

8 The dynamic Earth

The ground beneath you seems still. It might even seem dull. But first appearances can be deceiving. In fact, the Earth's crust is not still — it is constantly moving and changing. Nor is it dull — deep beneath the surface is a layer of red-hot molten rock, which sometimes bursts through and creates a volcano like the one shown (Eyjafjallajökull, Iceland, which erupted in 2010). Volcanoes and earthquakes provide spectacular evidence that the Earth is a dynamic, ever-changing planet.

Think about these

- How can something as large as a continent move?
- Why do volcanoes make a 'ring of fire' around the Pacific Ocean?
- How could Captain Cook have walked to Australia 250 million years ago?
- Why are the Himalayas growing in height?
- What causes tsunamis?
- How can a volcano suddenly appear from nowhere?
- Where is the largest volcano in the solar system?

In this chapter:

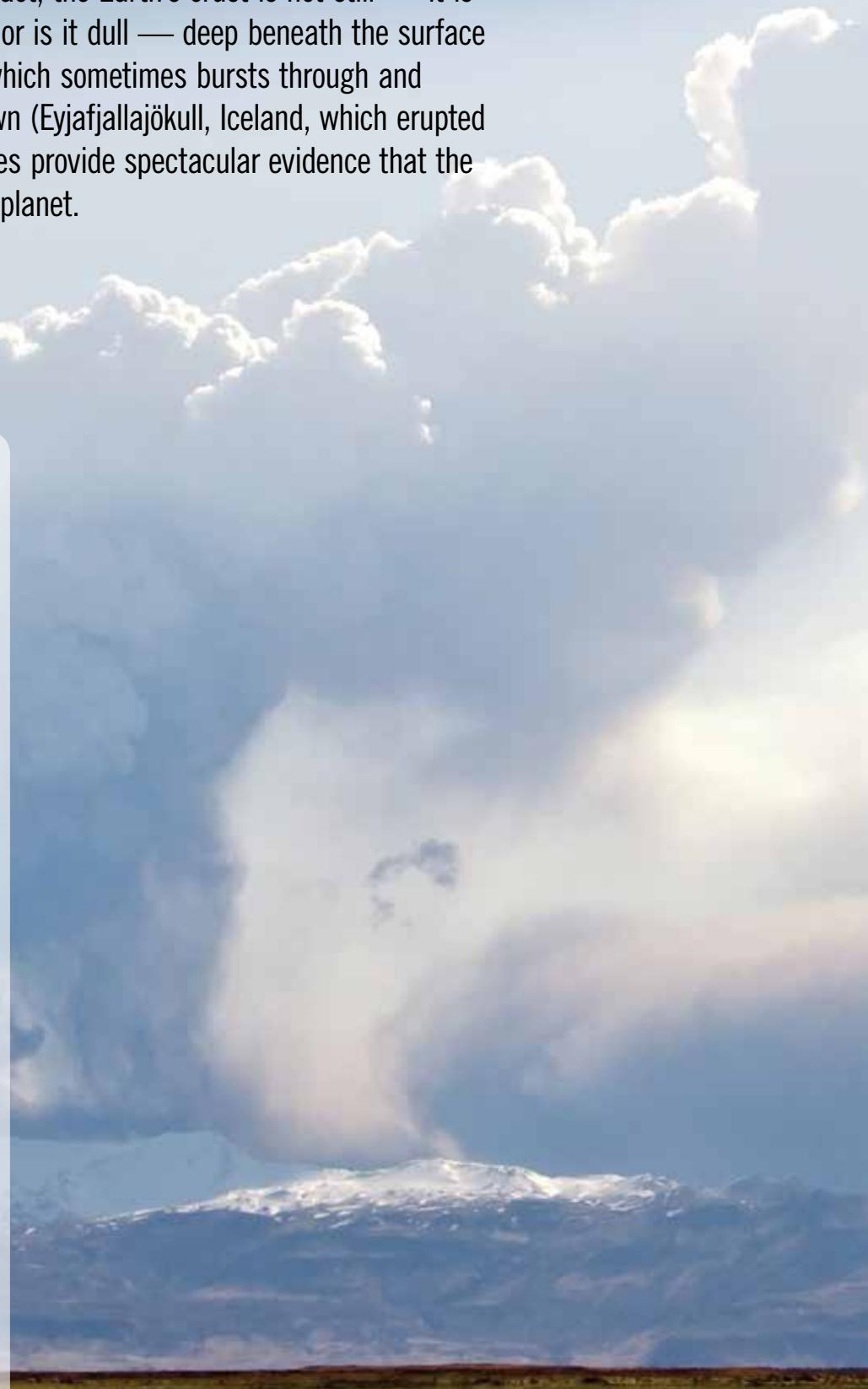
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YOUR QUEST

Journey to the centre of the Earth ...

'Descend into the crater of Yokul of Snejfells, which the shade of Scataris caresses before the Kalends of July, audacious traveller, and you will reach the centre of the Earth. I did it.'

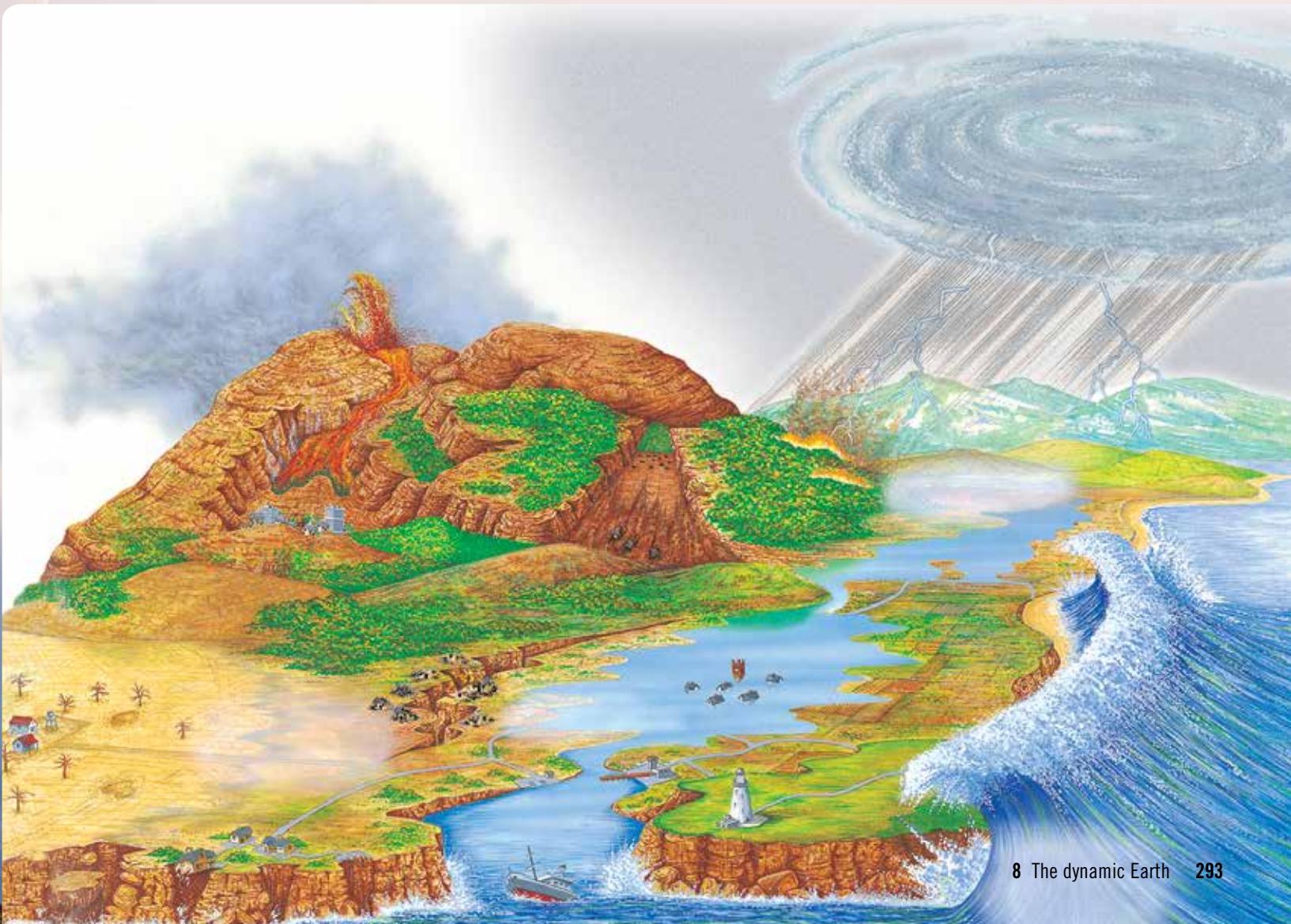
So wrote Jules Verne in his science fiction novel *Journey to the centre of the Earth*, which was published in 1864. The novel describes a fascinating journey by the adventurous Professor Lidenbrock, his nephew Axel and their guide Hans to the centre of the Earth. Their quest begins with a descent into the crater of the extinct volcano Snæfellsjökull in Iceland.

CREATE

- 1 Write your own science fiction short story about an attempted journey to the centre of the Earth. Before starting, think about what you would really expect to find beneath the surface and what sort of vehicle you would need to travel in.

THINK

- 2 What would you expect to find at the very centre of the Earth?
- 3 Think about the substances found close to the surface of the Earth — close enough to the surface to be able to reach with drills and tunnels. Make a list of substances that are:
 - (a) used to provide energy for heating, transport and industry
 - (b) used for building and other construction
 - (c) exceptionally valuable
 - (d) able to find their way naturally to the surface.
- 4 The Earth's crust (the outer solid layer) is constantly changing. Make a list of events that occur because of these changes.



The Earth's crust

The Earth's crust is the very thin, hard, outer layer of our planet. To get an idea of how thin the Earth's crust is, compare it to a medium-sized apple. Imagine that the apple is the Earth. The crust would be as thin as the skin of the apple. Two questions have intrigued geologists for more than a hundred years: What lies beneath the crust? Why is the crust moving?



Comparing the Earth's crust to the skin of an apple makes it easier to understand how thin it is.

Beneath the crust

Questions about what is beneath the Earth's surface have inspired curiosity and imaginative writing — such as Jules Verne's novels. The idea of drilling through to or even travelling to the centre of the Earth is appealing. There could be no better way to find out what is down there. But the deepest man-made holes in the Earth have been drilled to only about 15 km of the 6370 km distance to the centre. Other methods had to be found to find out what is beneath the surface of the Earth.

Scientists use data from earthquakes to find out what lies inside the Earth. Earthquakes produce waves, known as **seismic waves**, that transfer energy through the crust. It is the energy of these waves that causes destruction at the surface. Seismic waves travel at different speeds and behave differently as they pass through different substances below the crust.

By analysing the behaviour of seismic waves, scientists have been able to identify the state and chemical composition of the substances inside the Earth.

The structure of the Earth

Crust (or lithosphere)

The Earth's crust, which includes landforms, rocks and soil. It is mostly solid rock, is rigid and has high strength. It varies in thickness from as little as 5 km under the ocean to about 70 km under mountain ranges like the Himalayas.

Atmosphere

A blanket of gases that surrounds the Earth to a height of approximately 145 km. Mostly made up of nitrogen and oxygen, which support life on Earth.

Mantle

Partially molten rock. Temperatures mostly between 500 °C and 2000 °C. About 2900 km thick. The top part of the mantle is the source of magma that erupts onto the surface.

Outer core

Molten iron and nickel. Temperatures mostly between 4000 °C and 6000 °C. About 2300 km thick.

Hydrosphere

The water on or at the surface of the Earth, including oceans, lakes, rivers, rain and mist.

Inner core

Mostly iron. Solid owing to the extreme pressure. Temperatures up to 7000 °C. About 1200 km thick.

Moving continents

The shrinking theory

Geologists of the 1800s believed that, as the Earth cooled, the crust began to shrink and wrinkle. They believed that the continents were the high parts of the wrinkles and that oceans covered the lower parts. During the late 1800s and early 1900s evidence was found that showed that the continents were moving. At first,

geologists thought that the movement was caused by the wrinkles moving relative to each other.

The continental drift theory

In 1912, a German meteorologist named Alfred Wegener proposed a new theory. He had noticed that the present day continents looked as though they would fit together very much like a jigsaw puzzle. Wegener suggested that the continents were floating, or drifting, on a denser material underneath. He proposed that the continents were breaking apart and rejoining in a process that he called **continental drift**.

