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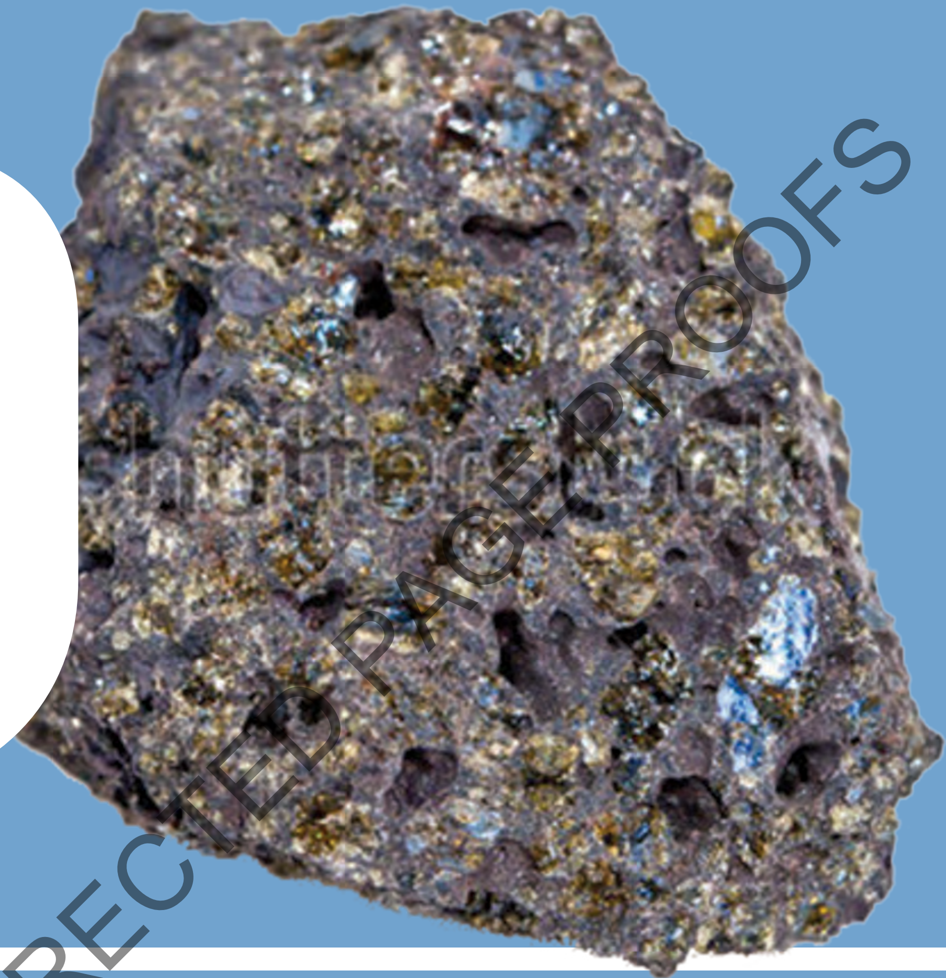


PLATE TECTONICS

Earthquakes in Christchurch and northern Japan in 2011 and the Haiti earthquake in 2010 caused massive destruction and loss of life. What caused these and other earthquakes and volcanic eruptions in the Earth's history? From space, the Earth looks very peaceful, but movements of the Earth's surface can cause huge changes. Did you know that the highest place on the Earth, Mount Everest, was once under the sea? It has been pushed up by movements of the Earth's surface. Similar fossil specimens and rock types have been found on opposite sides of vast oceans. How can this be explained?

TECTONIC PLATES 5.1

Looking at a map of the world it is easy to see why people started wondering if the continents once fitted together like a giant jigsaw puzzle. The distribution of some plants and animals and even fossil species cannot be explained unless the continents had drifted apart over time. These continents have slowly moved across the face of the planet, separating and potentially isolating populations. Whilst these organisms have adapted to their new unique environmental conditions, the rocks that were formed when the continents were joined have remained the same.

Students:

» •outline how the theory of plate tectonics changed ideas about the structure of and changes in the Earth's surface

» •relate continental drift to convection currents and gravitational forces

ACTIVITY AT PLATE BOUNDARIES 5.2

As the huge tectonic plates move across the surface of the Earth, they collide, grind past one another or slowly pull away from each other. This movement produces massive forces that result in earthquakes, volcanic eruptions and even the creation of new land surfaces. The type of interaction between the plates often determines the type of geological activity or landform.

Students:

» outline how volcanic activity, earthquakes and formation of new landforms can be explained using the theory of plate tectonics

THE EARTH IN THE FUTURE 5.3

Advancements in technology have allowed greater understanding of the structure of the Earth and geological activity. Geologists are now able to predict global patterns in the movement of the tectonic plates, which in turn enables geologists to predict climate change and natural disasters.

Students:

» •describe examples of how technological advancements have increased scientific understanding of geological activity, including in the Asia–Pacific region

5.1 TECTONIC PLATES

The movements that cause volcanic eruptions, earthquakes and tsunamis can be described using plate tectonics. The Earth's surface can be thought of as several large, thick plates floating on the liquid magma below the surface. They move slowly and sometimes interact dramatically with each other. Plate tectonics dominates how we think of the Earth's geology because it can explain so many features found here.

PLATE TECTONICS

The understanding of plate tectonics is a combination of two theories: continental drift and sea-floor spreading. **Continental drift** is the idea that the continents are found on plates that continually move and have significantly changed positions over millions of years. The Earth's lithosphere is comprised of **tectonic plates**, which are each made of a solid crust. Tectonic plates are lower in **density** than the molten magma below them and therefore float on the surface. **Convection currents** in the liquid magma means there is continuous movement below the surface, pushing, pulling and stretching the tectonic plates.

Sea-floor spreading is a theory proposing that the middle of the ocean is spreading apart, moving very slowly in opposite directions and pushing the plates away.

Some of the evidence that supports the theory of plate tectonics includes:

- Outlines of the continents fit together well enough to suggest they were once joined.
- The same fossils are found on different continents with vast distances between them, which can only be explained if those two continents were once joined.
- There is significant geothermal, volcanic and seismic activity along the edges of the continental plates.
- Growth of the sea floor and its destruction near continents explains the movement of continents. Studies of magnetism of ancient rocks (palaeomagnetism) and the discovery of mountain ranges in the middle of oceans support the theory of sea-floor spreading.

Figure 5.1 Tectonic plates of the world.

ACTIVITY 5.1.1: WHERE IN THE WORLD ARE TECTONIC PLATES?

Examine Figure 5.1 using the key on the map. In small groups discuss what all the symbols mean and find them on the map.

What are the links between the symbols? For example, how do the yellow arrows explain what 'convergent' means? What do you notice about the locations of many of the yellow triangles and brown dots? What do you notice about Australia's location and lack of dots and triangles? Australia has many ancient extinct volcanoes and has had many smaller earthquakes – how does your group think these formed?

Continental drift

For many years in the past, people noted the similarities in shape between the coastlines of Africa and South America. They seem to fit together like a jigsaw puzzle. In the early 20th century, a German meteorologist named Alfred Wegener put this idea, with a range of other evidence, into a book where he outlined the theory we know today as continental drift. He proposed that the continents once all fitted together into a giant continent known as **Pangaea**.

Pangaea was a supercontinent that Wegener proposed to have existed 220 million years ago. When it started to break up, the continents slowly drifted apart as they moved through the oceanic crust. He backed up his claims with evidence such as the shapes of coastline that 'fit' together, similar fossils, and rocks and landforms created by glaciers in now widely separated continents.

Convection currents

The semi-molten rock of the **mantle** closest to the core of the planet is heated by the radioactive decay of radioisotopes. As this viscous liquid is heated, it expands and becomes less dense than the surrounding material. The hotter mantle rises towards the surface of the planet and spreads out beneath the solid crust of the tectonic plates, pushing and pulling them around. As the mantle cools again, it sinks deeper towards the core to be reheated. The cyclic movement of heated and cooling mantle creates the convection currents that move the tectonic plates. While this sounds very dramatic, the movement of the mantle is only about as fast as the growth of human fingernails!

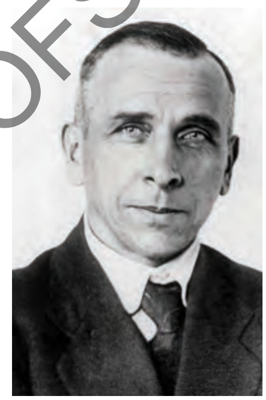


Figure 5.2 Alfred Wegener pioneered the theory of continental drift in his book *The Origin of Continents and Oceans* (published in 1915).

Figure 5.3 The Pangaea supercontinent.

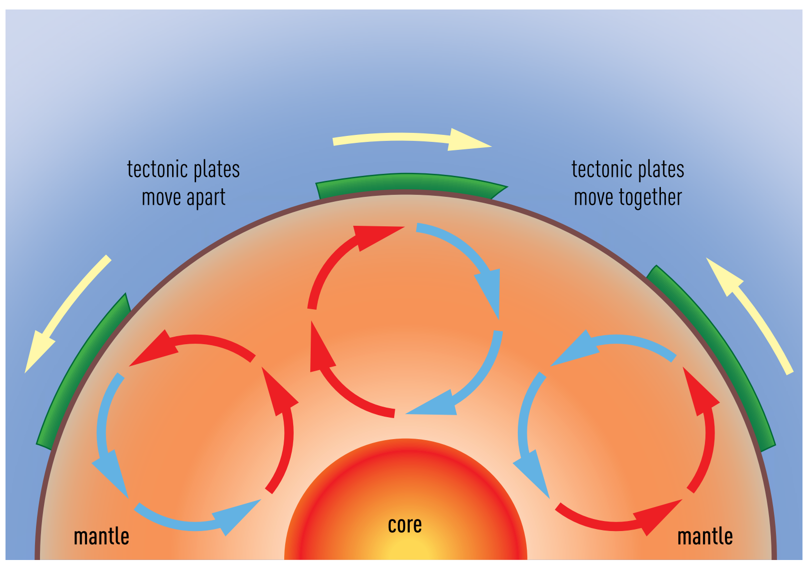


Figure 5.4 Continental drift is explained by the convection currents of the mantle below the solid crust of the tectonic plates.

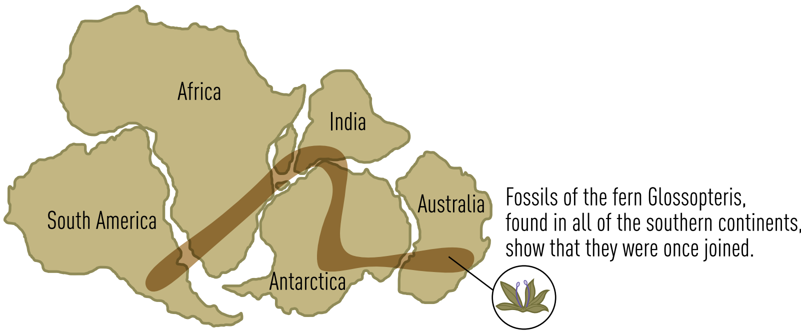


Figure 5.5 Given that the fossil fern *Glossopteris* cannot walk, swim or fly, how can its isolated occurrence in so many different parts of the world be explained?

