

PEARSON  
**Science**

STUDENT BOOK | NEW SOUTH WALES

Stage

**4**

**NSW**  
SYLLABUS



# TOPIC 13

## Geological change

Earth's surface is dynamic and has changed many times over the millennia. It has been shaped by the movement of the tectonic plates under Earth's surface and by the movement of wind and water. The rocks you see around you were once part of larger rock formations that have also changed continuously over thousands of years.

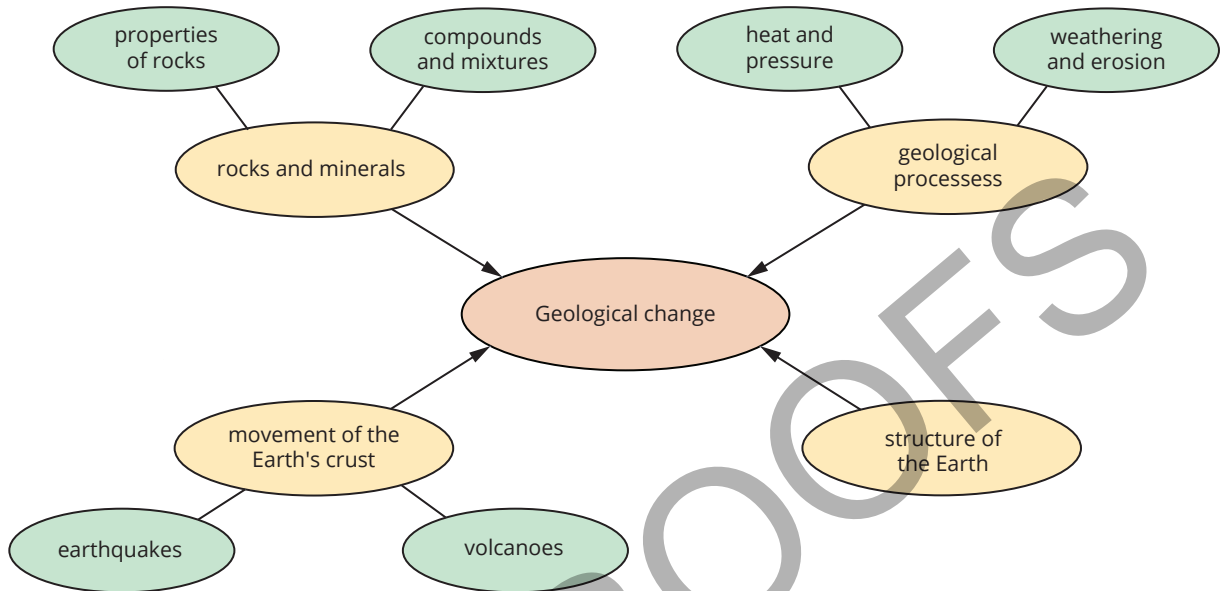
In this topic you will learn about the rocks that form Earth's structure, how they change as a part of the rock cycle, and the value of rocks and minerals in Australian society. You will also learn about the theory of plate tectonics and explore how pressure and movement in Earth's crust affect both the geological features and living organisms on Earth's surface.

### Learning intentions

- To understand the internal structure of Earth **xx**
- To understand how rocks on the surface of Earth can change **xx**
- To be able to investigate physical and chemical weathering **xx**
- To understand the formation of sedimentary rocks **xx**
- To understand the formation of igneous rocks **xx**
- To understand the formation of metamorphic rocks **xx**
- To be able to investigate the source of metamorphic rocks **xx**
- To understand how environmental changes affect the rock cycle **xx**
- To understand the theory of plate tectonics **xx**
- To understand the geological features and events that occur at the different types of plate boundaries **xx**
- To be able to model the different types of plate boundaries **xx**
- To understand the reasons for patterns of earthquake and volcanic activity around the globe **xx**
- To understand how accounts of First Nations Australians provide evidence of earthquakes and volcanoes on Country or under the sea **xx**
- To understand evidence that supports the theory of plate tectonics **xx**

# Geological change

The key concepts that you will use in this topic:



The following prior knowledge questions will help to support your learning in the topic and can be attempted before the first lesson.

## Structure of Earth

- 1 Name the two layers of the Earth closest to the surface.
- 2 Describe how temperature and pressure change from Earth's surface to Earth's centre.

## Geological processes

- 3 Compare the processes of weathering and transportation of rocks.

## Rocks and minerals

- 4 Describe the difference between rocks and minerals, and give two examples of each.

## Movement of the Earth's crust

- 5 Movement of the Earth's crust can be responsible for what two natural disasters.
- 6 Suggest why marine fossils are found in rocks high up in the Himalayan mountains.

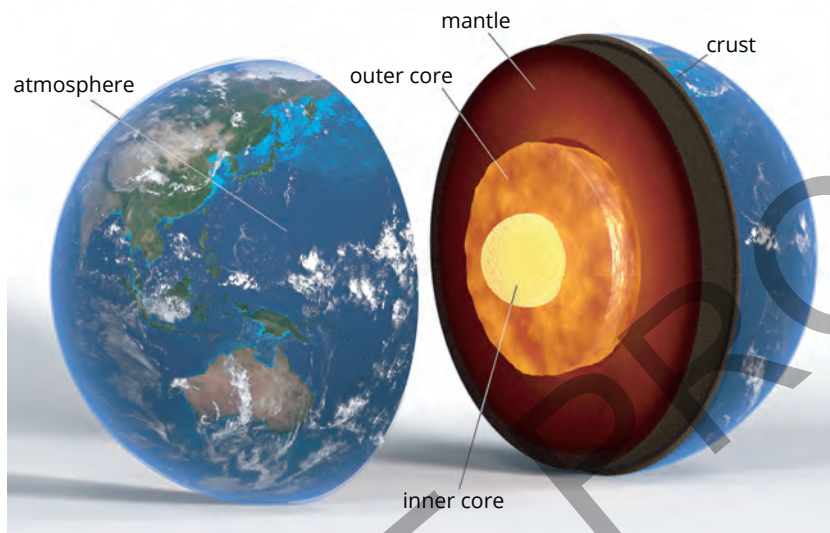
# 13.1 Structure of Earth

## Lesson overview

Earth is not a solid uniform mass. Instead, it is made up of different layers that have different properties. In this lesson you will learn about Earth's structure, its layers, and how heat energy is distributed throughout Earth.

**SC 1** I can identify the different layers of Earth

The structure of Earth consists of four main sections: the crust, the mantle, and the outer and inner core. Figure 13.1.1 shows how these layers are arranged.



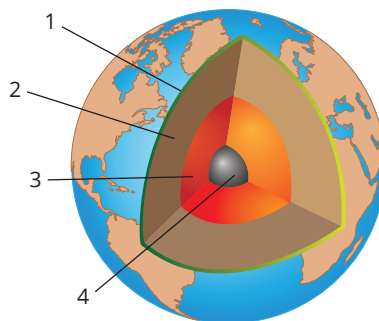
**FIGURE 13.1.1** The four layers of Earth

Earth was formed approximately 4.5 billion years ago. Over time, the internal structure of Earth became made up of a solid inner core, a liquid outer core, a hot, solid mantle that behaves like a fluid over long periods, and a solid **rock** crust. The liquid outer core is responsible for Earth's magnetic field.

### SC 1 CHECK YOUR UNDERSTANDING

Refer to the diagram below showing the internal structure of Earth.

- Identify each of the layers of Earth (numbered 1 to 4).
- For the two innermost layers, state whether they are solid or liquid.



### Learning intention

To understand the internal structure of Earth

### Success criteria

**SC 1:** I can identify the different layers of Earth.

**SC 2:** I can describe the layers of Earth's internal structure and compare them to other planets in the Solar System.

**SC 3:** I can describe the distribution of heat energy within the internal structure of Earth.

### KEY TERMS

**rock** a solid mass of one or more minerals.

**crust** the outermost layer of Earth, composed of solid rock

**SC 2** I can describe the layers of Earth's internal structure and compare them to other planets in the Solar System.

Each layer of the Earth is different in its composition and state.

## Crust

The outermost layer of Earth is the **crust**. The crust is solid and very thin compared to the other layers. Its thickness varies from 7 kilometres beneath the oceans, to 30 or more kilometres beneath the continents. It is composed mostly of magnesium, silica and aluminium.

## Mantle

The **mantle** is the layer underneath the crust. It is much hotter than the crust, and the composition of this layer changes as it gets deeper. The mantle consists mainly of magnesium, silica and iron.

The uppermost solid layer of the mantle combines with the crust to create Earth's rigid outer shell called the **lithosphere** (Figure 13.1.2).

The **asthenosphere** is near the top of the mantle (Figure 13.1.2), just below the solid lithosphere, and it contains rock that can move very slowly. This rock is described as behaving plastically because it can bend or change shape under pressure, like plasticine, without breaking.

However, in the deepest part of the mantle (the lower mantle) the rock flow is also slow, but these rocks are rigid and break under pressure (Figure 13.1.2).

### KEY TERMS

**mantle** solid layer of Earth between the crust and the outer core

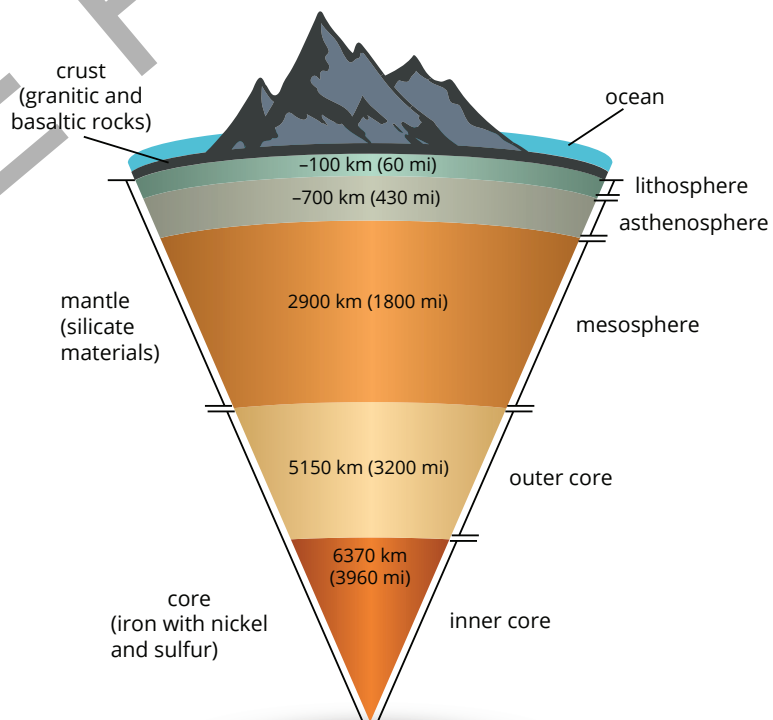
**lithosphere** name for the crust and the upper mantle together

**asthenosphere** near the top of the mantle, just below the solid lithosphere, and it contains rock that can move very slowly

### Scifile

#### Earth's Deepest Hole

The deepest hole ever drilled by humans is the Kola Superdeep Borehole in Russia. It is about 12 kilometres deep. That's not even halfway through Earth's crust! The attempt to reach the mantle had to stop after 20 years when the temperature in the crust reached 180°C – far too hot for the drilling equipment.



**FIGURE 13.1.2** The mantle is divided into the lithosphere, asthenosphere and lower mantle

## Outer core

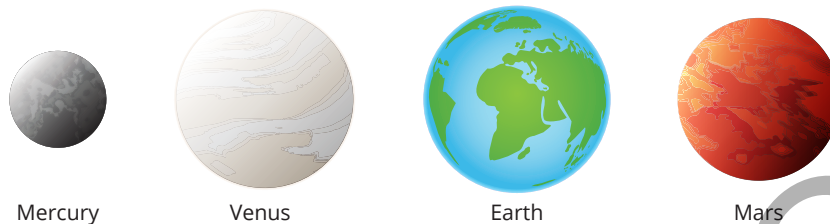
The **outer core** is liquid (Figure 13.1.2). It is believed to consist of iron and nickel and is responsible for Earth's magnetic field.

## Inner core

The **inner core** of Earth (Figure 13.1.2) is also believed to consist of iron and nickel. It is so dense and the pressure so great inside the inner core that the iron and nickel do not melt.

## Comparing Earth to other planets

Earth is one of the four **terrestrial planets** in the Solar System. These terrestrial planets include Mercury, Venus, Earth, and Mars (Figure 13.1.3).



**FIGURE 13.1.3** The inner planets of the Solar System, called the terrestrial planets, have a similar structure and elemental composition

Earth, and Mars (Figure 13.1.3). Each of these planets have a core that consists mainly of iron, with some nickel and sulfur. Some of these planets have solid cores, while others can have liquid layers. Above the core is the mantle, which is composed of silicate minerals that contain iron and magnesium. These silicates are rocks that can be solid or can flow like plasticine over a long period of time. All the terrestrial planets have a solid crust made of lighter rock material like granite and basalt.

Other planets in the solar system are called **gas giant planets**, which include Jupiter and Saturn (Figure 13.1.4). Astronomers think that these planets could have a rocky metallic core surrounded by metallic hydrogen. Around the core are layers of atmosphere that contain hydrogen and helium under immense pressure. Higher in the atmosphere there are other gasses like ammonia, methane and water vapour.

Further out from the gas giants are the **ice giant planets**, which include Uranus and Neptune (Figure 13.1.5). These planets have a core of solid rock and metallic elements. Above their cores are semi-solid layers of water, ammonia and methane.

### SC 2 CHECK YOUR UNDERSTANDING

Compare the core of the Earth with the core of Neptune in terms of their composition and physical state.

#### KEY TERMS

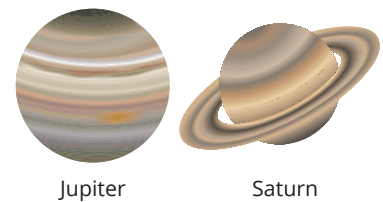
**outer core** a liquid layer of Earth's interior, primarily composed of liquid iron and nickel. Located beneath the solid mantle and surrounds the inner core

**inner core** extremely hot, solid ball made of iron and nickel at the very centre of Earth

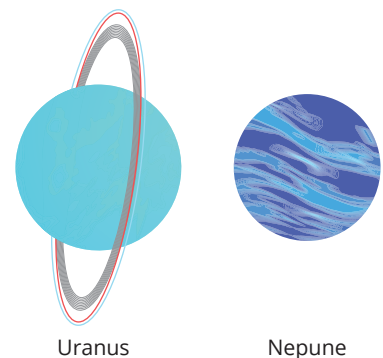
**terrestrial planets** smaller planets in the Solar System that have a similar internal structure and composition as the Earth.

**gas giant planets** large planets in the Solar System that are mainly composed of hydrogen and helium gas.

**ice giant planets** large planets in the Solar System that are mainly composed of water, ammonia, and methane.



**FIGURE 13.1.4** The largest planets of the Solar System, called the gas giant planets, have a similar structure and elemental composition



**FIGURE 13.1.5** The most distant planets of the Solar System, called the ice giant planets, have a similar structure and elemental composition

**KEY TERMS**

**primordial** something that originated during the planet's formation process a very long time ago

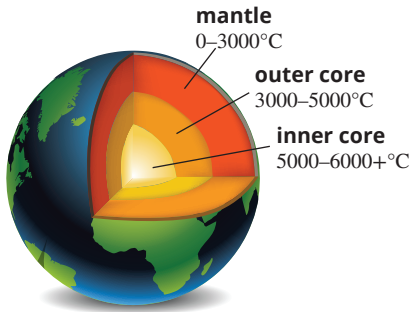
**geothermal energy** the heat energy that comes from within the Earth

**SC 3** I can describe the distribution of heat energy within the internal structure of Earth

The inner core of Earth is very hot with a temperature ranging from 5000 to over 6000 degrees Celsius (°C) (Figure 13.1.6). The heat is generated from radioactive decay and **primordial** heat from when Earth was formed. The solid core is so dense, and the pressure inside the core so great, that it does not melt.

The outer core is liquid, and it is the movement of this liquid that helps distribute heat to the mantle and Earth's crust. Heat flows from warmer objects to cooler objects, so the heat from the warmer core is transferred to the cooler mantle and crust.

Heat energy that is generated within Earth is known as **geothermal energy**. It is geothermal energy that produces hot springs and geysers at the Earth's surface (see Figure 13.1.7).



**FIGURE 13.1.6** Estimated temperatures within the Earth's three interior layers

**SC 3 CHECK YOUR UNDERSTANDING**

Why does heat makes its way from the inner core to the mantle and crust?



**FIGURE 13.1.7** Geothermal energy produces hot springs that feed the Great Artesian Bore Baths in the tiny village of Goodooga in northern NSW

**Lesson review**

Use these questions to check whether you have met the learning intention for this lesson.

- 1 Explain the location of the Earth's mantle in relation to the other layers.
- 2 Which part of the Earth's internal structure is responsible for its magnetic field.
- 3 Which planets in the Solar System would have an internal structure and elemental composition similar to the Earth's internal structure and composition?
- 4 Identify the layers of Earth which have the following characteristics:
  - a Generates the Earth's magnetic field
  - b Contains the asthenosphere
  - c Mainly consists of the elements nickel and iron in a solid state
  - d Composed of solid rock with thickness ranging from 7 to 50 kilometres
  - e Contains material at the hottest temperature and highest pressure
  - f Consists mostly of magnesium, aluminium, and silica
  - g Contributes to the rigid outer shell of Earth known as the lithosphere
- 5 Outline two sources of heat within Earth's internal structure.
- 6 Explain the formation of hot springs.

# 13.2 Changes to rocks on the surface of Earth

## Lesson overview

When you look at a rock, you may not consider that the rock was originally part of a larger rock. The rocks you see in your garden, parks and at the beach were once part of a larger rock mass. These larger rock masses have changed over time, affecting their appearance and creating smaller rocks. In this lesson you will learn how and why rocks change and how this impacts the landscape.

**SC 1** I can describe different types of weathering

**Weathering** causes rocks to change and break down. There are three main categories of weathering.

## Physical weathering

**Physical weathering** (sometimes referred to as mechanical weathering) breaks rock into smaller pieces without changing its chemical composition. Physical weathering can happen in four ways.

- 1 Wind can carry fine particles of rock which cause wear to the surface of other rocks as they scrape past.
- 2 Rocks can crack when they expand and contract quickly due to a change in temperature.
- 3 Water enters cracks in rocks and expands when freezing, causing rocks to break.
- 4 When salt water evaporates, it can form crystals inside cracks. This process is called **crystallisation**. The crystals apply a **force** on the rocks which causes fractures.

Often, more than one of these processes can occur at the same time, contributing to the formation of unique landscape features, like the ones shown in Figure 13.2.1.



**FIGURE 13.2.1** Sawn Rocks near Narrabri in New South Wales have been created through a combination of physical weathering processes.

### Learning intention

To understand how rocks on the surface of Earth can change

### Success criteria

**SC 1:** I can describe different types of weathering.

**SC 2:** I can describe, with examples from Australia, the difference between weathering and erosion.

**SC 3:** I can explain, with examples from Australia, the process of deposition and the land formations produced as a result.

### KEY TERMS

**weathering** processes that break rocks down into smaller pieces

**physical weathering** mechanical processes, such as wind, freezing water, changes in temperature, and crystallisation of salts, that break rocks down into smaller pieces

**crystallisation** evaporation of a solvent from a solution, leaving solute behind as crystals

**force** a push, pull or a twist that can change an object's shape or motion

**KEY TERMS**

**chemical weathering**

chemical processes that break rocks down into smaller pieces, like acid rain, and oxidation

**biological weathering** living organisms that break rocks down into smaller pieces through the action of roots, organic acids, and enzymes

**humus** dark material in soils produced by the decomposition of plant or animal remains

**erosion** the movement of weathered rock particles from the site of the weathering

## Chemical weathering

**Chemical weathering** occurs when water dissolves chemicals from the surrounding soil and air. These chemicals may then react with the minerals in a rock, causing it to crack or change.

