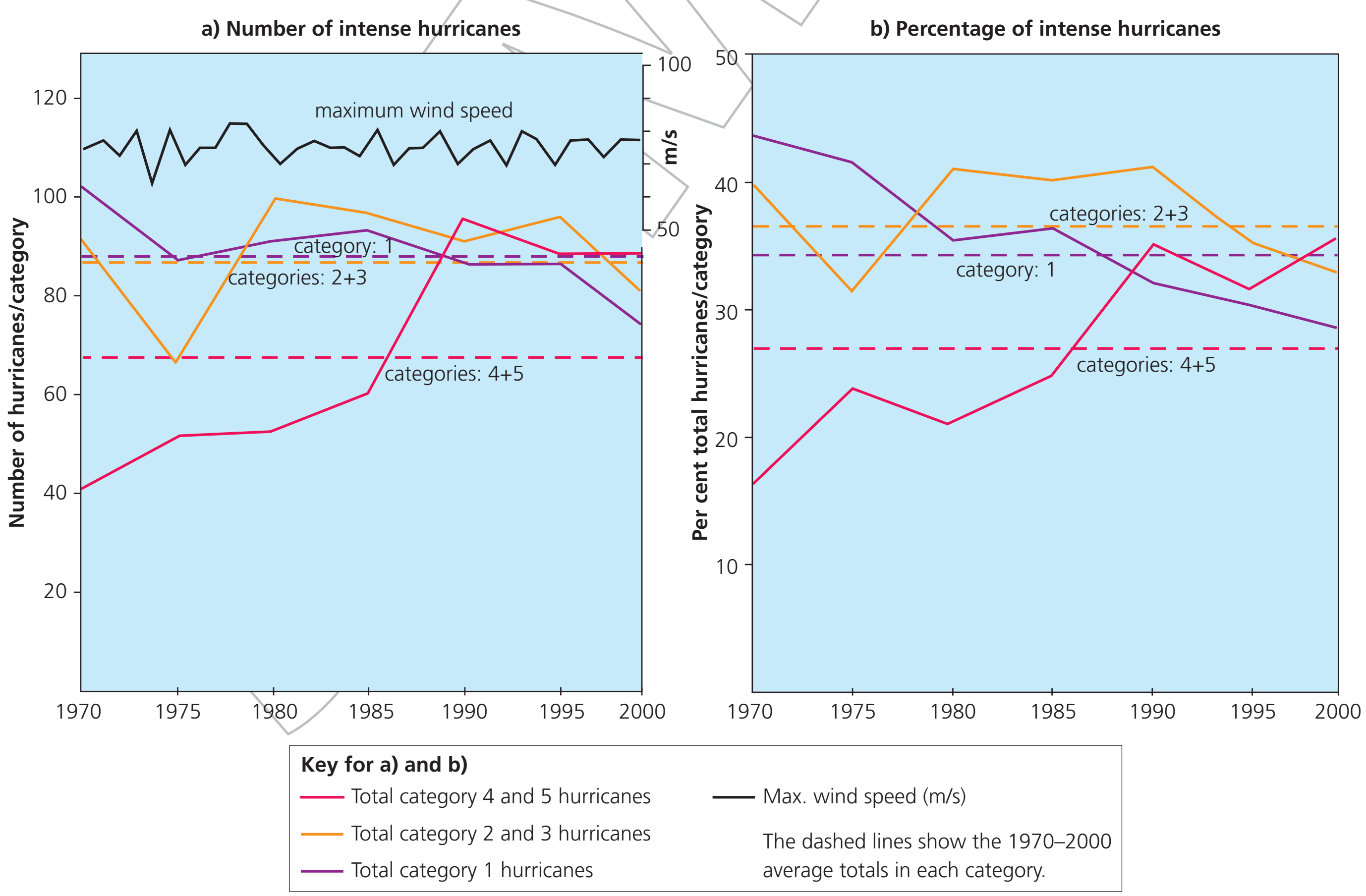


Figure 3.9 The number, and percentage, of intense hurricanes according to the Saffir-Simpson scale (categories 1 to 5)

Intensity

The impact of climate change on tropical storms is unknown. However, there is evidence of a link between warmer oceans and the intensity (destructive power) of tropical storms. The strength of tropical storms is classified using the Saffir-Simpson hurricane wind scale. Category 5 is the most intense and 1 the least intense (see Figure 3.11 on page 31).