Wegener's theory did not include forces large enough to separate the continents. His ideas were accepted by some geologists but rejected by others, who thought the geological features of the Earth were caused by cyclic heating and cooling of the planet. This cycle of heating and cooling was thought to cause the continents to expand and contract, resulting in earthquakes, volcanic eruptions and other geological movement.

ACTIVITY 5.1.2: RECONSTRUCTING PANGAEA

What you need: photocopy of a map of the world, scissors and glue

1. Roughly cut out the continents of the world and fit them back together in the shape of Pangaea. You may use Figure 5.2 as a guide.
2. Remember to cut off India from Asia because it was once separated.
3. When you are happy with your supercontinent, glue the pieces into your work book.
4. You may like to add to your supercontinent what you know about the locations of the fossil and glacier evidence.

Tectonic plate movement

We now know it is not just the continents themselves that are moving: the large moving areas include continental and oceanic crust. Geologists call these moving areas tectonic plates; 'tectonic' means 'building', so tectonic plates are the 'building blocks' of the Earth.

Movement of the plates explains the existence of landforms such as **continental shelves** (shallower ocean around a continent that drops off steeply into deep water) and deep trenches in the ocean floor, as there are areas where the continents are being pulled apart from each other. It also explains earthquake and volcano distributions found on the edges of the plates, and the very young age of parts of the sea floor. Plate tectonics is a good example of how a scientific hypothesis can be suggested, discounted, modified and then reborn.

Figure 5.6 The Mid-Atlantic Ridge is evidence of sea-floor spreading.

Sea-floor spreading

Harry Hess, an American geologist, proposed the hypothesis of sea-floor spreading. His evidence came from the discovery of the Mid-Atlantic Ridge, a continuous underwater mountain range in the middle of the Atlantic Ocean. Hess's original hypothesis was that convection currents deep inside the mantle caused spreading.

If convection does occur within the Earth's mantle, then rising hot magma can push up the thin oceanic crust to form a ridge crest. Oceanic crust is typically thinner than continental crust, which is why ridged crests are only formed under water.

Mantle rock moves away from the ridge on each side and creates tension, causing the ridge to crack, forming a rift zone and shallow earthquakes. The mantle rock carries the sea floor with it. The rock cools, becomes denser, and eventually the force of **gravity** causes it to sink back into the mantle. It has been found that magnetic patterns on opposite sides of **mid-ocean ridges** are mirror images of each other, supporting the idea that rock is spreading away. This has been confirmed using methods such as drilling in the sea floor and estimating the age of the rocks.

Every ocean in the world has been found to contain a mid-ocean ridge. These combine to form the longest mountain chains on the Earth. One of the fastest spreading areas is along the southern edge of the East Pacific Rise, a mid-ocean ridge in the Pacific Ocean. Scientists discovered the East Pacific Rise using a technique called echo sounding, a type of sonar that measures the depth of the ocean. Sound waves are 'bounced' off the ocean floor and the time the sound wave takes to return is used to calculate the water's depth.

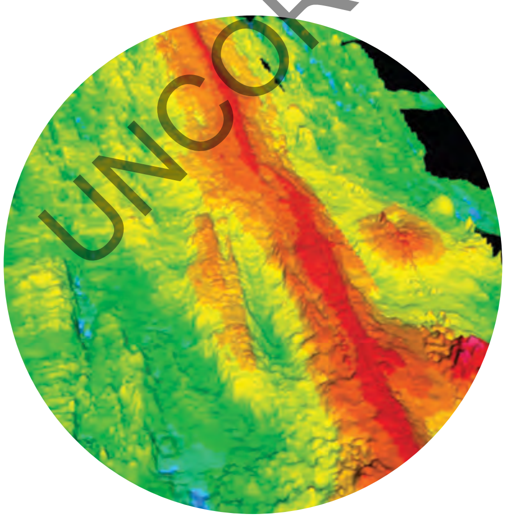


Figure 5.7 This image was formed by echo-sounding equipment. The fast-spreading centre of the East Pacific Rise is shown in red.

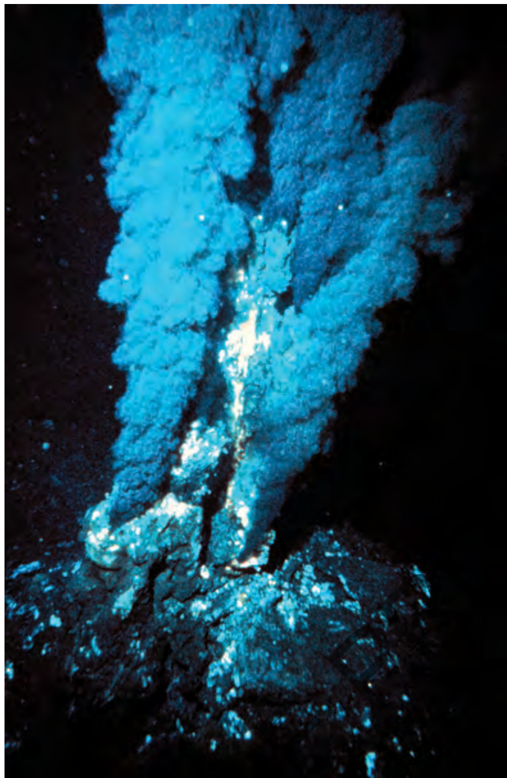


Figure 5.8 A 'black smoker' or ocean vent.

Scientists analyse echo-sounding images to determine how a particular feature was formed and to predict what might be happening below it, deep inside the Earth's mantle.

In 1977, unusual geological structures called black smokers were discovered near the East Pacific Rise. They form when superheated water, rich in dissolved minerals, exits the Earth's crust through a vent hole. When the hot water reaches the cold ocean, the dissolved minerals precipitate (move out of the solution as a solid), forming a chimney-like structure that can reach a height of up to 60 metres. The black smoker named 'Godzilla', off the coast of Oregon in the United States, reached a height of 40 metres before it toppled over. In some places these cracks give rise to hot springs or geysers.

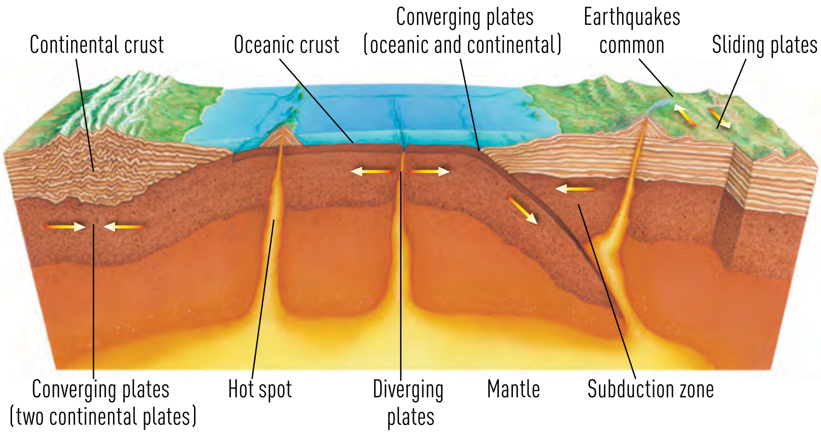


Figure 5.9 Some common landforms created as a result of tectonic plate movement.

The idea that plates move is widely accepted by geologists, but exactly how the movement happens is not fully understood. Convection currents are the most widely accepted theory and explain the landforms seen in Figure 5.9. If the edges of two plates are both land masses, a collision zone occurs and folded mountain ranges result.

The centre of a plate usually lacks earthquakes, volcanoes or folded mountain ranges because it is a long way from a plate boundary, although these landforms are still possible in areas of weakness or thinning of the plate. The theory of plate tectonics and what happens at the plate boundaries corresponds nicely with the distribution of most earthquakes and volcanoes around the world (refer back to Figure 5.1). Consider Australia's location and the frequency of earthquakes and volcanoes on our continent.

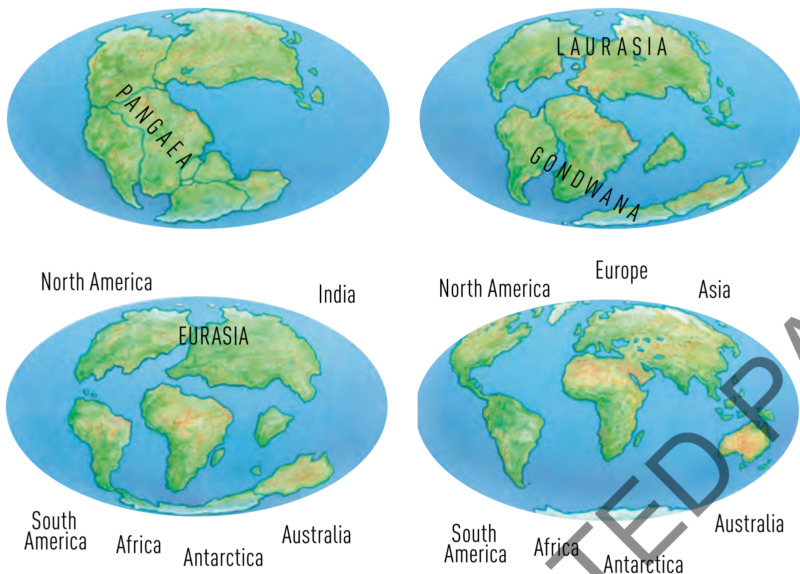


Figure 5.10 How the continents have drifted: (a) 220 million years ago; (b) 135 million years ago; (c) 65 million years ago; (d) the continents today.

EXPERIMENT 5.1.1: CONVECTION CURRENTS

Aim

To investigate how a supercontinent may have broken up into smaller pieces.

Hypothesis

Read the method and predict what will happen when the beaker contents are cooled, based on your scientific knowledge. Give reasons for your prediction.

Materials

- Bunsen burner
- Tripod
- Heatproof mat
- Gauze mat
- Beaker (250 mL)
- Big spoon
- Rice (alternatives include waste paper from a hole punch or broken instant noodles)
- Cooking oil

Method

1 Place a spoonful of rice into the beaker and add 100 mL of water.

2 Pour a thin layer of cooking oil over the surface of the water.

3 Set up the heating equipment and heat the water in the beaker. The rice will show how the water moves as it is heated.

Results

Describe what happens to the rice and the oil when the water begins to boil.

Discussion

1 Why did the rice move as it did when the water was heated?

2 How does this experiment relate to the breaking up of Pangaea?

Conclusion

Write a conclusion for this experiment and relate it to your aim and the breaking up of Pangaea. How accurate was your prediction?

The Hawaiian Islands

The Hawaiian Islands are in the centre of the Pacific Plate. Hawaii is not near a mid-ocean ridge, yet it has frequent volcanic activity. Most geologists believe this volcanic activity is caused by the movement of the Pacific Plate over a 'hot spot' beneath the plate. This is where a plume of hot magma from the mantle comes up through the crust and creates a volcano. In the case of the Hawaiian Islands, the hot spot formed an undersea volcano. As time goes by, the volcano grows until it pokes above the ocean surface and creates an island. As the plate moves over the hot spot, other islands are built over millions of years and an island 'chain' is created.