A supercontinent

Wegener also believed that, at one time, all of the continents were joined together in a single 'supercontinent' that he called **Pangaea**. This belief was supported by the discovery of fossils of the same land animals on different continents. Pangaea was surrounded by a vast sea called **Panthalassa**.

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Drifting continents

Learn how the supercontinent Pangaea broke up to form the continents we know today.

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INVESTIGATION 8.1

Continental drift

AIM To create a simple model to demonstrate continental drift

Materials:

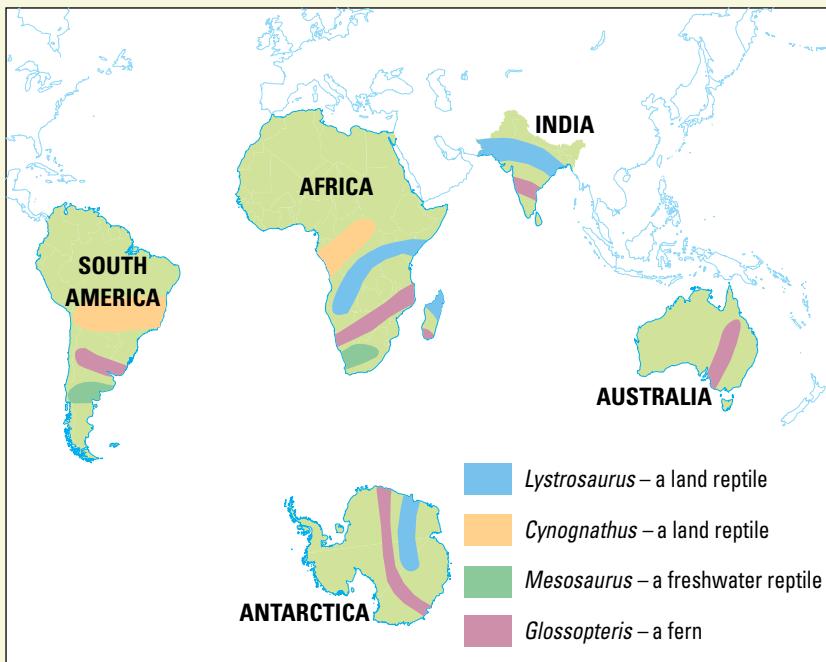
enlarged copy of the map above
scissors

METHOD

- ▶ Cut out the continents from the enlarged copy of the map above.
- ▶ Examine the distribution of fossils on each continent.
- ▶ Rearrange the continents into one supercontinent by matching the distribution of fossils.

DISCUSS AND EXPLAIN

- 1 How do you think the distribution of fossils helps to prove Wegener's theory of continental drift?
- 2 Suggest at least one other way in which the continents can be put together.



UNDERSTANDING AND INQUIRING

REMEMBER

- 1 Copy and complete the table below.

Layer	Description
Atmosphere	
Hydrosphere	
Crust	
Mantle	
Outer core	
Inner core	

- 2 Even though the inner core is hotter than the molten outer core, it is solid. Explain why this is the case.

- 3 Outline how the shrinking theory, popular during the 1880s, explained the existence and movement of the continents.

- 4 Describe two observations that provided evidence for Wegener's theory of continental drift.

- 5 What were Pangaea and Panthalassa?

THINK

- 6 According to Wegener's theory of continental drift, upon which layer of the Earth are the continents floating?

CREATE

- 7 Create a poster of the Earth that shows the four main layers beneath the surface and the important characteristics of each layer.

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work sheet

8.1 Continental drift

Stability and change: Plate tectonics

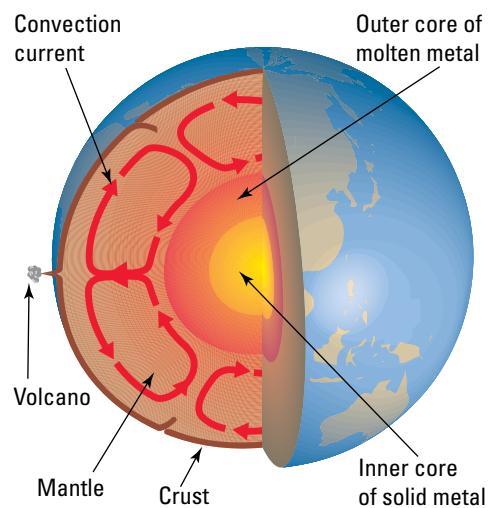
The theory of continental drift paved the way for the more recent theory of **plate tectonics**, which explains much more than the movement of continents. The theory of plate tectonics explains, for example, why the Himalayas are growing in height, why Iceland is slowly splitting in two and why new rock is being formed in the middle of the ocean.

Plates on the move

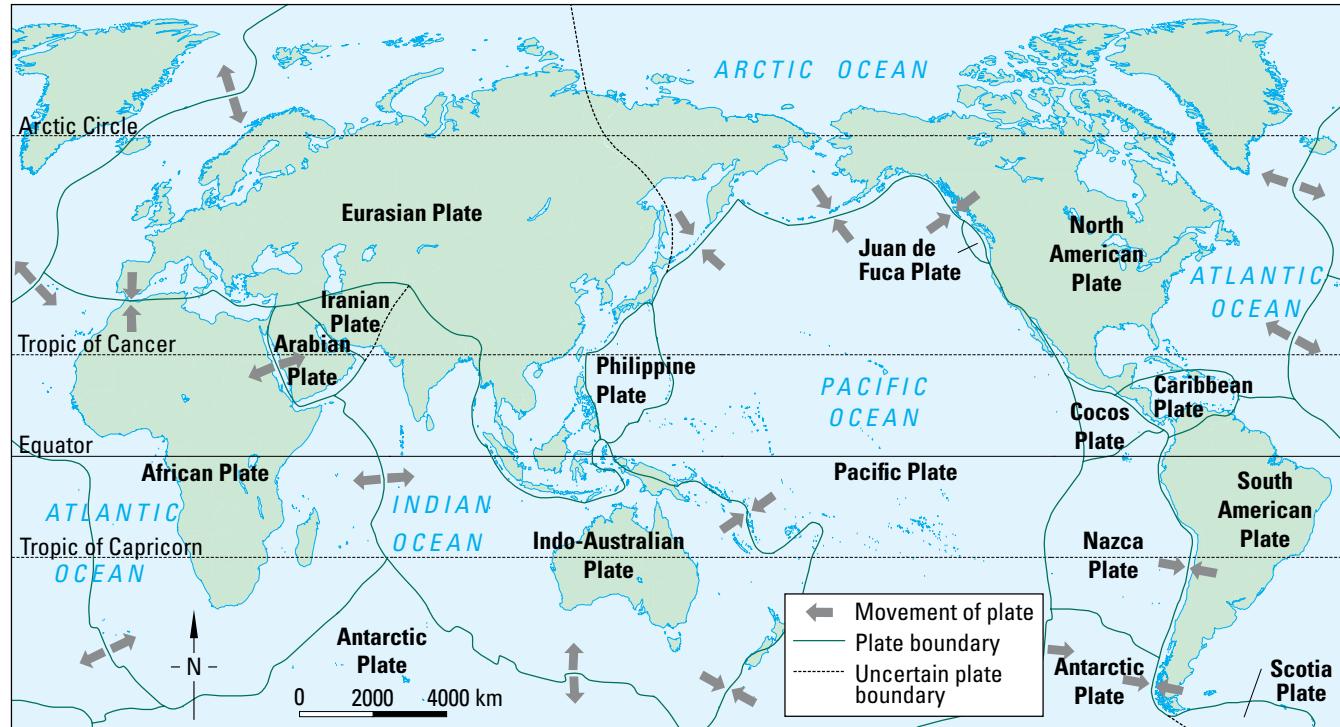
With the use of technology such as sonar and satellite imaging, geologists have been able to demonstrate that the Earth's crust is divided into approximately 30 plates, not just the separate continents.

The plates move on a layer of partially molten rock in the upper **mantle**. Some of the plates are very large, while others are quite small. The plates move because heat causes the partially molten rock in the mantle to expand and rise towards the surface. It spreads out, cools and falls back under the force of gravity. This creates a **convection current** that keeps the plates moving slowly.

The plates can consist of two types of crust. The continents are made up of **continental crust**, which is between 30 km and 70 km thick. The plates beneath the oceans consist of **oceanic crust**. Oceanic crust is much thinner than continental crust and has an average thickness of about 6 km. It is also a little denser than continental crust due to differences in its chemical composition.



Convection currents in the mantle



A simplified map showing the major tectonic plates that make up the Earth's crust. The arrows show the direction of plate movement.

The plates move slowly (usually just a few centimetres in a year), and can slide past each other, push against each other or move away from each other.

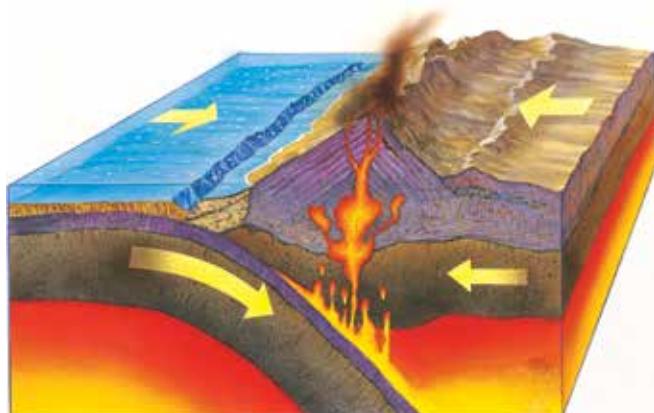
The map opposite shows the location of some of the major plates and boundaries. The location of some of the boundaries is still not certain. These are shown on the map by dotted lines.

Converging plates

When two plates push against each other, two separate changes take place. Where oceanic crust pushes against continental crust, a process called **subduction** occurs,

as shown in the diagram below. The oceanic crust sinks below the less dense continental crust. This movement causes powerful earthquakes and creates explosive volcanoes when the oceanic crust melts and cold sea water meets hot magma. The boundaries between converging plates are called **destructive plate boundaries** because solid ocean crust melts into the mantle.

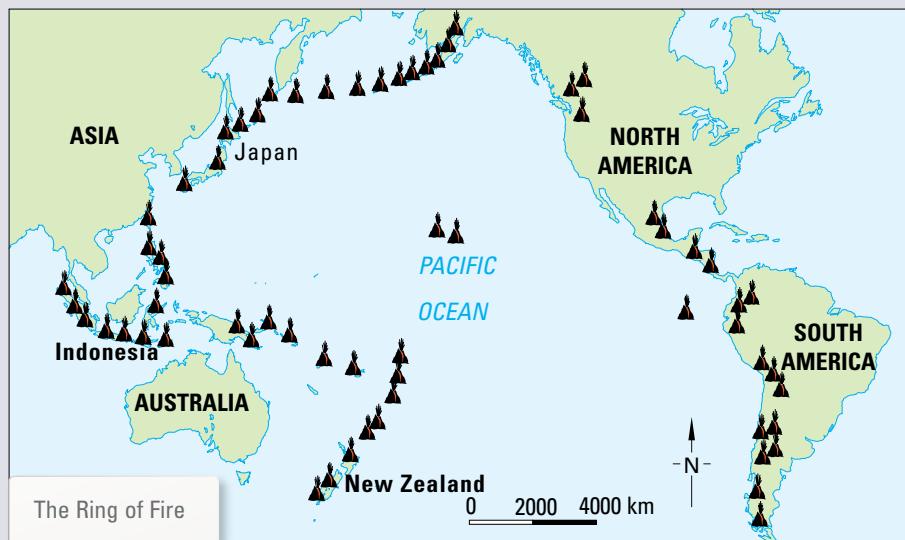
When two continents on colliding plates push against each other, huge mountain ranges are formed as continental crust crumples upwards. The Himalayas are still being raised as the Indo-Australian Plate pushes upwards against the Eurasian Plate.



Converging plates: oceanic crust melts as it sinks under continental crust. Magma bursts through the crust to form a volcano.