Air contains 21% oxygen and 0.03% carbon dioxide. When these gases are dissolved in water, they can react with minerals in nearby rocks. These reactions may cause the rock to crumble or change colour on the surface.

Uluru is a well-known example of the process of chemical weathering. The original rock of Uluru is grey and called arkose. Water from the rain and oxygen in the air react with the iron in the rock to produce oxides of iron, which give Uluru its famous red colour (Figure 13.2.2).

## Biological weathering

**Biological weathering** is caused by moss, lichens, algae, and plant or tree roots forcing themselves through small cracks in rocks to create larger cracks (Figure 13.2.3). Biological weathering can even split the rock. Some plant roots can travel through rocks by releasing acids or an enzyme (a protein which speeds up chemical reactions) that softens the surrounding rocks. Some plant material will decay to produce **humus**, which contains a type of acid that seeps into the rocks below.

### SC 1 CHECK YOUR UNDERSTANDING

Compare physical and chemical weathering in terms of their processes.



**FIGURE 13.2.2** The red colour of these rocks at Uluru is due to the presence of iron.



**FIGURE 13.2.3** These tree roots have pushed through cracks in the rocks and caused the rock to split.

### SC 2 I can describe, with examples from Australia, the difference between weathering and erosion

Weathering weakens rocks and creates small rock particles, but **erosion** moves these particles elsewhere by the action or movement of gravity, ice, water or wind.

## London Bridge, Victoria

The limestone rock formation known as ‘London Bridge’ (Figure 13.2.4) is on the Great Ocean Road in south-west Victoria. It was originally connected to the mainland until the inner span collapsed in 1990. When it rains, limestone slowly dissolves due to a chemical reaction with the rainwater in a process of chemical weathering. The limestone is further weakened by physical weathering (the action of wind and salt crystallisation). The movement of wind and water against rock, and gravity, causes small pieces of the rock to erode. Over time, this process has created natural arches or bridges, one of which has since collapsed.



**FIGURE 13.2.4** London Bridge, a natural arch limestone formation in coastal Victoria, has been formed by chemical weathering and erosion.

## Karlu Karlu (Devils Marbles), Northern Territory

Karlu Karlu (or the Devils Marbles) (Figure 13.2.5) are giant granite boulders in the Northern Territory. They were formed by molten rock that became solid when it cooled underneath a layer of sandstone. Once this rock solidified, vertical and horizontal cracks appeared due to physical weathering, forming rectangular blocks. These blocks have since become rounded due to further rapid temperature changes. The ‘marbles’ appear to be stacked on top of each other as the sandstone surrounding the granite has been eroded.



**FIGURE 13.2.5** Karlu Karlu (Devils Marbles) have formed as a result of rapid temperature changes (physical weathering) and erosion.

### SC 2 CHECK YOUR UNDERSTANDING

Explain how weathering and erosion are different.

## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

- 1 What are the three main types of weathering?
- 2 Compare physical weathering and biological weathering in terms of their processes and their effects on rocks.
- 3 In the desert regions of Australia, how might weathering and erosion work together to shape the landscape?
- 4 Carlotta Arch in the Jenolan Caves at the Blue Mountains are a famous limestone rock formation. The caves in this area are the World’s oldest known cave complex at 340 million years old. The cave network follows an underground section of the Jenolan river.
  - a Describe the role of weathering in the formation of the Jenolan cave system. Consider the type(s) of weathering that has occurred.
  - b Explain how erosion has contributed to the formation of the Jenolan cave system. Consider the main agents of erosion.
  - c Predict the long-term impacts of weathering on Carlotta Arch.



## 13.3 Weathering of rocks

### Learning intention

To be able to investigate physical and chemical weathering

### Success criteria

**SC 1:** I can conduct an experiment to model and compare the weathering of rocks.

**SC 2:** I can use knowledge of weathering to explain observations.

**SC 3:** I can analyse the effectiveness of an experiment as a representation of the weathering of rocks in the environment.

### Introduction

Weathering is the process of rocks breaking down into smaller pieces. Weathering can occur because of physical, chemical and biological processes.

The rocks in Sydney's coastline in New South Wales (Figure 13.3.1) have been broken into smaller rocks and particles over thousands of years.



**FIGURE 13.3.1** Varied patterns, colours, shapes and layers of natural weathered sandstone rocks on the Sydney coast.

In this practical investigation you will investigate how chemicals and changes in temperature can cause the weathering of rocks.

### Background

The two types of weathering involve chemical or physical processes. Chemical reactions involve the creation of new substances. Physical processes involve changing the form of a substance and are easier to reverse than chemical processes.

Scientific models play a crucial role in understanding weathering processes. A scientific model is a representation based on data and observations of real-world phenomena. By analysing data from observations and experiments, scientists can create models that simulate the weathering process, providing valuable insights into how rocks change over time. These models are essential tools for predicting geological changes and for educational purposes, helping students visualise and comprehend the intricate processes involved in weathering.

## Aim

To investigate how the formation of ice, and the presence of chemicals, cause weathering

## Apparatus

- vinegar
- 2 small samples each of granite, limestone and sandstone (to fit in test tubes)
- 6 test tubes and a test-tube rack
- plaster of Paris
- 2 margarine containers or milk cartons
- small water balloon
- spoon or spatula
- rubber gloves

### SAFETY NOTES

- ▶ Do not mix plaster with bare hands; mix with a spoon or spatula or use rubber gloves.
- ▶ Wear laboratory safety glasses and a dust mask when using dry plaster of Paris.

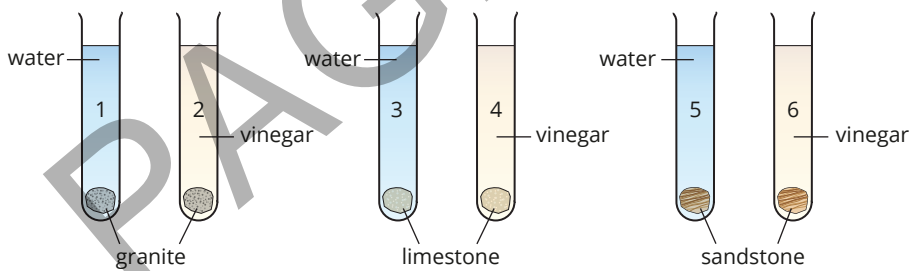
## Assessment of risk

Ensure you are aware of the risks of this practical investigation and have considered how safety can be improved before carrying out this activity.

## Method

### Part A: The effect of acid and water

- 1 Label your test tubes with numbers 1 to 6 (Figure 13.3.2). Put small samples of granite into test tubes 1 and 2, limestone in test tubes 3 and 4, and sandstone in test tubes 5 and 6 as shown in the diagram.
- 2 Add water to test tubes 1, 3 and 5.
- 3 Add vinegar to test tubes 2, 4 and 6.



**FIGURE 13.3.2** Set-up of test tubes to investigate the effect of acid and water on three rock types.

- 4 Leave the test tubes in the test-tube rack overnight, or until your next science class, and record any observations.

## Part B: The effect of temperature

- 5 Mix enough plaster with water to half-fill two margarine containers or cut-down milk cartons.
- 6 Fill a small balloon with water and tie it. Push the balloon below the plaster in one container only. Ensure it stays below the surface as the plaster sets. The container without the balloon will be your control.
- 7 When the plaster is solid put both of the containers in a freezer overnight, or until your next science class, and record any observations.

## Results

Copy the results tables below into your notebook and record your observations.

### Part A

Test tube	Rock	Liquid	Observations
1	granite	water	
2	granite	vinegar	
3	limestone	water	
4	limestone	vinegar	
5	sandstone	water	
6	sandstone	vinegar	

### Part B

Container	Observations
1 Plaster without water balloon	
2 Plaster with water balloon	

## Discussion

Evaluate how well this experiment models the weathering of rocks in the environment.

## Conclusion

- 1 Use the observations in Part A to explain the weathering of rocks by chemicals.
- 2 Use the observations in Part B to explain a possible effect of freezing temperatures and water on rocks.

# 13.4 Sedimentary rocks

## Lesson overview

Sedimentary rocks are rocks made from sediments (Figure 13.4.1). Sediments are small particles of weathered rock or crystals that have been deposited and left behind by ice, water, and wind. In this lesson you will learn how sedimentary rocks are formed, the observable features of sedimentary rocks, and how fossils preserved in sedimentary rocks can be used to predict how and when a rock was formed.

**SC 1** I can describe how and where sedimentary rocks are formed

## Sedimentary rocks

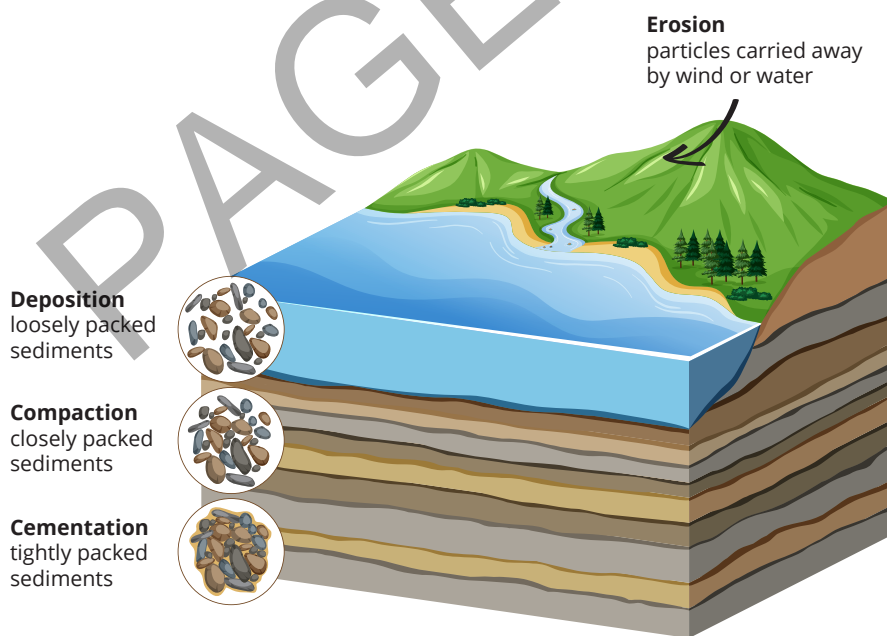
Sedimentary rocks are formed at the bottom of large bodies of water, including oceans and large lakes. Some also form in deserts and caves.

Sediments are small fragments of rocks that pile up over time. The laying down of these rock fragments is called deposition.

As sediments layer on top of one another, they push down on the underlying sediments. This squeezes out excess water, and a more compact denser structure forms. This process is known as **compaction**.

Naturally occurring minerals in water, such as silica and lime, can bind or cement the sediments together and create a more solid rock structure in a process called **cementation**.

Sediments that have undergone compaction and cementation form **sedimentary rocks** (Figure 13.4.2).



**FIGURE 13.4.2** The three main stages in the formation of sedimentary rock.

## Learning intention

To understand the formation of sedimentary rocks

## Success criteria

**SC 1:** I can describe how and where sedimentary rocks are formed.

**SC 2:** I can explain how the law of superposition and fossil evidence can be used to predict how and when a rock was formed.



**FIGURE 13.4.1** Sediment has been deposited in layers to form sedimentary rocks.

## KEY TERMS

**compaction** the squeezing of layers of sediments caused by pressure from layers above  
**cementation** the binding together of sediments as part of the formation of sedimentary rock  
**sedimentary rock** rock made by sediments being compacted and cemented together

## SC 1 CHECK YOUR UNDERSTANDING

Outline the three main stages of the formation of sedimentary rock.

**SC 2** I can explain how the law of superposition and fossil evidence can be used to predict how and when a rock was formed

Sedimentary rocks are formed from the accumulation and compaction of mineral and organic particles over long periods. These rocks often contain fossils and are typically found in layers, or strata, which provide valuable information about Earth's history.

## Law of superposition

One of the key principles used to understand sedimentary rocks is the law of superposition. This geological principle states that in any undisturbed sequence of sedimentary rocks, the oldest layers are at the bottom, and the layers become progressively younger towards the top. This allows geologists to determine the relative ages of rock layers and to construct a chronological sequence of geological events.

## Fossil evidence

Fossil evidence within these layers further aids in predicting the age and formation of sedimentary rocks. Fossils are the preserved remains or traces of ancient organisms, and they are often found in sedimentary rocks. By studying the types of fossils present in different layers, geologists can correlate the ages of rocks from different locations.

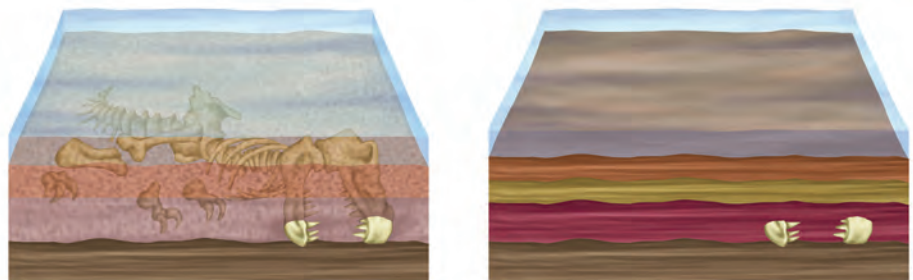


**FIGURE 13.4.3** An organism's remains can become buried in sediments in a water body.

If the remains of a dead organism are quickly covered by sediment, then it may be preserved and become a fossil.

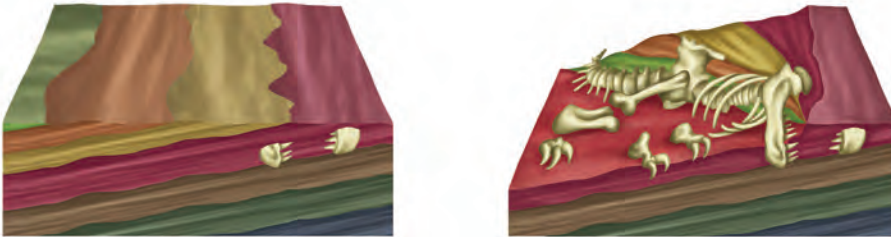
Fossils are often found in deep water bodies such as oceans, lakes, or rivers (Figure 13.4.3). This means there is very little oxygen in the sediment which results in little or no decomposition.

The fleshy parts of the organism will gradually decompose. The hard remains of the organism, such as bones, are replaced by minerals and so turn into rock, becoming fossilised. Over time, sediments continue to build up, compacting and cementing, and become sedimentary rock (Figure 13.4.4).



**FIGURE 13.4.4** Hard remains of the organism are replaced by minerals and become compacted in the surrounding sedimentary rock.

Changes to Earth's surface such as movements in Earth's crust, weathering and erosion can expose the fossil at Earth's surface (Figure 13.4.5).



**FIGURE 13.4.5** Fossilised remains of an organism can become exposed at Earth's surface due to weathering and erosion.

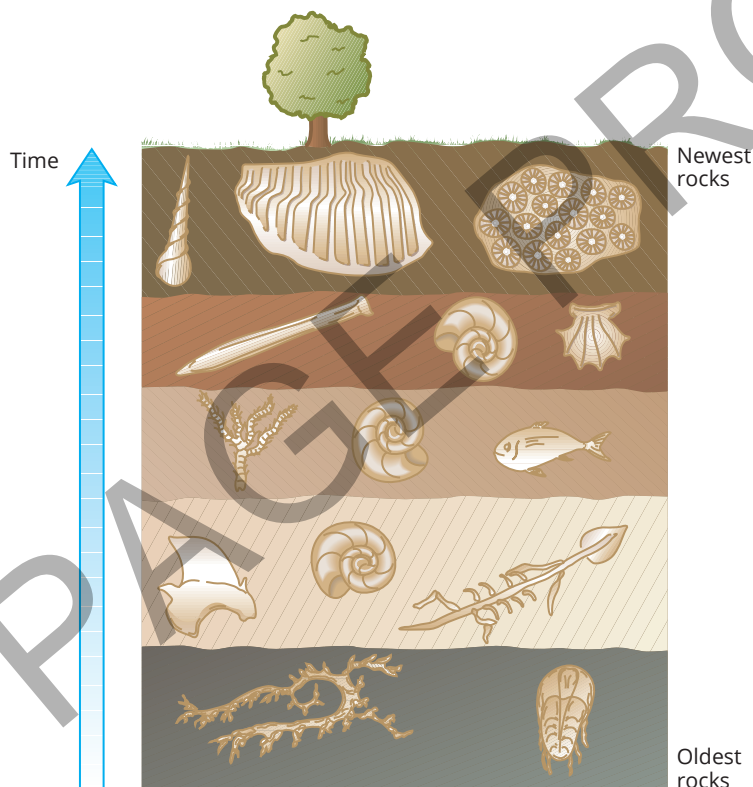
## Index fossils

As layers of sedimentary rock are built up over time, deeper layers will generally be older than those closer to the surface (Figure 13.4.6). It is possible to compare the relative ages of rocks from different places using **index fossils**.

Index fossils within layers can mark layers that were formed around the same time but at different locations. Index fossils can be used to check the order of the layers and to check the age of the rock strata that housed the fossils.

### KEY TERMS

**index fossil** a fossil that can be used to compare the relative age of rock strata in different locations



**FIGURE 13.4.6** Index fossils can help to date the age of sedimentary rock.

## SC 2 CHECK YOUR UNDERSTANDING

Explain how fossils are preserved in sedimentary rocks.

## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

- 1 Identify the type of environment in which sedimentary rocks are typically formed.
- 2 Explain the processes of compaction and cementation in the formation of sedimentary rocks.
- 3 Explain the law of superposition and how it helps in determining the relative age of rock layers.
- 4 Explain how fossil evidence can be used to determine the age of rock layers.
- 5 Explain the role of water in the formation of sedimentary rocks.
- 6 Compare and contrast the process of dating sedimentary rocks using the law of superposition and using fossil evidence.

PAGE PROOFES

# 13.5 Igneous rocks

## Lesson overview

Earth's crust was originally formed when molten rock cooled to form igneous rock. The word igneous means 'born of fire'. Molten magma and lava crystallise to form these rocks.

In this lesson you will learn how and where igneous rocks are formed, and the observable features of igneous rocks.

**SC 1** I can describe how and where igneous rocks are formed

A volcano is a formation that allows extremely hot material from inside Earth to erupt at Earth's surface (Figure 13.5.1). The molten rock below Earth's surface is called **magma**, and magma reaching Earth's surface is called **lava**.

**Igneous rock** is formed when magma or lava cools and hardens into rock.

This can happen in different ways:

- 1 Magma may cool on the surface of Earth, in the air, underwater, or underground.
- 2 Igneous rocks that form above the ground are called **extrusive igneous rocks**.
- 3 Igneous rocks that form when magma gets trapped underground and cools are called **intrusive igneous rocks**.

### SC 1 CHECK YOUR UNDERSTANDING

Where are intrusive igneous rocks formed? Compare this to extrusive igneous rocks.

**SC 2** I can describe observable features of igneous rocks

As the molten rock cools into an igneous rock, it forms crystals that grow together. This causes the crystals to interlock, so the rock is hard.

## Making observations

When observing igneous rocks, you should note their texture and colour. For example, their texture could be rough or smooth and the varying size of the crystals should be noted. The colour of the rock indicates what **minerals** it may contain.

