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Rebecca Kitchen , David Payne , Alison Rae , Emma Rawlings Smith , John Rutter , Helen Young , John Pallister , Edited by David Payne
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1 Tectonic hazards

In this chapter you will learn about...

- the global distribution of earthquakes and volcanoes
- how the movement of plates leads to earthquakes and volcanic eruptions
- the benefits of living in tectonically active areas
- the primary and secondary effects of earthquakes and volcanic eruptions
- how people respond to tectonic activity
- how the effects of and responses to earthquakes vary between areas of contrasting levels of wealth.

1.1 What is the Earth made of?

The Earth is made up of several layers (Figure 1.1). The top layer, called the **crust**, is between 5 km and 90 km in thickness. Underneath this is the **mantle**, a mass of hotter material which includes **magma**. This becomes denser towards the centre of the Earth, which is called the **core** and is so dense it is like solid rock.

Key terms

crust: the outermost layer of the Earth

mantle: a layer of rock between the core and crust made of molten rock

magma: heat from the Earth's core is hot enough to melt rock in the mantle; this molten (liquid) rock is called magma

core: dense hot rock at the centre of the Earth

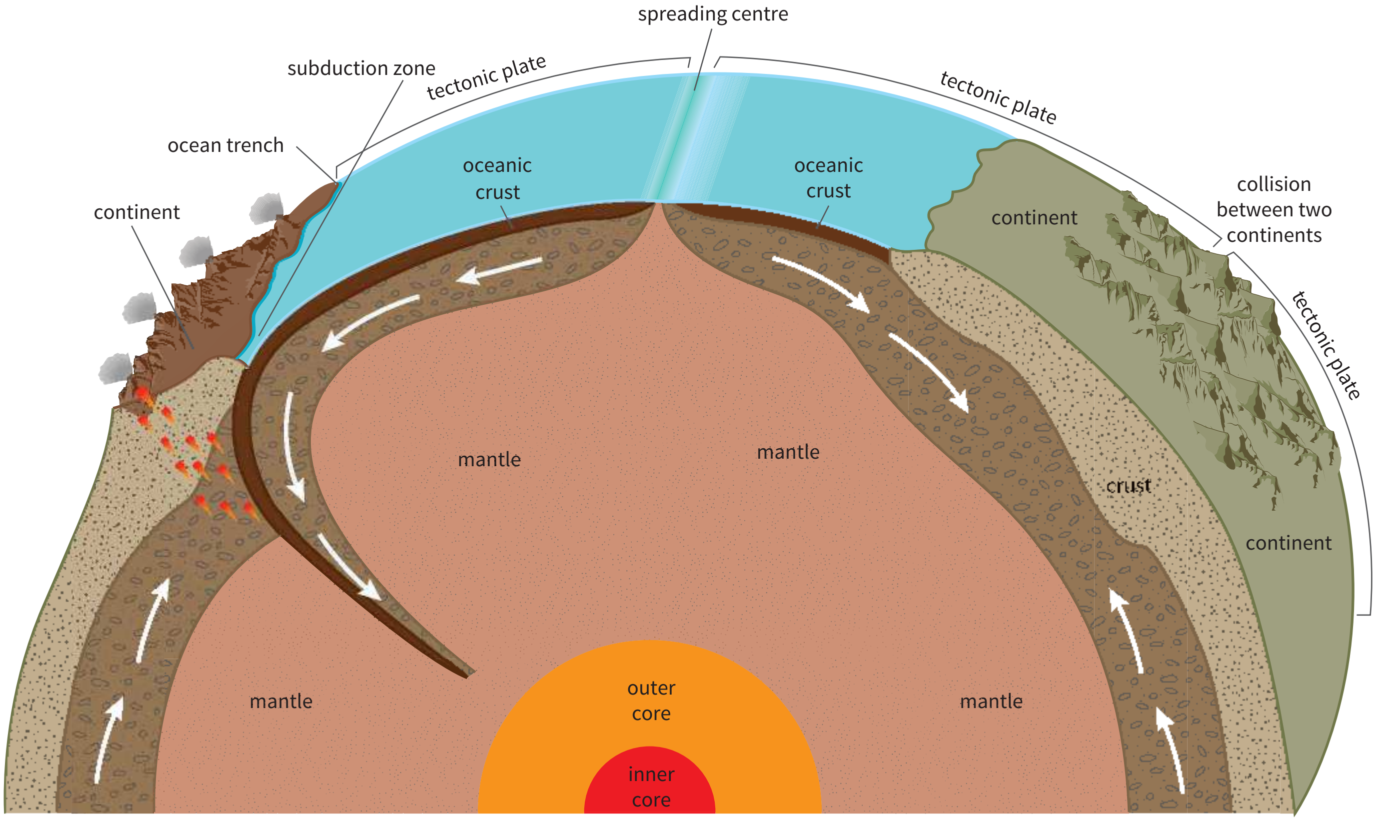

Figure 1.1 The structure of the Earth.