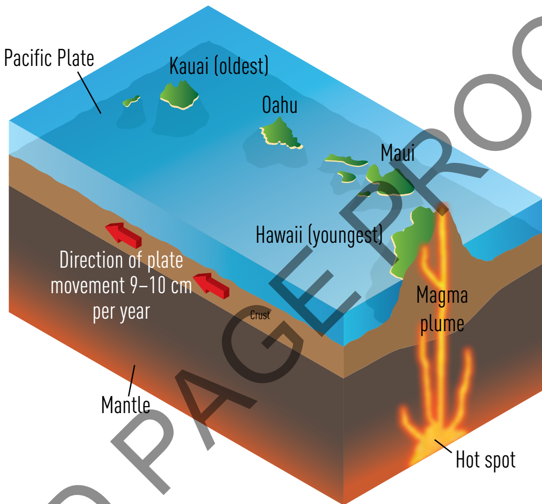


Figure 5.11 How the Hawaiian Islands were formed. (Only the largest islands are shown.)

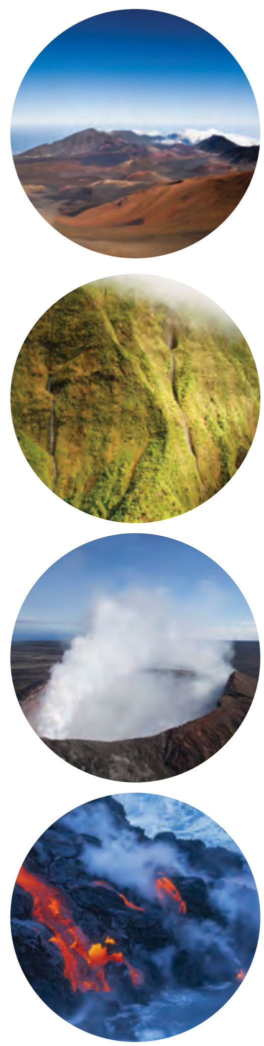


Figure 5.12 (clockwise, a–f) There is a lot of evidence of volcanic activity on the Hawaiian islands such as rocks that appear to flow into the sea formed from old lava flows (a), mountains that rise out of the sea (b), volcanic rock formations (c), lava flows from active vents (d), steam that rises from craters (e), and steep cliffs of volcanic rocks (f).

NUMERACY BUILDER

Age of the Hawaiian Islands

The Hawaiian Islands are volcanic islands that have formed over a hot spot in the Pacific Ocean (Figure 5.11). This type of island formation leaves a characteristic pattern of rock ages (see Table 5.1). The location of the islands is shown in Figure 5.13.

Table 5.1 Age of formation of the Hawaiian Islands.

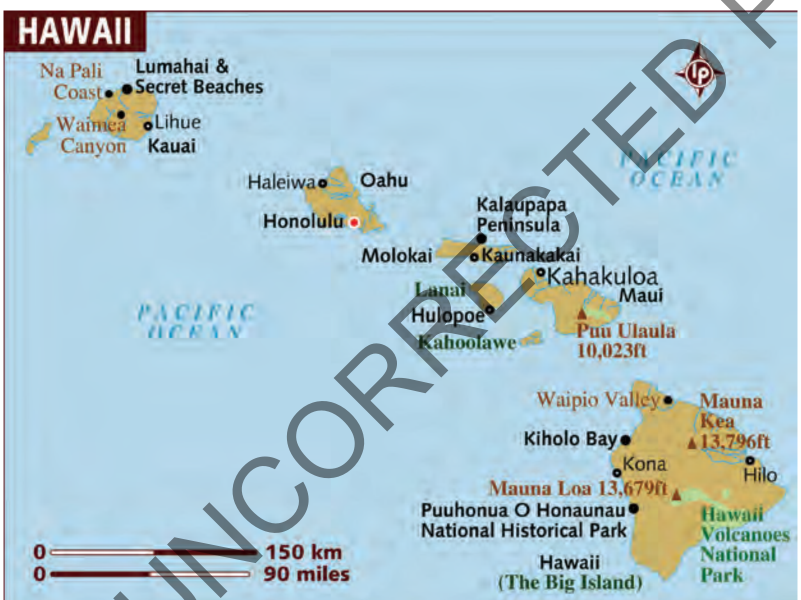
Island	Oldest rock age (× 100 000 years)
Kauai	51.0
Oahu	30.0
Molokai	18.0
Maui	13.2
Hawaii	4.0

1 Measure the distance between each pair of islands.
2 Use the scale on the map to convert each measurement to kilometres.
3 Draw up a results table as shown, subtracting the ages of the islands to determine the age difference.
4 Calculate the movement of the

Results

Island pair	Distance (mm)	Distance (km)	Age difference	Speed of Pacific Plate (km per 100 000 years)
Kauai – Oahu				
Oahu – Molokai				
Molokai – Maui				
Maui – Hawaii				

Figure 5.13 Map of the Hawaiian Islands.



- What trend do you observe in the age of islands and their location?
- What is the relationship between island size and age? Can you explain this trend?
- What direction is the Pacific Plate moving?
- Does the Pacific Plate move at a constant rate? What factors might affect the rate of movement?
- What are the advantages and disadvantages of calculating plate movement using a hot spot island chain? What other technology might be useful for this purpose?

QUESTIONS 5.1.1: PLATE TECTONICS

Remember

1 Outline how convection currents work.
2 Explain how gravitational forces help move the Earth's plates.
3 Explain how a rift zone forms at the top of a mid-ocean ridge.
4 Identify the land formation that forms as plates move away from each other at the mid-ocean ridges due to sea-floor spreading.

Apply

TECTONIC PLATES

5.1 CHECKPOINT

Remember and understand

1 Match the following terms with their definitions. [5 marks]

tectonic plate	theory where large plates of the Earth's crust gradually move
convection current	large area that may include continent and sea floor
magma	theory where the continents moved through oceanic crust
continental drift	movement in liquids or gases caused by the rising of hot material
plate tectonics	hot liquid rock that comes up from the mantle

2 Is Alfred Wegener responsible for the theory of continental drift, sea-floor spreading, plate tectonics or a combination of these? Explain your answer. [3 marks]

3 Outline what Pangaea was and what happened to it. [2 marks]

4 Outline the evidence Alfred Wegener used to support his theory of continental drift. [2 marks]

5 Explain what provides the force for moving tectonic plates over the surface of the Earth. [1 mark]

6 Identify some of the causes of major volcanic eruptions and earthquakes on the Earth. [1 mark]

7 In point form, summarise the main components (or parts) of the theory of plate tectonics. [3 marks]

8 Describe a technology that is helping scientists learn more about geological activity. [1 mark]

Apply

9 Most earthquakes occur at plate boundaries. Examine how an earthquake can occur in the middle of a plate. [1 mark]

10 Research the Ring of Fire and answer the following questions: Where is it found? Why does it have that name? What is the connection with plate tectonics? What happens in this region more often than in other regions of the Earth? Why do they occur here? What do trenches and mountain ranges have to do with the Ring of Fire and plate tectonics? [6 marks]

Analyse and evaluate

11 Examine Figure 5.14, which shows an image of the East Pacific Rise. Explain how this provides evidence for sea-floor spreading [2 marks]

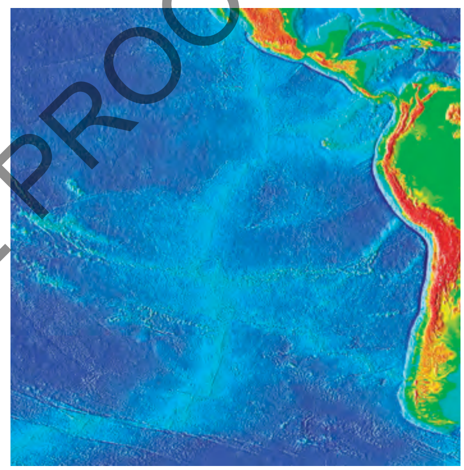


Figure 5.14 Topographical image of the East Pacific Rise off the west coast of South America. The 'hotter' the colour, the higher the elevation.

12 If a part of the Pacific Plate is moving at a rate of 10 cm per year, calculate how far would it move in:

a 100 years [1 mark]

b 10 000 years [1 mark]

c 1 million years [1 mark]

Critical and creative thinking

13 Create a poster or multimedia presentation about a famous earthquake or volcanic eruption, listing the facts of the earthquake/eruption and what plate movement caused it. Also include the social, environmental and economic impact of the quake/eruption and the subsequent recovery process. Use a recognised method to acknowledge your sources of data and information. [5 marks]

Making connections

14 Long ago, there was a supercontinent on the Earth called Pangaea. Initially it split into two parts: Laurasia moved north, Gondwana moved south. Laurasia gave rise to Europe, Asia and North America. Gondwana gave rise

overmatter

TOTAL MARKS
[/40]

5.2 ACTIVITY AT PLATE BOUNDARIES

Plate tectonics has become an important theory of geology because it can explain a wide range of features of the Earth. These features, once studied separately, can now be unified by a single concept: plate behaviour at plate boundaries. There are three general types of plate boundaries, based on the direction of plate movement. At transform boundaries plates slide past one another; at converging boundaries they come together; at diverging boundaries they move apart. Earthquakes and volcanoes are only some of the **natural disasters** that can occur at plate boundaries.

TRANSFORM BOUNDARIES

One plate can slide past another along a single fault line (see Figure 5.15). This is called a **transform boundary**. A **fault** is a fracture in rock where movement has occurred. A transform boundary is also often referred to as a **strike-slip** fault zone.

The two plates involved in a transform boundary can become jammed over a period of time until the pressure builds up and the plates suddenly slip. This slipping causes earthquakes such as the magnitude

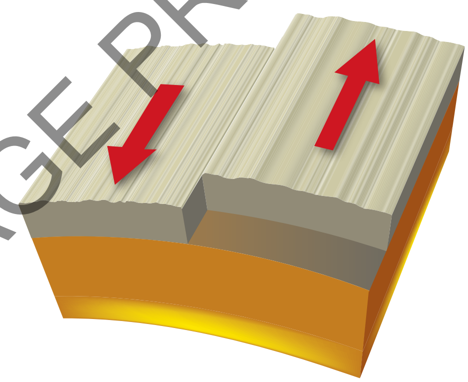


Figure 5.15 Transform boundaries: one plate slides against another.