Tropical storms are expected to become more intense, by 2–11 per cent, by 2100. The number of the most severe category 4 or 5 tropical storms (see Section 3.5) has increased since the 1970s (Figure 3.9). Predictions suggest that every 1°C increase in tropical sea surface temperatures will mean a 3–5 per cent increase in wind speed.

Frequency and distribution

Scientists are uncertain whether climate change will lead to an increase in tropical storms. They mostly agree that the overall frequency of tropical storms is expected to either remain the same, or decrease, as a result of climate change – although the number of more severe tropical storms (categories 4 and 5) will probably increase, while category 1–3 storms will decrease (see Figure 3.9). The regions where tropical storms are experienced are not expected to change significantly as a result of climate change.

Uncertainty

The reasons for all this uncertainty is due to:

- Inaccurate data: wind speed monitoring has only become more accurate in recent decades, so the use of previous data – which is less accurate – to decide how tropical storms are affected by climate change is questionable.
- Unreliable predictions: predicting the impact of climate change is unreliable, as the rate of and impact of climate change in the future is uncertain.
- Other impacts: potential risk to life and property has already increased due to population growth and building in coastal locations, even without factoring in climate change.

➜ Activities

1 What conditions will climate change affect that cause tropical storms to form?
2 Is climate change expected to affect:
   a) the intensity of tropical storms?
   b) the frequency of tropical storms?
   c) the distribution of tropical storms?

   In each case, explain why.
3 Explain how climate change may make the impact of tropical storms worse.
4 What makes the link between climate change and tropical storms uncertain?
5 Using Figure 3.10, suggest how increased rainfall would make tropical storms more destructive.

▲ Figure 3.10 Marines transporting supplies in the Hurricane Harvey relief effort

KEY LEARNING

- The primary and secondary effects of a tropical storm
- The immediate and long-term responses
- How tropical storms are measured

The effects of and responses to tropical storms

What are the effects of a tropical storm?

Tropical storms have significant effects on people and environments. The impacts of a tropical storm are strong winds, torrential rainfall and storm surges (when the sea level rises rapidly and particularly high due to the storm). Landslides and tornadoes can also be caused by tropical storms.

Primary effects

Wind speeds are at least 119 kilometres per hour. As a direct result of the tropical storm, the winds can demolish houses across whole towns and villages, destroy infrastructure, such as electricity power lines, and wipe out crops. The amount of destruction will depend on the storm's strength and how well people and property are protected.

Flooding is caused by the heavy rain and storm surges. Storm surges can be up to five metres and are driven by the wind pushing seawater onto the coastline. Heavy rainfall can be up to 500 millimetres falling within 24 hours. The cause of death for the majority of victims is due to flooding, which can be made worse when aid is hampered if roads are flooded.

Secondary effects

Some effects of tropical storms occur later and indirectly as a result of the tropical storm itself. Torrential rain can also trigger landslides, causing further devastation. Furthermore, water supplies can be contaminated with seawater, sewage and industrial waste, which increases the risk of waterborne diseases such as cholera.

What are the responses to a tropical storm?

Immediate responses

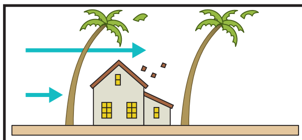
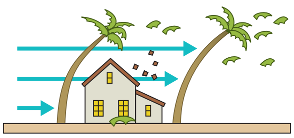
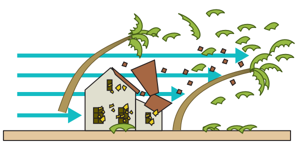
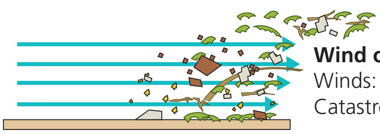
As tropical storms can generally be predicted, warning systems provide crucial information regarding strong winds, heavy rain and storm surges, which are broadcast to the public. This allows vital time to prepare and protect property (see Section 3.7).