Plate tectonic theory has shown that the Earth's crust is not a solid mass but is split into smaller crustal plates which 'float' on the semi-molten upper mantle. There are two types of crustal plate: continental crust and oceanic crust (Table 1.1). The places where the plates meet are called **plate margins**. In these areas the Earth is particularly unstable and **tectonic hazards** (earthquakes and volcanic activity) are common.

	Continental crust	Oceanic crust
Thickness (km)	30–90	5–10
Oldest rock (years)	4 billion	200 million
Main rock type	granite	basalt

Table 1.1 Characteristics of continental and oceanic crust.

Scientists once believed that **convection currents** in the mantle, generated by high temperatures, were the main force driving the movement of tectonic plates. It is now thought that **tectonic plate** movement is driven by the weight of denser, heavier tectonic plates sinking into the mantle at ocean trenches. This drags the rest of the plate with it and is called **slab pull theory**. In some places the plates are moving towards each other and the Earth's crust is being destroyed. In other places the plates are moving apart and new crust is being created (Figure 1.2).

Key terms

plate margins: the place where tectonic plates meet and the Earth is particularly unstable

tectonic hazards: natural hazards caused by movement of tectonic plates (including volcanoes and earthquakes)

convection currents: circular movements of heat in the mantle; generated by radioactive decay in the core

tectonic plate: a rigid segment of the Earth's crust which floats on the heavier, semi-molten rock below

slab pull theory: a theory that outlines how large and dense tectonic plates sinking into the mantle at ocean trenches drives tectonic plate movement.