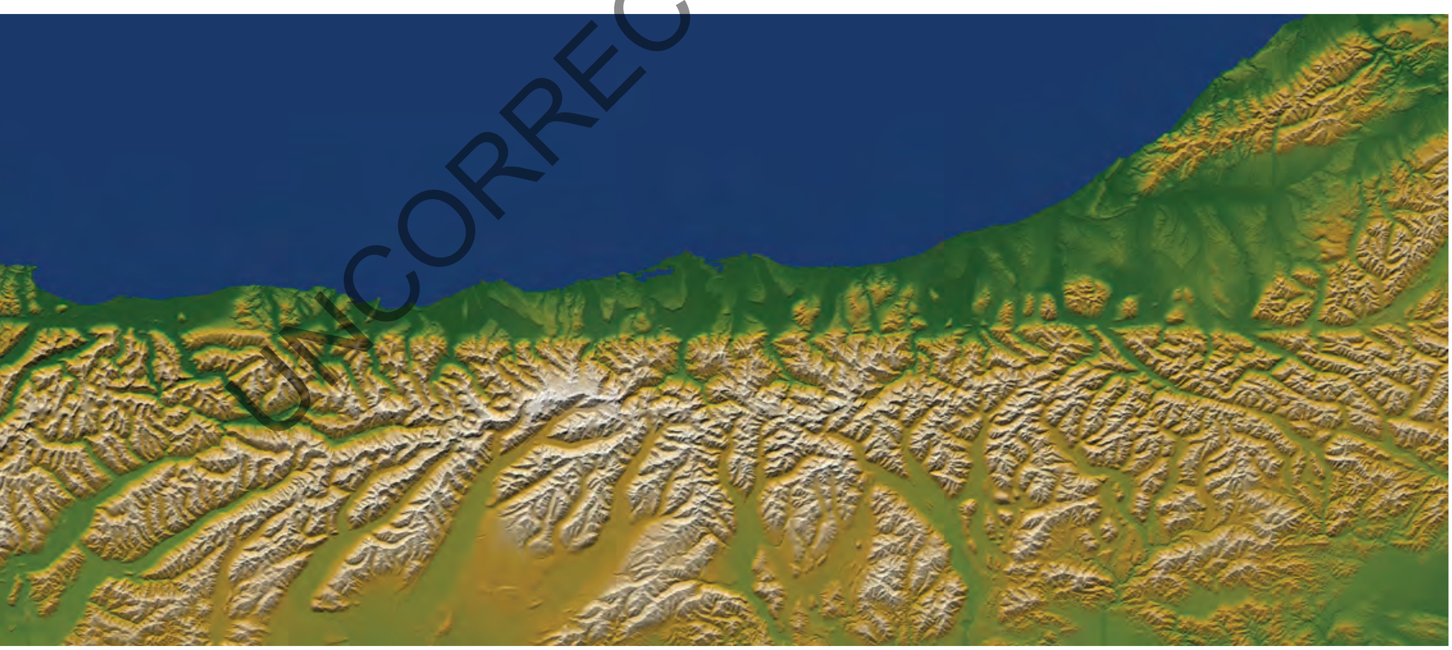


Figure 5.16 A satellite image of the Southern Alps, New Zealand. The Alpine Fault, a transform boundary, runs along the western edge of the snowline on the South Island.

7.8 earthquake that destroyed San Francisco in 1906, where the rock of the transform fault slipped by up to 5 metres. The recent earthquakes in Haiti and Christchurch, New Zealand, were also caused by transform faults.

Plate material is not created or destroyed; the plates just slide against each other. There are several types of transform faults but all are characterised by shallow **focus** earthquakes that are usually aligned along the fault.

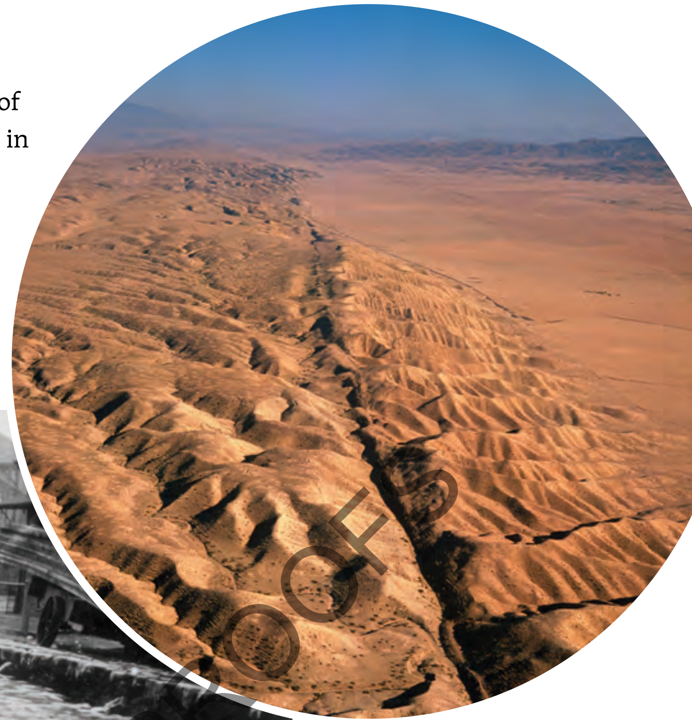


Figure 5.17 The San Andreas Fault in the United States.

Figure 5.18 The San Francisco earthquake in 1906 destroyed much of the city.

QUESTIONS 5.2.1: TRANSFORM BOUNDARIES

Remember

1 Identify the type of plate movement that happens at a transform boundary.

2 Recall if earthquakes that occur along fault lines are deep or shallow.

3 Identify some famous transform fault lines and state where they are located.

Apply

4 Are the earthquakes that occur along transform faults ever violent? Explain your answer.

5 Explain if transform boundaries occur between continental plates, oceanic plates, or between continental and oceanic plate boundaries.

6 Transform boundaries are also called strike–slip fault zones. Explain why this name is appropriate.

CONVERGING BOUNDARIES

At converging plate boundaries, two plates move towards each other. There are generally three types of converging boundaries, depending on the plates involved. Mountain ranges, volcanoes and trenches can all be formed by **converging boundaries** and devastating earthquakes can also occur. Many of the world's major landforms are formed by the collision of plates at converging boundaries.

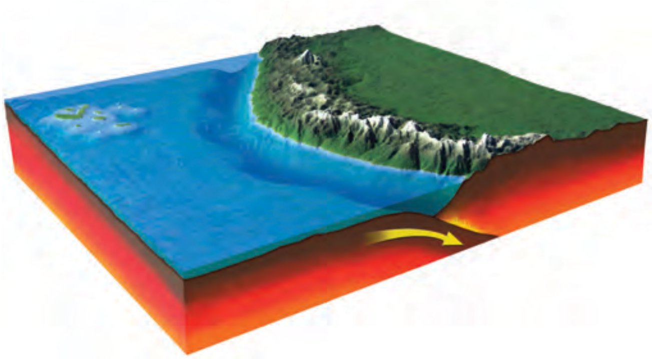


Figure 5.19 Ocean-to-continent collision causes subduction. It creates mountains, volcanoes and an ocean trench.

Ocean-to-continent collision

When oceanic plates collides with continental crust, the oceanic crust is pushed downwards into the mantle because it is denser than the continental crust. This is known as **subduction**. It creates a line of mountains along the crumpled edge. Volcanoes are also formed as the subducting plate begins to melt and the molten material rises back up through the crust. An **ocean trench** will form at the line of plate contact, on the edge of the continent.

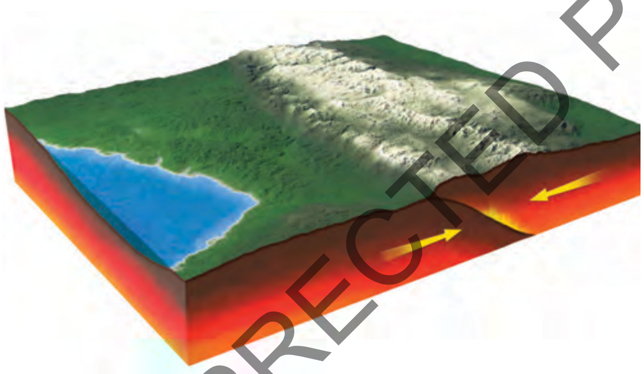


Figure 5.20 Continent-to-continent collision creates high mountain ranges.

Continent-to-continent collision

When two continental plates collide, they have similar densities, so no subduction takes place. Instead, the edges of the two plates crumple and fold into high mountain ranges. The Himalayas are still growing in height as the Indian plate continues to push into the Eurasian plate.

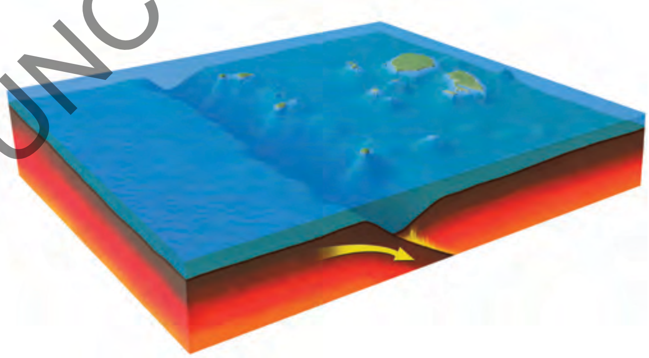


Figure 5.21 Ocean-to-ocean collision causes subduction. It creates a trench and a line of undersea volcanoes.

Ocean-to-ocean collision

When two oceanic plates collide, the older, denser crust will subduct below the newer crust, creating a deep ocean trench. The subduction also creates a line of undersea volcanoes that may reach above the ocean surface as an island arc. Many of the islands of Japan and Indonesia have been formed in this way.

ACTIVITY 5.2.1: CHOCOLATE PLATES

What you need: soft chocolate bar (such as Mars Bar or Milky Way), spatula, baking paper

WARNING

> Wash your hands before starting this activity.

1. Lay a sheet of baking paper on the desk to provide a clean surface for this activity.
2. Use a clean spatula to cut the chocolate bar in half.
3. To illustrate a transform boundary, gently push the 'plates' back together, then slide one half of the chocolate bar forward and the other backwards.
   - Describe what happens.
4. To illustrate the force of compression associated with mountain building when continental plates collide, push on both ends of the chocolate bar to squeeze it together.
   - What do you notice about the plates now?

DEEPER UNDERSTANDING

Mariana Trench

The Mariana Trench is the deepest part of the world's oceans, making it the lowest surface of the Earth's crust. Its current depth is estimated to be up to 10 971 m. This means if Mount Everest (the highest mountain on the Earth, at 8848 m) were placed into the deepest part of the Mariana Trench, there would still be 2123 m of water above it. The trench is located in the western Pacific Ocean, near the Philippine Islands and to the east of the Mariana Islands (Figure 5.22). The trench is about 2550 km long and has an average width of 69 km. The deepest part of the trench is called Challenger Deep and is a small slot-shaped valley in its floor at its southern end.

The Mariana Trench forms the boundary between two tectonic plates: the Pacific Plate and the small Mariana Plate. The Pacific Plate is subducting under the Mariana Plate.

Figure 5.22 The location of the Mariana Trench.

ACTIVITY 5.2.2: VOLCANIC BUBBLES

Carbonated soft drinks contain large amounts of dissolved carbon dioxide gas. These are supersaturated solutions, and contain more carbon dioxide than they would normally because they are under high pressure. As the pressure is released, the excess carbon dioxide comes out of solution in the form of bubbles.

Part 1

What you need: an unopened bottle of soft drink (lemonade is best because it is clear)

1 Observe the unopened soft drink bottle. Make a note of the number, position and relative size of any bubbles you can see.
2 Carefully twist the lid of the bottle until you hear the seal break. Again, observe the bottle for bubbles.
3 Slowly continue to open the bottle and take note of the amount, size and movement of the bubbles that form.
   - Draw a flow chart to show the changes in the observed bubbles as you opened the soft drink bottle.
   - Describe what happens to the bubbles (size, number and movements) as the pressure is released.
   - Suggest an explanation for these changes.
   - The magma inside a volcano is under huge amounts of pressure. When a section of the crust is weakened for some reason, the pressure can break through the crust allowing the hot magma below to expand out of the break, resulting in an eruption. Explain how this process is similar to the bubble formation in an opened bottle of soft drink.