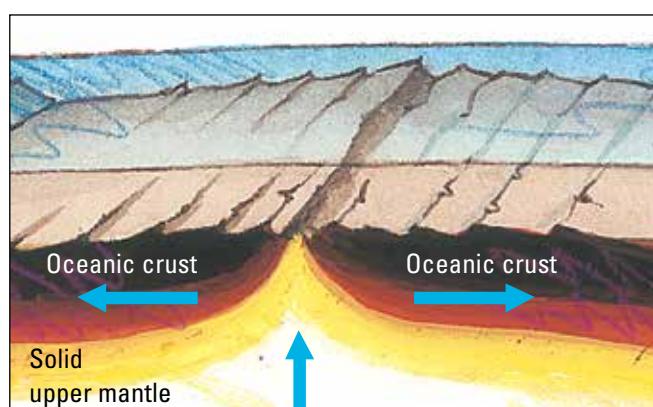
HOW ABOUT THAT!

The majority of the world's active volcanoes lie along the edges of the Pacific Plate. They form a circle around the Pacific Ocean known as the Ring of Fire.



Plates moving apart

The map on the previous page shows that, in the middle of some major oceans, plates are moving away from each other in opposite directions. That is, the plates are diverging. As they move apart, magma from the mantle rises. As it cools and solidifies in the sea water, it forms underwater volcanoes and creates new oceanic crust. An underwater ridge is formed as magma along the plate boundaries rises. Because of the emergence of new crust, these boundaries are known as **constructive plate boundaries**. The sea floor spreads as new volcanoes appear and more new crust is created. New segments of the Earth's crust are continuously being formed at these **ocean ridges**.

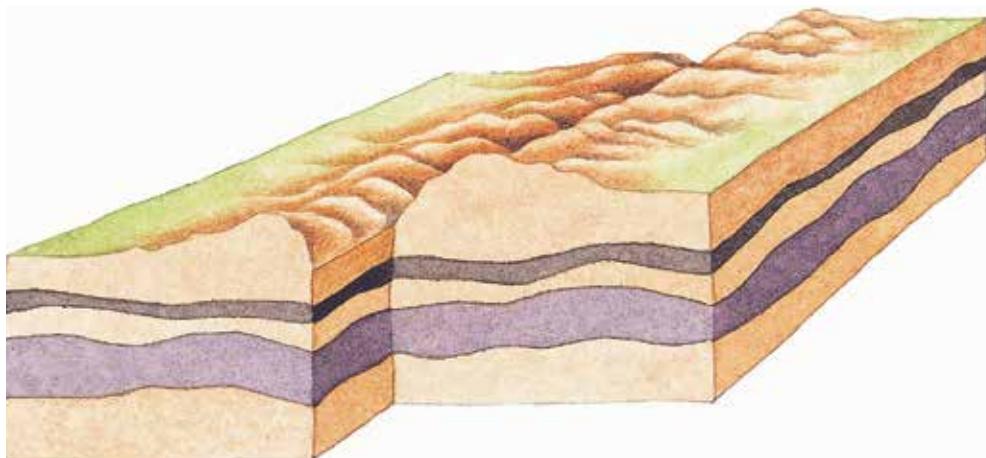


Plates moving apart: the spreading sea floor

Slipping and sliding

When two neighbouring plates slide past each other, earthquakes occur. Even when the sliding is smooth, small earthquakes, or tremors, occur. More severe earthquakes occur when something prevents the plates from sliding. Pressure builds up until there is enough force to restart the sliding with a jolt. The boundaries

between sliding plates like the San Andreas Fault in the United States are known as **conservative plate boundaries**. Solid crust is neither created nor destroyed at these boundaries. The San Andreas Fault is perhaps the best known example of a boundary between sliding plates.



Sliding plates

WHAT DOES IT MEAN?

The word *tectonic* is derived from the Greek word *tektonikos*, meaning 'builder'.

Magma recycled

While new oceanic crust is formed from cooling lava at ocean ridges, old oceanic crust is pushed downwards at subduction zones, eventually melting to form magma. This slow and continuing natural process of 'recycling' old crust and producing new crust takes place over millions of years.

Further evidence

Strong evidence for the theory of plate tectonics has been provided by the location of volcanoes and earthquakes, growing mountain ranges, spreading ocean ridges and the movement of the continents. However there is further evidence:

- Two-hundred-million-year-old fossils of the same land animals have been found in all of the southern continents. As these animals could not swim from one continent to another, this is evidence for the theory of continental drift and therefore supports the theory of plate tectonics.
- The rocks further away from the mid-lines of ocean ridges are older than those closer to the centre. This supports the idea that new rock is being formed in the middle of ocean ridges, continuously pushing the older rock aside.

The continental jigsaw

The theory of plate tectonics enabled a more complete reconstruction of the movement of continents proposed by the continental drift theory. Geologists now believe that about 200 million years ago the supercontinent Pangaea broke up into two smaller continents called **Laurasia** and **Gondwanaland**. The continents of Africa, South America, Antarctica and Australia were all part of Gondwanaland.

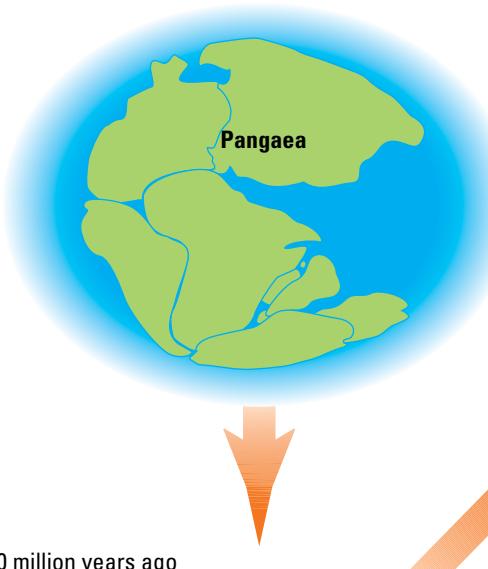
Australia on the move

Since Australia began to separate from Antarctica about 65 million years ago, it has slowly moved northward. Its climate has changed — from cold, to cool and wet, to warm and humid, to the hot and dry conditions that most of the continent experiences today. The movement of the tectonic plates is continuous and they are still moving today, taking the continents with them. Australia will continue to move north at the rate of a few centimetres each year.

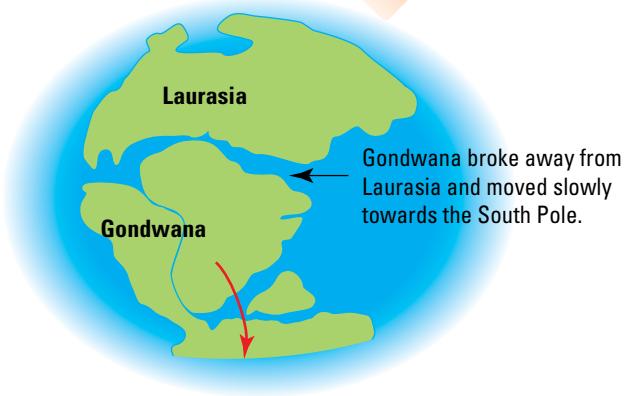
A stable continent

Australia is geologically stable because it is near the centre of a tectonic plate, well clear of the boundaries. Volcanic activity and severe earthquakes are unlikely.

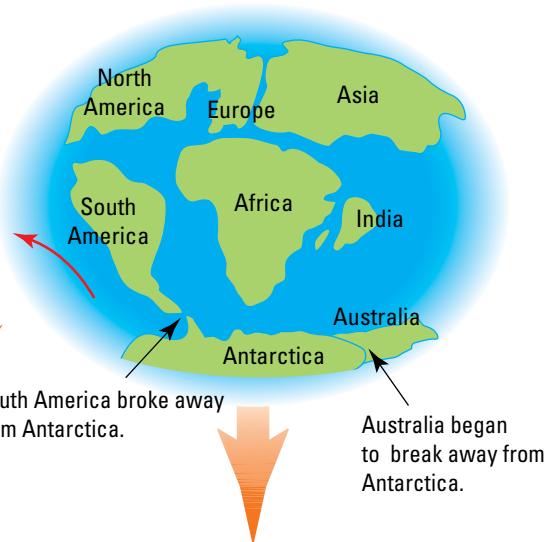
(a) 250 million years ago



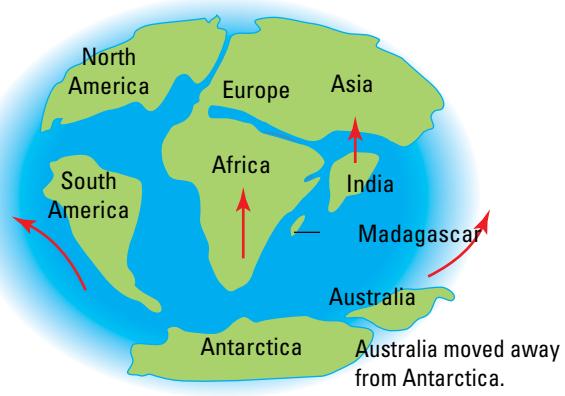
(b) 200 million years ago



(c) 65 million years ago



(d) 45–38 million years ago



The extreme age of Australia's rock is due to its distance from subduction zones, where new rock is formed.

Australia experiences relatively small earthquakes, weaknesses and movement within the Indo-Australian Plate. Most of Australia's volcanoes erupted millions of years ago. The most recent eruption on the continent was Mount Gambier in South Australia, about 4500 years ago.

Hotspots

Australia's volcanoes have formed over **hotspots**, regions in the crust where rocks in the upper mantle melt and magma surges upwards into the crust.

Hotspots occur within plates. The active volcanoes in the Hawaiian Islands are caused by hotspots. The old volcanoes of Australia are also the result of hotspots.

HOW ABOUT THAT!

Fossils of ancient sea creatures can be found at the top of the Himalayas, thousands of metres above sea level. How did they get there?

If you look at a map of the world, you will notice that India is joined to Asia. But that was not always the case. India has been moving towards Asia since it broke away from Gondwanaland millions of years ago. At first, seas separated the two lands. But now, the Indo-Australian Plate and the Eurasian Plate have collided. The current edges of these plates are both made of continental crust, so one plate will not easily slide under the other. Instead, the two are crumpling against each other, forming the Himalaya mountains. Sediments that once lay at the bottom of the sea between the two landmasses have been forced upward and can be found at the peaks of the mountain range.

UNDERSTANDING AND INQUIRING

REMEMBER

- 1 What is the theory of plate tectonics?
- 2 If the Earth's surface consists of moving plates, what are the plates moving on?
- 3 How is oceanic crust different from continental crust?
- 4 Describe what happens at the boundaries between plates when the plates:
 - (a) slide past each other
 - (b) push against each other
 - (c) move away from each other.
- 5 State one location on Earth where:
 - (a) two plates are sliding past each other
 - (b) subduction is occurring
 - (c) volcanoes have formed away from the edges of plates.
- 6 What is Gondwanaland?
- 7 What is a hotspot?
- 8 Use the **Plate tectonics** weblink in your eBookPLUS to answer the following questions about the changes that take place at plate boundaries.
 - (a) Describe and compare convergent and divergent boundaries.
 - (b) Are divergent boundaries constructive or destructive boundaries? Explain your answer.
 - (c) What drives the formation of mid-ocean ridges?
 - (d) Explain how scientists were able to prove that new crust was being formed at mid-ocean ridges.
 - (e) At which type of plate boundary are the Earth's major earthquakes most likely to occur?
 - (f) How are plates moving relative to each other at conservative boundaries?

THINK

- 9 Explain why earthquakes are common in the regions surrounding the Himalayas.
- 10 What is the Ring of Fire and why, according to the theory of plate tectonics, does it exist?
- 11 List, in point form, the evidence that supports the theory of plate tectonics.
- 12 The theory of continental drift was first proposed in 1912, over 50 years before the theory of plate tectonics was put forward. The evidence for the theory of continental drift also supports the theory of plate tectonics. Explain the difference between the two theories.
- 13 The illustration at top right represents part of a plate boundary.
 - (a) Identify the type of boundary shown.
 - (b) Describe the movement of the plates on either side of the plate boundary.
 - (c) Should this boundary be described as a constructive or a destructive boundary? Explain your answer.



14 Explain why the climate of most of the Australian continent has changed from cold to hot and dry during the past 65 million years.