### KEY TERM

**mineral** a naturally occurring solid substance that is inorganic, has a characteristic crystalline structure and a fairly constant chemical composition

### Learning intention

To understand the formation of igneous rocks

### Success criteria

**SC 1:** I can describe how and where igneous rocks are formed.

**SC 2:** I can describe observable features of igneous rocks.

### KEY TERMS

**volcano** a place where extremely hot material from inside Earth erupts at the surface

**magma** molten rock below Earth's surface

**lava** molten rock that reaches Earth's surface

**igneous rock** rock formed by the cooling of molten rock, for example basalt

**extrusive igneous rock** igneous rock that forms on the surface of Earth

**intrusive igneous rock** igneous rock that forms below the surface of Earth



**FIGURE 13.5.1** Volcano Fuego (Antigua, Guatemala) erupts bringing molten lava to Earth's surface.



**FIGURE 13.5.2** Pumice is an example of an extrusive igneous rock that trapped gas as it cooled



**FIGURE 13.5.3** Granite is an example of an intrusive igneous rock

## Extrusive igneous rocks

Extrusive igneous rocks cool very quickly when lava is exposed to air or water. They have specific observable features:

- Large crystals don't have time to grow, so the crystals are tiny and are only visible under a microscope.
- They might have a bubbly texture as can be seen in Figure 13.5.2. This is due to trapped bubbles of gas within the lava as it cooled rapidly.

Some examples of extrusive igneous rocks are basalt, obsidian (volcanic glass), scoria, and pumice.

## Intrusive igneous rocks

Intrusive igneous rocks cool more slowly because they cool underground. They tend to have large crystals that can be seen without the help of a microscope. The large crystals form because the slow cooling time means that large crystals have time to grow. Some examples of intrusive igneous rocks are dolerite, gabbro, and granite (Figure 13.5.3).

### SC 2 CHECK YOUR UNDERSTANDING

An igneous rock sample has been identified as being intrusive. What does this tell you about:

- where it formed?
- the size of its crystals?

## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

- 1 Explain the difference between the crystal size in intrusive igneous and extrusive igneous rocks.
- 2 If you find an igneous rock with large, visible crystals, what can you infer about its formation?
- 3 You are examining igneous rock samples to identify their features.
  - a List the observable features you would look for in igneous rocks.
  - b Explain how the cooling rate affects the texture of igneous rocks.
  - c Compare the textures of intrusive and extrusive igneous rocks.
  - d Explain the importance of colour in identifying igneous rocks.
  - e One of the rock samples has crystals of varying sizes – some are visible to the naked eye and others are microscopic. What type of igneous rock is this likely to be?
- 4 There are times when magma that is cooling below the ground is forced up above the ground. Explain how increasing the rate that igneous rocks cool affects the crystal size within the rock.
- 5 A fine-grained igneous rock with a bubbly texture has been found on the beach.
  - a Which type of igneous rock is this specimen most likely to be?
  - b Is the molten material from which it formed likely to be lava or magma?
  - c Describe the rate at which heat energy would have been lost as this rock cooled.
  - d What is the likely cause of the bubbly texture?
  - e Suggest the name of the igneous rock.

# 13.6 Metamorphic rocks

## Lesson overview

All rocks can be altered by heat and/or pressure to form metamorphic rocks. Even metamorphic rocks can be further metamorphosed. This process turns ordinary limestone into beautiful marble (Figure 13.6.1), and soft sandstone into hard quartzite.

In this lesson you will learn about the formation of metamorphic rocks, what a parent rock is, and the role of pressure and heat energy in the formation of metamorphic rocks.

**SC 1** I can describe how and where metamorphic rocks are formed

When large amounts of heat energy and/or pressure are applied to rocks, the properties of the rock can change. This is how **metamorphic rocks** are formed.

Both physical and chemical changes can occur when rocks are metamorphosed. Crystals can transform into crystals of new minerals (recrystallisation). Crystals can deform into flattened sheets. Bands of different minerals can form when crystals are squashed flat by forces within Earth while they are hot.

### Scifile

#### Gemstones

Many gemstones, like emerald and garnet, form in metamorphic rocks through the process of recrystallisation. The intense heat and pressure create the perfect conditions for these beautiful minerals to grow. Trace elements give the gemstones their different colours. For example, sapphire and ruby are varieties of the same mineral corundum, but ruby's red colour is due to traces of chromium in its structure. Sapphire's colours come from traces of elements such as iron, nickel and titanium.



### SC 1 CHECK YOUR UNDERSTANDING

Name two effects of metamorphism on rocks.

### Learning intention

To understand the formation of metamorphic rocks

### Success criteria

**SC 1:** I can describe how and where metamorphic rocks are formed.

**SC 2:** I can describe examples of specific metamorphic rocks and their parent rock.



**FIGURE 13.6.1** Marble caves in Chile have been formed from metamorphosed limestone.

### KEY TERM

**metamorphic rock** rock formed when temperature and/or pressure alter existing rock

**SC 2** I can describe examples of specific metamorphic rocks and their parent rock

### KEY TERMS

**parent rock** the original rock that experiences metamorphism, or changes form, to become a new kind of rock

**foliate** a process where minerals under pressure realign and the rock develops layers or bands

## Parent rocks

Metamorphism changes the original rock or **parent rock** into a completely new rock. The parent rock can be sedimentary, igneous or metamorphic.

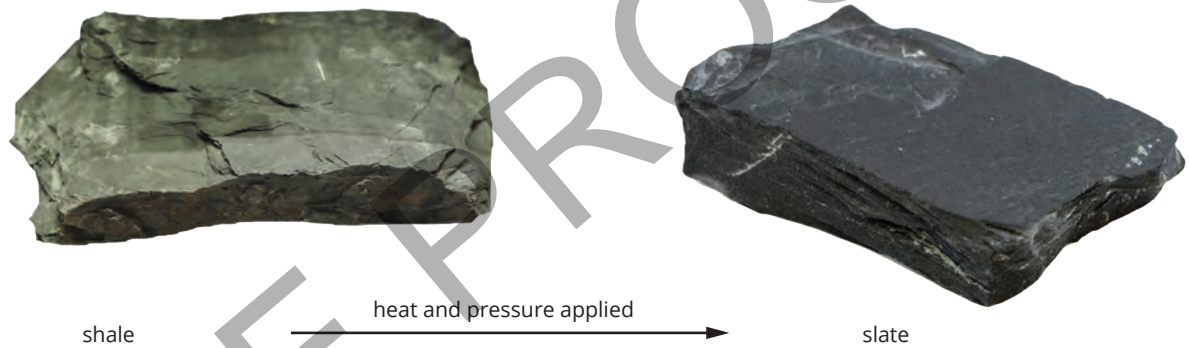
When the minerals in a rock are forced into layers, the rock is said to be **foliated**. These bands of minerals can also have a wavy pattern when pressure is applied and squeezes the layers. Metamorphic rocks are either foliated or non-foliated.

## Foliated metamorphic rocks

The following are examples of metamorphic rocks that are foliated.

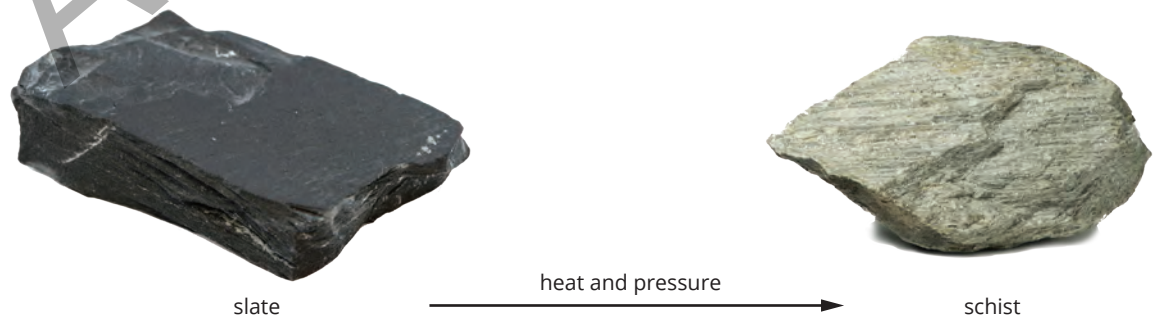
Shale (mudstone) is the sedimentary parent rock that forms slate under pressure and heat.

Slate is a foliated metamorphic rock. Note the cleavage lines through the rock shown in Figure 13.6.2. Slate is still fine-grained like its parent rock.



**FIGURE 13.6.2** Shale is metamorphosed to foliated slate.

If slate is subject to more pressure and higher temperatures, it will change again to form schist (Figure 13.6.3). New minerals are formed, the crystals are larger, and the rock remains foliated.

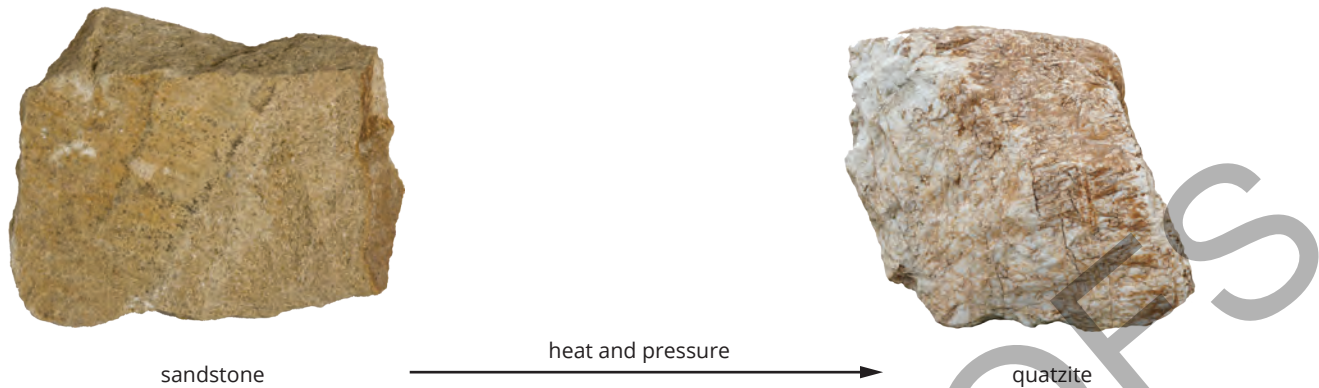


**FIGURE 13.6.3** Slate is metamorphosed to form schist.

## Non-foliated metamorphic rocks

The following are examples of metamorphic rocks that are non-foliated.

Quartzite is much harder than its parent rock sandstone (Figure 13.6.4). Sandstone will shatter into many individual grains of sand while quartzite will break across the grains. Quartzite is non-foliated.



**FIGURE 13.6.4** Sandstone is metamorphosed to form quartzite.

### SC 2 CHECK YOUR UNDERSTANDING

Shale can undergo a number of stages of metamorphism to form the metamorphic rock schist.

- a Identify the original parent rock in this process.
- b Is schist an example of a foliated or a non-foliated metamorphic rock?

## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

- 1 Describe how metamorphic rocks typically form.
- 2 Explain the role of pressure and temperature in the formation of metamorphic rocks.
- 3 If you find a rock that has been subjected to high pressure but low temperature, what type of metamorphic rock might it be?
- 4 Compare the parent rocks and the resulting metamorphic rock types for both quartzite and schist.
- 5 You are studying the formation of metamorphic rocks under different conditions of heat and pressure.
  - a Describe the role of heat energy in the metamorphic process.
  - b Explain how pressure influences the texture of metamorphic rocks.
- 6 Slate is a metamorphic rock that has been used for centuries as roof, floor and wall tiles, and as the base for billiard tables. Outline the characteristics of slate that make it suitable for these purposes. Consider grain size, foliation, and hardness in your response.

# 13.7 The source of metamorphic rocks

## Learning intention

To be able to investigate the source of metamorphic rocks

## Success criteria

**SC 1:** I can use a dichotomous key to identify igneous, sedimentary and metamorphic rocks.

**SC 2:** I can use observations and secondary data to match the metamorphic rocks to their parent rocks.

**SC 3:** I can describe changes that have occurred to the properties of rocks because of the production of the metamorphic rock.

## Introduction

Metamorphic rocks, such as the marble shown in Figure 13.7.1, are formed from other rocks when placed under pressure and/or heat. In this practical investigation you will investigate the source of metamorphic rocks by using an identification tool called a dichotomous key.



**FIGURE 13.7.1** Marble formed from the parent rock of limestone.

## Background

**Dichotomous keys** are used in classification processes. They give the user two choices at each point in the procedure. Dichotomous keys can be used to classify rocks.

### KEY TERM

**dichotomous key** a classification key with two choices at each stage

## SkillBuilder

### Classifying rocks

#### Using dichotomous keys to classify rocks

Do the following when observing and classifying rocks.

- 1 Spray the rock with water to make it easier to see any contrasting colours.
- 2 View the rock through a magnifier.
- 3 Use a ruler to estimate the size of any crystals.

Note that very fine-grained rocks may be difficult to classify without extra techniques such as taking a thin slice of the rock to observe under a microscope.

## Dichotomous key for classifying rocks

1	Rocks have crystals – go to 2. Rocks do not have crystals – go to 6.
2	Rocks are made entirely of interlocking crystals. <i>Igneous</i> – go to 3. Rocks are not made entirely of interlocking crystals. <i>Metamorphic</i> – go to 10.
3	Rocks have crystals large enough to see using a hand lens. <i>Igneous intrusive</i> – go to 4. Rocks have crystals but their crystals are difficult to see using a hand lens. <i>Igneous extrusive</i> – go to 5.
4	Rocks are dark and dense. <i>Igneous, intrusive and mafic (rich in magnesium and iron), e.g. gabbro</i> Rocks are neither dark nor dense. <i>Igneous, intrusive and felsic (rich in feldspar and silicon), e.g. granite, pegmatite</i>
5	Rocks are dark and dense. <i>Igneous, extrusive and mafic (rich in magnesium and iron), e.g. basalt</i> Rocks are neither dark nor dense. <i>Igneous, extrusive and felsic (rich in feldspar and silicon), e.g. rhyolite</i>
6	Rocks are non-crystalline and are made of pieces or chunks of smaller rock. <i>Sedimentary, clastic</i> – go to 7. Rocks are non-crystalline but are not made of pieces or chunks of smaller rock. <i>Sedimentary, biogenic, e.g. limestone, chalk, coal</i>
7	Rocks have large pieces or chunks of smaller rock – go to 8. Rocks do not have large pieces or chunks of smaller rock – go to 9.
8	Rocks have large pieces or chunks of smaller rock that are rounded. <i>Sedimentary, clastic, e.g. conglomerate</i> Rocks have large pieces or chunks of smaller rock that are not rounded. <i>Sedimentary, clastic, e.g. breccia</i>
9	Rocks have medium rounded pieces or chunks of smaller rock. <i>Sedimentary, clastic medium grained, e.g. sandstone</i> Rocks have pieces or chunks of smaller rock that are less than medium size. <i>Sedimentary, clastic fine grained, e.g. siltstone, mudstone</i>
10	Rocks are foliated (or banded). <i>Metamorphic, e.g. slate, schist and gneiss</i> Rocks are not foliated (or banded). <i>Metamorphic, e.g. quartzite and marble</i>

## Worked example

### Classifying rocks

This worked example uses the dichotomous key from the SkillBuilder to classify a rock sample.



#### Problem

Use the dichotomous key to classify the unknown rock sample as shown in the figure. Note that each bar on the scale is 1 cm.

#### Solution

Thinking	Working
Does the rock have crystals?	Yes, go to 2.
Are the crystals interlocking?	Yes, go to 3.
Can you see the crystals using a hand lens?	Yes, go to 4.
Is the rock dark and dense?	The rock is neither dark nor dense – it is light in colour. This means it is an igneous, intrusive and felsic rock (rich in feldspar and silicon), such as granite or pegmatite. (Note: The sample is granite.)

#### Try yourself

Use the dichotomous key to classify this rock. Note that each bar on the scale is 3 cm.



## Aim

Your investigation has two aims:

- 1 To classify unknown rock samples as igneous, sedimentary or metamorphic
- 2 To compare metamorphic rocks with their parent igneous, sedimentary and metamorphic rocks

## Apparatus

For Task 1, you will need:

- numbered but unlabelled rock samples
- stereo microscope and/or hand lens.

For Task 2, you will need:

- labelled rock samples in containers: gneiss, granite, limestone, marble, quartzite, sandstone, schist, shale, slate
- stereo microscope and/or hand lens.

## Method

### Task 1

- 1 Choose a numbered rock sample. Your first task is to describe the characteristics of the rock.
- 2 Use your microscope and/or hand lens to take a closer look. Then, using the dichotomous key, decide whether it is igneous, sedimentary or metamorphic. Record your reasons in your results table. If you feel confident, try to name the rock.
- 3 Repeat step 2 for each rock.
- 4 Record all observations in your results table.

### Task 2

- 1 Use the microscope and/or hand lens to examine the rock samples.
- 2 Use the information in the 'Metamorphic rocks' lesson, and any other information available to you, to match each metamorphic rock to its parent rock.
- 3 For each pair of rocks, write the name of the parent rock first and describe its characteristics, including its rock type. Then, do the same for the metamorphic rock.
- 4 For each metamorphic rock, describe the characteristics that enable you to decide it is metamorphic.
- 5 Describe changes that have occurred in each metamorphic rock as it altered from its parent rock.

### HINT

It is possible that a particular rock is the parent rock for more than one metamorphic rock.

It is also possible that a metamorphic rock may have more than one parent rock.

## Results

Copy the results tables below into your notebook and record your observations.

## Task 1

Rock number	Description	Classification	Rock name

## Task 2

	Parent rock	Description	Metamorphic rock	Description
Pair 1				
Pair 2				
Pair 3				
Pair 4				
Pair 5				

Rock name	Reasons you have decided it is metamorphic	What changes occurred to make it metamorphic?

## Discussion

Evaluate your practical investigation by considering how you could improve the process of classification.

### GO TO ►

For more help with evaluating investigations, go to Toolkit, section x.x, page yy.

## Conclusion

Summarise how you were able to classify rock samples (Task 1) and determine the parent/metamorphic rock relationships (Task 2).

# 13.8 The rock cycle in action

## Lesson overview

Rocks have been constantly changing since Earth formed. The rock cycle is a model that outlines these processes and the resultant changes to rock types. In this lesson you will learn about the formation of different types of rock within the rock cycle and the impact of environmental factors on the structure of rocks.

**SC 1** I can compare the formation of different types of rock within the rock cycle

## The rock cycle

Since Earth was formed, rocks have been continually changing. The **rock cycle** is a model used by scientists to explain the endless cycling of rocks and rock types.

The rock cycle diagram in Figure 13.8.1 shows that a range of geological processes such as weathering, erosion, deposition, melting, heat, pressure, and crystallisation cause changes to the structure of rocks. Some of these occur deep in Earth's lithosphere where there are higher levels of heat and pressure. Others are the result of environmental changes on Earth's surface itself.