Part 2

What you will need: powdered chalk, vinegar, red food dye

1 Mix a small amount of powdered chalk with a few drops of food dye.
2 Add a teaspoon of vinegar. The reaction produces carbon dioxide bubbles and the food dye makes the froth look like lava.
3 Scientists use many different types of models in order to explain how scientific or physical phenomena work. Using this activity, suggest the scientific process that you have modelled. Identify any faults to your model and explain how you could have improved your model.

Figure 5.23 Gas bubbles formed the holes in this piece of pumice rock.

Earthquakes in Australia

Unlike New Zealand, Australia is not located near a plate boundary and so our earthquake activity is minimal. However, there are still over 300 earthquakes of magnitude 3.0 or greater in Australia every year. Our plate, the Indo-Australian Plate, is moving north towards the Eurasian, Philippine and Pacific plates. This creates stress within our plate, and release of this stress causes earthquakes. One of Australia's worst earthquakes was of magnitude 5.6 and struck near the city of Newcastle in New South Wales on 28 December 1989. It killed 13 people and injured another 160. Larger earthquakes have occurred in Australia, but the damage depends on how close they are to the surface and to large cities. A large earthquake in the outback is unlikely to cause large loss of human life.

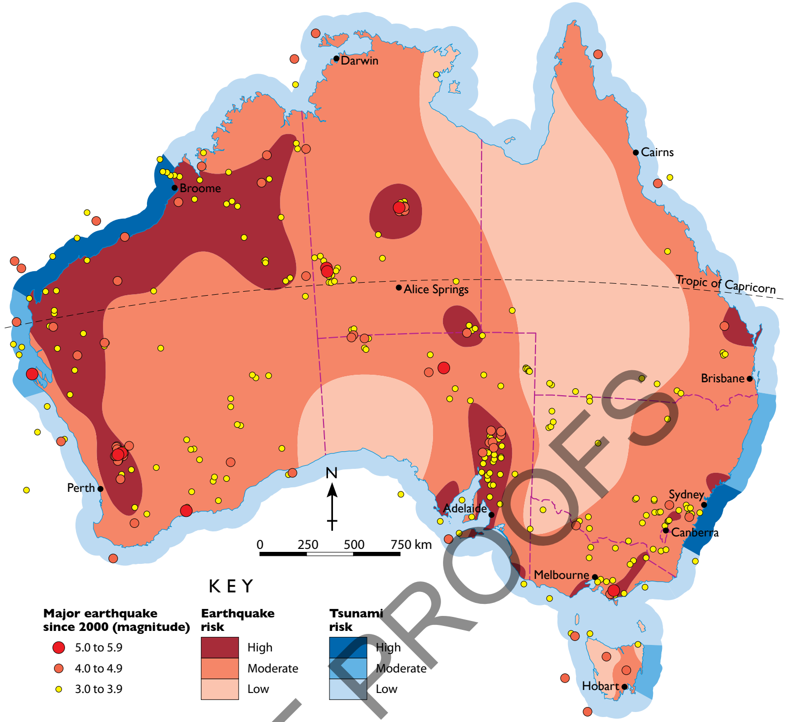


Figure 5.24 Earthquake and tsunami risk in Australia.

STUDENT DESIGN TASK

Measuring the density of rocks

Different types of rock have characteristic densities. Differences in density determine what happens when tectonic plates collide.

Challenge

Determine the density of rocks from continental crust (granite) and oceanic crust (basalt).

Materials

Hand-sized samples of basalt and granite
Selection of containers
Measuring cylinder
Balance – accurate to 0.1 g
Tap water

Planning and conducting

- To calculate the density of a rock, you need to measure its mass and volume. To determine the volume of an irregular object, you can measure, as Archimedes did, the volume of water that it displaces. Apply Archimedes' idea to your rock samples to measure volume.
- Use a balance to measure mass. Mass divided by volume equals density. Be sure to include your units.
- Write a step-by-step description of your method. Remember to identify and assess any risks involved.

Processing, analysing and evaluating

1 Compare your density results to those of your classmates.
   - Did everyone get similar values or is there variation?
   - Can you account for the variation in measurements?

2 How could you improve your method and/or equipment to get more accurate results?

3 Compare the class results to published values for the density of granite and basalt. How close did you come to the accepted values?

4 Explain how density can be used to predict whether one plate will slide under another when they collide.

Communicating

Write up your experiment as a formal scientific report. Make sure you include all the appropriate sections and write in the third person.

Earthquakes causing tsunamis

Undersea earthquakes can move the sea floor and push up the water to form giant waves known as **tsunamis**. The earthquake in northern Japan in 2011 was a magnitude 9.0 earthquake centred 140 km off the coast. It sent a 10-metre-high wall of water towards coastal towns and cities along the shore. The tsunami wave also travelled away from Japan, right across the Pacific Ocean, and was experienced as far away as North and South America, the Pacific Islands and even in northern Australia as a smaller wave.

Japan is one of the most seismically active countries in the world because it lies near the boundaries of three tectonic plates: the Pacific, Eurasian and Philippine plates. The force of a tsunami can be enormous, enough to demolish buildings and lift cars, and even small ships.

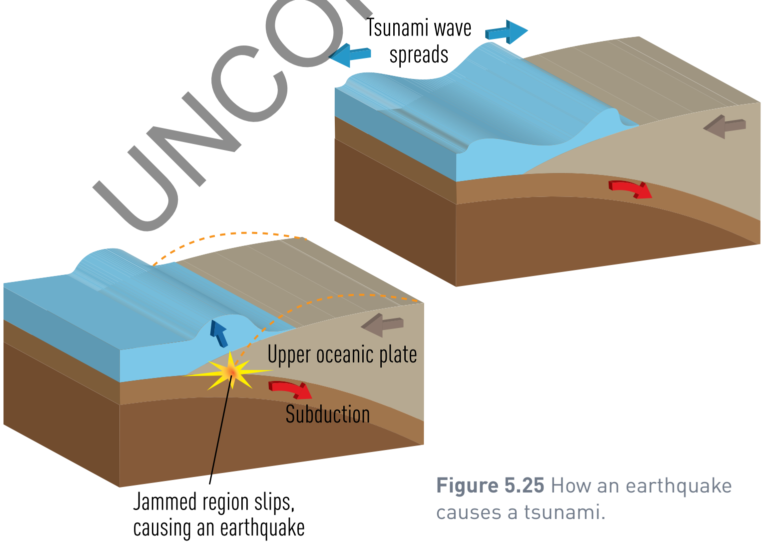


Figure 5.25 How an earthquake causes a tsunami.

Volcanoes causing tsunamis

Like earthquakes, volcanoes pose great dangers to those who live near them. The volcanic eruption of Krakatoa in 1883 caused a tsunami that raced across the ocean and crashed onto nearby islands, killing 36 000 people. The blast was heard 5000 kilometres away and ash rose 80 kilometres into the atmosphere. Volcanic eruptions spew lava and ash onto the surrounding land. When this material is broken down by the action of wind and water, and mixed with organic material from plants and animals, it forms some of the richest soil in the world. So, in spite of the dangers, people continue to live near volcanoes due to the fertile soil they provide.

Figure 5.26 The aftermath of the earthquake and tsunami in northern Japan in 2011.

QUESTIONS 5.2.2: CONVERGING BOUNDARIES

Remember

1 Explain what is meant by the term 'subduction'.

2 Outline what determines the plate that subducts at a converging boundary.

3 Identify the three possible plate combinations at converging boundaries and what landforms they create.

4 Describe how density is important at a converging boundary.

Apply

5 Are volcanic mountains or islands always formed at converging boundaries? Explain your answer.

6 Describe how earthquakes cause tsunamis.

7 Suggest how volcanoes can cause tsunamis.

8 From your answers in questions 6 and 7, suggest an explanation as to how tsunamis form.

DIVERGING BOUNDARIES

Figure 5.27 The East African rift valleys represent the initial stages of the breaking up of a continent.

Diverging boundaries, or spreading plate boundaries, form features different from those of converging and transform boundaries. These spreading boundaries can occur in the middle of the ocean or in the middle of land. The breaking up of the supercontinent Pangaea was probably due to diverging plate boundaries.

Hot rising mantle rock from deep within the Earth is the first step in a continent breaking apart. As the mantle rock rises, the continental crust is lifted and thins out. Cracks form and large slabs of rock sink into the cracks, forming a **rift valley** like those found in East Africa.

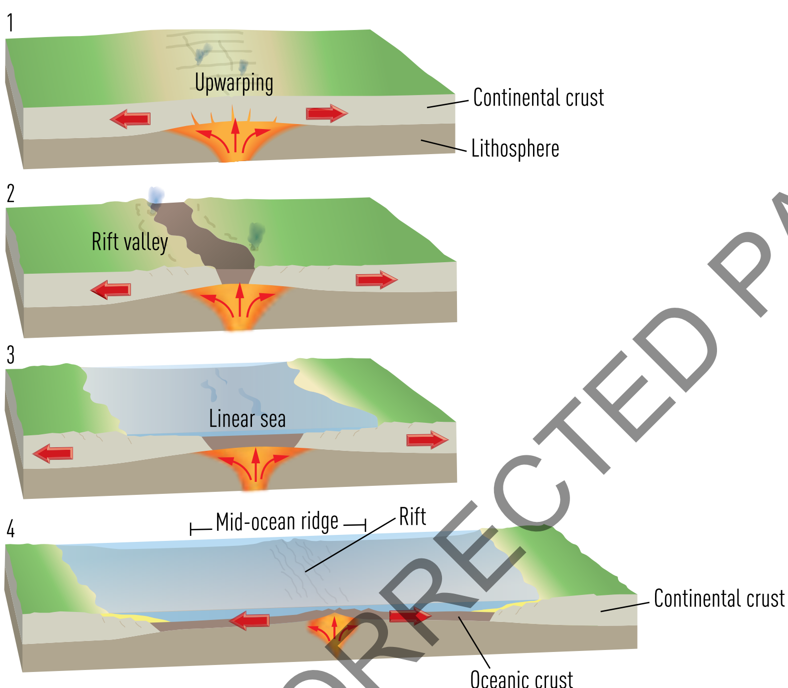


Figure 5.28 How diverging boundaries form oceans.

Making oceans

As the divergence process continues, the continental crust separates and a narrow sea or lake may form. The Red Sea, between the Arabian and African plates, is thought to be a diverging boundary at this stage of development. Eventually it will widen to form an ocean with a mid-ocean ridge.

New ground

Mid-ocean ridges wind through all of the Earth's major oceans and, at 70 000 kilometres long, they are the longest physical features on Earth. Although called ridges, they are actually incredibly wide – up to 4000 kilometres. This sea-floor spreading occurs at a rate of only 5 centimetres per year, but none of the ocean floor is dated as older than 180 million years. Oceanic rock is much younger because it gets constantly recycled in subduction zones. Divergent boundaries are often associated with underwater volcanic activity because they are continuously creating thin and unstable areas of the Earth's crust.

Figure 5.29 The Red Sea has formed as the African and Arabian plates have diverged.