15 Explain why there are volcanoes in Australia, even though it is not on a plate boundary.

INVESTIGATE

- 16 The plates that make up the Earth's crust move only a few centimetres each year. Do some calculations to see whether it is really possible that Australia could have moved as far from South America as it is today.
- 17 Research and report on the use of sonar in mapping the ocean floor.
- 18 Find out how climate change, whether due to the northward movement of the Indo-Australian Plate or global warming, is likely to affect amphibians such as frogs and toads.

CREATE

- 19 Construct a model of converging continental crust. Use two piles of paper to represent the two sections of crust. Push the two piles of paper together.
 - (a) What happens at the point where the paper piles meet?
 - (b) Describe how this relates to the way the Himalayas have formed.
 - (c) What would you expect the rocks to look like in a mountain range formed by converging plates?
- 20 Create your own model of sea-floor spreading using paper or other readily available materials.
- 21 Test your knowledge of plate boundaries by completing the **Does the Earth move?** interactivity. int-0674

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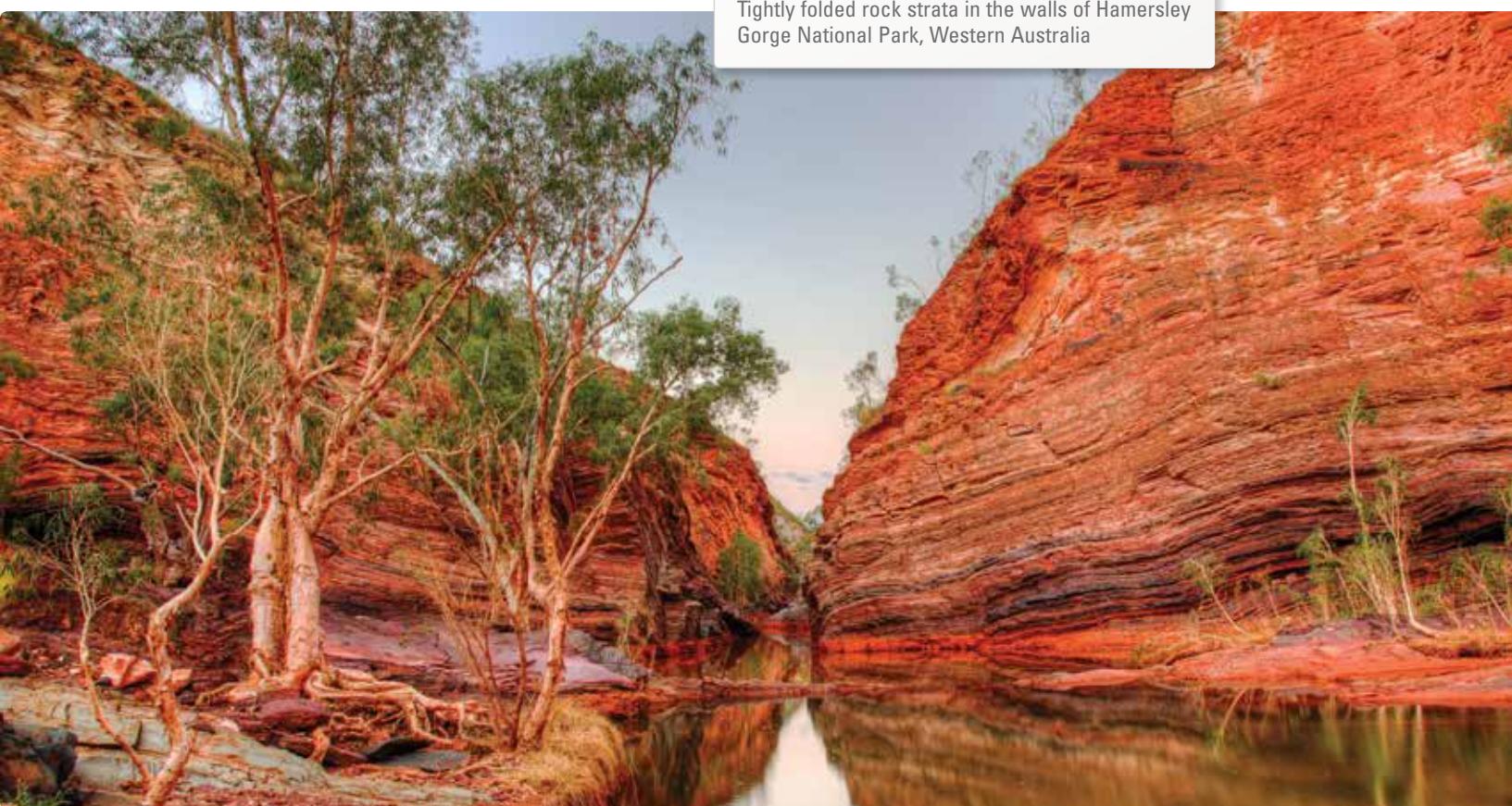
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8.2 Plate tectonics

Rocks under pressure

As the plates that make up the Earth's crust slowly move, solid rock is pushed, pulled, bent and twisted. The forces on the rocks in the crust are huge — large enough to fold them into rolling hills and valleys and

large enough to crack them and move them up, down or sideways. Folded and broken rocks are found well beyond the edges of the plate boundaries.



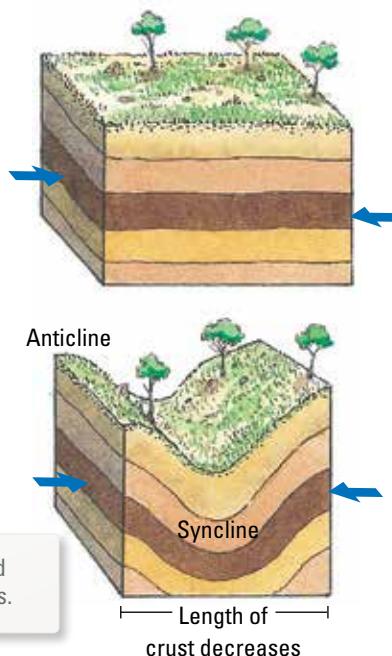
Tightly folded rock strata in the walls of Hamersley Gorge National Park, Western Australia

Bending without breaking

If you hold a sheet of paper with one hand on each end and move the ends towards each other, the paper bends upwards or downwards.

The forces beneath the Earth are so large that layers of rock bend and crumple without breaking, just as the paper does. This process is known as **folding**.

Forces on solid layers of rock fold them into anticlines and synclines.



The folding of the Himalayas continues as two parts of the Earth's crust collide with each other.

INVESTIGATION 8.2

Modelling faults

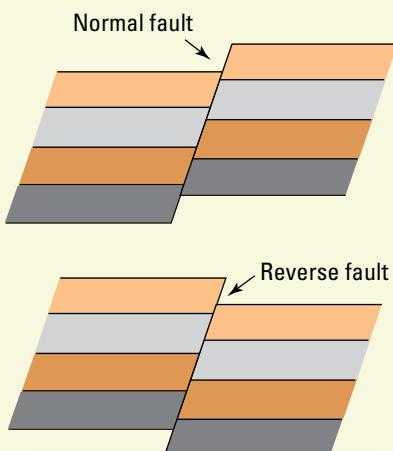
AIM To model normal and reverse faults

Materials:

3 or 4 pieces of differently coloured plasticine
a thin sheet of polystyrene
knife or blade

METHOD AND RESULTS

- Place the first piece of plasticine on the bench and flatten it into a rectangular shape. Do not make it too thin. Cut a piece of polystyrene the same size, and fit it over the plasticine rectangle.



- Add two or three more layers of plasticine with a layer of polystyrene between each layer.
- Cut through the layers on an angle as shown in the diagram above. Use the two parts to model each of the two types of fault shown above.

- Draw a diagram of each fault. Label it with arrows to show the direction in which each block moved to create the fault.

DISCUSS AND EXPLAIN

- Describe the plate movement that could be responsible for each type of fault.

Most of the major mountain ranges around the Earth have been shaped in this way. The shape of the Himalayas is the result of the folding of rock as two of the plates that make up the Earth's crust slowly collide. They are still rising as the plates continue to grind into each other.

Folds that bend upwards are called **anticlines**. Those that bend downwards are called **synclines**. Generally anticlines and synclines are formed well below the surface of the Earth and are not visible unless they are exposed by erosion of softer rock. They can often be seen in road cuttings or in cliffs formed by fast-flowing streams.

INVESTIGATION 8.3

Modelling folds

Rocks are usually folded well below the Earth's surface. The anticlines and synclines can be seen only along road cuttings or where erosion has exposed the layers of rock. A model is a useful way to describe how folded rocks would appear under the surface.

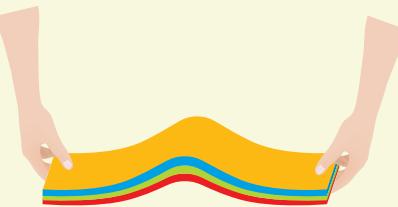
AIM To model the folding of rocks

Materials:

3 or 4 pieces of differently coloured plasticine
knife or blade
board

METHOD AND RESULTS

- Roll the pieces of plasticine into 1 cm thick layers.
- Place the layers of coloured plasticine on top of each other. Press down lightly on the layers, so that they stick together.
- With the palms of your hands, very gently compress the layers from the side.
- Model the processes of weathering and erosion on your plasticine layers.



- Describe the appearance of the plasticine when the layers are compressed.
- Draw a diagram of the plasticine after compression, labelling anticlines and synclines.

DISCUSS AND EXPLAIN

- Imagine that the rock layers are eroded at the Earth's surface. Draw diagrams of the eroded layers when viewed from above and when viewed from the side. Label the oldest and youngest layers. (Remember that the oldest layers are deposited before the younger ones.)

The Great Dividing Range

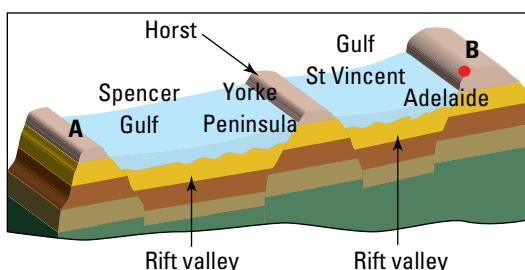
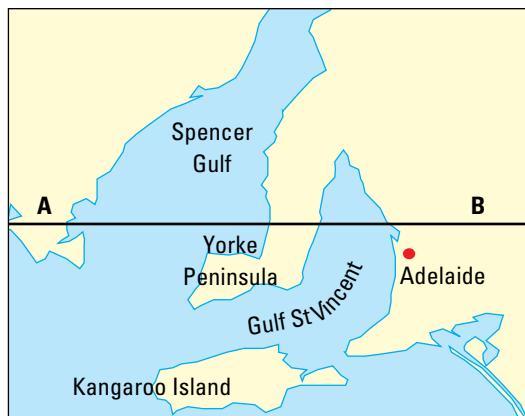
Australia's Great Dividing Range, which stretches all the way from northern Queensland to Tasmania, was formed by folding. It is actually a chain of separate mountain ranges, including the Carnarvon Range in central Queensland, the Blue Mountains of New South Wales, the Australian Alps, the Dandenong Ranges near Melbourne and the Central highlands of Tasmania.



Faults

Sometimes rocks crack as a result of the huge forces acting on them. Once movement occurs along a crack, it is called a **fault**.

The Gulf region of South Australia has been formed by a series of faults. Two blocks of crust have dropped down between faults to form Spencer Gulf and Gulf St Vincent. Between these sunken blocks, which are called **rift valleys**, is a block that has been pushed upwards by the forces below. This block, called a **horst**, has formed Yorke Peninsula. The movement along these faults is responsible for the occasional earthquakes in the Adelaide area.



The Gulf region of South Australia has been formed by a series of faults.

If movement along a fault is sideways, that is, where the blocks of crust slip horizontally past each other, it is termed a **slip fault**. The San Andreas Fault in California is a slip fault. It stretches about 1200 kilometres along the coast, passing through San Francisco and to the north of Los Angeles. A large movement of the blocks on either side of this fault line in 1989 created a major earthquake in San Francisco, killing at least 62 people. The earthquakes experienced in this area in recent years appear to be caused by a buildup of pressure along the fault. Scientists believe that it will not be long before the pressure is relieved through a catastrophic earthquake.



The San Andreas Fault

UNDERSTANDING AND INQUIRING

REMEMBER

- 1 What is *folding* and how is it caused?
- 2 Explain why the Himalayas are still growing in height.
- 3 Explain the difference between a syncline and an anticline.
- 4 What causes earthquakes along the San Andreas Fault?
- 5 Explain the difference between a reverse fault and a normal fault.