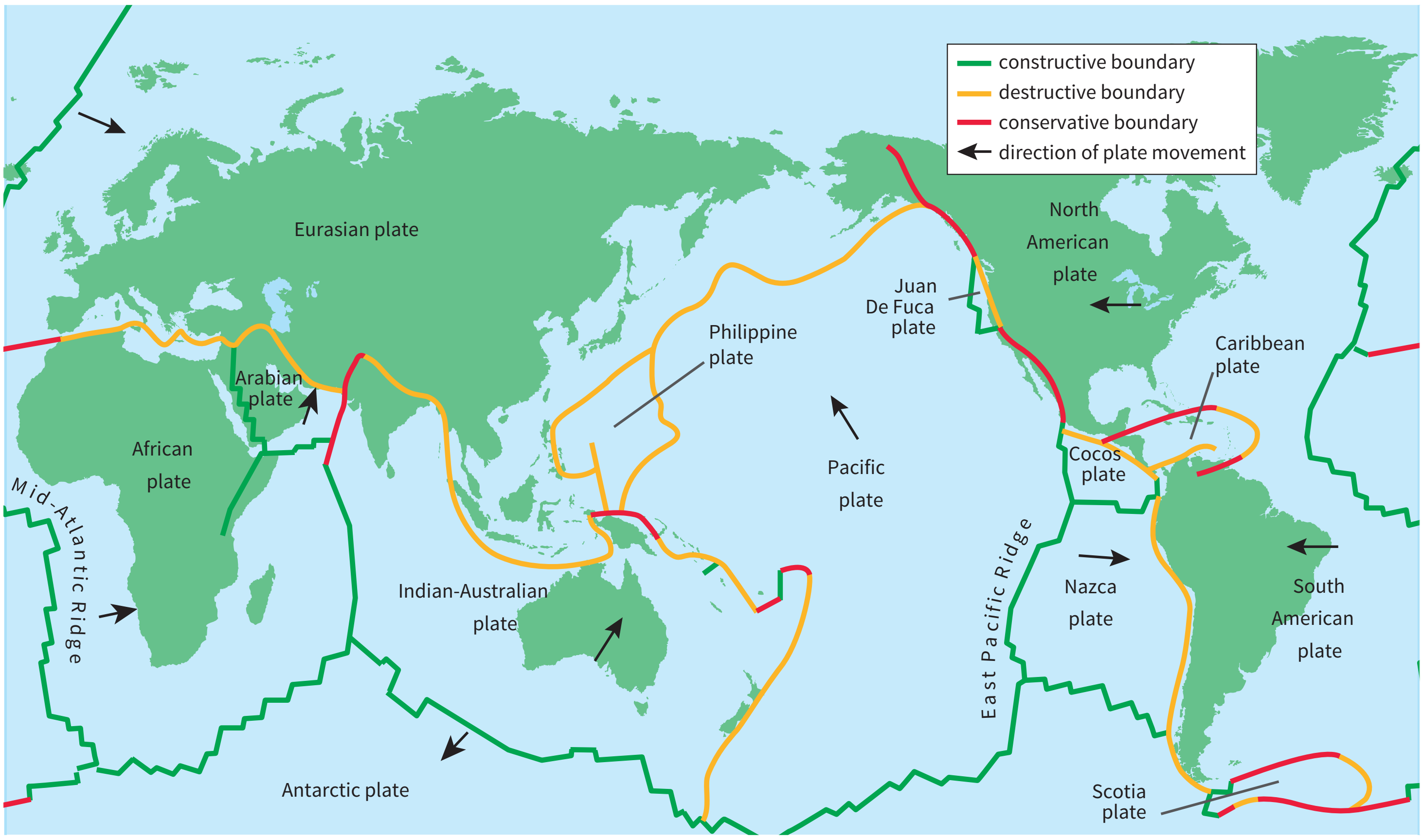

Figure 1.2 The Earth's major plates and plate margins.

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1.2 What are the different types of plate margins and their resulting landforms?

Destructive plate margins

Destructive plate margins occur where two plates move towards each other (converge). This happens at **subduction** and collision zones.

Subduction zones

Where an oceanic plate converges with a continental plate, the denser oceanic plate is forced under the lighter continental plate and sinks into the mantle; a process known as subduction. This creates a deep ocean trench on the edge of the continental plate. Where plates subduct, heat in the mantle melts the crust to form magma. Magma rises to the Earth's surface because it is hotter and less dense than the surrounding rock. Close to the surface, the pressure decreases and gases dissolved in the magma build up to eventually form volcanoes that erupt violently (Figure 1.3).

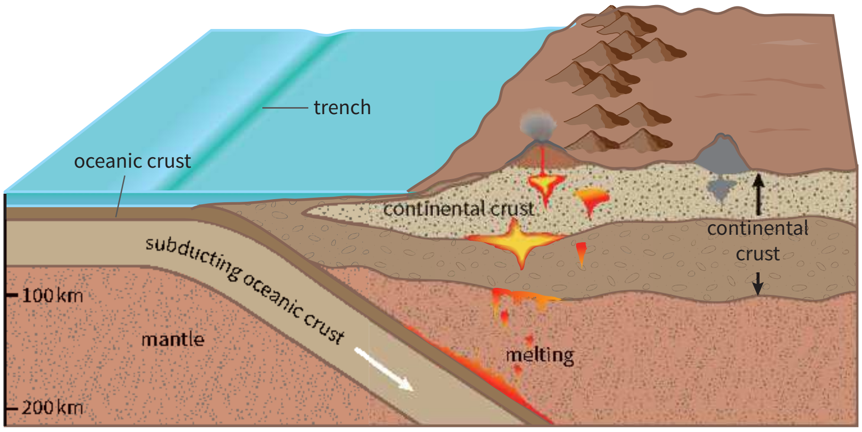

Figure 1.3 A destructive plate margin.