ACTIVITY 5.2.3: MODELLING SEA-FLOOR SPREADING

What you need: A4 sheet of paper, scissors, cereal box

1 Fold the paper in half lengthwise (top to bottom), then cut along the fold.
2 Cut a 12 cm × 0.5 cm slit in the front of the box and lay it flat so the slit points up.
3 Place the two pieces of paper on top of each other then push them through the slit in the box. Leave about 5 cm of the paper out of the box.
4 Hold the ends of each piece of paper in separate hands and slowly pull them apart along the top of the box.
    - Draw a diagram of this activity, showing the motion of the paper.
    - What does the paper represent?
    - Do you think this model accurately represents diverging boundaries? How could you improve it?
    - Suggest a way in which this model could be modified to represent converging or transform boundaries.

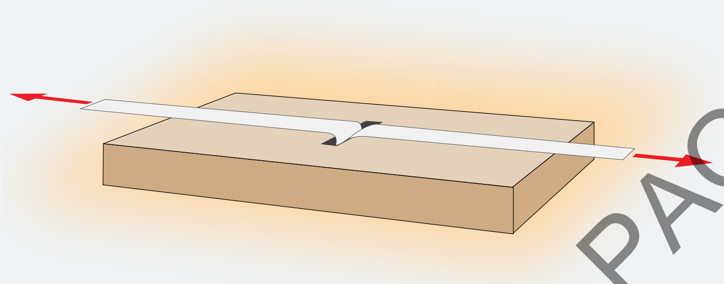


Figure 5.30 Slowly pull the strips of paper away from each other.

QUESTIONS 5.2.3: DIVERGING BOUNDARIES

Remember

1 Recall what causes the continental crust to spread and break at a diverging boundary.
2 Referring to Figure 5.1, identify the locations of the major mid-ocean ridges.
3 Referring to Figure 5.1, identify the locations of the diverging plate boundaries.

Apply

4 Calculate the total distance of sea-floor spreading over 200 million years if the rate is 5 centimetres per year. Compare this to the maximum width of the Atlantic Ocean at 6400 kilometres and explain the significance of this result.
5 Explain how divergent boundaries produce earthquakes and volcanic activity.

5.2 CHECKPOINT

ACTIVITY AT PLATE BOUNDARIES

Remember and understand

1 Write a definition or description for each of these terms:

- a subduction [1 mark]
- b rift valley [1 mark]
- c transform fault [1 mark]
- d diverging boundary [1 mark]
- e converging boundary [1 mark]
- f ocean trench [1 mark]
- g magma [1 mark]
- h mid-ocean ridge [1 mark]
- i sea-floor spreading [1 mark]

2 Explain how each of the following features formed:

- a Mid-Atlantic Ridge [2 marks]
- b Mariana Trench [2 marks]
- c Red Sea [2 marks]
- d East African rift valleys [2 marks]
- e San Andreas Fault [2 marks]

Apply

3 Explain why continental crusts are not likely to be subducted. [2 marks]

4 Outline how sea-floor spreading accounts for the young age of the sea floor. [2 marks]

Analyse and evaluate

5 Identify the longest mountain range in the world and how it formed. (Think carefully!) [2 marks]

6 Identify the highest mountain range in the world and how it formed. [2 marks]

7 Describe what features the island of Iceland has that indicate it is located along a plate boundary. What type of boundary is it on? [2 marks]

8 The Himalayas formed when India collided with the Eurasian Plate. Mount Everest, the highest mountain on the Earth, reaches a height of 8848 metres and continues to be uplifted at a rate of about 1 centimetre per year. Calculate how high Mount Everest might be in 1 million years if it maintains its current rate of increase. [2 marks]

9 In your opinion, can the Himalayas continue to rise forever? Justify your answer. [2 marks]

10 If Africa and Australia are moving apart at a rate of 4.4 centimetres per year, evaluate how long it will take for the Indian Ocean to widen by 1000 kilometres. [2 marks]

Critical and creative thinking

11 Create a poster, multimedia presentation or model showing the stages in the formation of the Gulf of California. Indicate clearly what is happening at each stage. [5 marks]

12 Read articles from newspapers about seismic activity. Identify the date and location of the seismic activity and describe the plate boundary involved in each case. [2 marks]

13 Surprisingly, ocean explorers have found life at the bottom of the Mariana Trench. Research what lives so deep and how it survives. [3 marks]

Making connections

14 Earth is a dynamic planet. This means it is constantly changing its form, and plate tectonics is one aspect of this change. Investigate some major features that change. Do any changes occur quickly? Can we see any changes as they occur? What evidence do we have to support our understanding of the dynamic processes occurring? [5 marks]

15 Movement of tectonic plates, and therefore continents, is responsible for many changes in biology as well. Research the 'Isthmus of Panama' and examine some of the effects it caused

overmatter

TOTAL MARKS
[/55]

THE EARTH IN THE FUTURE

5.3

Plate tectonics is an ongoing process that will have a major effect on the shape of the Earth over the next 50 million years and beyond. If the motion of the continents continues at the same rate as today, portions of California will separate from the rest of North America, the Mediterranean Sea and Italy's 'boot' will disappear, Australia will move north and become linked to the rest of Asia, and mainland Africa will separate from East Africa and a new sea will form. Imagine the headlines if those events happened overnight!

A FUTURE EARTH

The theory of plate tectonics proposes that the Earth's continents are moving at the rate of a few centimetres each year. This is expected to continue into the future, causing the plates to take up new positions. Forecasting future continental motion has become a popular area of geology and now draws on new insights, theories, measurements and technologies.

Today, geologists measure changes in the continents' positions with great precision using global positioning satellites (GPS) and small base stations in remote areas of our planet. Base stations are carefully selected to represent known locations and act as calibrators for GPS systems.

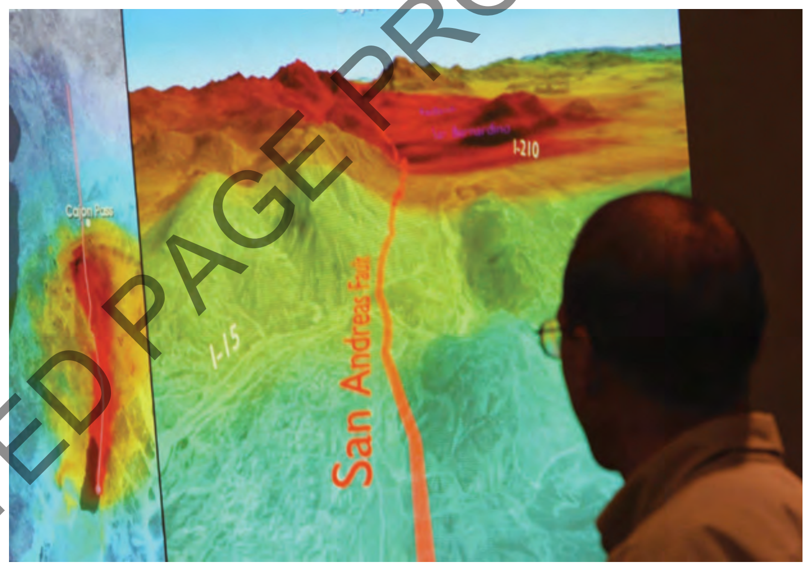


Figure 5.31 Scientists produce maps and animations to help explain the Earth's geology to more and more people.


Figure 5.32 A global positioning satellite base station.

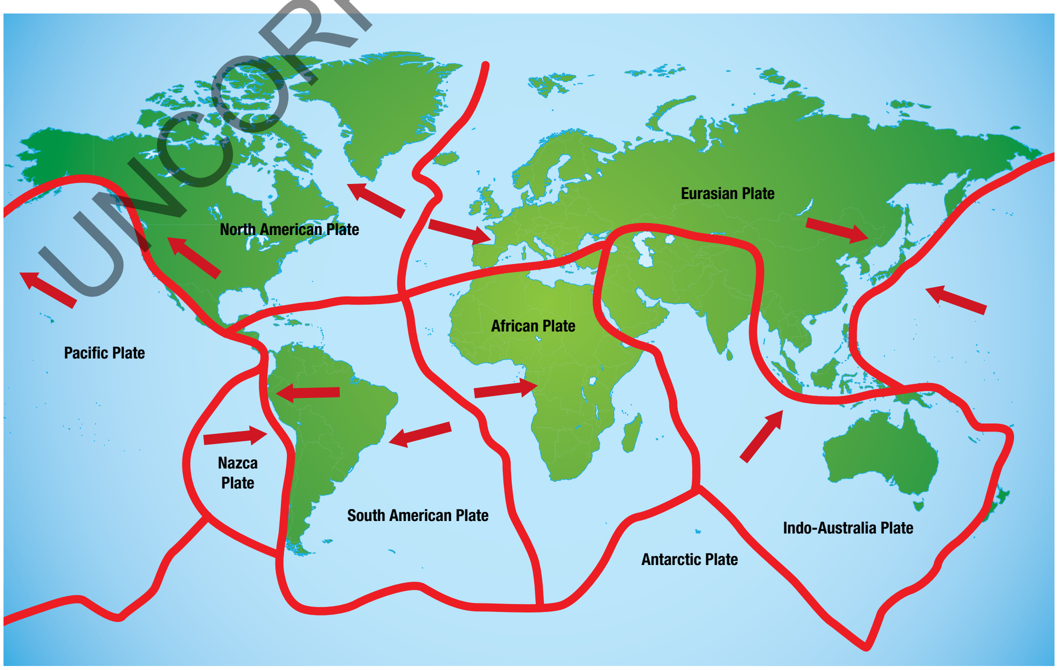


Figure 5.33 The present-day movement of the world's tectonic plates.

At present, the continents of North and South America are moving west from Africa and Europe. Researchers have produced several models that show how this plate movement might continue into the future. Since the theory of plate tectonics was proposed, geologists have worked hard to discover what it revealed about Earth's past. The supercontinent of Pangaea was the result.

In the 1970s, US geologist Robert Dietz proposed that in 10 million years Los Angeles will be moving north and passing the point where San Francisco is now. For his predictions he focused on the San Andreas Fault in California. Some modelling predicts that Africa will continue drifting north, eventually joining up with Europe and eliminating the Mediterranean Sea, which will be replaced with the Mediterranean Mountains. The continents of North and South America may continue to move across the Pacific Ocean until they begin to merge with Asia. This new supercontinent might be known as Amasia.

US geologist Christopher Scotese and his colleagues have mapped out the predicted positions several hundred million years into the future as part of the Paleomap Project. According to their predictions, in 250 million years North America will collide with Africa while South America will join up with South Africa. The result will be the formation of a new supercontinent, Pangaea Proxima, encircling the old Indian Ocean. The massive Pacific Ocean will stretch halfway across the planet.