A common immediate response for predicted disasters is evacuation, to higher ground (away from the potential impact of storm surges) or even to emergency storm shelters. Shelter provided by public buildings, or tents provided by **international aid**, are also necessary where homes are extensively damaged or even destroyed.

Distributing emergency food and water is essential for survivors in the aftermath of a tropical storm. High-income countries (HICs) are more likely to have the resources available to do this, though during large-scale disasters international help is often necessary and welcomed. Aid may be hindered if roads have become blocked by debris or fallen trees, or flooded. Equally, if there is large-scale devastation, it can take longer for aid to reach where it is needed, especially in more remote locations.

Long-term responses

Governments, **nongovernmental organisations (NGOs)** and charities aim for **sustainable development** after the initial relief effort has saved lives. Projects range from repairing damage to existing buildings, infrastructure and businesses, to ensuring the country is capable of managing a future hazard by investing in methods of protection and prediction of tropical storms, such as a new early-warning system for storm surges or new sea defences. The speed to start and complete long-term responses will depend on how much destruction was caused, the wealth of the country to pay for the work, and the help available from other countries, organisations and charities.

	**Wind category 1** Winds: 119–153 km/h 74–95 m/h Very dangerous winds will produce some damage	Well-constructed frame homes could have some damage to the roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles will likely result in power outages that could last a few to several days.
	**Wind category 2** Winds: 154–177 km/h 96–110 m/h Extremely dangerous winds will cause extensive damage	Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
	**Wind category 3** Winds: 178–208 km/h 111–129 m/h Devastating damage will occur	Well-built frame homes will incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
	**Wind category 4** Winds: 209–251 km/h 130–156 m/h Catastrophic damage will occur	Well-built frame homes can sustain severe damage, with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Most of the area will be uninhabitable for weeks or months.
	**Wind category 5** Winds: 252 km/h 157 m/h or higher Catastrophic damage will occur	A high percentage of frame homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to months. Most of the area will be uninhabitable for weeks to months.

▲ Figure 3.11 Saffir–Simpson hurricane wind scale

How are tropical storms measured?

Tropical storms are measured using the Saffir–Simpson hurricane wind scale (Figure 3.11). This scale was updated in 2012 and is now based on wind speed, which is considered easier to understand. (Previously, storm surge, flooding impact and central pressure were included, but surges and flooding are influenced too much by local conditions.) The higher the category scale, the higher the intensity of the tropical storm.

➜ Activities

1. Define primary and secondary effects.
2. List three ways tropical storms affect (a) people, (b) the environment and (c) the economy.
3. Describe the scale used to measure tropical storms.
4. Distinguish between immediate and long-term responses.
5. Suggest why food, clothes and water are needed following a tropical storm.
6. Explain why emergency aid can be slow to arrive after a tropical storm.
7. Why are both immediate and long-term responses necessary? Explain your answer.
8. Suggest three reasons why some tropical storms could cause more damage than others.
9. How would you expect the responses to be different in an HIC from those in an LIC?

Example

KEY LEARNING

- Primary and secondary effects of a typhoon
- The immediate and long-term responses

In numbers

- 6,190 people died
- 14.1 million people affected, of which 4.8 million already lived in poverty
- US$12 billion overall damage
- Over 1 million farmers and 600,000 hectares of agricultural land affected
- 1.1 million tonnes of crops destroyed
- 1.1 million houses damaged
- 4.1 million people homeless

The trouble with Typhoon Haiyan

What were the primary effects?

On 8 November 2013 at 4.40 a.m. local time, a category 5 typhoon struck the Philippines. Typhoon Haiyan, also known as Typhoon Yolanda, originated in the northwest Pacific Ocean. It was incredibly powerful, with recorded wind speeds of up to 314 kilometres per hour.