THINK

- 6 Explain with the aid of some labelled diagrams how mountains could be formed by faulting.
- 7 There is a lot of faulting as well as folding in the Himalayas. Explain how it is possible for folding mountains to develop faults later in their geological history.

CREATE

- 8 Construct a model to demonstrate the formation of the Gulf region of South Australia.

INVESTIGATE

- 9 Imagine that you were offered the chance to spend a year in a high school in a leafy northern suburb of Los Angeles, just two kilometres from the San Andreas Fault. Would you accept the offer? Explain your response.

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8.3 Folding and faulting

Shake, rattle and roll

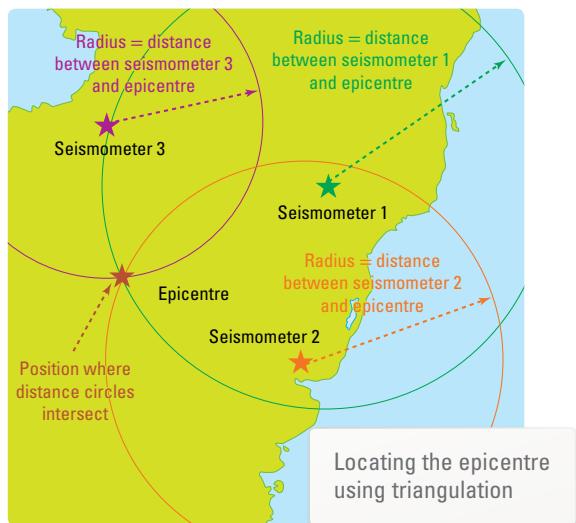
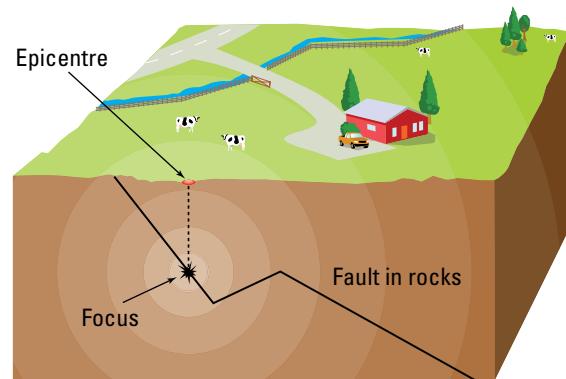
Earthquakes result from movements in the Earth's crust up to 700 kilometres below the surface. These movements cause vibrations or **tremors** on the Earth's surface. Fortunately most of the tremors are too weak to be felt. When the tremors are sudden and strong, they are called earthquakes.

Major earthquakes occur at or near the plate boundaries where plates are:

- pushing against each other in subduction zones
- spreading apart to form ocean ridges and new underwater volcanoes or volcanic islands
- slipping and sliding against each other in sudden jolts.

Tremors and minor earthquakes can take place wherever there is a weakness in the Earth's crust, especially along faults.

The **epicentre** of an earthquake is directly above the point below the surface where the movement in the crust began. The point at which the earthquake begins is called the **focus**.



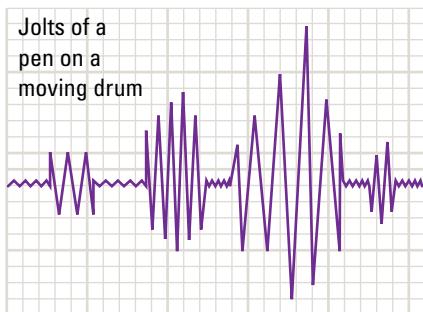
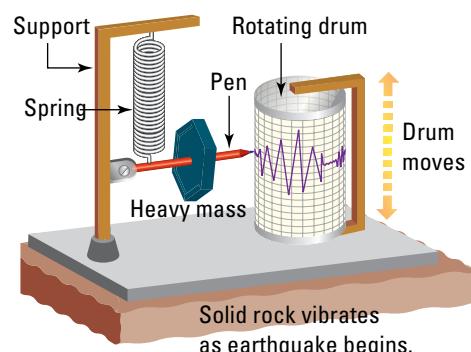
By using readings from at least 3 different seismic stations, the position of the epicentre can be determined. This process is known as **triangulation**.

Measuring earthquakes

Movements in the Earth are recorded with a **seismograph**. The graph below shows what a seismograph records during an earthquake. The strength of an earthquake can be measured in a number of ways. The most well-known way of measuring the strength of earthquakes is the **Richter scale**.

The Richter scale

The Richter scale is a measure of the amount of energy released by an earthquake. Earthquakes measuring less than 2.0 on the Richter scale are called microquakes and are rarely detected by people. Earthquakes of magnitude 5.0 on the Richter scale are detectable and may even cause objects on shelves or in cupboards to rattle. Each increase of 1.0 on the scale represents a 30-fold increase in the amount of energy released. So an earthquake of magnitude 6.0 releases 30 times as much energy as one of magnitude 5.0. That means that an earthquake of magnitude 7.0 releases 900 times as much energy as one of magnitude 5.0.



An earthquake recorded on a seismograph. A strip of paper moves past a stationary pen. When the seismograph is jolted by the earthquake it jumps up and down. However, the pen is attached to a heavy mass which does not move. As the paper turns on the drum, the pen leaves a record of the vibrations.

The Richter scale is not always a good indication of the destructive power of an earthquake. In a crowded city, small earthquakes can cause many deaths, injuries and a great deal of damage, cutting off water, gas and electricity supplies. Larger earthquakes in remote areas cause few injuries and little damage.

Destructive power

The destructive power of an earthquake in any location also depends on its distance from the epicentre. For example, the Tennant Creek earthquake of 1988 in the Northern Territory had a Richter magnitude of 6.7; however, only two buildings and the natural gas pipeline were damaged. The epicentre of the earthquake was 40 kilometres north of the town. Yet the smaller earthquake that devastated Newcastle in New South Wales in 1989 registered 5.6 on the Richter scale, killed 13 people, hospitalised 160 others and demolished 300 buildings. The epicentre of that earthquake was only five kilometres west of the city.

Seismic waves

Energy released during an earthquake travels in the form of waves. There are three main types of wave that are generated by earthquakes: P-waves, S-waves and L-waves. These waves differ in their speed and the regions of the Earth through which they travel.

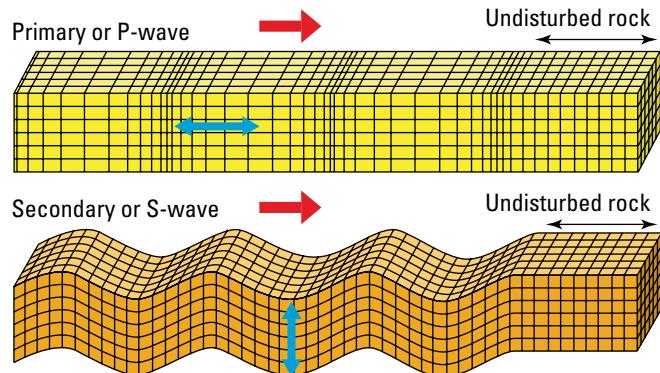
P-waves (or **primary waves**) are compression waves, moving through the Earth in the same way that sound waves move through air. They are the fastest of the seismic waves.

After the P-waves, the second sets of waves to be detected are the **secondary waves** or **S-waves**. These travel in the form of transverse waves.

Both P-waves and S-waves are **body waves**, because they travel through the 'body' of the Earth, rather than the surface.

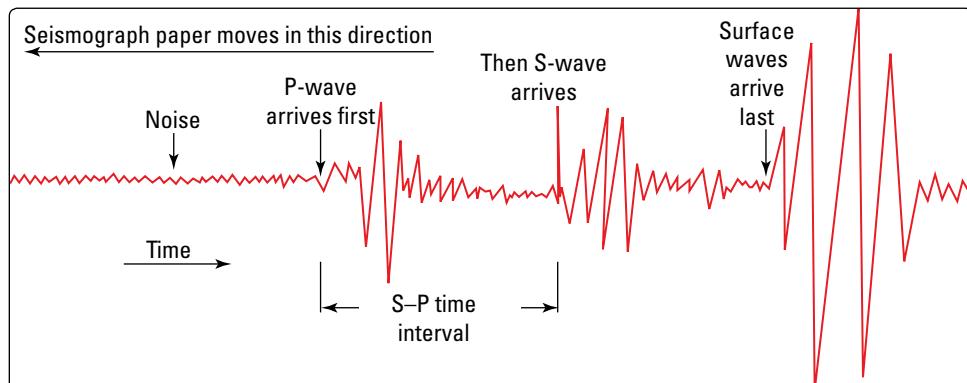


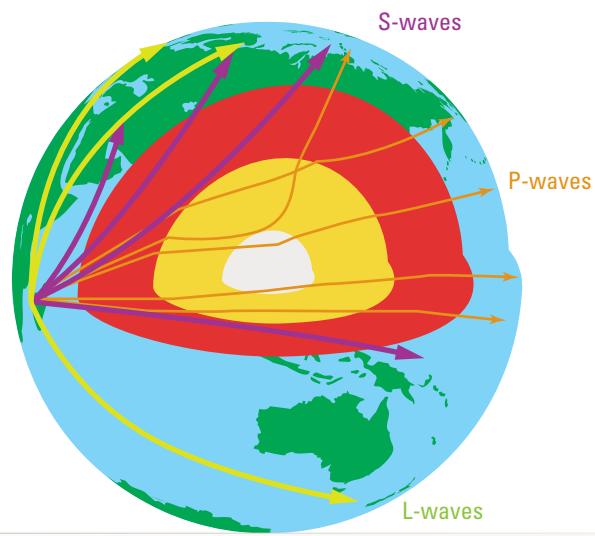
Some of the destruction caused in Christchurch, New Zealand, by a magnitude 6.3 earthquake in February 2011. The earthquake destroyed many buildings and homes, injured thousands, and killed 185 people.



P-waves travel through the earth as compression waves while S-waves are transverse waves.

L-waves are **surface waves** and travel around the Earth. While they travel much more slowly than either the P-waves or S-waves, it is these surface waves that are responsible for the majority of an earthquake's destructive power. This is because all of the L-wave energy is distributed across the surface of the Earth rather than being spread out through the Earth's interior like P- and S-waves.





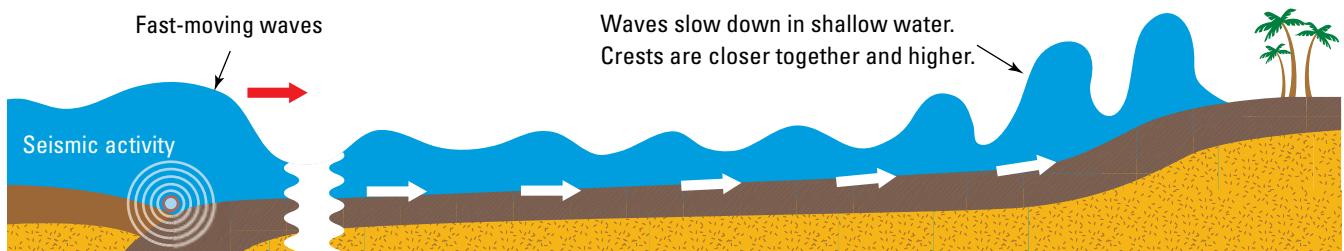
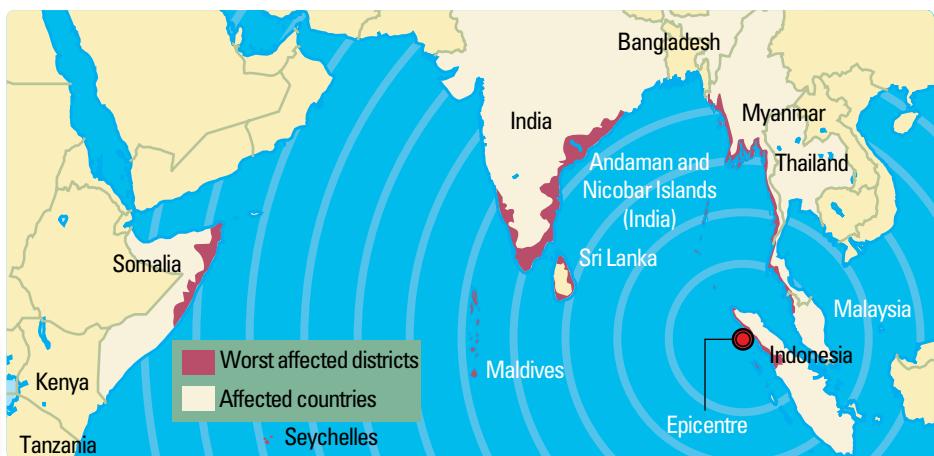
P-waves are able to travel through the inner and outer core as well as the mantle; S-waves travel in the mantle; L-waves travel on the Earth's surface.