### Learning intention

To understand how environmental changes affect the rock cycle

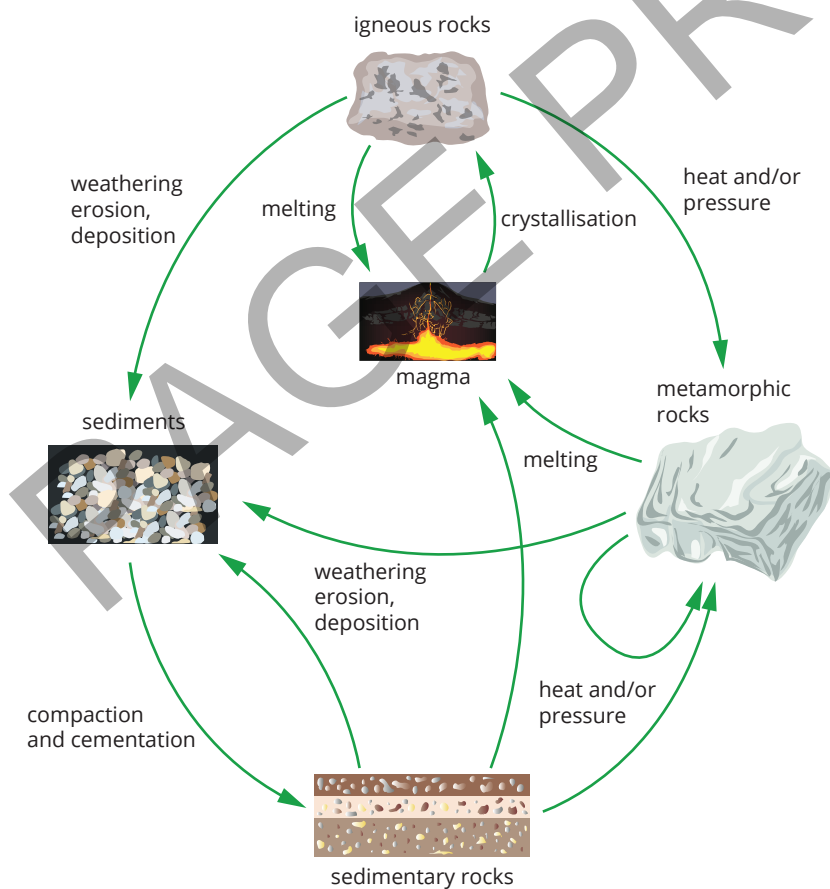
### Success criteria

**SC 1:** I can compare the formation of different types of rock within the rock cycle.

**SC 2:** I can predict and explain locations where specific types of rocks are found.

### KEY TERMS

**rock cycle** a model geologists use to explain the endless cycle of change that rocks undergo



**FIGURE 13.8.1** A more detailed version of the rock cycle showing geological processes and changes to rock type.

The processes that form sedimentary, igneous and metamorphic rocks are a continuous cycle that began when Earth was first formed. It is possible for igneous rocks to melt and cool, forming new igneous rocks. A sedimentary rock may metamorphose when subjected to high levels of heat and/or pressure, then go through uplift and erosion to form a new sedimentary rock.

**SC 1 CHECK YOUR UNDERSTANDING**

Identify the series of geological processes that can change:

- a** an igneous rock into a sedimentary rock
- b** a sedimentary rock into an igneous rock
- c** a metamorphic rock into an igneous rock.

**SC 2** I can predict and explain locations where specific types of rocks are found

**Where specific types of rocks are found**

Most of the rocks found in Australia are either igneous or sedimentary rocks. However, metamorphic rocks can be found in some regions of Australia, particularly in the East MacDonnell Ranges of the Northern Territory where ancient quartzite rock formations are common.

**Igneous landmarks**

Mount Kosciuszko in New South Wales (Figure 13.8.2) is formed of igneous granite rocks. Igneous rocks are often found at mountain ranges where volcanic activity has occurred, or where there has been large-scale uplift of igneous rock formed deep in the crust.

**Sedimentary landmarks**

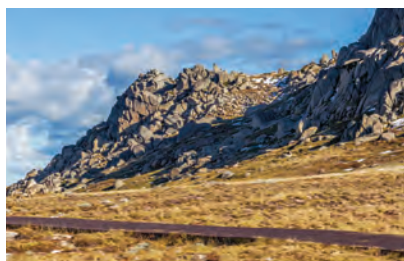
Most of the Sydney area is situated on a bedrock of Sandstone (Figure 13.8.3). Ancient sediments were buried and compressed to form harder rock, resulting in the sedimentary Sydney sandstone. This yellowish coloured rock can be seen in many of the coastal cliffs around Sydney.

**Metamorphic landmark**

Trephina Gorge is in the East MacDonnell Ranges of the Northern Territory (Figure 13.8.4). This gorge has sheer cliffs made of metamorphic quartzite. The rocks were once sandstone, but heat and pressure metamorphosed the sandstone to quartzite.

**SC 2 CHECK YOUR UNDERSTANDING**

Identify the rock type or types that are the most abundant in Australia.



**FIGURE 13.8.2** Mount Kosciuszko is part of a mountain range formed when igneous granite was uplifted.



**FIGURE 13.8.3** The headlands of Sydney's Bondi B each show the sandstone that is the bedrock under most of the Sydney area.

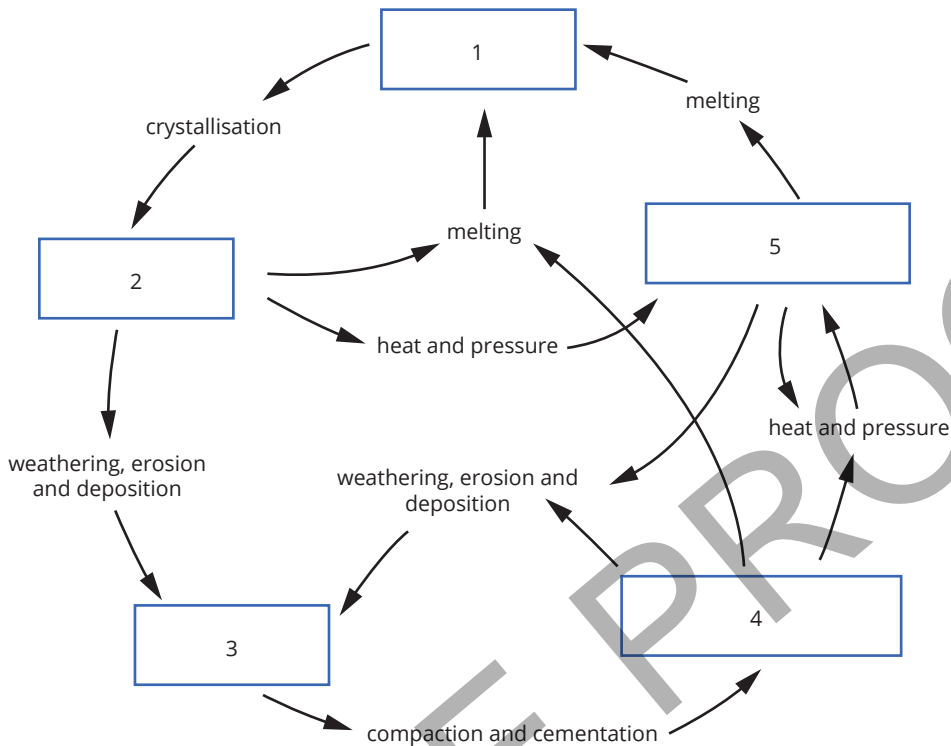


**FIGURE 13.8.4** The MacDonnell Ranges formed when metamorphic quartzite was uplifted.

## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

- 1 Outline the five stages involved in the formation of sedimentary rocks.
- 2 Compare the role of heat in the formation processes of igneous and metamorphic rocks.
- 3 Identify the stages of the rock cycle labelled 1 to 5.
- 4 You are mapping the distribution of different rock types in various geological settings.
  - a Identify the types of rocks you would expect to find in a volcanic region.
  - b Explain the processes that lead to the formation of these rocks.
  - c Predict the types of rocks found at the mouth of a river and explain their formation.
  - d Evaluate the role of uplift on the distribution of all three rock types.
- 5 'Australia has the best sand beaches in the world because the landscape is so old.' Evaluate this statement, considering the role of the rock cycle in creating these beaches.



# 13.9 The theory of plate tectonics

## Learning intention

To understand the theory of plate tectonics

## Success criteria

**SC 1:** I can describe the formation of the Earth and the tectonic plates.

**SC 2:** I can identify the tectonic plates.

**SC 3:** I can explain the forces of motion of tectonic plates.

## Lesson overview

The tectonic plate theory says that the surface of Earth is divided into large segments (Figure 13.9.1). Due to the geology of Earth, these segments can move across the surface, pushing against, separating from, and sliding past each other. This theory was developed in the early 1900s, and today there is large body of evidence to support it.

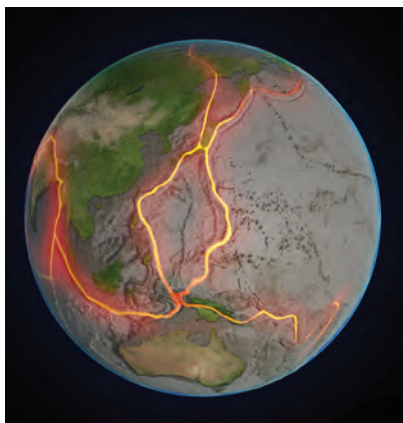
In this lesson, you will learn about the theory of plate tectonics, how plates are able to move, and what impact these motions have on Earth.

### SC 1 I can describe the formation of the Earth and the tectonic plates

A very, very long time ago (4.5 billion years), Earth was formed when a part of a cloud of gas and dust, formed from a previous star's supernova explosion, clumped together under gravity.

Initially, Earth was an extremely hot, molten ball of all the elements. Due to gravitational forces, the heavy materials, such as iron and nickel, sunk to the centre of Earth, leaving the lighter materials near the surface. Eventually, this process created different layers within Earth, each of which have different properties.

These layers include the core, the mantle and the crust. The crust and the top layer of the mantle together form a hard, brittle layer called the lithosphere (Figure 13.9.2). Just below the lithosphere is the asthenosphere which is a part of the mantle that is solid but behaves plastically as the solid rock can bend and flow over long periods of time. At some point during the formation of Earth the lithosphere fractured into pieces which we call **tectonic plates**.



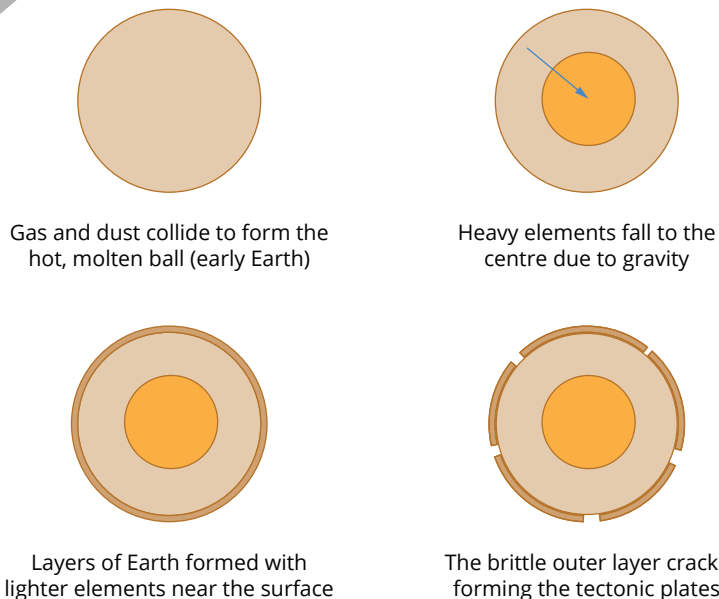
**FIGURE 13.9.1** Tectonic plate boundaries in the Asia-Pacific region.

### KEY TERMS

**tectonic plate** large section of Earth's lithosphere that moves about on Earth's surface

**oceanic crust** more dense part of the crust that forms the ocean floor

**continental crust** less dense part of the crust that forms the continents



**FIGURE 13.9.2** Stages in the formation of Earth's layers and the tectonic plates.

## Continental or oceanic crust

The lithosphere's outer crust layer comes in two different types: oceanic and continental.

**Oceanic crust** is found on the ocean floor, and **continental crust** is found where there are continents.

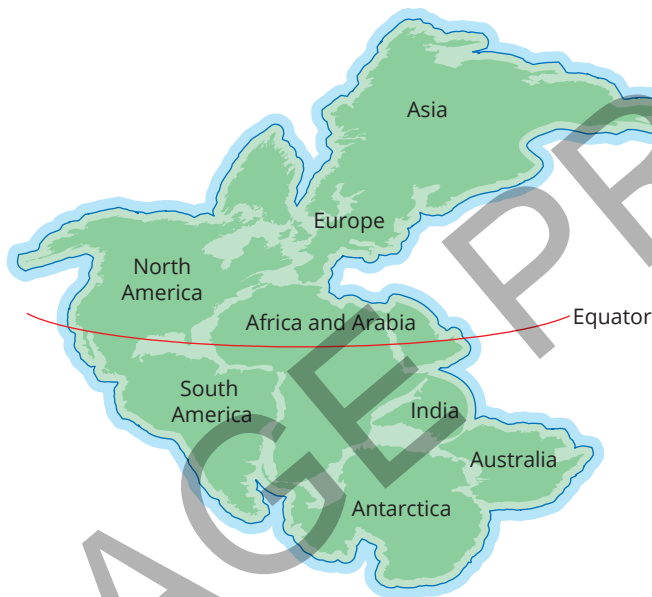
Oceanic crust is generally more dense than continental crust.

### SC 1 CHECK YOUR UNDERSTANDING

Compare the properties of the lithosphere and the asthenosphere.

### SC 2 I can identify the tectonic plates

In 1912, Alfred Wegener proposed a theory that the continents were drifting across the surface of Earth, and that they once had all been joined together in one super continent. Wegener called this large landmass Pangaea, meaning 'all Earth' (Figure 13.9.3).



**FIGURE 13.9.3** Earth's continents are believed to have once been joined together in a supercontinent called Pangaea.

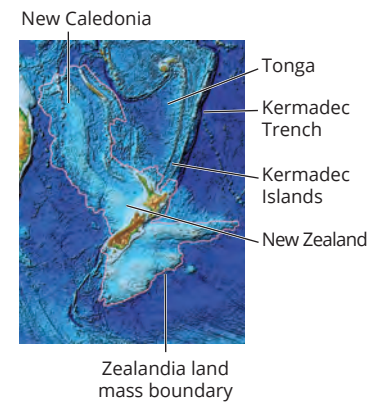
This theory was called continental drift, and at the time Wegener proposed it, it was highly contested. Today, the **theory of plate tectonics**, which now describes how this motion can occur, is widely accepted by the scientific community.

There are seven major tectonic plates on Earth. The massive, solid plates are constantly in motion over very long timescales. Each year, the tectonic plates move (on average) 1.5 cm. This isn't a big difference over a few years, but over geological time scales of millions of years, this movement causes some big changes to the structure of Earth's surface.

### Scifile

#### Australia's new and old neighbours

To Australia's east, the Pacific Plate is sinking beneath the Australian Plate. This forms the Kermadec Trench. Tonga and New Zealand's Kermadec Islands are island arcs forming as a result of this process. New Zealand and New Caledonia were once part of an ancient landmass, more than half the size of Australia, called Zealandia. It is believed that the central part of Zealandia sank under the ocean more than 23 million years ago. The remains of this landmass can be seen on satellite imagery.

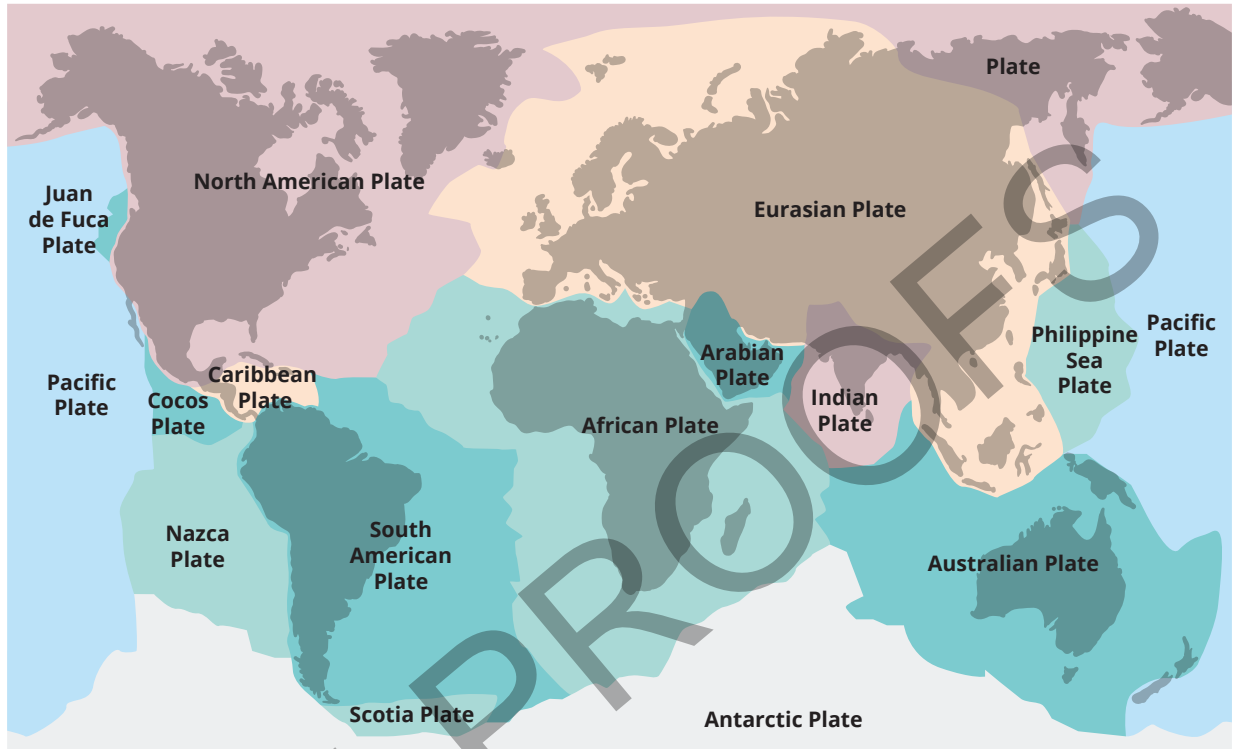


### KEY TERMS

#### theory of plate tectonics

scientific theory that describes the existence, and motion, of tectonic plates

The major tectonic plates are the African, Antarctic, Eurasian, North American, South American, Australian, and Pacific Plates. These are called major plates because they each have an area greater than 20 million km<sup>2</sup>. The smaller plates are called the minor plates. The minor plates include the Arabian, Caribbean, Cocos, Indian, Juan De Fuca, Nazca, Philippine (also known as Philippine Sea), and Scotia Plates (Figure 13.9.4).



**FIGURE 13.9.4** Earth's lithosphere is broken up into major and minor tectonic plates.

### SC 2 CHECK YOUR UNDERSTANDING

Name the seven major tectonic plates of Earth.

### SC 3 I can explain the forces of motion of tectonic plates

Tectonic plate movement is a fundamental process that shapes Earth's surface, leading to the formation of mountains, earthquakes, and volcanic activity. This movement is driven by several key mechanisms, including convection currents in the mantle, slab pull, and ridge push.