The strong winds battered people's homes and even the evacuation centre. Those made homeless were mainly in the Western and Eastern Visayas. Power was interrupted, the airport was badly damaged and roads were blocked by trees and debris. Leyte and Tacloban had a five-metre storm surge, and 400 millimetres of heavy rainfall flooded one kilometre inland. Ninety per cent of the city of Tacloban was destroyed (Figure 3.14).

Coconut, rice and sugarcane production made up 12.7 per cent of the Philippines' GDP before the typhoon. The harvest season had just ended before it struck, but rice and seed stocks were lost in the storm surges. The damage to rice cost US$53 million and 75 per cent of farmers and fishers lost their income. The UN totalled the recovery costs for agriculture and fishing at US$724 million.

What were the secondary effects?

An oil barge ran aground at Estancia, causing an 800,000 litre oil leak. Most of this washed ashore, contaminating 10 hectares of mangroves (see Figure 3.17, page 35). Looting was rife as survivors fought for food and supplies. Eight deaths were reported in a stampede for rice supplies. By 2014, rice prices had risen by 11.9 per cent.

The flooding caused surface and groundwater to be contaminated with seawater, chemicals from industry and agriculture, and sewage systems.

Figure 3.12 Tracking co-ordinates of Typhoon Haiyan

Date	Time	Lat.	Long.	Wind (mph)
05/11	00:00	6°N	146°E	75
05/11	12:00	7°N	143°E	105
06/11	00:00	7°N	140°E	150
06/11	12:00	8°N	136°E	160
07/11	00:00	9°N	133°E	175
07/11	12:00	10°N	129°E	190
08/11	00:00	11°N	125°E	185
08/11	12:00	12°N	121°E	155
09/11	00:00	12°N	116°E	135
09/11	12:00	15°N	113°E	115
10/11	00:00	16°N	110°E	100
10/11	12:00	19°N	108°E	85
11/11	00:00	22°N	107°E	70

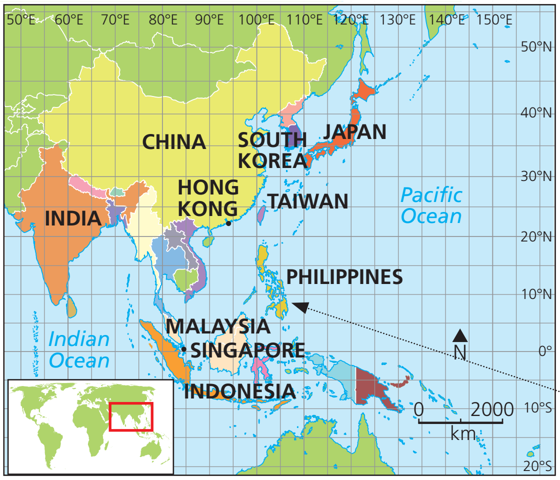


Figure 3.13 Location map of the Philippines

This meant fishing had to stop in Estancia. The likelihood of infectious diseases spreading increased.

What were the immediate responses?

The president televised a warning. The authorities evacuated 800,000 people. Many sought refuge in an indoor stadium in Tacloban. Although this had a reinforced roof, they died when it was flooded. The government sent out essential equipment and medical supplies. In one region these supplies were washed away.

Emergency aid supplies arrived three days later by plane once the main airport reopened. It was a week before power was fully or partially restored. Within two weeks, over 1 million food packs and 250,000 litres of water were distributed. A curfew was imposed two days after the typhoon to reduce looting.

Thirty-three countries and international organisations pledged help and sent rescue operations. Celebrities, such as the Beckhams, and large multinational organisations, such as Coca-Cola, Walmart, Apple and FIFA, donated and used their influence to raise awareness and encourage public donations. Over US$1.5 billion was pledged in foreign aid.

What were the long-term responses?