Living on the edge

For the people living near the plate boundaries, particularly on the edges of the Pacific Ocean, the ability of scientists to predict earthquakes and tsunamis is critical. The scientists who study earthquakes are called **seismologists**.

Although it is difficult to predict the time, location and size of earthquakes, seismologists can use sensors to monitor movement along plate boundaries and fault lines. When pressure build-ups occur they can at least warn authorities that an earthquake is likely. As yet there is no reliable early warning system in place. However, seismologists are experimenting with a variety of methods using satellites, Earth-based sensors and even animal behaviour.

This map shows the huge area affected by the tsunami on 26 December 2004.



Waves of destruction

Earthquakes occurring under the water or near the coast can cause giant waves called **tsunamis**. These huge waves travel through the ocean at speeds of up to 900 kilometres per hour. When the waves approach land the water gets shallower. This causes the waves to slow down and build up to heights of up to 30 metres.

The destructive power of tsunamis became very clear on 26 December 2004 when about 300 000 people across South-East Asia, southern Asia and eastern Africa died. Millions more lost their homes. The tsunami, known as the Sumatra–Andaman tsunami, was caused by a huge earthquake under the ocean floor about 250 kilometres off the coast of the Indonesian island of Sumatra. The earthquake measured 9.0 on the Richter scale. It pushed a 1000 km-long strip of the ocean floor about 30 metres upwards.

The tsunami pushed a three-metre-high wall of water, mud and debris a distance of 10 kilometres inland near the Sumatran city of Banda Aceh. Thousands were killed in Sri Lanka, India and Thailand as well. Death and destruction also occurred in Malaysia, Myanmar, Bangladesh and the Maldives. More than eight hours after the earthquake, the tsunami arrived at the east coast of Africa, more than 5000 kilometres from the epicentre of the earthquake. Even at that distance from the earthquake, the tsunami caused flooding which killed more than 160 people on the coasts of Somalia, Kenya and Tanzania.

INVESTIGATION 8.4

Making a seismograph

AIM To construct a working model of a seismograph

Materials:

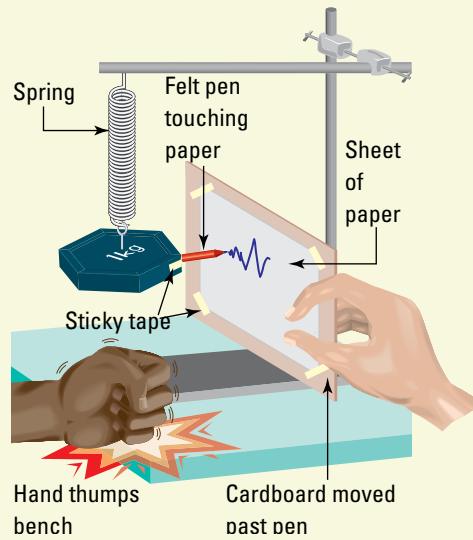
retort stand, bosshead and rod
 spring sticky tape
 cardboard felt pen
 A4 paper
 500 g or 1 kg weight (or a can full of sand)

METHOD

- Set up the equipment as shown in the diagram on the right.
- Have your partner move the cardboard past the pen while you thump the surface on which your seismograph sits.

DISCUSS AND EXPLAIN

- Does the model work?
- How could you improve the model?



A model seismograph

The world was reminded of the destructive power of tsunamis in March 2011, when an earthquake struck that was of the same magnitude as the 2004 Sumatra-Andaman earthquake. The epicentre of this earthquake was only 70 kilometres off the coast of the Japanese island of Honshu. The nearest major city was Sendai, where the port and airport were almost totally destroyed.

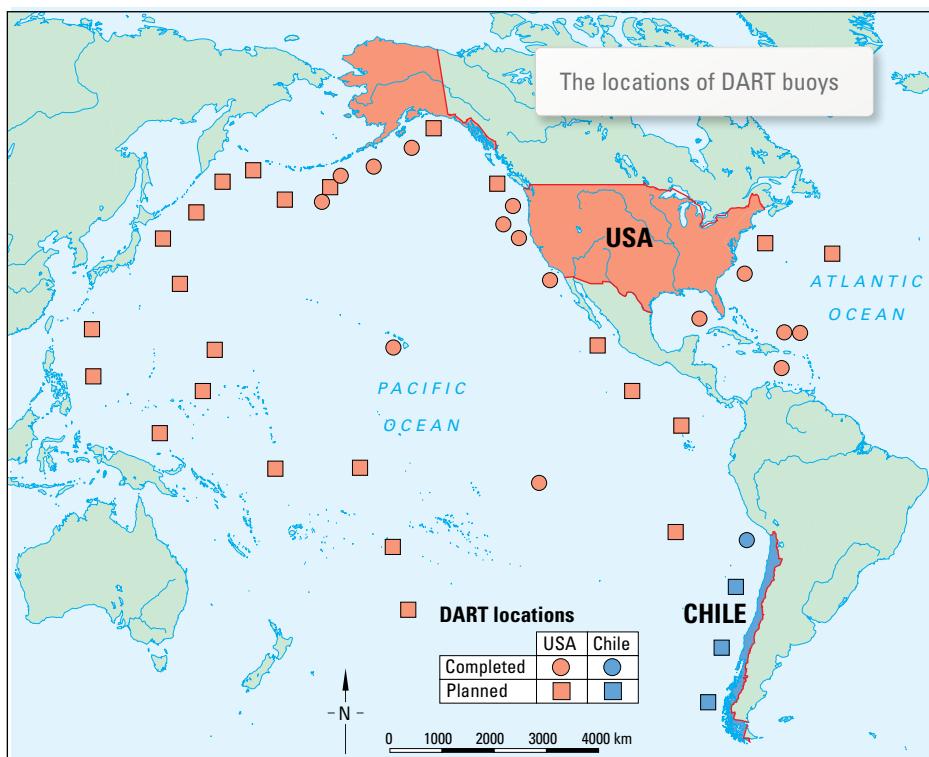
In that city at least 670 people were killed and about 2200 were injured. Around 6900 houses were totally destroyed, with many more partially destroyed. Waves of up to 40 metres in height were recorded on the coast and some caused damage as far as 10 kilometres inland.

Several nuclear reactors were shut down immediately following the earthquake that caused the tsunami.

However, that wasn't enough to prevent **meltdowns** in three reactors at the Fukushima Daiichi Power Plant, resulting in explosions and the leakage of radiation into the atmosphere, water and soil.

Early warning

Tsunami early warning systems rely on the early detection of earthquakes and a system of buoys placed around the Pacific and Atlantic Oceans. This system is called DART (Deep-ocean Assessment and Reporting of Tsunamis). Sudden rises in sea level are detected by the buoys and alerts are sent to tsunami warning centres.



UNDERSTANDING AND INQUIRING

REMEMBER

- 1 How are earthquakes caused?
- 2 Distinguish between an Earth tremor and an earthquake.
- 3 What name is given to the point at which an earthquake begins?
- 4 Where is the epicentre of an earthquake?
- 5 What quantity is the Richter scale a measure of?
- 6 Explain why a tsunami only a few metres high in open ocean can reach heights of up to 30 metres by the time it reaches land.
- 7 Explain how seismologists are able to make predictions about the likelihood of an earthquake.

The tsunami of March 2011 in Japan destroyed entire cities.



ANALYSING DATA

- 8 The table below shows the number of people killed in some of the major earthquakes in recent years.
- (a) List two pairs of earthquakes that provide evidence that the Richter scale does not indicate the loss of life in earthquakes.
 - (b) What factors, apart from the Richter scale measurement, affect the number of deaths in an earthquake?
 - (c) How much more energy was released by the 2004 Sumatra earthquake than the 2010 Haiti earthquake?
 - (d) Suggest why there were more fatalities as a result of the Haiti earthquake.

Year	Location	Number of deaths (approx.)	Richter scale magnitude
1994	Los Angeles, USA	57	6.6
1995	Kobe, Japan	6 400	7.2
1999	Izmit, Turkey	17 000	7.4
2001	Gujarat, India	20 000	7.9
2003	Bam, Iran	26 000	6.6
2004	Sumatra, Indonesia	230 000	9.0
2008	East Sichuan, China	90 000	7.9
2010	Haiti (Caribbean Sea)	316 000	7.0
2011	Sendai, Japan	21 000	9.0

THINK

- 9 Explain why Indonesia is more likely to experience major earthquakes than Australia.
- 10 Outline some of the long-term consequences of the damage done to nuclear power stations by the Sendai tsunami.

INVESTIGATE

- 11 Use the internet or other resources to research and compare the 2004 Sumatra earthquake and the 2011 Japan earthquake. Write a report about the differences between the earthquakes and their consequences.
- 12 Use the **Tsunami** weblink in your eBookPLUS to learn more about the 2004 Sumatra–Andaman tsunami.

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work
sheets

- 8.4 Earthquakes
8.5 Plotting earthquake activity

Mountains of fire

Although most changes in the Earth's crust are slow and not readily observable, the eruption of volcanoes provides evidence that the changes can also be explosive, fiery and spectacular.

Volcanoes are formed when molten rock, or **magma**, from the Earth's mantle bursts through a weakness in the Earth's crust. The eruption of a volcano is usually spectacular. The red-hot molten rock released is called **lava**. It is a mixture of magma and gases, including steam, carbon monoxide and hydrogen sulfide ('rotten egg' gas). A scientist who studies volcanoes is called a **vulcanologist**.

What comes out?

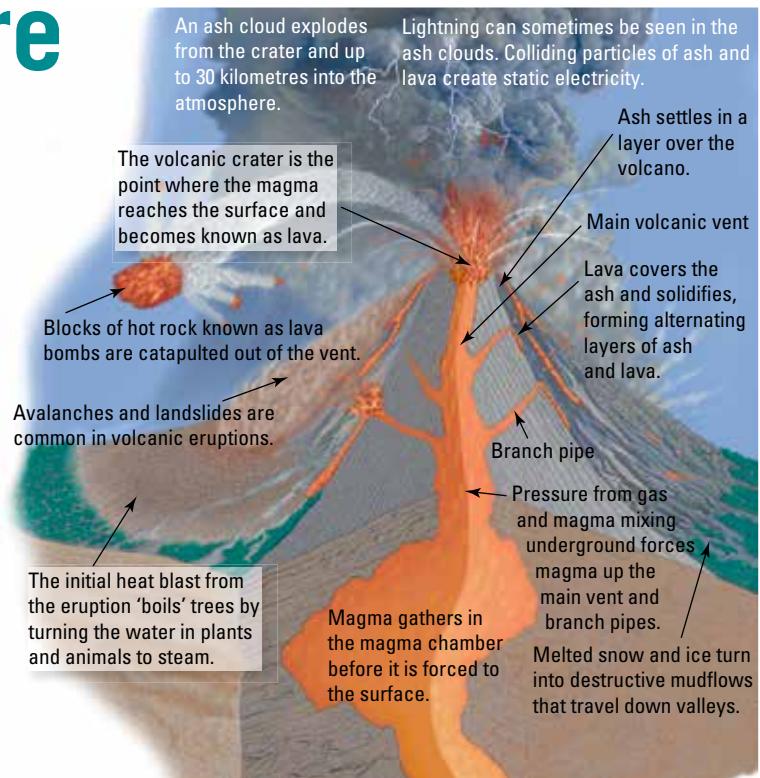
As the pressure builds up in the magma chamber, ash and steam emerge from the vents of a volcano. When the volcano erupts, lava flows from the vents and red-hot fragments of rock, dust and ash, steam and other gases shoot out of the crater. Exploding gases often destroy part of the volcano. The larger fragments of rock blown out of the crater are called **volcanic bombs** or **lava bombs**.