Collision zones

Where two continental plates collide they push the Earth's crust upwards forming fold mountains. The Himalayas are being created by continental plates carrying India colliding with the Eurasian plate.

Where two oceanic plates converge, subduction of the cooler, denser plate results in volcanic eruptions that form a chain of volcanic islands, known as island arcs. The Mariana Islands in the western Pacific Ocean were formed as a result of the Pacific plate being forced under the Mariana plate.

Constructive plate margins

Constructive plate margins occur where two plates move away from each other (diverge). Where two oceanic plates diverge, the crust fractures. Initially, magma rises from the mantle and creates new sea floor along the mid-oceanic ridge. This process is known as sea-floor spreading. As more magma rises, submarine (underwater) volcanoes form, and if they grow enough, they can rise above sea-level to form volcanic islands (Figure 1.4). The islands of Iceland and Saint Helena are both formed by volcanic on the Mid-Atlantic Ridge.

Rift valleys

Where two continental plates are moving apart a rift valley can form. Rift valleys are relatively narrow compared to their length, with steep sides and a flat floor.

Key term

subduction: the process by which one tectonic plate moves under another tectonic plate and sinks into the mantle

Discussion point

The theory of plate tectonics introduced by Alfred Wegener suggests that North and South America once fitted together with Europe and Africa – what evidence supports this theory?

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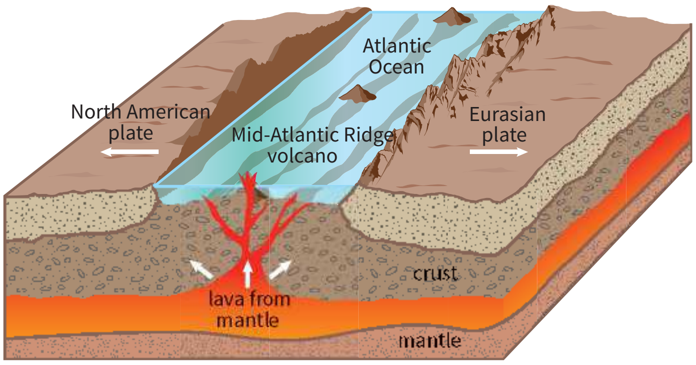

Figure 1.4 A constructive plate margin.

As the sides of a rift valley move farther apart, the floor of the valley sinks lower. Millions of years ago, Africa was attached to the Arabian Peninsula. The African plate moved away from the Arabian plates and the rift valley was flooded by the Indian Ocean, creating the Red Sea (Figure 1.5).

Figure 1.5 Satellite image of the Red Sea.

Conservative plate margins

Conservative plate margins occur where two plates move past each other in opposite directions or they move in the same direction at different speeds. The movement of plates is not always smooth and sometimes plates stick together and pressure builds up over time. The eventual release of this pressure results in earthquakes. In California, USA, the cities of San Francisco and Los Angeles, are located on or near the San Andreas fault (part of a conservative plate margin), and consequently prone to earthquakes. There is no volcanic activity at conservative plate margins as the crust is not being created or destroyed.

ACTIVITY 1.1

1 Define the terms:
   a subduction zone
   b sea-floor spreading
2 Study Figure 1.1.
   a Draw a cross-section through the Earth and label each layer.
   b On your cross-section, add a definition for each layer.
3 Study Table 1.1.
   a How does continental crust differ from oceanic crust?
   b Why is continental crust much older than oceanic crust?
4 a Explain how convection currents cause plate movement.
   b Draw a simple annotated diagram to explain how volcanoes are formed at destructive plate margins.
5 Study Figure 1.2.
   a Name five areas in the world where tectonic activity is common.
   c Name five areas where tectonic activity is uncommon.