In July 2014, the Philippine government declared it was working towards long-term recovery, 'building back better' so that buildings would not just be rebuilt, but upgraded and therefore future-proof. The government also has:

- a 'no build zone' along the coast in Eastern Visayas, which was later changed to a 'no dwelling zone' so commercial buildings can be built
- a new storm-surge warning system
- replanted mangroves
- plans to build the Tacloban-Palo-Tanauan Road Dike.

Restoring previous livelihoods has been hard, especially for farmers and fishers. It is expected to take 5–10 years for new coconut trees to grow and bear fruit. Rebuilding permanent homes was also slow, with 100,000 families still in temporary accommodation in 2015.

Figure 3.14 Tacloban city after Typhoon Haiyan, 2013

Activities

1 Study Figure 3.14. What evidence is there of (a) strong winds, (b) torrential rainfall and (c) storm surges?
2 Describe the following effects of the typhoon: (a) social (b) environmental (c) economic.
3 Suggest reasons why Typhoon Haiyan was so destructive.
4 Do you think people in the Philippines were prepared for the typhoon? Explain your answer.

Geographical skills

1 Use Figure 3.12 to:
   a) Plot the path of Typhoon Haiyan on a map using the latitude and longitude co-ordinates.
   b) Label the countries and islands Typhoon Haiyan passed through on your map. Give your map a suitable title.
   c) Draw a line graph to show the speed of wind over the duration of the typhoon.
   d) State a reason why a line graph is more suitable than a bar graph.

KEY LEARNING

- How tropical storms are monitored
- How tropical storms are predicted
- How people and property can be protected
- How risks can be reduced through planning

Reducing the effects of tropical storms

How are tropical storms monitored?

Monitoring tropical storms allows predictions to be made which can save lives and reduce damage. The following explains some of the ways in which they are monitored.

Satellites

There is a classic cloud pattern associated with tropical storms that satellites monitor. In 1997, it was accidentally discovered that the appearance of rainclouds which reach approximately 16 kilometres in altitude are more likely to indicate that a tropical storm will intensify within 24 hours. Seven years later, the Global Precipitation Measurement satellite was launched. It monitors precipitation every three hours between latitudes 65° north and south of the Equator to identify the high-altitude rainclouds.

Aircraft

A plane first flew purposely into a hurricane in 1943 to make observations. Now, specially equipped aircraft frequently fly through tropical storms at 10,000 feet to collect air pressure, rainfall and wind speed data. They release dropsondes (sensors) which send measurements every second, by radio, back to the aircraft.

The US National Aeronautics and Space Administration (NASA) monitors weather patterns across the Atlantic using two unmanned aircraft called Global Hawk drones. On-board radar and microwaves help scientists to understand more about the formation of tropical storms to improve forecasting models.

Figure 3.15 Global Hawk drone

Can tropical storms be predicted?

All available weather data are fed into supercomputers which run models to predict the path and intensity of tropical storms. In the following cases, this has had some success:

- In 2013, the National Oceanic and Atmospheric Administration (NOAA) developed two new supercomputers. In 1992, the location of a tropical storm, predicted with three days' warning, could be wrong by 480 kilometres. Supercomputers can now give five days' warning and a more accurate location within 400 kilometres.
- The National Hurricane Centre in Florida predicts a tropical storm's path and intensity for up to seven days using a 'track cone' (Figure 3.16). The cone shape allows for error with the unpredictable behaviour of the tropical storm, especially when it hits land. Around 70 per cent of tropical storms occur within the predicted cone.
- In 2013, Cyclone Phailin in India was successfully predicted. As many as 1.2 million people were evacuated. Twenty-one people died. A further 23 died in **flash flooding** after. Yet in 1999, a similar cyclone hit the same area and more than 10,000 lives were lost.
- National Hurricane Centres around the world issue early warnings so people have time to prepare to evacuate – but some may not bother. Additionally, evacuation is costly and time-consuming, particularly if the path of the tropical storm does not actually pass the area in which they live.

Is protection possible?