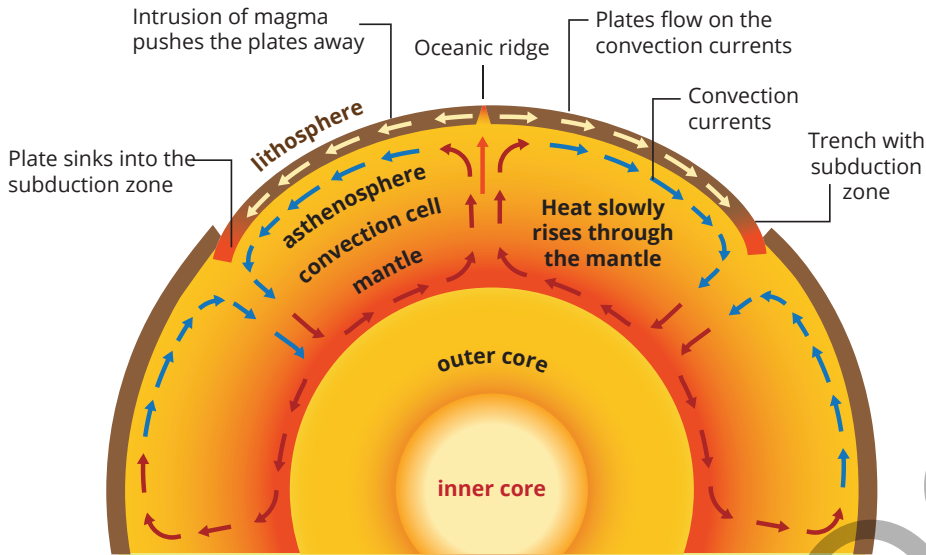
## Convection currents in the mantle

One of the primary drivers of tectonic plate movement is the convection currents in Earth's mantle. The mantle, which lies beneath Earth's crust, is composed of solid but slowly flowing rock. Heat from Earth's core causes the mantle material to heat up, become less dense, and rise towards the surface. As it reaches the upper mantle, it cools down, becomes denser, and sinks back towards the core. This continuous cycle of rising and sinking material creates **convection currents**.

#### KEY TERMS

**convection current** current that forms when warmer less-dense fluids rise while cooler, denser fluids sink

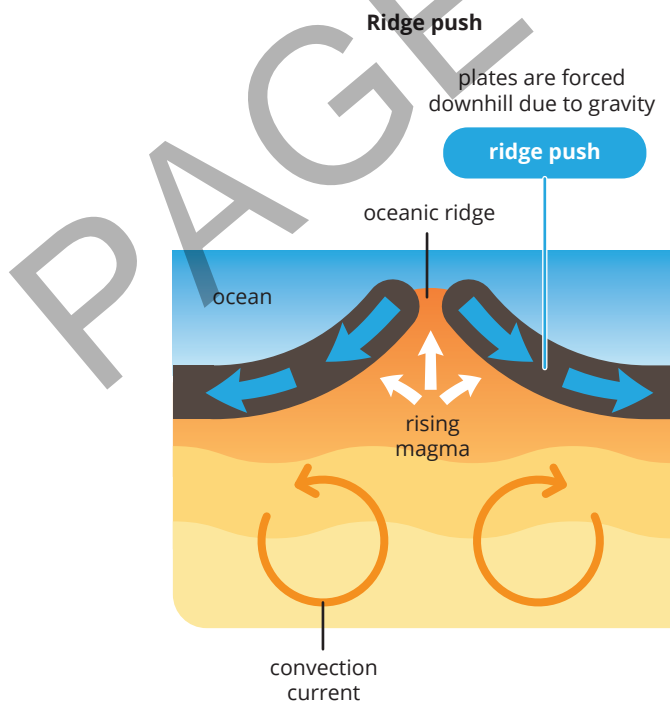
These convection currents act like a conveyor belt, dragging the overlying tectonic plates along with them (Figure 13.9.5). The movement of these plates can cause them to collide, pull apart, or slide past each other, leading to various geological phenomena.



**FIGURE 13.9.5** Convection currents in the mantle drag the crust along with them.

## Slab pull and ridge push

New crust is made at places called **mid-ocean ridges**. A **rift valley** at the centre of a mid-ocean ridge is where magma rises to the surface. As the new crust cools and becomes denser, it spreads downwards and outwards from the ridge, pushing the tectonic plates apart with a force called **ridge push**. This allows new magma to rise to the surface and form rock at the mid-ocean ridge (Figure 13.9.6).



**FIGURE 13.9.6** Rising crust at an oceanic ridge is pulled down and outward due to gravity.

### KEY TERMS

**mid-ocean ridge** a mountain chain on the floor of the ocean along the boundary of two tectonic plates

**rift valley** a low-lying valley created by the action of a geological rift or split, often at a diverging plate margin

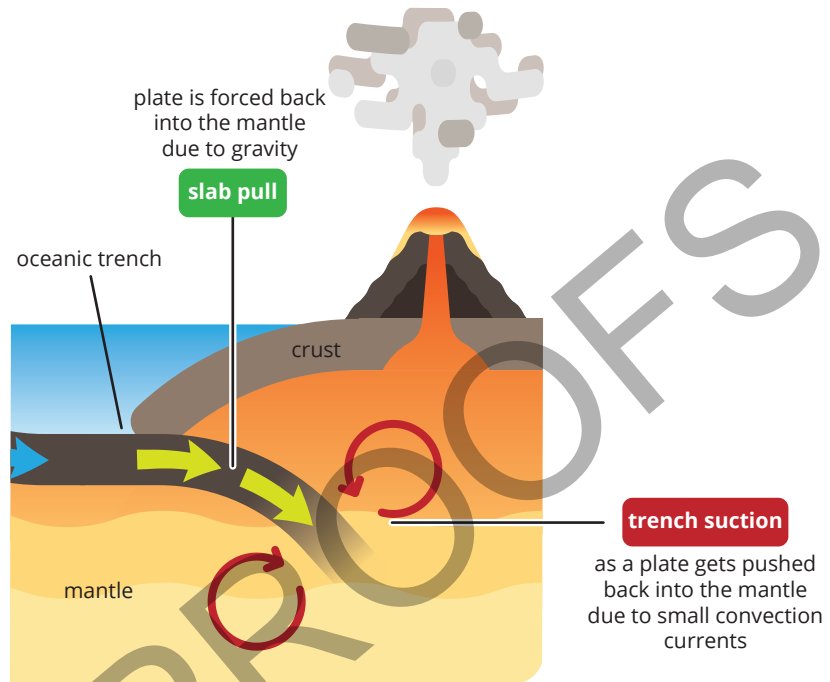
**ridge push** older crust is pushed by new ocean crust at mid-ocean ridges, forcing plates apart

**KEY TERMS**

**subduction** when a more dense plate sinks below another, less dense plate during a collision

**slab pull** pulling force exerted by an older, colder and denser oceanic plate sinking down into the asthenosphere due to gravity, dragging the rest of the plate with it

At the boundaries between colliding plates, the plate that is denser will undergo a process called **subduction** due to gravity, in which the plate sinks below the less dense plate into the asthenosphere. The denser plate will then pull the following rock down with it. In the process of subducting the denser plate material heats up and melts to form magma. This process is called **slab pull** and is believed to be the main driving force for the motion of the tectonic plates (Figure 13.9.7).



**FIGURE 13.9.7** Denser crust is pulled down under the less dense crust due to gravity.

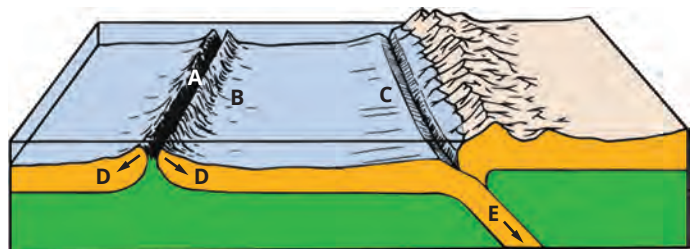
These two processes occur together so that, as sinking crust is destroyed while subducting into the mantle, new crust is created at the ridges.

Understanding the mechanisms behind tectonic plate movement, including the role of convection currents in the mantle, is crucial for comprehending the dynamic nature of our planet.

**SC 3 CHECK YOUR UNDERSTANDING**

Choose from the following terms to identify the features and processes labelled A to E in the diagram below.

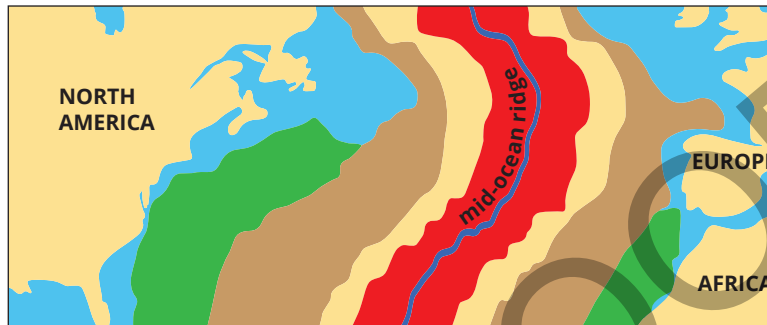
- ridge push
- mid-ocean ridge
- newer oceanic crust
- subduction and slab pull
- older and denser oceanic crust



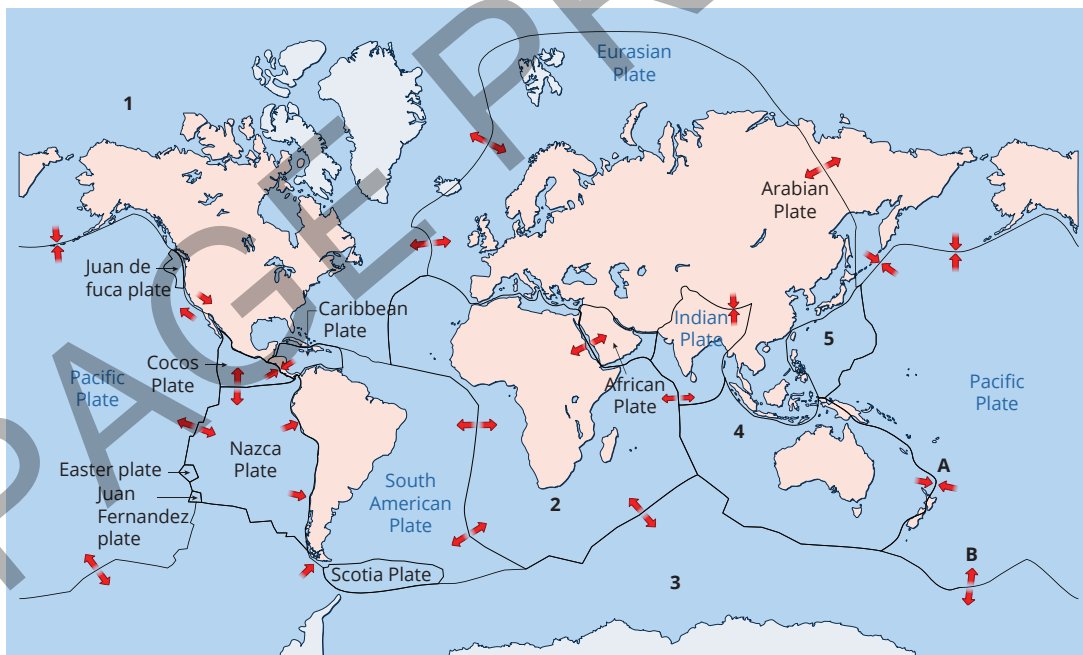
## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

- 1 You are studying the internal structure of Earth.
  - a State when scientists believe Earth first started to form.
  - b Describe the influence of gravitational forces on the formation of Earth's layers.
  - c What properties of the asthenosphere allow the tectonic plates of the crust move relative to each other?
- 2 Outline how oceanic crust differs from continental crust.
- 3 The image below shows a mid-ocean ridge found in the Atlantic Ocean. Four colours (brown, green, orange and yellow) indicate different ages of the oceanic crust. Name the four colours in order from youngest crust to oldest.



- 4 Describe the processes of convection in the mantle, slab pull and ridge push.
- 5 Refer to the map of tectonic plates below.



Key

- ◄► Magma can rise to the surface where plates are moving apart
- ◄◄ Subduction occurs where plates are colliding

- a Name the tectonic plates labelled 1 to 5.
- b Slab pull and ridge push occur along many plate margins. Identify which process is occurring at the locations labelled A and B.
- c Identify the location (A or B) where the oceanic crust would be younger and less dense. Explain why you selected this location.

# 13.10 Plate boundaries

## Learning intention

To understand the geological features and events that occur at the different types of plate boundaries

## Success criteria

**SC 1:** I can describe differences between convergent, divergent and transform plate boundaries.

**SC 2:** I can analyse the role of plate boundaries in the formation of geological features.

## Lesson overview

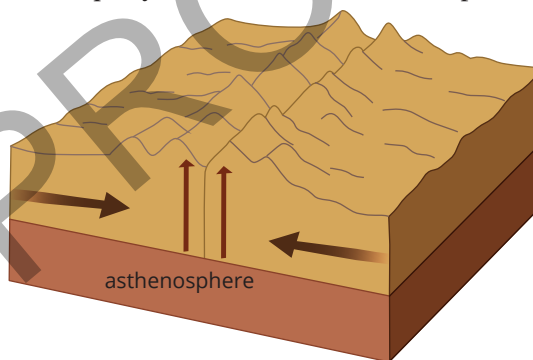
The movement of the tectonic plates produces different geological features, changing the surface of Earth. The features that are formed depend on the types of plate boundaries that are interacting (Figure 13.10.1).

In this lesson, you will learn about the three types of plate boundaries and the different geological features they can produce.

**SC 1** I can describe differences between convergent, divergent and transform plate boundaries

## Convergent boundary

A convergent boundary is a boundary at which plates are being pushed together (Figure 13.10.2). Depending on the densities of the plates, one may subduct (go under) the other. Collisions between two lighter continental crusts produce mountain ranges as the equally dense continental crust is pushed up on both sides.

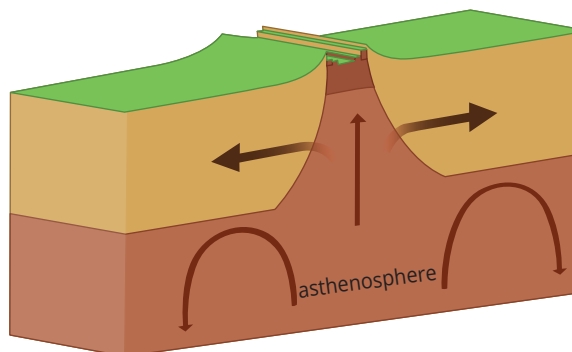


**FIGURE 13.10.1** The divergent tectonic boundary between the North American and Eurasian Plates forms a surface rift in the Mid-Atlantic Ridge at Silfra in Iceland.

**FIGURE 13.10.2** Continental plates at convergent plate boundaries result in the uplift of the lithosphere to create mountain ranges.

## Divergent boundary

In a divergent boundary, two plates move apart from each other (Figure 13.10.3). New crust forms at a divergent boundary as magma rises from the mantle to Earth's surface between the two plates.



**FIGURE 13.10.3** At divergent plate boundaries, tectonic plates move apart allowing magma to rise to the surface.

## Transform boundary

In a **transform boundary**, two plates move alongside each other, either in opposite directions or in the same direction, but at different speeds (Figure 13.10.4). This movement sometimes generates earthquakes as pressure created by the movement is released.

### SC 1 CHECK YOUR UNDERSTANDING

Identify the type of plate boundary that shows the following features:

- plates slide past each other either in opposite directions or in the same direction but at different speeds
- plates collide with each other, resulting in subduction or the formation of mountain ranges
- plates are moving apart from each other resulting in the formation of new crust at the plate boundary.

### SC 2 I can analyse the role of plate boundaries in the formation of geological features

The interactions of different types of plate boundaries form different geological features. The outer crust of Earth can be categorised as either continental or oceanic. Oceanic crust is generally denser than continental crust. This difference in density can cause different formations to occur at plate boundaries.

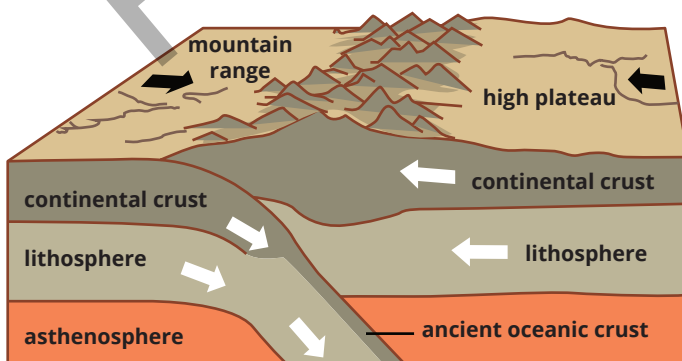
## Mountains

When two plates collide the crust crumples and deforms, it can produce fold mountains (Figure 13.10.5).

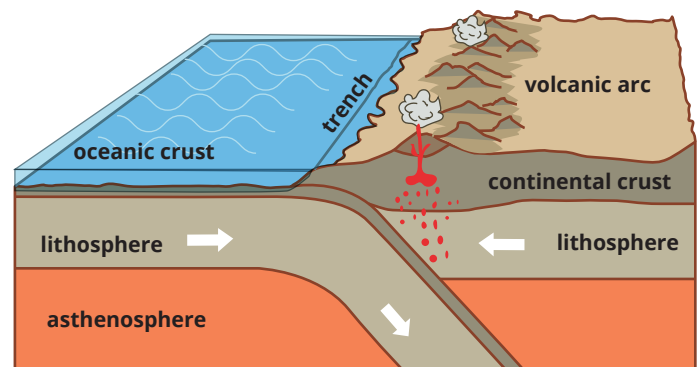
The crust can be manipulated in two ways.

- At a convergent boundary of two continental plates, one plate may subduct under the other, but generally the plates are pushed upwards to form mountain ranges such as the Himalayas, due to their similar densities.
- At a convergent boundary between oceanic and continental crust, the denser oceanic plate subducts under the continental crust. During this process, the continental plate deforms and can create mountains and volcanoes such as in the Andes.

Convergence at boundary of two continental plates



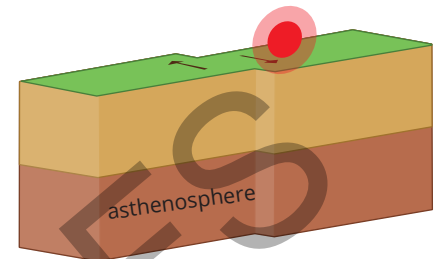
Convergence of oceanic and continental plates



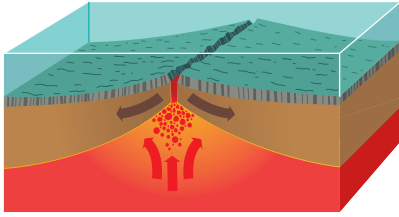
**FIGURE 13.10.5** Fold mountains form where two plates converge. When oceanic and continental plates converge, volcanoes also form.

### KEY TERMS

**transform boundary** tectonic plate boundary where plates are sliding past each other either in opposite directions or in the same direction but at different speeds



**FIGURE 13.10.4** At a transform plate boundary, tectonic plates move alongside each other, sometimes resulting in earthquakes.



**FIGURE 13.10.6** Mid-ocean ridges form either side of a rift valley where magma rises to fill the gap left when two tectonic plates diverge.

## Rift valleys and ridges

Rift valleys are low-lying regions that form at divergent plate boundaries. When two tectonic plates separate, magma rises into the deep crack created. Rift valleys are mostly found at the bottom of the ocean where they are commonly associated with mid-ocean ridges (Figure 13.10.6). As the magma solidifies rapidly underwater, it creates new oceanic crust to form ridges with a rift valley in the centre of the ridge line, such as the Mid-Atlantic Ridge.