Use the resources on the **National Geographic website** to find out more about plate tectonics (www.cambridge.org/links/gase40001)

Download Worksheet 1.1 from Cambridge Elevate for additional questions.

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1.3 Why is volcanic activity found near plate margins?

There are more than 500 active volcanoes in the world and more than half of these encircle the Pacific Ocean. Volcanic eruptions occur where molten rock and ash erupts from inside the Earth. Most volcanic activity occurs near plate margins where the Earth's crust is unstable. However, in places where the Earth's crust is thin magma can reach the surface. These places are known as volcanic hotspots, for example the lava flows in Hawaii (Figure 1.6).

An inactive volcano is said to be **dormant**. If it has not erupted in the last 10 000 years, it is thought to be **extinct**. Evidence of past volcanic activity can be seen in the form of hot springs and geysers where underground water is superheated by the hot rocks close to the Earth's surface.

Volcanoes are closely associated with disturbed crust found at constructive and destructive plate margins (Figure 1.7). Around 80 per cent of the world's active volcanoes are composite volcanoes (Figure 1.8) which occur along destructive plate margins. The longest of these is known as the Pacific 'Ring of Fire' and marks the location where the Pacific plate is subducted under several continental plates including the Eurasian and North American plates. Shield volcanoes occur along constructive plate margins (Figure 1.9).

Figure 1.6 Lava flow in Hawaii.

Key terms

dormant: has not erupted in living memory, but it could become active in the future

extinct: has not erupted in historic times, in the last 10 000 years

Figure 1.7 The global distribution of active volcanoes.

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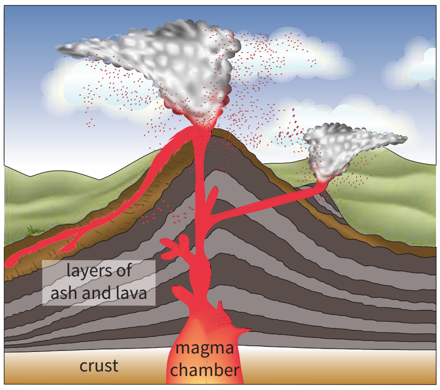
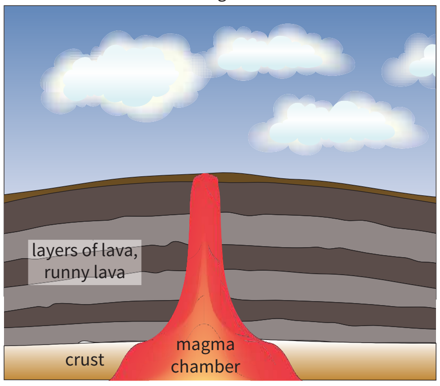
Volcano shape	composite volcano	shield or basic volcano
Form of volcano	steep slopes tall cone with narrow base made of alternative layers of lava and ash	gentle slopes low cone with wide flanks made of numerous lava flows
Cross-section of volcano	**Composite volcano** – layers of ash and lava, viscous lava travels short distances  Figure 1.8 The characteristic features of a composite volcano.	**Shield volcano** – layers of lava, runny lava travels long distances  Figure 1.9 The characteristic features of a shield volcano.
Lava	volcanic gases do not escape the lava easily viscous, less hot and slow flowing flows for short distances violent, infrequent eruptions	volcanic gases remain dissolved in the lava low viscosity – hot and runny flows over long distances mild, frequent eruptions
Formation	Where the plates collide at a destructive margin, the cooler, denser plate is subducted into the mantle. Heat melts the plate and generates magma. Being less dense than the surrounding rock, the viscous magma forces its way to the Earth's surface and erupts violently.	Where the plates diverge at a constructive margin, the crust fractures and magma rises to the surface. This adds new crust to the sea floor and submarine volcanoes form. Some volcanoes grow tall enough to rise above sea-level and form volcanic islands.
Examples	Krakatoa in Indonesia Mount St Helens, USA (Figure 1.10)	Mauna Loa in Hawaii Heimaey in Iceland

Table 1.2 Comparing composite and shield volcanoes.