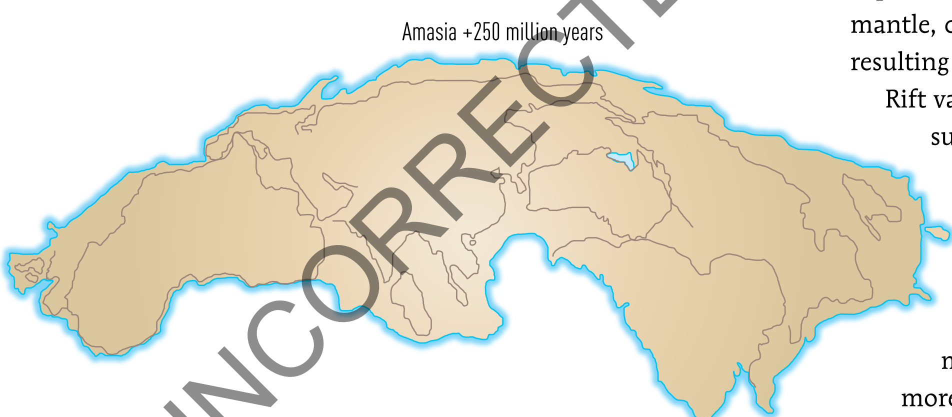


Figure 5.34 Amasia is one possible supercontinent modelled by geologists.

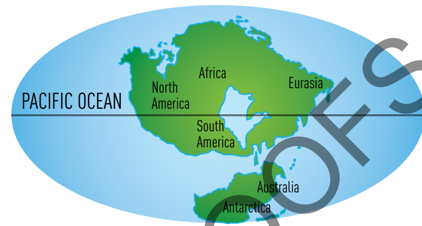


Figure 5.35 Pangaea Proxima: the world in 250 million years according to predictions by Scotese.

The formation of another supercontinent will dramatically affect the environment. The collision of plates will result in mountain-building and major climate changes. Global temperatures will increase and oxygen in the atmosphere may increase. These changes will cause massive extinctions of some organisms and the emergence of new species. The supercontinent will insulate the Earth's mantle, concentrating the flow of heat, resulting in more volcanic activity.

Rift valleys will form, causing the supercontinent to split up once more.

Scientists believe that, in the next few decades, progress in geology is likely to reveal more about the Earth's inner workings, making plate forecasting easier and more accurate.

Although peering hundreds of millions of years into the future may seem like a

ACTIVITY 5.3.1: GEOLOGY IN THE HEADLINES

Use one of these headlines about the future shape of the Earth's continents and imagine the event has happened 'overnight'. Write a newspaper article about the new development and what it implies for the climate, vegetation and people of the region.

California splits from North America
Australia heads north
Africa wakes up to new sea

LITERACY BUILDER

Plate tectonics may grind to a halt, then start again

ScienceDaily (7 January 2008)

Plate tectonics, the geologic process responsible for creating the Earth's continents, mountain ranges, and ocean basins, may be an on-again, off-again affair.

Scientists have assumed that the shifting of crustal plates has been slow but continuous over most of the Earth's history, but a new study from researchers at the Carnegie Institution [USA] suggests that plate tectonics may have ground to a halt at least once in our planet's history—and may do so again.

A key aspect of plate tectonic theory is that on geologic time scales ocean basins are transient features, opening and closing as plates shift. Basins are consumed by a process called subduction, where oceanic plates descend into the Earth's mantle. Subduction zones are the sites of oceanic trenches, high earthquake activity and most of the world's major volcanoes.

Writing in the 4 January issue of *Science*, Paul Silver of the Carnegie Institution's Department of Terrestrial Magnetism and former postdoctoral fellow Mark Behn (now at Woods Hole Oceanographic Institution) points out that most of today's subduction zones are located in the Pacific Ocean basin. If the Pacific basin were to close, as it is predicted to do in about 350 million years when the westward-moving Americas collide with Eurasia, then most of the planet's subduction zones would disappear with it.

This would effectively stop plate tectonics unless new subduction zones start up, but subduction initiation is poorly understood. 'The collision of India and Africa with Eurasia between 30 and 50 million years ago closed an ocean basin known as Tethys,' says Silver. 'But no new subduction zones have initiated south of either India or Africa to compensate for the loss of subduction by this ocean closure.'

Silver and Behn also present geochemical evidence from ancient igneous rocks indicating that around one billion years ago there was a lull in the type of volcanic activity normally associated with subduction. This idea fits with other geologic evidence for the closure of a Pacific-type ocean basin at that time, welding the continents into a single 'supercontinent' (known to geologists as Rodinia) and possibly snuffing out subduction for a while. Rodinia eventually split apart when subduction and plate tectonics resumed.

Plate tectonics is driven by heat flowing from the Earth's interior, and a stoppage would slow the rate of the Earth's cooling, just as clamping a lid on a soup pot would slow the soup's cooling. By periodically clamping the lid on heat flow, intermittent plate tectonics may explain why the Earth has lost heat slower than current models predict. And the build-up of heat

overmatter

QUESTIONS 5.3.1: A FUTURE EARTH

Remember

1 Describe what could happen to Los Angeles and San Francisco as their plate motion continues.

2 Explain how future inhabitants of the Earth would know that the Mediterranean Mountains were once under the sea.

Apply

3 Propose a good name for the merging of Africa and Europe.

4 If 50 million years were represented by 4 days, calculate what 1 month (30 days) represents. Using this scale, how old is the Earth?

5 Explain why rift valleys cause a supercontinent to break apart.

GEOLOGICAL TECHNOLOGY

As with all branches of science, as technology improves so too does our scientific understanding of geological patterns and changes. Geology is the main study of the Earth and rocks, and the ways in which they change. Scientists can specialise further within the field of geology and become, for example, a volcanologist (volcano expert) or a seismologist (earthquake expert).

Specific technologies help geologists investigate their particular areas of interest. As these technologies have improved, so has the amount and accuracy of information that we know about the Earth's crust and the movement of the tectonic plates. The greater understanding of the geology of the Earth has enabled geologists to predict global patterns in geological activity, such as the continuing movement of the tectonic plates. Some of the technology commonly used by geologists includes magnetometers, seismometers and seismic surveys.

Magnetometers

Seismologists study movements inside the Earth's crust to understand what causes earthquakes and predict when they are likely to occur. When the stress around a fault line builds up, the heat generated changes the magnetic properties of the minerals in the rocks around the fault. One of the instruments used to measure changes in the Earth's magnetic field is a sensitive instrument called a **magnetometer**. Magnetometers can be carefully placed around a fault line for monitoring. Any large iron or steel objects, such as cars or trucks, electrical cables, or even mobile phone towers, can affect the readings, so remote areas give the most reliable results. To cover wider areas quickly, magnetometers can be towed behind boats in the ocean or behind aircraft.

Figure 5.36 Ancient rocks keep the magnetic field direction that existed when they solidified millions of years ago.

Seismometers

Seismologists also often use **seismometers** to measure movement in the ground, which is usually caused by earthquakes or volcanoes. A seismometer consists of an internal mass attached to an immobile frame. The mass swings or moves relative to the stable frame to measure ground movement. A computer records the amount of movement of the mass, which is an indication of the strength of movement in the ground. The size and frequency of the waves of movement can help locate the source and strength of the earthquake or volcanic eruption.

Seismic surveys

Seismic surveys send sound waves into the Earth and use the time taken for the wave to bounce back as an indication of the different structures of materials in the Earth's layers. The waves are usually reflected at the points of change in the physical properties of the material, like density. The way in which the sound waves reflect can indicate the type of rock, and any fractures or abnormalities within the layer.

3D seismic surveys utilise multiple observation points across a carefully marked grid. The result is a three-dimensional cube compiled from a series of surveys from different locations and angles. This information can then be represented by a computer as a 3D image like the one in Figure 5.38. 3D seismic surveys are commonly used to look for minerals before mining, and to map the ocean floor.

Predicting and managing natural hazards

Technologies such as magnetometers, seismometers and seismic surveys are used to predict natural hazards like earthquakes and volcanic eruptions. These hazards become natural disasters when people are exposed to them and may be harmed.

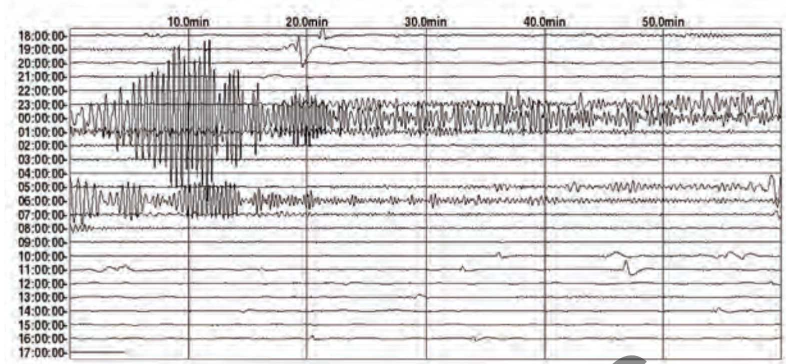


Figure 5.37 A seismograph usually appears as a series of waves. The higher the amplitude and frequency, the stronger the movement.

While nothing can be done to prevent an earthquake or volcanic eruption, in the short term, people can be warned to evacuate, or in the long term, people can be advised not to build in particular areas prone to such geological activity.

The Asia–Pacific region experiences some of the highest frequencies of natural disasters like earthquakes and volcanic eruptions. This region is also densely populated, so the effects of these distastes can be extreme. Geoscience Australia is one company that is gathering information to help predict the frequencies of natural disasters. They predict the region will experience at least one 'megadisaster' that will seriously affect millions of people in the 21st century. Whether the megadisaster will be an earthquake, a volcanic eruption or another tsunami like in December 2004, is still being debated.

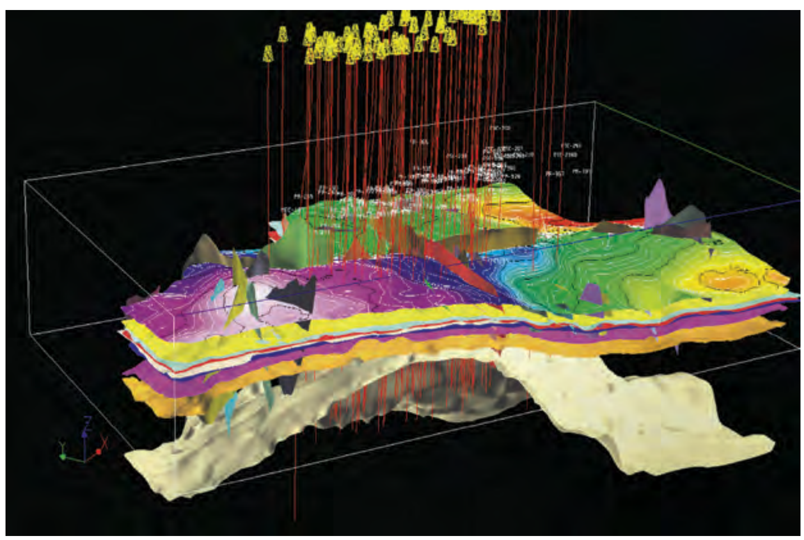


Figure 5.38 Seismic surveys can be used for many purposes including detection of different minerals within the structure of the Earth and mapping the surface of the ocean floor.

QUESTIONS 5.3.2: GEOLOGICAL TECHNOLOGY

Remember

1 Identify what the following specialist scientists study:
   a Geologist
   b Seismologist
   c Volcanologist
2 Recall how the effect of an earthquake or volcanic eruption can be minimised.
3 Describe the difference between a natural hazard and a natural disaster.

Apply

4 Explain how advances in technology have improved the management of natural disasters.
5 Suggest industries that would make use of seismic surveys and explain why they would be helpful to those industries.
6 Explain why the presence of steel objects would interfere with the reading of a magnetometer.