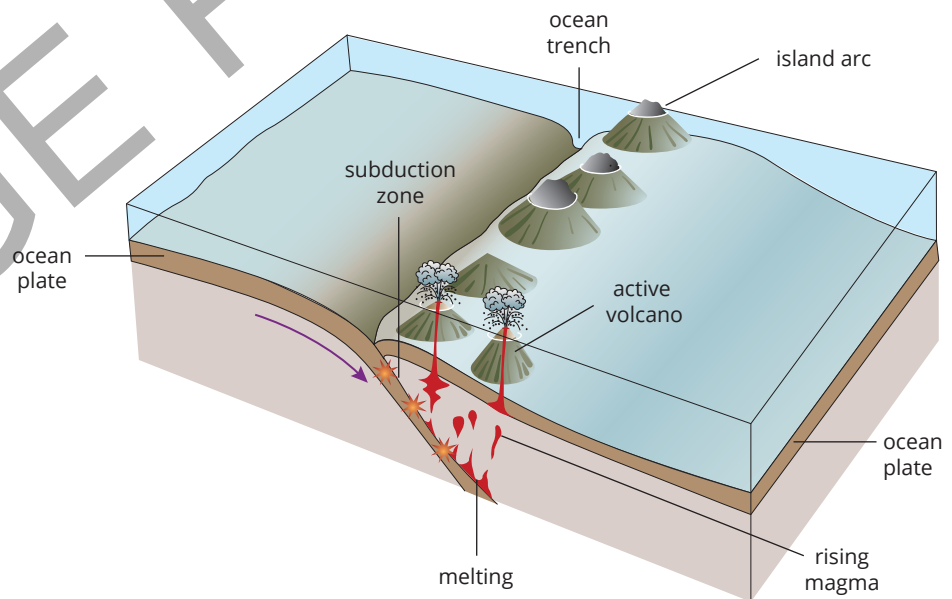
Rift valleys are sometimes found on continental lithosphere, such as the East African Rift Valley, which is forming where the African Plate and the Arabian Plate are diverging. On land, volcanoes may form along the ridge line when magma reaches the surface.

## Volcanoes

Volcanoes can be found at various types of plate boundaries:

- Convergent boundaries between oceanic and continental crust: When an oceanic plate subducts, or moves beneath, a continental plate, it causes the continental plate edges to crack, leading to the formation of volcanoes in the process (Figure 13.10.5).
- Convergent boundaries between two oceanic plates: In this scenario, when two oceanic plates converge, they create a chain of volcanic islands, forming what is known as a volcanic island arc (Figure 13.10.7).

Volcanoes can also form away from plate boundaries. These are known as hot spot volcanoes.



**FIGURE 13.10.7** Convergence between two oceanic plates can result in the formation of a volcanic island arc.



## SCIENCE IN CONTEXT

### Krakatoa – a world media sensation

Indonesia has over 150 active volcanoes, the most of any country. These are concentrated in the volcanic island arcs of Java and Sumatra where the Australian Plate subducts under the Eurasian Plate. Between the two lies Sunda Strait. Here, where the crust is believed to be stretched thin, magma rose to the surface to create four volcanoes in the Krakatoa Archipelago (Figure 13.10.8). One of these was known as Krakatoa.



**FIGURE 13.10.8** The Krakatoa Archipelago is located in Sunda Strait between the islands of Sumatra and Java in Indonesia.

On 26–27 August 1883, Krakatoa erupted violently in a series of explosions, destroying two thirds of the island and creating a caldera (a depression left by an exploding volcano). Scientists estimate that 25 km<sup>3</sup> of rock was ejected. Ash is estimated to have risen to 80 km in the atmosphere, with the local area in darkness for two and a half days. Global temperatures are recorded as falling by 0.5°C in the year following because the ash blocked radiation from the Sun. Pumice was so

thick on the sea that it halted ships. The eruption was so violent it was heard in Alice Springs, Perth, and in Mauritius nearly 5000 km away. Scientists hypothesise that anyone within 16 km would have been deafened. However, people in this zone were more likely to have been killed either by the series of **tsunami** events triggered by the explosions, the suffocating ash cloud, and pyroclastic flows (eruptions of extremely hot gas, ash, and rock, some of which reached the Sumatran coast about 48 km away).

A total of 165 villages and towns were destroyed, and 132 seriously damaged, mostly by the series of tsunamis. The death toll was estimated to be up to 120 000 people.

Krakatoa still makes the news. However, it is now Anak Krakatoa (Son of Krakatoa) that is newsworthy. Anak Krakatoa emerged as an active volcano from the sea in the centre of the caldera in 1930 (Figure 13.10.9). In December 2018, part of Anak Krakatoa collapsed into the sea, generating a tsunami that killed more than 400 people and displaced 47 000.



**FIGURE 13.10.9** The active volcano Anak Krakatoa (Son of Krakatoa) emerged in 1930 in the caldera left behind by the 1883 explosion of Krakatoa.

#### KEY TERMS

**tsunami** a large and destructive ocean wave, or series of waves, caused by either a large earthquake on the seafloor, a landslide, or a volcanic eruption

**KEY TERMS**

**trench** a depression in the ocean floor

**Scifile****Mariana Trench**

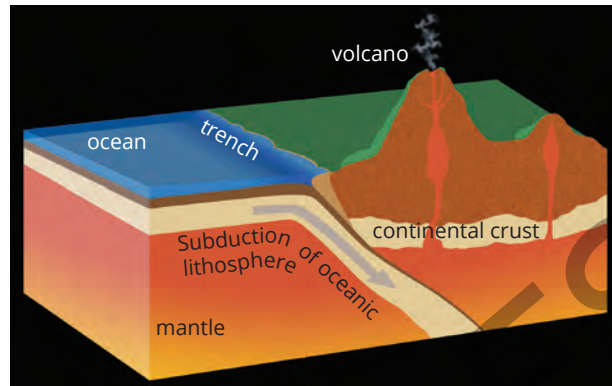
In the western Pacific where the Pacific Plate subducts beneath the Philippine Plate, the 2550 km long Mariana Trench and the Mariana Islands, a mostly dormant volcanic island arc, have formed. Mariana Trench is Earth's deepest oceanic trench, with the maximum known depth of 1000 m at a location called Challenger Deep.



**FIGURE 13.10.11** The San Andreas Fault in California is a transform plate boundary.

**Ocean trenches**

A **trench** is a deep depression in the ocean floor. Trenches usually occur when an oceanic plate subducts (goes under) another oceanic or continental plate (Figure 13.10.10).



**FIGURE 13.10.10** Deep trenches form when an oceanic plate subducts under another tectonic plate.

**Earthquakes**

Almost all earthquakes occur at the boundaries between plates. As the plates interact, sometimes energy is released. When one plate moves suddenly, we feel it as an earthquake.

Most earthquakes occur at convergent boundaries.

Earthquakes are also felt at transform boundaries, such as the San Andreas Fault between the Pacific and North American Plates which runs through California (Figure 13.10.11).

**SC 2 CHECK YOUR UNDERSTANDING**

In the interactions between oceanic and continental plate boundaries, identify the crust that is most likely to subduct, and explain why.

**Lesson review**

Use these questions to check whether you have met the learning intention for this lesson.

- 1 Define convergent, divergent and transform plate boundaries.
- 2 Explain why collisions between two continental crusts produce tall mountain ranges.
- 3 Identify the type(s) of plate boundaries involved in the formation of the following geological features:
  - a fold mountains
  - b mid-ocean ridges
  - c earthquakes.
- 4 Compare the formation processes of ocean trenches and mid-ocean ridges.
- 5 Identify a real-world example of a geological feature found at each of the following types of plate boundary. Describe the processes involved in forming them.
  - a convergent
  - b divergent
  - c transform

13.11

# Inquiry activity: Modelling the different types of plate boundaries

## Introduction

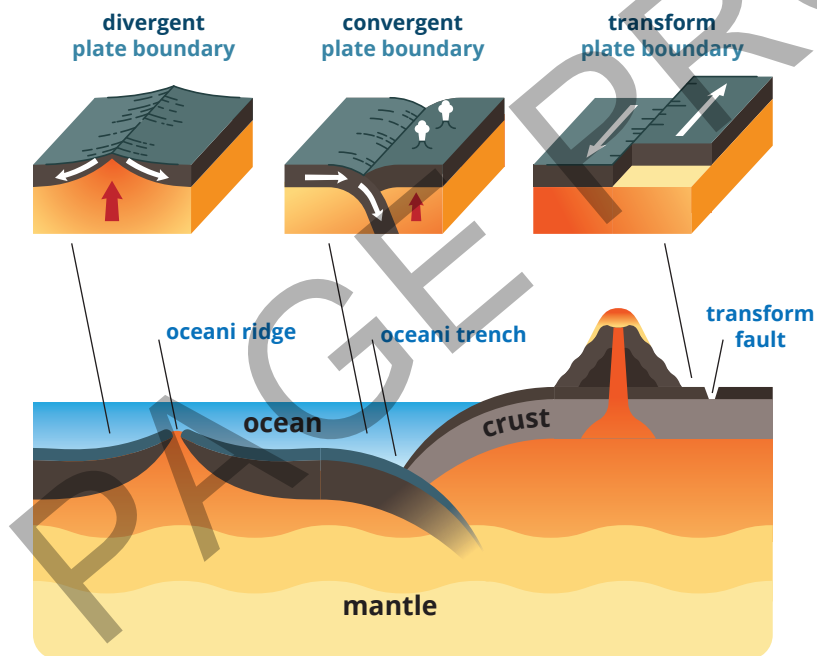
There are three different types of boundaries between tectonic plates: convergent, divergent and transform. The boundaries produce different geological features due to the interactions between plates.

In this inquiry activity, you will create a model of one of the three boundary types and explore alternative models that you could use to demonstrate the interaction between tectonic plates.

## Background

The three boundary types are:

- convergent – where the two plates are moving towards each other
- divergent – where the two plates are moving away from each other
- transform – where the two plates are moving alongside each other (Figure 13.11.1).



**FIGURE 13.11.1** The three types of boundaries between tectonic plates

When plates interact, geological features such as mountains, rift valleys, ridges, trenches and volcanoes are formed.

### Learning intention

To be able to model the different types of plate boundaries

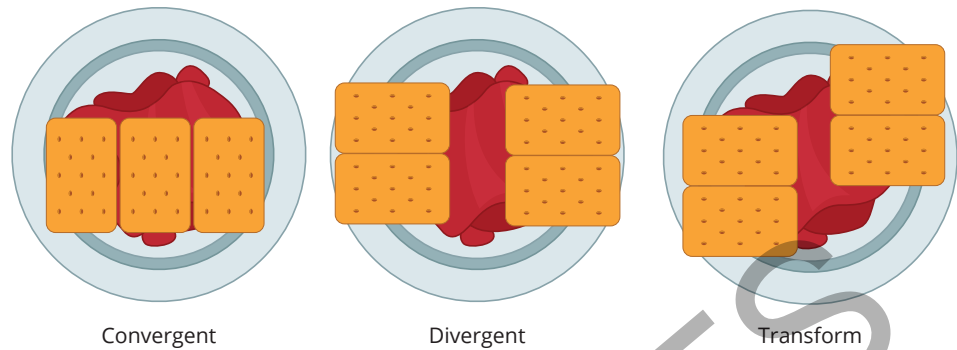
### Success criteria

**SC 1:** I can design a model that represents the different types of plate boundaries.

**SC 2:** I can use a model to explain the differences between types of plate boundaries.

**SC 3:** I can propose alternative models (physical or digital) to demonstrate plate boundaries.

Oceanic crust is denser than continental crust, and this difference plays a part in the way plates interact between oceans and continents. You can make models by using different household items to show how the plates move and interact (Figure 13.11.2).



**FIGURE 13.11.2** Modelling plate boundaries with biscuits and jam

## Aim

To model the interactions between different plate boundaries by using household items.

To film a stop-motion video of your chosen plate boundaries.

## Plan

- 1 There are many types of interactions between plate boundaries that you can model. For your investigation, you will model one boundary type, which will be assigned by your teacher.
- 2 In your group, write down the boundary interaction you will be modelling. Work together as a group and note the types of crust (oceanic or continental) you will be representing with your model. Consider the density of the types of crust (i.e. is one crust type denser than the other?). Your group is to also select a geological formation formed at the boundary such as mountains, rift valley, ridge, ocean trench, volcano and fault.
- 3 Draw a diagram of your plate interaction. Include labels for the types of crust, lithosphere, asthenosphere and your chosen geological formation, and add arrows to show each plate's direction of movement.
- 4 Describe the physical properties of both the lithosphere and asthenosphere. Use the following terms in your descriptions: brittle, can flow, liquid, plastic and solid.

## Design

- 1 For your chosen plate boundary, select a household material to use for each layer. Some examples are:
  - biscuits
  - jam
  - chocolate bars
  - play dough
  - deck of cards
  - honey
  - cardboard
  - paper.

Record the materials you have chosen to model the lithosphere and the asthenosphere for both your boundary type and the types of crust involved in the interaction. Safety Note: If you chose a food to represent the crust, make sure you check with your teacher in case any of your classmates have allergies.

- 2 Explain why you chose each material.
- 3 Present your model design to your classmates. Comment on any design features or materials from your classmates' proposed boundaries that could also work in your boundary type.
- 4 In your group, finalise your model design by incorporating any improvements identified after the sharing of ideas by the class.
- 5 Determine how you will set up the recording of movement in your model to create the stop-motion video. Remember to get permission to the camera on a device, or alternately book a camera, or draw diagrams of the model.

## Conduct

- 1 Collect your materials and set up your model.
- 2 Manipulate your materials to represent the interaction at your designated plate boundary. As you do so, draw or get permission to record the interaction of the 'lithosphere' and 'asthenosphere' to create your stop-motion video.

## Improve

- 1 Review your classmates' videos. Describe how effective their presentations were at demonstrating the different boundary types.
- 2 What could you do to improve your own model?

## Discussion

- 1 Evaluate the benefits and limitations of each model in showing the differences between plate boundaries.
- 2 In this activity, you made a physical model of a plate boundary and used digital media to communicate it. Write a proposal to a STEM company about a digital model they could use to demonstrate the different plate boundaries and the importance of understanding plate tectonics. Your proposal could include:
  - software used or how the model is built
  - format of communication
  - annotations of the model
  - three key impacts of plate tectonics on the environment.

# 13.12 Earthquake and volcanic activity

## Learning intention

To understand the reasons for patterns of earthquake and volcanic activity around the globe

## Success criteria

**SC 1:** I can describe patterns in the locations of earthquakes and volcanoes.

**SC 2:** I can describe how earthquakes are detected.

## KEY TERMS

**earthquake** the rapid movement of the ground, usually back and forth and up and down in a wave motion, due to the movement of tectonic plates

**seismometer** an instrument that detects the seismic waves from an earthquake

## Lesson overview

Volcanic eruptions and earthquakes can cause a great deal of destruction. By understanding the processes involved when an earthquake occurs and a volcano erupts, scientists and engineers can better prepare people for a possible disaster.

In this lesson, you will learn about the locations of earthquakes and active volcanoes and how scientists measure the magnitude of an earthquake.

**SC 1** I can describe patterns in the locations of earthquakes and volcanoes

## Earthquakes

**Earthquakes** are sudden movements in Earth's crust. Some can cause significant damage, while others are weak and can only be detected by sensitive instruments, called **seismometers**.

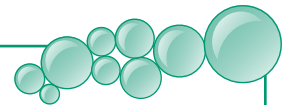
## Volcanoes

A volcano is formed where there are cracks or gaps in Earth's crust. This allows lava, ash and gases to escape from below the surface, often forced out by extreme pressures.

## Scifile

### Volcano lightning

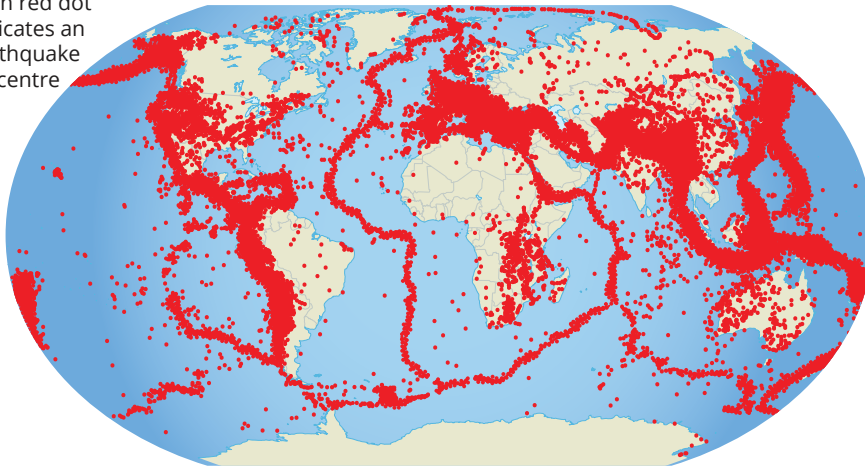
During eruptions from the more explosive composite volcanoes, lightning can often be seen in the ash plume or ash cloud. This happens because the ash particles create static electricity, similar to how thunderclouds produce lightning. During the eruption of Washington's Mt St Helens volcano in 1980, bolts of lightning struck the ground, sheet lightning lit up the ash plume, and very rare ball lightning was also observed.



## Volcanoes and earthquakes around the world

Figures 13.12.1 and 13.12.2 show data of earthquakes and volcanoes around the world. Notice some of the similarities between these two maps.

- Each red dot indicates an earthquake epicentre



**FIGURE 13.12.1** Distribution of earthquakes around the world.



**FIGURE 13.12.2** Distribution of active volcanoes around the world.

Earthquakes and volcanic activity are recorded by a network of **seismographs**. The **seismic data** is then used to predict potential follow-up earthquakes (aftershocks) and the likelihood of volcanic eruptions. Countries use the live data to plan for evacuations and other disaster preparations.

### Patterns in the data

Active volcanoes and earthquakes don't usually occur evenly all over the surface of Earth. The live seismic data shows that volcanoes and earthquakes more commonly occur together in concentrated areas along tectonic plate boundaries. In the Asia-Pacific region, these areas are concentrated around Indonesia, Philippines, Japan and New Zealand. These islands coincide with where the Australian, Philippine, Eurasian and Pacific Plates interact.

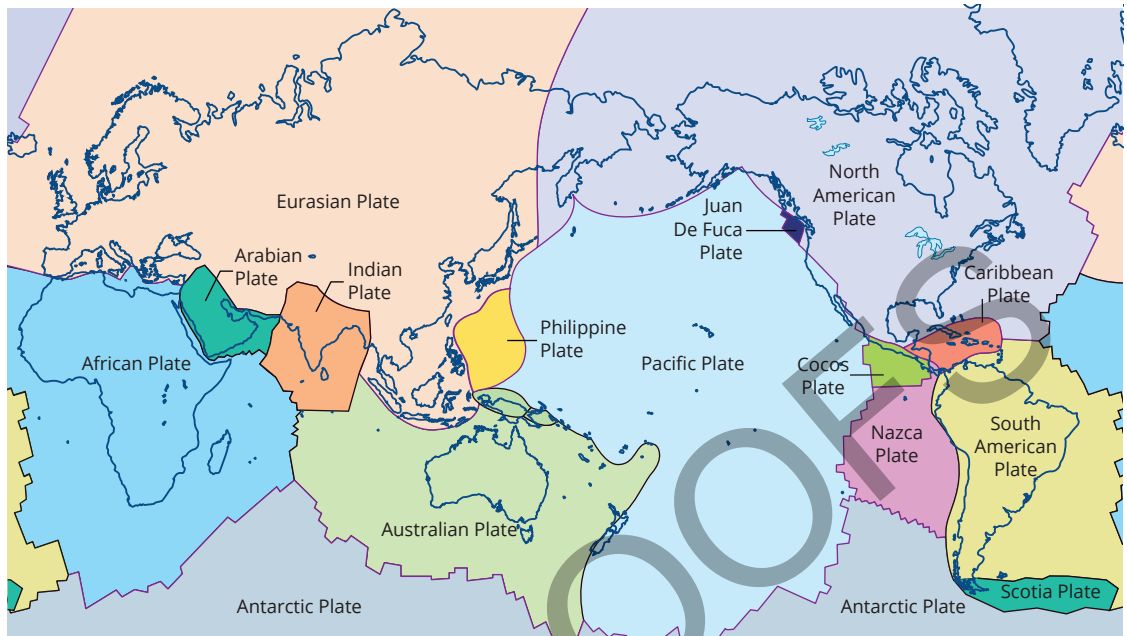
#### KEY TERMS

**seismograph** a seismometer that is connected to a recording device

**seismic data** data about movements of the ground that is used by scientists to study and monitor earthquakes

## Tectonic plates

Earth is made up of different layers of material. The outermost layer is broken up into large pieces known as tectonic plates (Figure 13.12.3).