Figure 1.10 Mount St Helens, after it erupted on 18 May 1980.

Skills link

Locating plate margins, volcanoes and earthquakes on a map is an important geographical skill. You can develop this skill by mapping all the named locations in this chapter on a world map.

Did you know?

Scientists now believe that the mantle contains more water than all the oceans combined.

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1.4 Volcanic hazards

Volcanic eruptions are hazardous. Volcanic bombs, pyroclastic flows, ash and gas clouds can all kill people when volcanoes erupt suddenly. As the time between eruptions can be long, many people can live safely near volcanoes, never experiencing any of the hazards shown in Table 1.3.

Volcanic eruptions have primary and secondary hazards. **Primary hazards** are directly caused by the volcano while **secondary hazards** are caused indirectly, as a result of the primary hazards.

Primary hazards	Secondary hazards
Volcanic bombs: solid lumps of lava which fly through the air; some can be the size of a house (Figure 1.11)	**Lahars:** volcanic mud flows which travel along river valleys (Figure 1.13)
Pyroclastic flows: very hot (around 800 °C) flows of gas and ash reaching speeds of 700 km/h (Figure 1.12)	**Glacier bursts:** large floods caused by the melting of ice beneath a glacier
Lava flows: streams of molten rock which slow as they cool	**Landslides:** rock and earth which tumble down a slope, triggered by tectonic activity
Ash falls (<2 mm in size): small erupted material which can travel long distances	**Tsunamis:** giant sea waves generated by undersea volcanoes (Figure 1.14)
Gas clouds (including carbon dioxide, hydrogen sulphide and sulphur dioxide) can suffocate people	**Climate change:** volcanoes send ash into the atmosphere. This reflects radiation from the Sun back to space, causing cooling

Table 1.3 Primary and secondary volcanic hazards.

Key terms

primary hazards: those caused directly by the hazard, such as lava flows, ash falls as a result of a volcano erupting

secondary hazards: hazards caused as an indirect result of the primary hazard; for volcanoes these include landslides and tsunamis

Discussion point

Are primary hazards or secondary hazards more dangerous to people and property?

Skills link

You might be asked to draw a sketch or a simple diagram of a geographical feature. Drawing simple labelled diagrams quickly and accurately can be a useful revision technique.

Figure 1.11 Boiling lava and volcanic bombs on the slopes of the crater of the volcano cone Tolbachik, Kamchatka, Russia.

Figure 1.12 Pyroclastic flow descending down Tar River Valley, Soufrière Hills volcano, Montserrat, Caribbean.

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Figure 1.13 Lahar damage to road from Mount Merapi volcano eruption, Yogyakarta, Indonesia.

Figure 1.14 Devastation on the West Coast of Aceh, Sumatra, Indonesia following a tsunami.

Primary or immediate effects	Secondary or longer-term effects
• people killed and injured • farmland and buildings destroyed • communications damaged or disrupted (transport, water, electricity and gas supply)	• spread of disease with no clean water or broken sewers • hospitals overwhelmed by people needing attention • shortage of food, water, shelter and medicine/healthcare • loss of farmland and local businesses reduces income and food production • economic impact from air travel disruption and the cost of rebuilding

Table 1.4 Primary and secondary effects of volcanic eruptions.

Immediate and long-term responses to a volcanic hazard

After successive eruptions of the Soufrière Hills volcano, large areas of Montserrat have been destroyed by pyroclastic flows, ash and lava (Figure 1.12). Islanders responded immediately by setting up an exclusion zone in the volcanic region, abandoning the capital city of Plymouth and evacuating to safety in the north of the island or overseas.

In the longer-term the Montserrat Volcano Observatory (MVO) was built to monitor volcanic activity. New roads, houses and a port have been constructed at Little Bay in the north for returning residents. The tourist industry has expanded, with the volcano as the prime attraction, replacing jobs lost in the farming industry. Residents are now better prepared to cope when the Soufrière Hills volcano violently erupts again.