The lava flowing from a volcano can be runny or pasty like toothpaste. If it is runny, it can flood large areas, cooling to form large basalt plains like those in Victoria's western district and in Melbourne, and to the city's north and south.

Thick, pasty lava builds up on the sides of volcanoes and can also block the vents as it cools. When this happens, gases build up in the magma below. As the pressure increases, the volcano can bulge and 'blow its top', thrusting rocks, gases and hot lava high into the air.

Birth of a volcano

On a cool winter's day in 1943, a small crack opened up in a field of corn on a quiet, peaceful Mexican farm. When red-hot cinders shot out of the crack, the shocked farmer tried to fill it with dirt. The next day, the crack had opened up into a hole over two metres in diameter. A week later, the dust, ash and rocks erupting from the hole had formed a cone 150 metres high! Explosions roared through the peaceful countryside and molten lava began spewing from the crater, destroying the village of Paricutin. The eruptions continued and, within a year, the new mountain, named Paricutin, was 300 metres high. When the eruptions stopped in 1952, Paricutin was 410 metres high.



Hot spots

Although most of the world's volcanoes are found at the edges of the plates of the Earth's crust, some lie over hot spots. These hot spots are regions of the crust where the mantle below is extremely hot. The volcanoes of western Victoria and Queensland have formed over hot spots.

Dead or alive?

Volcanoes that are erupting or have recently erupted are called **active** volcanoes. Mount Pinatubo in the Philippines, which erupted in June 1991 killing 300 people, is an active volcano. There was so much smoke and ash coming from Mount Pinatubo that scientists believe that the Earth's weather was cooler for over a year. The cloud of smoke and ash was believed to have blocked out about four per cent of the heat from the sun.

Extinct volcanoes are those that have not erupted for thousands of years. They are effectively dead and are most unlikely to erupt again.

Land ahoy!

Active volcanoes also erupt under the sea. An active volcano below the sea is generally not visible. If layers of lava build up, however, they may eventually emerge from the sea as a volcanic island. Lord Howe Island, off the coast of New South Wales, was formed in

**Volcanoes**

Learn how volcanoes are formed, and what happens when they blow their tops.

eles-0130

this way about 6.5 million years ago. A more recent example is the island of Surtsey, which emerged from the sea off the coast of Iceland in 1963.

There are many extinct volcanoes in Australia. The Glasshouse Mountains of Queensland are the remains of cooled lava trapped in the central vents of volcanoes. Mount Gambier is an extinct volcano whose collapsed craters have filled with water to form beautiful clear lakes. There are many extinct volcanoes in Victoria. Tower Hill, near Warrnambool, is just one example, and there are many others just to the north of Melbourne.

Volcanoes that have not erupted for over 20 years and are not considered to be extinct are called **dormant** volcanoes. Dormant means 'asleep' and these volcanoes could 'wake up' at any time and erupt. Mount Pinatubo was a dormant volcano before its eruption in 1991.

The lack of recent volcanic eruptions and the small number of earthquakes in Australia is due to the fact that most of it is close to the centre of the Indo-Australian Plate (see the map in section 8.2). It is far away from the plate boundaries where new mountains form, major earthquakes occur and new crust is formed.

**Deep-sea mining**

Watch an ABC *Catalyst* video to learn more about where most volcanic activity takes place — not on land, but under the sea.

eles-1086

UNDERSTANDING AND INQUIRING**REMEMBER**

- 1 What can cause a volcano to erupt?
- 2 List the substances that emerge from a volcanic crater during an eruption.
- 3 Explain the difference between a dormant volcano and an extinct volcano.
- 4 What is a hot spot?
- 5 Explain in terms of the plates that form the Earth's crust why Australia experiences little volcanic or earthquake activity.

THINK

- 6 Use a Venn diagram to show the differences and similarities between magma and lava.
- 7 How do you know that many of the volcanoes in the western district of Victoria had runny lava?
- 8 Explain how a volcano can affect the world's weather.
- 9 Should Mount Gambier be described as an extinct or dormant volcano? Explain your answer.

IMAGINE

- 10 Imagine that you are the Mexican farmer who found the crack that gave birth to the volcano Paricutin. Write an account of what you saw and how you felt during the week after you first found the crack.

CREATE

- 11 Write a short story about an underwater volcano entitled *The birth of an island*.

- 12 Compile a collection of newspaper articles about recent volcanic eruptions. Display the collection in your classroom.
- 13 Create a papier-mâché model volcano. Shape some chicken wire into a cone with a small crater at the top. Soak small pieces of newspaper in a pasty mixture of flour and water and attach the sticky newspaper to your wire cone. You will need to apply several layers of newspaper. Use colour to brighten up your model.

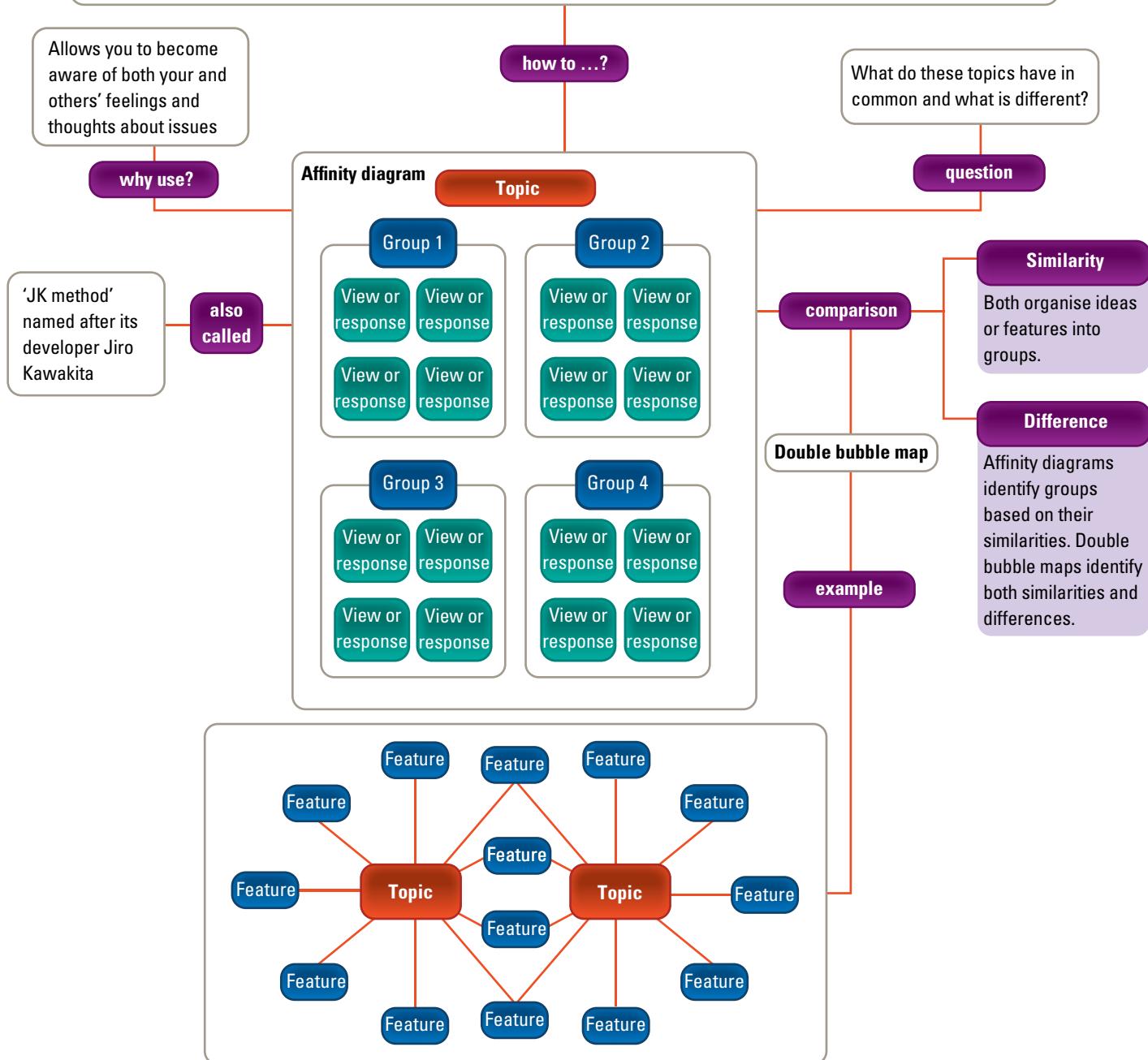
INVESTIGATE

- 14 Find out the name and location of a dormant or extinct volcano that is close to your school.
- 15 Two of the most famous volcanoes in the world are Mount Vesuvius and Mount Krakatoa. Find out where they are, when they erupted and what damage they caused.
- 16 Write an account of a recent major volcanic eruption. Some that you might choose from are:
 - Mount Ruapehu, New Zealand, 1994 and 1996
 - Mount Tavurvur, Papua New Guinea, 1994
 - Eyjafjallajökull, Iceland, 2010.

- 17 Use the **Volcano explorer** weblink in your eBookPLUS to build a virtual volcano and watch it erupt.

Affinity diagrams and double bubble maps

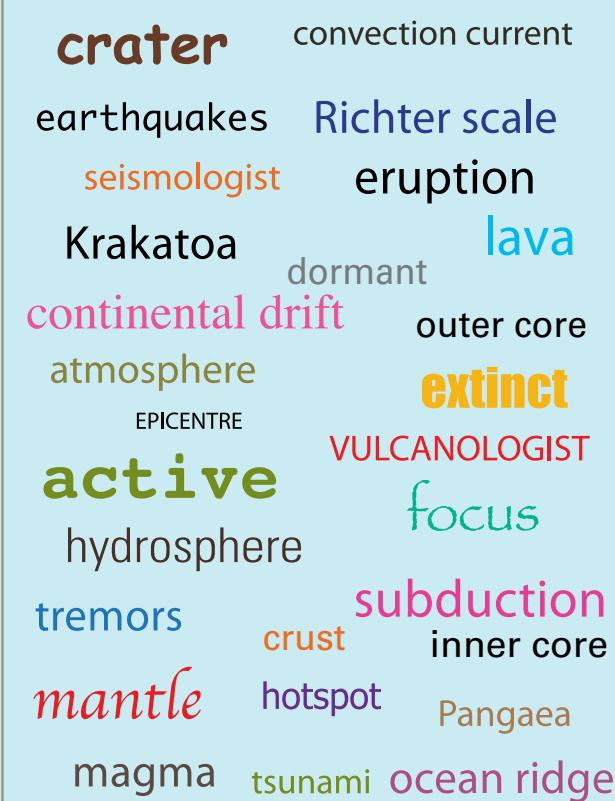
1. Think about a topic and write any ideas you have onto small pieces of paper.
2. Examine your pieces of paper and put similar ideas into groups. Feel free to rearrange your groups until you are happy with them.
3. Think of names for your groups.
4. Now you are ready to draw an affinity diagram like the one below.



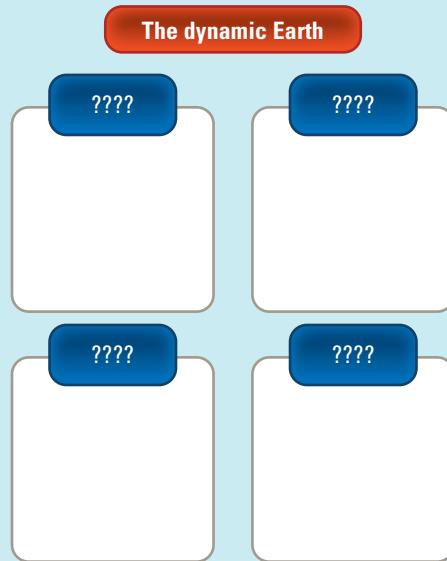
UNDERSTANDING AND INQUIRING

THINK AND CREATE

- 1 (a) Write each of the ideas listed below on a small card or sticky note.