**FIGURE 13.12.3** The surface of Earth is broken up into major and minor tectonic plates.

The areas where two plates meet coincide with the areas where the greatest number of active volcanoes and earthquakes occur. The interaction of the tectonic plates generally causes both natural events to occur.

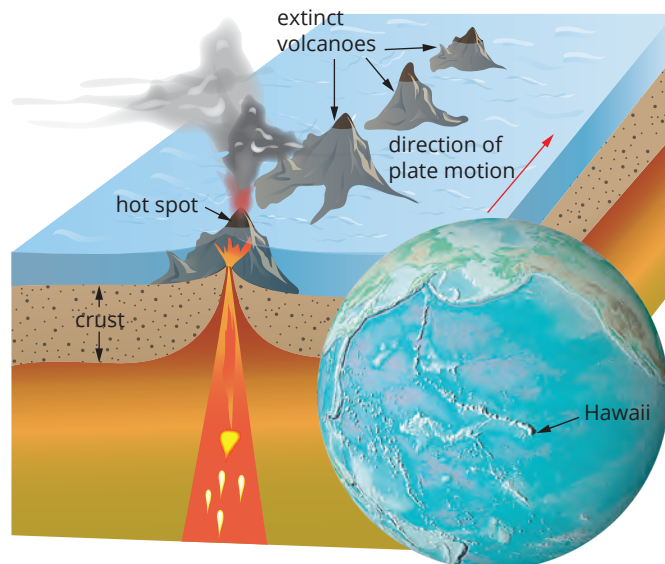
Not all volcanoes occur on these boundaries though.

### KEY TERM

**hot spot** isolated place away from plate boundaries where a lot of hot magma is collecting

## Hot spot volcanoes

Sometimes volcanoes form far away from a plate boundary. These are known as **hot spot** volcanoes (Figure 13.12.4). A hot spot is an area where super-hot material rises from inside Earth. The hot spot does not move.



**FIGURE 13.12.4** Volcanoes are formed as a tectonic plate moves across a hot spot.

As a tectonic plate moves over a hot spot area, a volcano can form. As the plate continues to move, a chain of island volcanoes is created. The volcanoes become firstly dormant and then extinct as they move away from the hot spot. This phenomenon can be seen in Hawai'i, where a chain of extinct and active volcanoes has been formed as the plate moves over the hot spot.

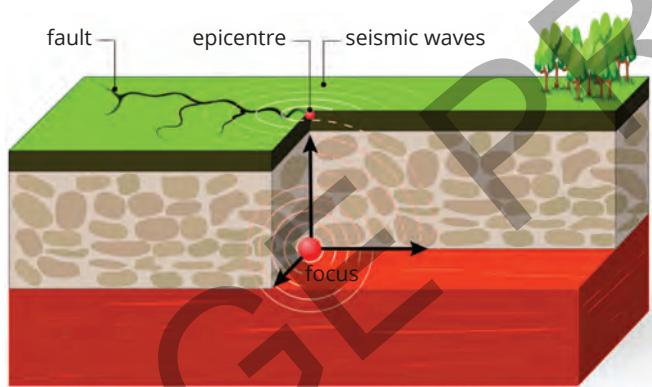
### SC 1 CHECK YOUR UNDERSTANDING

Compare the location of hot spot volcanoes and the location of most of Earth's active volcanoes.

### SC 2 I can describe how earthquakes are detected.

When an earthquake causes the ground to shake, it transfers energy from the interaction between the plate boundaries into the back-and-forth, up-and-down or side-to-side wavelike motion of the ground. These waves are called **seismic waves**. The waves travel outward from the point where the earthquake occurred underground. This point is called the **focus**. The focus can be anywhere from deep underground to close to the surface.

The **epicentre** of an earthquake is the point on the surface of Earth directly above the focus (Figure 13.12.5).



**FIGURE 13.12.5** The location of an earthquake's focus and epicentre.

There are three types of waves involved resulting from an earthquake:

### Primary waves (P-waves)

Primary waves travel the fastest and can travel through solids, liquids and gases.

### Secondary waves (S-waves)

Secondary waves are slower than P-waves and can only travel through solids.

### Surface waves

**Surface waves** only travel along the surface of Earth and can cause the most damage. They are also the slowest of the three waves.

### DISCOVER MORE

When a volcano no longer has a magma supply and it is unlikely to erupt in the future, it is considered extinct. Volcanoes that have not erupted for a long time but may erupt in the future are called dormant (or inactive). Active volcanoes show signs of activity and may erupt in the near future.

#### KEY TERMS

**seismic wave** the shaking, wave-like movement of the ground in an earthquake

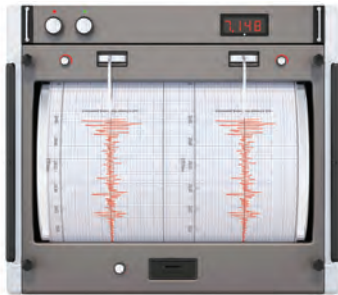
**focus** the place below ground where an earthquake starts

**epicentre** the point on Earth's surface directly above the focus of an earthquake

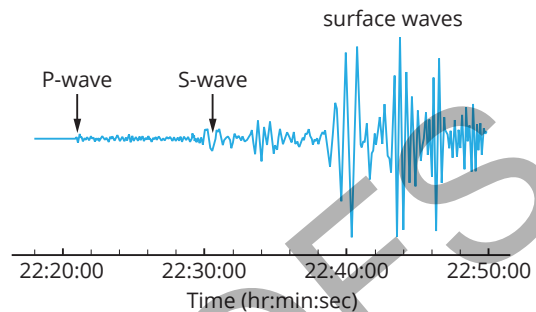
**surface wave** type of earthquake wave that does not penetrate Earth but travels along the ground

## Detecting earthquakes

Scientists invented instruments called seismometers, which can detect when an earthquake is occurring. The full device is called a seismograph when it is connected to some sort of recording device (Figure 13.12.6). A heavy mass resists the motion of the earthquake while the rest of the instrument is caused to shake. The motion is then recorded as a **seismogram** (Figure 13.12.7). Seismograms may be recorded on paper or recorded digitally.



**FIGURE 13.12.6** A seismograph detects, measures and records seismic vibrations.



**FIGURE 13.12.7** A seismogram is a record of seismic vibrations including the different arrival times of P-waves, S-waves and surface waves.

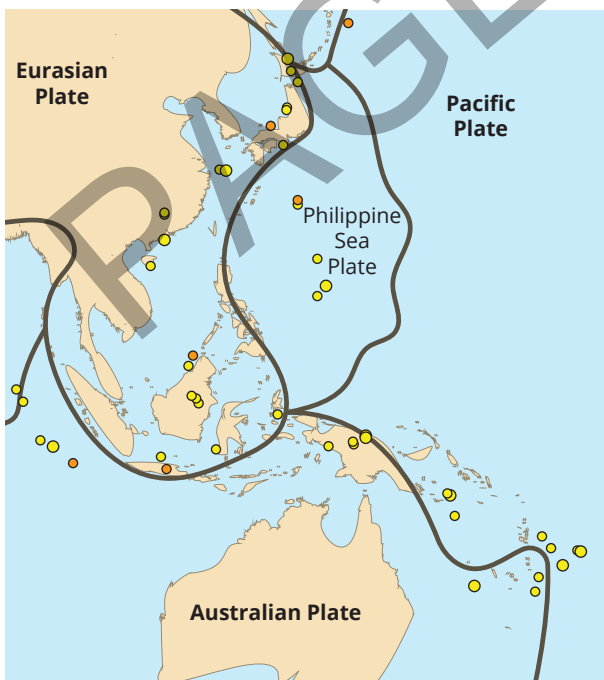
### SC 1 CHECK YOUR UNDERSTANDING

Describe the relationship between the epicentre and the focus of an earthquake.

## Lesson review

Use these questions to check whether you have met the learning intention for this lesson.

**1** Refer to the image below which shows the locations of magnitude 4.5+ earthquakes in the Asia-Pacific region.



- a** Describe the distribution of earthquakes.
  - b** Explain why the earthquakes are located where they are.
  - c** Name the tectonic plates that are interacting in this section of the Asia-Pacific region.
  - d** Identify a natural feature you could expect to see where earthquakes occur.
- 2** The Galapagos Islands are a series of volcanic islands in the Pacific Ocean. Many of the volcanoes are now extinct, but Isabela Island and Fernandina Island have several active volcanoes. The Galapagos Islands are located on the Nazca Plate at some distance from the plate's boundaries. Explain why these islands would be forming here.
- 3** Identify the type of seismic wave that has the following features:
- a** can only travel through solids and are slower than the waves that can travel through solids and liquids
  - b** can only travel along Earth's surface but, despite being the slowest of the seismic waves, they can do the most damage
  - c** travel the fastest and can travel through solids and liquids.

## 13.13

# First Nations Australians' accounts of geological events

## Introduction

Australia's First Nations Peoples have a rich history of storytelling that has been passed down through generations. These stories often contain detailed accounts of natural events, both on land and under the sea. Understanding these accounts can provide valuable insights into the geological history of Australia. For example, the Yuin People of New South Wales have stories about Gulaga (Mount Dromedary) (Figure 13.13.1), which describe the mountain's creation and its significance to the Yuin People.

In this inquiry activity, you will investigate First Nations accounts of geological events and explain how these stories contribute to our understanding of Australia's geology.



**FIGURE 13.13.1** Gulaga (Mt Dromedary) in the Gulaga National Park.

## Background

First Nations Australians have a profound and enduring connection to the land and sea that spans tens of thousands of years. This connection is deeply rooted in their cultural practices, spiritual beliefs, and daily lives.

Their oral histories, passed down through generations, include detailed accounts of significant geological events such as volcanic eruptions, earthquakes, and changes in sea levels. For instance, the Awabakal and Worimi Peoples' Dreaming story, 'The Kangaroo that lives inside Nobbys', speaks of a kangaroo believed to reside within Nobbys, a prominent headland in Newcastle, New South Wales (Figure 13.13.2), reflecting the cultural and geological significance of the landscape.

### Learning intention

To understand how accounts of First Nations Australians provide evidence of earthquakes and volcanoes on Country or under the sea

### Success criteria

**SC 1:** I can describe a case study of a First Nations account(s) related to a geological event or events.

**SC 2:** I can explain how First Nations Peoples remember geological event(s).

**SC 3:** I can describe how accounts of First Nations peoples has informed understanding of the geology of Australia.



**FIGURE 13.13.2** The Kangaroo that lives inside Nobbys is a dreamtime story by the Worimi people about the formation of the Nobbys headland in Newcastle.

Similarly, the Bundjalung Peoples' Dreaming stories about Wollumbin (Mount Warning), such as 'the Warrior Chief' and 'the Turkey', describe the creation and significance of the mountain formed by an ancient volcanic eruption. These stories are not only cultural treasures that preserve the rich heritage and identity of First Nations communities, but they also serve as valuable scientific records.

## Aim

To investigate First Nations accounts of geological events and understand their significance in geology

## Scifile

### Volcanoes and memory

Did you know that some First Nations Australians have stories about volcanic eruptions that happened thousands of years ago? These stories have been passed down through generations and provide valuable insights into the geological history of Australia.

## Plan

Choose a specific First Nations account of a geological event to research. Plan how you will gather information, including the sources you will use. Consider how you will present your findings, such as through a written report, presentation, or visual display.

## Design

- 1 Identify a First Nations group and a specific geological event they have documented.
- 2 Research the chosen account using reliable sources, such as academic articles, books, and reputable websites.
- 3 Take detailed notes on the account, focusing on the description of the event, how it was remembered, and its significance.

- 4 Plan how you will present your findings, ensuring you address all success criteria.
- 5 Create an outline of your presentation or report, including key points and supporting evidence.

## Conduct

- 1 Use the following websites to gather information:
  - a Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS): <https://aiatsis.gov.au>
  - b National Library of Australia: <https://www.nla.gov.au>
  - c Indigenous Weather Knowledge: <http://www.bom.gov.au/iwk/>
  - d The Conversation: <https://theconversation.com/au>
- 2 Collect information from multiple sources to ensure accuracy and comprehensiveness.
- 3 Organise your notes and evidence logically, ensuring you cover all aspects of the success criteria.
- 4 Begin drafting your report or presentation, incorporating quotes and references from your sources.

## Improve

- 1 Review your draft to ensure all success criteria are met.
- 2 Check for clarity and coherence in your explanations and descriptions.
- 3 Seek feedback from peers or your teacher and make necessary revisions.
- 4 Ensure your presentation or report is visually engaging and well-organised.
- 5 Practice presenting your findings to ensure confidence and fluency.

## Discussion

- 1 Reflect on the quality and depth of your research.
- 2 Assess how well you have explained the significance of the First Nations account in understanding Australia's geology.
- 3 Consider how effectively you have communicated your findings.
- 4 Identify any areas for improvement in your research or presentation process.
- 5 Evaluate the overall impact of your work on your understanding of the topic.

# 13.14 Evidence for the theory of plate tectonics

## Learning intention

To understand evidence that supports the theory of plate tectonics

## Success criteria

**SC 1:** I can identify evidence to support the theory of plate tectonics.

**SC 2:** I can analyse sources of data related to the theory of plate tectonics.

## KEY TERMS

**geology** the study of Earth

**geosphere** all the rocks, minerals and landforms that make up Earth

**divergent boundary** tectonic plate boundary where plates are moving apart from each other

**magnetic striping** patterns of magnetism trapped in rocks on each side of plate boundaries

## Lesson overview

The theory of plate tectonics has been developed over the past 100 years or so and became an accepted theory around the 1960s. Scientists use multiple pieces of evidence to support the theory.

In this lesson, you will learn about the types of evidence for plate tectonics, including the formation of mountains and volcanoes, seafloor spreading, and magnetic striping.

**SC 1** I can identify evidence to support the theory of plate tectonics

## Identifying evidence

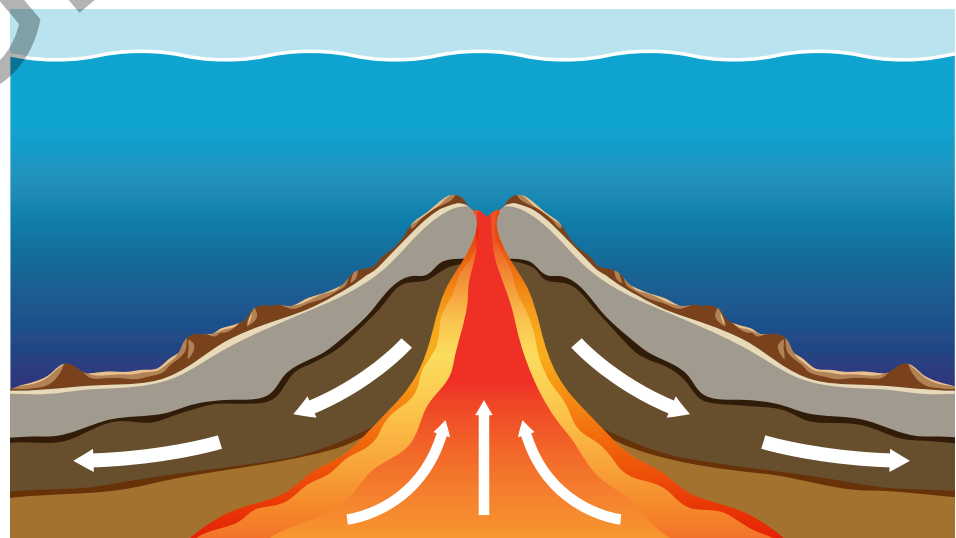
**Geology** is the science of Earth's structure and the substances it is composed of. The **geosphere** describes any of Earth's layers, from the surface all the way to the core. A constantly growing body of evidence from geologists supports the theory of plate tectonics.

We cannot see the plates moving with our eyes, so how do we know the tectonic plates are moving?

Some evidence of plate tectonics is easy to see, such as the formation of mountains or the existence of hot spot volcanoes, but other evidence is less obvious. Examples of evidence related to plate tectonics are provided below.

## Seafloor spreading

Seafloor spreading is a process that occurs because tectonic plates are separating. It happens at **divergent boundaries** (Figure 13.14.1).



**FIGURE 13.14.1** Sea floor spreading occurs at divergent plate boundaries.

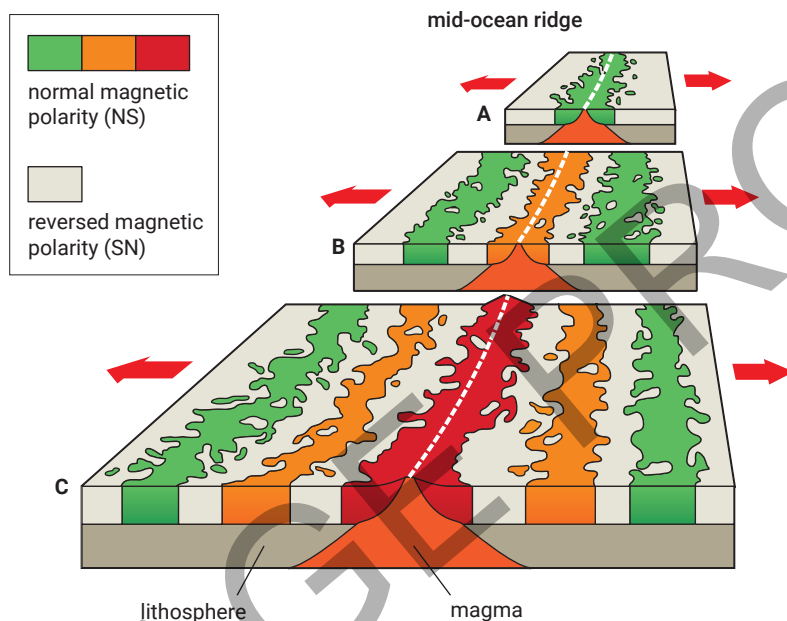
There is strong quantitative evidence to support the process of seafloor spreading, including **magnetic striping** and the dating of minerals.

## Magnetic striping

Earth has a magnetic field as discussed earlier in this topic. The direction of this magnetic field changes over time. For example, 780 000 years ago, Earth's magnetic field flipped, reversing the north and south poles.

When you hold a compass, the needle aligns itself with Earth's magnetic field so that it points north. Similarly, the particles in certain minerals (such as magnetite) align themselves with Earth's magnetic field.

In the 1950s, scientists analysed the data recorded of the direction of magnetism in the rocks along mid-ocean ridges. They found that as they moved further from the ridge on each side, an alternating pattern developed for the direction of Earth's magnetic field (Figure 13.14.2). This phenomenon is known as magnetic striping. The pattern that developed showed that the rocks magnetic direction recorded as they moved further from one side of the mid-ocean ridge matched the pattern on the other side. This pattern, recorded in the rocks, is what is referred to as 'magnetic striping'.