Critical and creative thinking

7 Examine Figure 5.1 again. Based on your knowledge of plate tectonics and natural disasters, predict whether the next megadisaster of the 21st century will be an earthquake, a volcanic eruption or a tsunami. Suggest a location most likely to be affected and explain your reasoning.

THE EARTH IN THE FUTURE

5.3 CHECKPOINT

Remember and understand

1 Recall what happens at a subduction zone. [1 mark]

2 Recall what happens when continents collide. [1 mark]

3 If Australia moves north to collide with Indonesia and Malaysia, describe what geographical features will form and how our climate will change. [3 marks]

Apply

4 Will Pangaea Proxima be the last supercontinent? Why or why not? [2 marks]

5 Will the predicted Mediterranean Mountains be volcanic? Why or why not? Justify your answer. [3 marks]

6 A new sea is predicted to form between Africa and East Africa. Explain what is the likely tectonic action to cause this to occur. [1 mark]

7 Explain why a subduction zone drags a continent towards the zone. [1 mark]

Analyse and evaluate

8 Analyse why modern GPS systems are useful for predicting future plate movements. [2 marks]

9 Examine Figure 5.35 and explain what new geographical features will form on the Earth in 250 million years. [2 marks]

10 Research and evaluate two of the different technologies involved in mapping the movement of the continents. [4 marks]

11 Australia, India, New Zealand and Indonesia are all on the Indo-Australian plate. Evaluate the differences in geological activity in these listed countries. Can this be linked to their positions on the plate? [5 marks]

Critical and creative thinking

12 In this chapter you modelled the interaction of tectonic plates with chocolate bars and the prediction of future continental positions with paper cut-outs. To enhance these models, create a claymation movie of one of the following: [5 marks]

- what happens at one of the plate boundaries
- the break-up of Pangaea
- the collision of India and Asia
- the future movement of the continents, forming Pangaea Proxima.

Making connections

13 Imagine you could travel into the future, to a time when your local environment is drastically different from today. Base your imagination on the scenarios of plate movement described in the text. Write a travel brochure of a future tourist destination or journey on this new Earth. [5 marks]

TOTAL MARKS
[/35]

5 CHAPTER REVIEW

1 Fill in the gaps using the words in the Word Bank below:

The Earth used to be thought of as a solid ball, however understanding of ______________________________ has changed this idea of the structure of the ________________. Plates on the Earth move around on its slightly liquid _________________ layer due to physical processes such as ______________________________ and gravitational forces. Movement of the plates causes natural disasters such as earthquakes, ______________________ and tsunamis. Movement of the plates also can cause changes in ____________________________, with the formation of new land and the ripping apart of continents, such as the case with ________________________.

WORK BANK

Convection currents	Earth	Landmass	Mantle
Plate tectonics	Rift valleys	Volcanoes	

Outline how the theory of plate tectonics changed ideas about the structure of and changes in the Earth's surface

2 Identify what is meant by the term 'Pangaea'. [1 mark]

3 Recall the definition of 'tectonic plates'. [1 mark]

4 Describe what scientists most likely believed about the structure of the Earth's crust before the theory of plate tectonics was proposed. [1 mark]

5 Analyse what the theory of plate tectonics says about the position and movement of the continents over geological time. [2 marks]

6 Propose how you could demonstrate tectonic plates to a primary school student. [2 marks]

7 'The fact that fossil seashells have been found on Mount Everest can be explained by saying it could have once been covered by an ocean.'

a Why is this statement unlikely to be true? [1 mark]

b What is a more likely explanation? [2 mark]

Relate continental drift to convection currents and gravitational forces

8 Outline the processes that cause tectonic plates to move. [3 marks]

9 Identify the type of boundary where density and gravity are important. Explain how density determines the movement of the two plates. [2 marks]

10 Describe how the process that drives the movement of tectonic plates can be easily demonstrated in the school laboratory. [3 marks]

Outline how volcanic activity, earthquakes and formation of new landforms can be explained using the theory of plate tectonics

11 Recall the meaning of a 'subduction zone'. [1 mark]

12 The Hawaiian Islands have grown in size and number over the history of the Earth. Explain how this is possible. [3 marks]

13 If the tectonic plates that cover the Earth are moving so slowly, explain how they could create a powerful earthquake. [2 marks]

14 Identify what type of landform the East Pacific Rise is. [1 mark]

15 Explain what created the East Pacific Rise. [2 marks]

16 Copy and complete Table 5.2. [5 marks]

Table 5.2 Plate boundaries and landforms.

Plate boundary name	Direction of plate movement	Typical landform feature at this boundary	Example
	Parallel to the boundary	Fault line	
Ocean-to-continent collision		Ocean trench, mountain range, volcanoes	
	Towards each other		Himalayas
Ocean-to-ocean collision		Ocean trench, undersea volcanoes, island arc	Mariana Islands
Continental diverging boundary			East African rift valley
Oceanic diverging boundary	Away from each other		

Describe examples of how technological advancements have increased scientific understanding of geological activity, including in the Asia–Pacific region

17 Mid-ocean ridges occur deep under the ocean, too deep for divers to reach. Name the technology that scientists use to examine them, and describe how it works. [3 marks]

18 Describe what geologists use a magnetometer for. [2 marks]

19 Using specific examples, describe how technology has increased the understanding of geological activity. [3 marks]

5 CHAPTER REVIEW

TOTAL MARKS
[/40]

RESEARCH

Choose one of the following topics to research. Some questions have been included to get you started. Present your findings in a format of your own choosing, giving careful thought to the information you are communicating and your likely audience.

Subduction zones

The subduction of one plate under another is well understood by scientists today, but how this process begins is not. What do geologists mean by subduction? Which plates are involved in subduction? What happens to the plates during subduction? What geological features are associated with subduction zones? How do new subduction zones form?

The Earth's crust

The lithosphere and asthenosphere are different internal layers of the Earth. What is the lithosphere? What is the asthenosphere? How do the two 'spheres' interact? What other 'spheres' exist? How do they interact with the lithosphere and asthenosphere?

Convection currents

Although the theory of convection currents in the Earth's mantle is the most widely accepted theory with regard to what drives plate movement, there are several other theories. What other theories exist? Choose one and find out what evidence supports the theory. Who proposed the theory? What does the theory say? Does

REFLECT

Me

1 What new skills have you learned in this chapter?

2 How would you deal with living near a plate boundary?

My world

3 Why is it important to hear about the action of plate boundaries around the world?

KEY WORDS

3D seismic survey
continental drift
continental shelves
convection currents
converging boundaries
diverging boundaries
density
fault
focus
gravity
magnetometer
mantle
mid-ocean ridges
natural disasters
ocean trench
Pangaea
rift valley
sea-floor spreading
seismometer
strike–slip
subduction
tectonic plates
transform boundary
tsunami

5

MAKING CONNECTIONS

The volcano that stopped Australia

In June 2011, much of Australia's air traffic was grounded. Most Australian airports were closed and thousands of people had their travel plans disrupted. Unlike problems caused by terrorism in other parts of the world, these disruptions were caused by a natural act. A Chilean volcano, Puyehue, was erupting, throwing huge volumes of ash into the atmosphere. The ash cloud stretched from Argentina to Australia, New Zealand and the Pacific islands. Australian airline companies were concerned the ash would cause aeroplane jet engines to stop, so they cancelled many flights in the region.

You might think a simple volcanic eruption would affect only people in the immediate area. Residents of Chile were well aware of the volcano's effects, but the impacts reached much further afield and continued long after the eruption finished.

Predictions of environmental effects can be made using satellite images. You can think of a satellite image as a photograph taken from space. About 3000 artificial satellites are orbiting the Earth and are used for all sorts of things such as transferring

Figure 5.39 A huge cloud of ash at Puyehue volcano.

phone calls, spying, monitoring the growth of crops and helping rescue teams following a natural disaster. They have become one of the most useful tools for a scientist because they give a snapshot of a large area of the Earth's surface at a given time. These snapshots allow us to identify and explain patterns and changes over time.

Satellite images of the ash cloud (Figure 5.39) were taken by the NASA *Terra* satellite. The Terra satellite completes an orbit of the Earth every 100 minutes and is about the size of a small bus. It orbits about 700 km above the Earth's surface.

1 Identify what geophysical phenomenon caused the Puyehue volcano to erupt.
2 Analyse how the volcano compares in size to other currently active volcanoes around the world.
3 Explain how people in the immediate area were affected by the eruption. How were people around the world affected by the eruption?
4 Did the eruption of the volcano cause anything in your life to change?
5 Examine how the volcano contributed to the enhanced greenhouse effect.
6 How did the volcano contribute to the enhanced greenhouse effect?
7 Prepare a photo story that illustrates before, during and after the eruption.

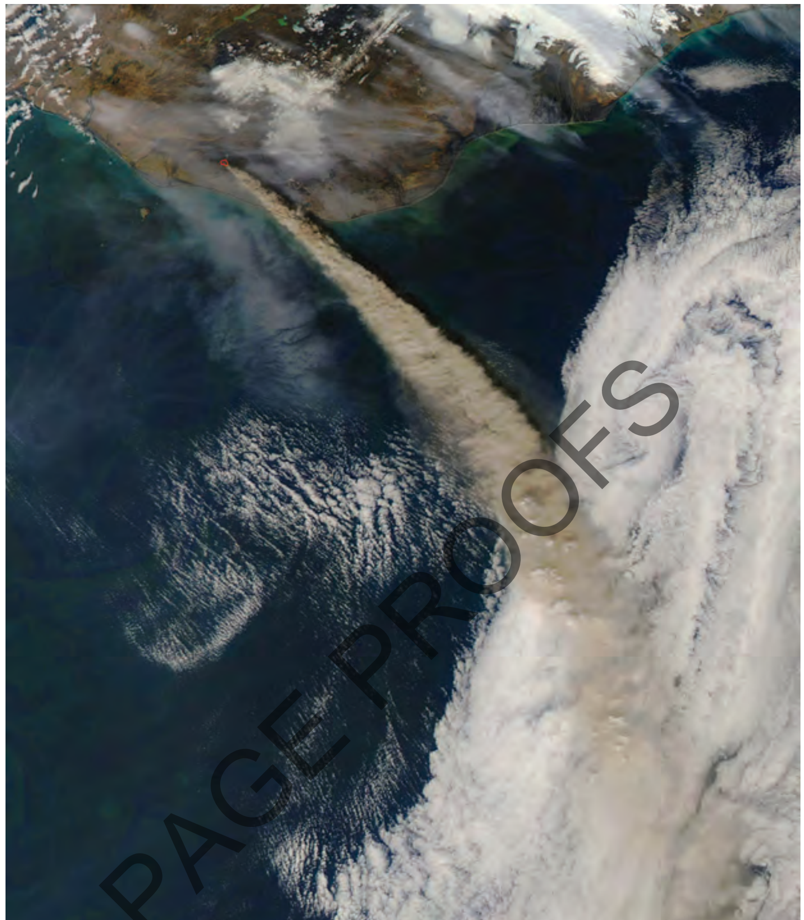


Figure 5.40 In this satellite image, the plume of ash from the Chilean volcano can clearly be seen.

Figure 5.41 The volcanic ash, carried by the prevailing winds, disrupted several Australian air services.