Buildings have areas of weakness which can be reinforced to reduce damage caused by the forceful winds of tropical storms. This is called mitigation (see Chapter 4, Section 4.5). In the USA, the Federal

Emergency Management Agency (FEMA) advises homeowners to:

- install hurricane straps (galvanised metal) between the roof and walls
- install storm shutters on windows
- install an emergency generator
- tie down windborne objects such as garden furniture
- reinforce garage doors
- remove trees close to buildings.

With the fierce storm surges and flooding that occur in tropical storms, salt marshes, wetlands and mangroves can protect against storm surges by reducing the waves' energy. Additionally, trees reduce wind energy and trap debris, which can cause damage – although trees can cause devastation too, if uprooted near buildings and infrastructure. Another way to protect land is to ensure that low-lying areas are not built on. Coastal flood defences (Chapter 10) such as **levées** and flood walls reduce the impact of storm surges as they hold back the seawater.

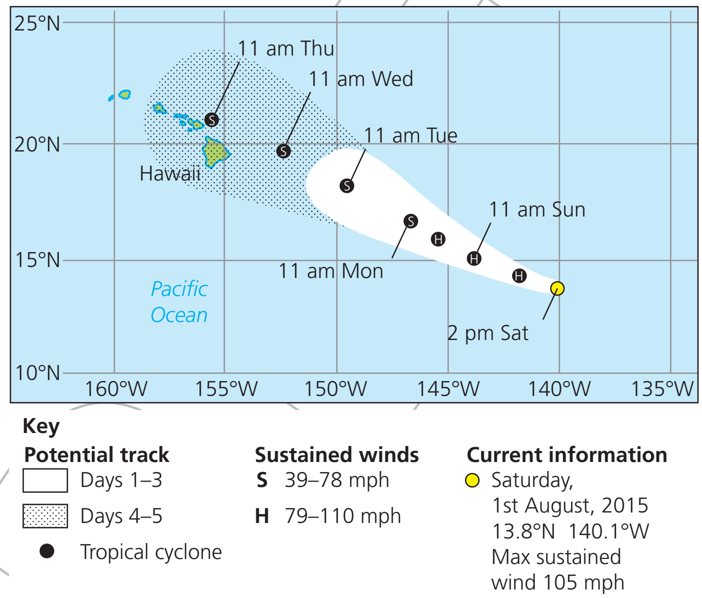


Figure 3.16 Hurricane Guillermo track forecast cone

How can planning reduce risks?

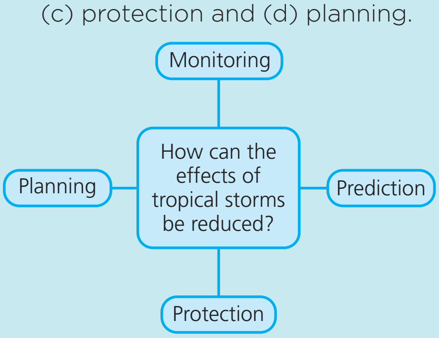
American National Hurricane Preparedness Week in May aims to encourage people to plan what they need to have and do in the event of a tropical storm. Advice includes:

- preparing disaster supply kits
- having fuel in vehicles
- knowing where official evacuation shelters are
- storing loose objects
- planning with family what to do.

Figure 3.17 Mangroves on the coast can protect against storm surges

Activities

1 Complete this spider diagram to show how the effects of a tropical storm can be reduced. List the different types of (a) monitoring, (b) prediction, (c) protection and (d) planning.



2 Describe how the Global Hawk drone (Figure 3.15) helps to monitor tropical storms.

3 How might track forecast cones such as the one in Figure 3.16 be (a) of benefit to citizens, (b) to the detriment of citizens?

4 Do you think all countries can plan for tropical storms? Explain your answer.

5 Study Figure 3.16.

a) Give the latitude and longitude co-ordinates that Hurricane Guillermo was expected to be on Thursday 6 August at 11 a.m.

b) Describe the track of Hurricane Guillermo.