Further research

Use the **Global Volcanism Program website** (www.cambridge.org/links/gase40002) to find out more about the volcanoes mentioned in Table 1.2. Start by downloading the Google Earth data layer to explore where active volcanoes are located.

ACTIVITY 1.2

1 Are these statements true? Give reasons for your answer.
   a Shield volcanoes are more dangerous than composite volcanoes.
   b Volcanoes are only hazardous for people living close to them.
2 Study Figures 1.8 and 1.9.
   a Draw simple labelled diagrams showing both composite and shield volcanoes.
   b Outline how and why composite and shield volcanoes are different and how and why they are similar.
3 Study the photograph of Mount St Helens in Figure 1.10.
   a Draw a sketch of the photograph of Mount St Helens.
   b Add labels for each of the volcano features you can see.
   c What features of the volcano can you not see in the photograph?

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1.5 Why do people live near areas of volcanic activity?

Over 500 million people live near active volcanoes. There are a number of reasons for this, including the economic opportunities that such areas can provide and the feeling of relative safety because the volcanic activity is being monitored. Since July 1995, the active Soufrière Hills volcano on the Caribbean island of Montserrat has been monitored and an early warning system is in place.

Economic opportunities

Tourism

Volcanic areas offer a variety of tourist attractions. Yellowstone, a volcanic **caldera** in the USA, draws 3 million tourists a year who come to view the geysers and other geothermal activity. Yellowstone National Park provides over 2000 rooms for guests, and jobs for 5000 permanent and seasonal workers.

Farming

Farming in southern Italy can be difficult as the limestone bedrock is nutrient poor. The region around Naples is famous for vines, olives, tomatoes and fruit trees grown on the volcanic soils from the many eruptions of Mount Vesuvius (Figure 1.15). Coffee production in Nicaragua is also only possible in the volcanic soil around Estelí and Jinotepe. Over time, weathering of mineral-rich volcanic rock produces rich fertile soil which is good for growing crops and provides a valuable income for farmers.

Geothermal energy

Iceland, a volcanic island located on the Mid-Atlantic Ridge, uses geothermal heat to supply a quarter of domestic electricity needs, as well as heat and hot water to 90 per cent of homes. Cucumbers, tomatoes and peppers are grown in geothermally heated greenhouses (Figure 1.16) and steel is produced using excess renewable energy.

How can monitoring reduce the risks from volcanic eruptions?

With 750 000 people living in the shadow of Mount Fuji and the **megacity** Tokyo located just 100 km away, it is no wonder that the Japanese carefully monitor tectonic activity. By monitoring and measuring volcanic activity, scientists can warn when the risk of an eruption is high. This gives people time to evacuate. The National Research Institute for Earth Science and Disaster Prevention and the Japan Meteorological Agency collect data (Figure 1.17) about Mount Fuji and 46 other active volcanoes through a network of Volcano Observation and Information Centres located across Japan.

Prediction, planning and preparation

The three Ps (prediction, planning and preparation) can reduce the impact of volcanic eruptions.

Prediction involves trying to forecast when a volcano will erupt. Indicators of an imminent eruption include the time between volcanic activities, changing ground conditions and rising steam and gases. A major volcanic eruption is often preceded by a series of earthquakes. In 1976, a false evacuation of 70 000 people from Guadeloupe Island in the Caribbean proved costly when La Soufrière volcano produced only minor explosions. Mount Fuji last erupted in 1707 and there are signs that it is still active, but it is difficult to predict when it might erupt again.

Planning helps communities to respond and recover from natural disasters. It includes drawing up emergency evacuation plans and using hazard maps to prevent building in high risk areas as well as setting up warning systems and volcano shelters for use in the event of a sudden eruption.

Figure 1.15 Farming on the fertile slopes of Vesuvius.

Figure 1.16 Greenhouses in Iceland heated using geothermal energy.

Watch the video on Cambridge Elevate which explains some of the reasons why people live near volcanoes in Iceland.