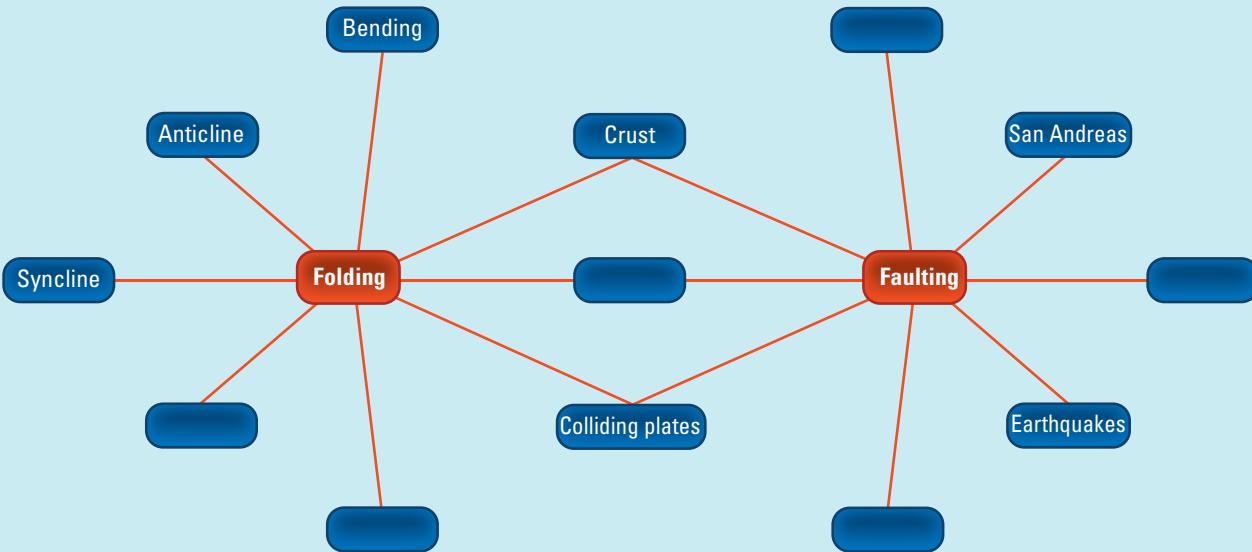


- (b) Arrange the ideas on the cards into four categories in an affinity diagram like the one shown below. Write a title for each category. If any of the ideas fit into more than one category, choose the single category that best suits it.



- (c) Add at least two more ideas to each category.
 2 Use your affinity diagram from question 1 and any other relevant terms to create double bubble maps that illustrate the similar and different features of the following pairs of topics:
 (a) folding and faulting
 (b) earthquakes and volcanoes
 (c) continental drift and plate tectonics.

The figure below can be used to help you get started on a double bubble map for folding and faulting.



STUDY CHECKLIST

THE THEORY OF PLATE TECTONICS

- describe the Earth's crust and compare it with other layers below and above the Earth's surface
- describe evidence supporting the theory of plate tectonics, including the location of volcanic activity and earthquakes
- recognise the major plates on a map of the Earth
- explain the movement of plates in terms of heat and convection currents in the Earth's mantle
- describe, compare and model the processes of subduction and the formation of ocean ridges
- distinguish between constructive and destructive plate boundaries

FOLDING AND FAULTING

- describe and model the processes of folding and faulting
- relate folding to the movement of tectonic plates and the formation of mountain ranges
- explain the formation of faults in terms of the forces acting within the Earth's crust and the movement of plates relative to each other

EARTHQUAKES AND VOLCANOES

- relate the occurrence of major earthquakes and volcanoes to the movements along plate boundaries

- compare the energy released by earthquakes with different values on the Richter scale
- associate tsunamis with earthquakes and volcanic activity
- identify the main features of a volcano
- distinguish between lava and magma
- describe and compare the characteristics of active, dormant and extinct volcanoes
- relate the age and stability of the Australian continent and its lack of volcanic and major earthquake activity to its location away from plate boundaries

SCIENCE AS A HUMAN ENDEAVOUR

- explain how the theory of plate tectonics developed from the earlier theory of continental drift and further evidence
- describe the use of scientific ideas and technology in the development of the theory of plate tectonics
- describe the role of seismologists and vulcanologists in the investigation of the Earth's crust
- explain the importance of early warning systems to people living near plate boundaries, particularly on the edges of the Pacific Ocean.

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DIGITAL RESOURCES



ANSWERS for this chapter can be found online in your eBookPLUS.

Online section

This section of the chapter can be found online in your eBookPLUS.

8.6 Affinity diagrams and double bubble maps

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ONLINE ONLY

Individual pathways

Activity 8.1

Revising the dynamic Earth
doc-8452

Activity 8.2

Investigating the dynamic Earth
doc-8453

Activity 8.3

Analysing the dynamic Earth
doc-8454

eLessons

Drifting continents

In this eLesson you will see how, over millions of years, the giant supercontinent Pangaea broke up to form the continents that we know today.

Searchlight ID: eles-0129

Deep-sea mining

Watch an ABC *Catalyst* video to learn more about where most volcanic activity takes place — not on land, but under the sea.

Searchlight ID: eles-1086

Volcanoes

In this eLesson you will learn how volcanoes are formed, what happens when they blow their tops and how volcanic eruptions change the face of the Earth.

Searchlight ID: eles-0130

Interactivity

Does the Earth move?

Test your knowledge of plate boundaries by clicking on the diagram which best fits a series of statements.

Searchlight ID: int-0674

FOCUS activity

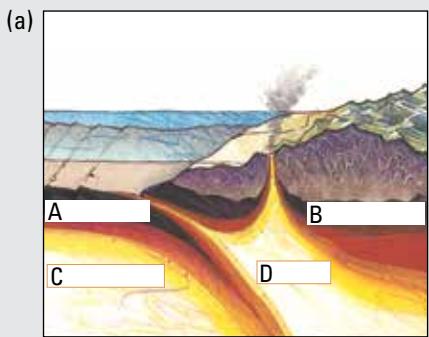
Access more details about focus activities for this chapter in your eBookPLUS.
doc-10658

Instructions
Why do volcanoes suddenly erupt or earthquakes shake and crack the land? The plate boundaries are where these events occur. And they remind us that the Earth crust moves. Test your knowledge of what's on the edge of plates! Click on the diagram that best fits these statements.

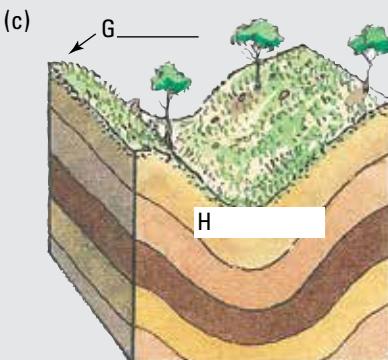
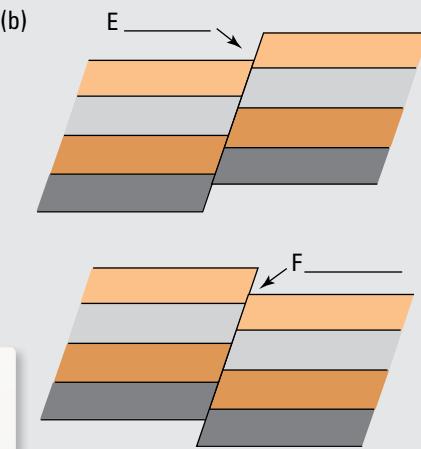
Print

LOOKING BACK

- 1 Which layers of the Earth have the following characteristics?
 - (a) Completely molten
 - (b) Partially molten
 - (c) Includes solid rock, soil and landforms
 - (d) Solid and mostly made up of iron
 - (e) Lies above the surface
- 2 Describe two pieces of evidence that supported Wegener's theory of continental drift.
- 3 Explain how scientists know about what lies deep below the surface of the Earth without going there.
- 4 According to the theory of plate tectonics, the Earth's crust is divided into a number of slowly moving plates.
 - (a) What makes the plates move?
 - (b) What can happen when two plates slide past each other?
 - (c) How does the plate tectonics theory explain the increasing height of the Himalayas?
- 5 What is the major difference between the continental drift theory and the theory of plate tectonics in terms of what makes up the Earth's crust?
- 6 Where on Earth is the Ring of Fire and why does it exist?
- 7 How is an ocean ridge different from a subduction zone?
- 8 When oceanic crust pushes against continental crust, why does the oceanic crust slide underneath the continental crust?
- 9 Describe the movements in the Earth's crust that cause the folding of rock that has shaped most of the Earth's mountains.
- 10 Explain how faults are created.
- 11 Copy the diagrams below and label them using the following words: anticline, continental crust, magma, normal fault, oceanic crust, reverse fault, solid upper mantle, syncline.
- 12 The San Andreas Fault makes much of coastal California, including the cities of Los Angeles and San Francisco, susceptible to earthquakes.
 - (a) Explain why the San Andreas Fault is called a slip fault.
 - (b) What causes major earthquakes along this fault?

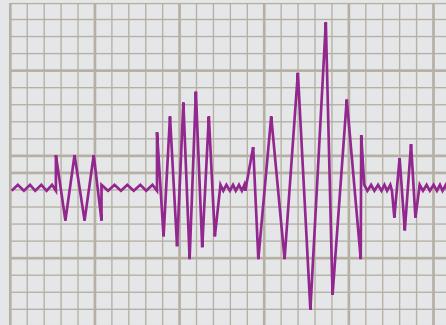


(a) A subduction zone
(b) Two types of faulting
(c) Folding upwards and downwards



Link to assessON for questions to test your readiness **FOR** learning, your progress **AS** you learn and your levels **OF** achievement. www.assesson.com.au

- 13 Distinguish between the epicentre of an earthquake and its focus.
- 14 What is a seismograph used to measure?



- 15 How much more energy is released by an earthquake that registers 6.0 on the Richter scale than by one that registers 7.0 on the Richter scale?
- 16 Suggest two reasons why an earthquake that registers 6.6 on the Richter scale can cause more deaths and devastation than an earthquake that registers 7.9 on the Richter scale.
- 17 Explain why Australia is less likely to experience volcanic activity and major earthquakes than New Zealand.
- 18 Before a volcano erupts, its vents are blocked with thick, pasty lava.
 - (a) What change takes place to cause the volcano to erupt?
 - (b) How is the lava emerging from a volcano different from magma?
- 19 Name three gases present in the lava that are released from a volcano.
- 20 Distinguish between a dormant volcano and an extinct volcano.
- 21 Identify two causes of tsunamis.

ICT ACTIVITY

projectsplus

Disaster-proof

SEARCHLIGHT ID: PRO-0108

Scenario

Earthquakes occur when pressure built up between adjacent sections of rock in the Earth's crust is suddenly released. The bigger the earthquake's magnitude, the greater the amount of energy that shakes the Earth. However, the magnitude of the earthquake is not necessarily a good indication of how deadly it will be. The May 2006 earthquake in Java had a magnitude of 6.2 and caused the deaths of nearly 6000 people, yet the 2004 Guadalupe earthquake was the same size but killed only 1 person. In some cases, magnitude 5.3 earthquakes have killed more people than those with magnitude 8.1. In fact, the key predictors other than magnitude of how deadly an earthquake will be are how heavily populated the area is and what type of buildings are there. Sadly, the majority of people who die in earthquakes do so because the buildings around them fail.

Unlike the more earthquake-prone regions of the world, Australia is not near a plate boundary, but we are not out of danger. The 1984 Newcastle earthquake had a magnitude of 5.6 and resulted in 13 deaths, 160 injuries and damage to over 60 000 buildings. With this in mind, your company — Shakeless Seismic Solutions — has been approached by a wealthy client who wishes to build an earthquake-proof five-storey office

block in Perth. However, yours is not the only company that she has approached. In order to determine which business she will award the contract to, she is asking each company not only to come up with a design, but also to have a scale model of their design tested on a shake-table earthquake simulator.

Your task

Your group will use research, ingenuity and online simulators to design a five-storey office block that will survive an earthquake. You will build a scale model of your design and compete with other groups to determine which model/design is able to withstand the most energetic shaking on the simulator. Your model will need to fulfil the following criteria:

- It should have a total mass of no more than 1.5 kg.
- It should have a base area no bigger than 20 cm × 20 cm and should have a height of at least 50 cm.
- No glue, staples, nails or pins are allowed; however, you may use interlocking pieces.
- It must be freestanding (it may not be stuck to the table in any way).

Before testing, you will be required to explain the main aspects of your design to the client (your teacher) and describe what makes the model and the real building earthquake-proof.

Process

Open the ProjectsPLUS application for this chapter located in your eBookPLUS. Watch the introductory video lesson and then click the 'Start Project' button to set up your project group.