Discussion point

What are the social, economic and environmental reasons that people continue to live in areas of volcanic and earthquake activity?

Key terms

caldera: a large, basin-like depression formed as a result of the explosion or collapse of the centre of a volcano

megacity: a city that has 10 million or more people

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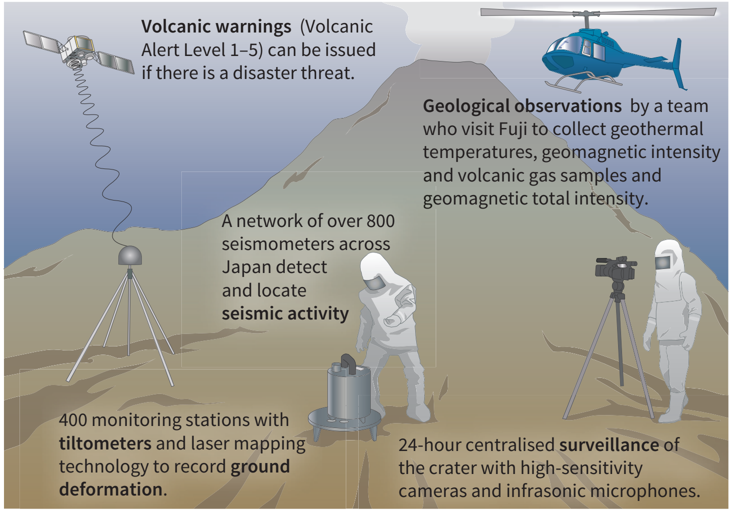

Figure 1.17 Techniques used to monitor Mount Fuji.

Preparation involves educating people about how to evacuate to safety and what to pack in a survival kit if they cannot get out of danger. Planning and preparation are common in higher income countries (**HICs**). Japan holds nationwide disaster drills on 1 September every year to mark the anniversary of the 1923 Tokyo earthquake.

Disasters occur when natural hazards threaten people's lives and property. The risk grows as the frequency or magnitude of hazards increases and people's vulnerability increases or their capacity to cope decreases. This can be presented as the **hazard risk** equation:

$$\text{RISK (R)} = \frac{\text{MAGNITUDE OF HAZARD (H)} \times \text{VULNERABILITY (V)}}{\text{CAPACITY TO COPE (C)}}$$

Increasing numbers of people are affected by hazards because more people are living in hazardous areas. Rapid urbanisation and poverty in lower income countries (**LICs**) means that increasing numbers of people are living in poorly constructed homes. People in richer countries are less vulnerable to natural disasters as they have the money available to monitor volcanoes and plan their response to disasters.

ACTIVITY 1.3

1 Study Figure 1.17.
   a Why is volcano monitoring so important in Japan?
   b Why is it that not all volcanoes in the world are monitored?
   c Outline how each technique used to monitor Mount Fuji can help to predict an imminent eruption.
2 a Outline the advantages and disadvantages of living in an area of tectonic activity such as Iceland.
   b Why is it not possible to prevent all loss of life or damage to property when a volcano erupts?
   c A local person who lives in an active volcanic region was asked why he lived there. His reply was 'because it is worth the risk'. Explain his response.
   d Study the hazard risk equation. Why has the risk of natural disasters increased over the last 30 years?
3 What items might you include in an Emergency Kit in the event of a nearby volcano erupting? Justify your choices.

Discussion point

Should a permanent 15 km exclusion zone be placed around all volcanoes to reduce the risk of death in the event of an eruption?

Further research

Use the **US Geological Survey website** (www.cambridge.org/links/gase40003).

- Outline the different tectonic hazards associated with particular volcanoes.
- Explain why more people die in some volcanic eruptions than others.
- Investigate how active volcanoes are being monitored.

Key terms

HIC: a higher income country is defined by the World Bank as a country with a gross national income per capita above US$12 735 in 2014

hazard risk: the probability or chance that people will be seriously affected by a natural hazard

LIC: a lower income country is defined by the World Bank as a country with a gross national income per capita below US$1 045 in 2014