**FIGURE 13.14.2** Magnetic striping is due to new seafloor forming on each side of a crack or rift in the crust. The time sequence here goes from A (oldest) to C (youngest).

The symmetrical pattern emerges because, as new crust forms simultaneously along the ridge, the magnetic fields of the rocks at each individual location, or point, align consistently in the same direction. This empirical evidence supports the theory of seafloor spreading and tectonic plates because it shows that new crust is being produced at mid-ocean ridges and is moving away.

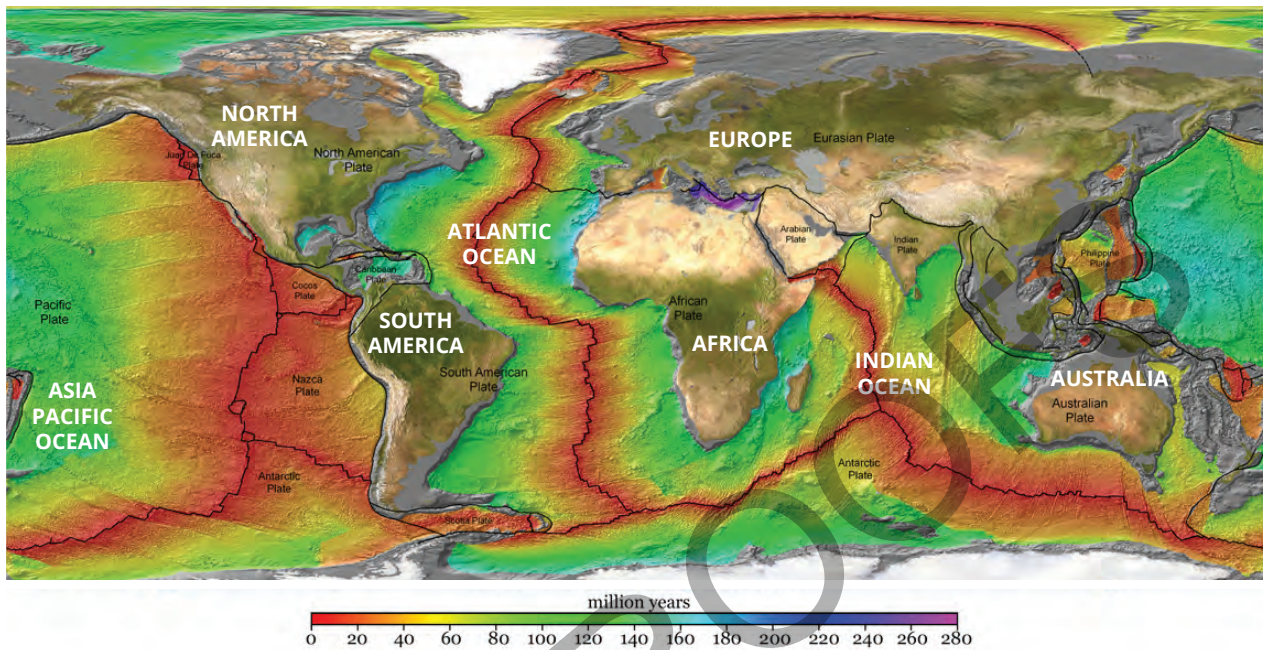
## Dating rocks

Scientists can determine the age of rocks with a range of dating techniques, including **radiometric dating**. Radiometric dating measures the radioactive elements in a substance. Some radioactive elements decay over extremely long periods of time. The amount of radioactivity left can be used to indicate the age of the substance it is found in.

### KEY TERMS

**radiometric dating** a technique for determining the age of rocks that measures the radioactive elements in a substance

Dating measurements have found that the rocks of the oceanic crust are youngest near the mid oceanic ridge and get progressively older as they get further away. Rocks on continents are much older, with some rocks dating back billions of years. These empirical findings show that new rocks are formed closer to divergent boundaries (Figure 13.14.3).



**FIGURE 13.14.3** Age of Oceanic Lithosphere in millions of years. Newer oceanic crust is found at mid-ocean ridges (shown in red). The further away from the mid-ocean ridges you go the older the rocks are.

This is evidence of plate tectonics because it shows new crust is being produced at mid-ocean ridges (similar to the evidence provided by magnetic striping). The evidence also supports the theory of ridge push occurring at these plate boundaries.



## SCIENCE IN CONTEXT

### Marie Tharp – Pioneering Geologist and Oceanographic Cartographer

Marie Tharp was a groundbreaking geologist and oceanographic cartographer whose work fundamentally changed our understanding of the ocean floor and the processes that shape it.

In 1948, Tharp joined the Lamont Geological Observatory at Columbia University, in New York, where she began working with geologist Bruce Heezen. Together, they embarked on a project to map the ocean floor, a task that had never been done before. Using data collected from echo soundings Tharp meticulously converted these measurements into detailed topographic maps.

### Discovery of the Mid-Atlantic Ridge

As she plotted the data, Tharp noticed a continuous, valley-like rift running down the centre of the Atlantic Ocean. This feature, known as the Mid-Atlantic Ridge, was a crucial piece of evidence supporting the theory of plate tectonics and continental drift, which were highly controversial at the time.

Tharp’s discovery of the rift valley was initially met with skepticism. However, her detailed and accurate maps provided compelling visual evidence that the ocean floor was not a flat, featureless expanse but a dynamic landscape shaped by tectonic processes. Her work helped to convince the scientific community of the validity of plate tectonics and altered our understanding of Earth’s geology.

## Hot spot volcanoes

Volcanic islands form where an oceanic plate sits over a hot spot. When the plate moves, the volcanic island moves with it, and a new volcanic island forms above the hot spot. The formation of volcanic island chains is implied evidence for the theory of plate tectonics.

The volcanoes on Fernandina Island and Isabela Island (Figure 13.14.4), two islands in the Galapagos Island arc, are very active as they are very near or above the Galapagos hot spot.

## GPS monitoring

The global positioning system (GPS) is a system of satellites, ground-based sites and receivers. GPS is used for navigation. For example, maps on your phone use GPS to show your location.

GPS is used alongside other mapping techniques to accurately determine how fast plates are moving and in which direction. To do this, GPS monitoring stations are fixed to the ground so that they move with the continental crust. The position of these stations is monitored by satellites that record their exact latitude and longitude over time. GPS monitoring has shown that the Australian Plate is moving north-east at about 7 cm each year. This is empirical evidence for the theory of plate tectonics.

### SC 1 CHECK YOUR UNDERSTANDING

Use the descriptors below to identify the type of evidence used to currently support the theory of plate tectonics

- a Satellites monitor both the direction and speed of movement of a particular point on Earth's surface.
- b The same patterns of magnetism in the rocks occur at similar distances either side of mid-ocean ridges.
- c New crust forms at mid-ocean ridges and slowly moves outwards.
- d There is more radioactivity of elements in rocks in oceanic crust found closest to the mid-ocean ridges.

### SC 2 I can analyse sources of data related to the theory of plate tectonics

## Analysing evidence

Research into the theory of plate tectonics and the inner workings of Earth are ongoing. However, there are still some big unanswered questions. The collection and analysis of evidence can take many forms.

## Continental fit

One of the earliest pieces of evidence for plate tectonics is the jigsaw-like fit of the continents. If you look at a map (Figure 13.14.5), you can see how the coastlines of South America and Africa seem to fit together. This observation was first noted by Alfred Wegener in the early twentieth century. He proposed that the continents were once part of a supercontinent called Pangaea, which later broke apart.



**FIGURE 13.14.4** The Galapagos hot spot has formed the active volcanoes on Fernandina and Isabela Islands.



**FIGURE 13.14.5** A stamp commemorating Alfred Wegener's life and work in plate tectonics

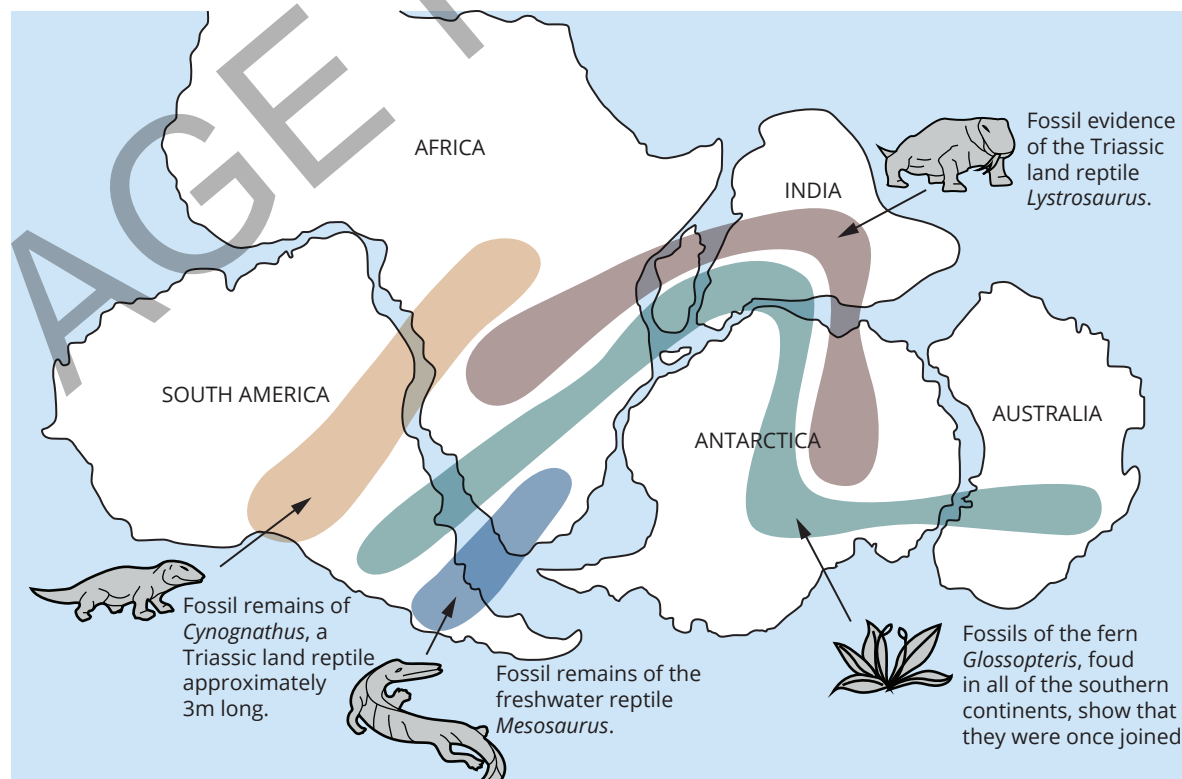
Wegener's observation was not just based on the visual fit of the coastlines. He also considered the geological structures and rock formations on these continents. For instance, the mountain ranges in eastern South America and western Africa align perfectly when the continents are placed together. This alignment suggests that these mountain ranges were formed as a single range before the continents drifted apart. Additionally, the types of rocks found in these regions are similar in age and composition, further supporting the idea that the continents were once connected.

### Fossil evidence

Fossils of the same species have been found on continents that are now widely separated by oceans. For example, fossils of the extinct plant *Glossopteris* have been found in South America, Africa, Antarctica, India, and Australia. This suggests that these continents were once connected, allowing the plants to spread across them (Figure 13.14.6). The distribution of *Glossopteris* fossils is particularly significant because this plant could not have dispersed across vast oceans.

Similarly, fossils of the reptile *Mesosaurus* have been found in both South America and Africa. *Mesosaurus* was a freshwater reptile, and it is unlikely that it could have crossed the Atlantic Ocean. The presence of its fossils on both continents supports the idea that they were once connected.

In addition to *Glossopteris* and *Mesosaurus*, other fossil evidence includes the remains of the land-dwelling reptile *Lystrosaurus*, which have been found in Africa, India, and Antarctica. The widespread distribution of these fossils provides strong evidence for the theory of plate tectonics and the existence of Pangaea.



**FIGURE 13.14.6** Fossil evidence spread across different continents that are now separated by vast oceans.

## Rock formations and mountain ranges

Similar rock formations and mountain ranges are found on continents that are now separated. For instance, the Appalachian Mountains in North America are geologically similar to the Caledonian Mountains in Scotland and Scandinavia. This indicates that these regions were once part of the same landmass.

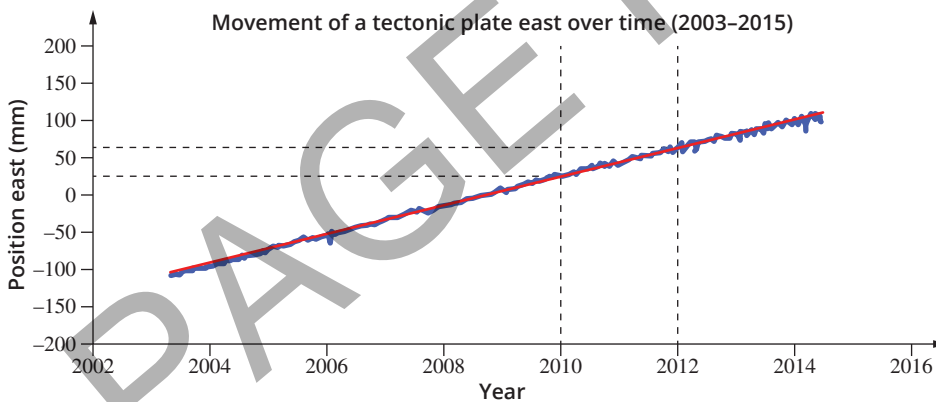
## Paleoclimatic evidence

Evidence of past climates (paleoclimates) also supports the theory of plate tectonics. For example, glacial deposits have been found in present-day tropical regions, suggesting that these areas were once located near the poles. Similarly, coal deposits, which form in warm, swampy conditions, have been found in Antarctica.

## GPS evidence

Ground-based stations are built into rock so they can move when the ground moves. GPS satellites monitor the positions of the ground-based stations over time.

Data from a Sydney-based site shows the position of the Australian Plate between 2003 and 2015 (Figure 13.14.7). Increasing positive numbers indicate that the plate is moving east. Increasing negative numbers indicate that the plate is moving west. Overall, this Sydney-based site moved in an easterly direction during the data collection period. Scientists can analyse the data in these graphs to find the overall rate at which a plate is moving by determining the gradient. For example, in the graph below, you can see that, between the years 2010 and 2012, the plate moved approximately 40 mm towards the east.



**FIGURE 13.14.7** Tectonic plate movement data from a ground-based GPS site near Sydney. Overall, the Australian Plate is moving in an easterly direction.

### SC 2 CHECK YOUR UNDERSTANDING

Explain how the distribution of *Glossopteris* fossils supports the theory of plate tectonics.

## Lesson review

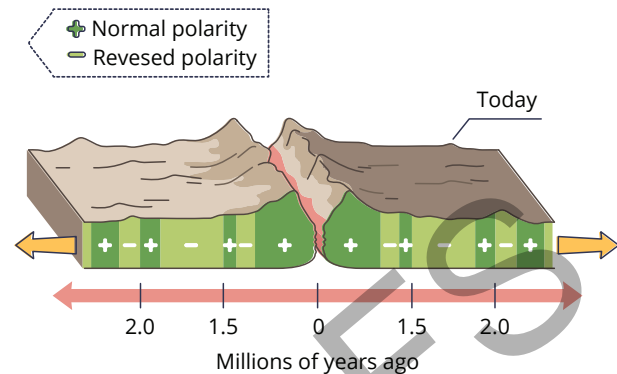
Use these questions to check whether you have met the learning intention for this lesson.

- 1 Explain how magnetic striping provides evidence for seafloor spreading.
- 2 Explain how the fit of the continents supports the theory of plate tectonics.
- 3 Suggest one piece of evidence that may be found at a convergent plate boundary and one piece of evidence at a divergent plate boundary that support the theory of plate tectonics.
- 4 The following is representative of data recorded at GPS stations in California in the region of the San Andreas Fault.

Station	Location	Speed (mm/year)	Direction
1	West coast of California	45.8	NW
2	West coast of California	46.2	NW
3	West coast of California	45.2	NW
4	East side of California	3.2	NW
5	East side of California	2.9	NW
6	East side of California	3.3	WNW

Compare the speed and direction of movement of the land on the west coast of California to the speed and direction of land on the east side of California.

- 5 Refer to the following diagram to answer the questions that follow.



- a How many episodes of normal polarity are shown on the image?
  - b Describe what happened to Earth's magnetic field between 2 million and 1.5 million years ago?
  - c Predict what will happen to Earth's magnetic field in the future.
  - d Evaluate the usefulness of changes in Earth's magnetic field as evidence to support tectonic plate theory.
- 6 Compare and contrast the evidence provided by fossil distribution and magnetic stripes on the seafloor in supporting the theory of plate tectonics.

# 13 Geological change

## Topic summary

The key concepts included in this topic are:

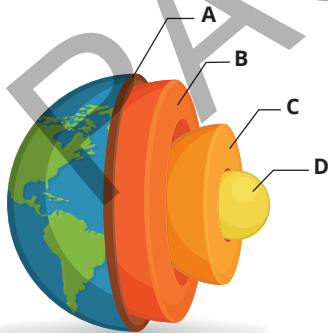
- Earth's internal structure is made up of four main layers.
- Rocks on the surface of Earth undergo constant change.
- Weathering of rocks can be physical (mechanical), chemical and biological.
- Sedimentary rocks form when rocks are weathered, eroded and deposited as sediments, with the sediments then undergoing the geological processes of compaction and cementation.
- Intrusive igneous rocks form when rocks melt to form magma and then solidify below Earth's surface. Extrusive rocks form when lava solidifies on Earth's surface.
- Metamorphic rocks form when rocks are exposed to high heat and/or pressure.
- Environmental changes affect the processes and rock types in the rock cycle.
- The theory of plate tectonics explains the patterns of mountain building, earthquake, and volcanic activity around the globe.
- Rock in the mantle moves through convection, most likely driven by slab pull and ridge push in the lithosphere.
- The theory of plate tectonics is supported by evidence such as the formation of mountains, magnetic striping, similarities in fossil records on different continents, GPS monitoring of tectonic plate movement and radiometric dating of rocks.

## Review questions

The following questions will assess your success in achieving the learning intentions for this topic.

### Remember

- 1 Compare the processes of erosion and deposition.
- 2 Identify the common features of sedimentary rocks.
- 3



- a Identify the layers of Earth shown on the diagram.
- b Which layer is liquid?
- c How do scientists know about the composition of Earth's internal layers?

- 4 Define the following terms:

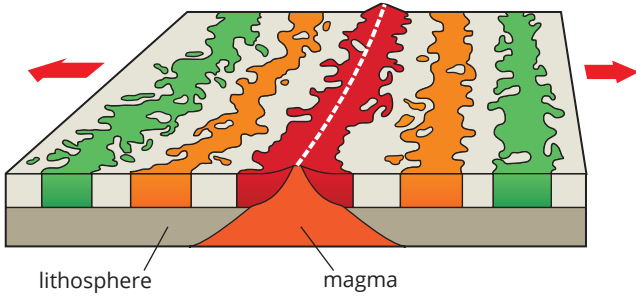
- |              |             |
|--------------|-------------|
| a subduction | c viscosity |
| b slab pull  | d epicentre |

- 5 Recall one way in which the fossil record contributes to the body of evidence in support of the theory of plate tectonics.

### Understand

- 6 Describe the difference between the lithosphere and the asthenosphere.
- 7 A dichotomous key is a useful tool to classify rocks.
  - a Describe the features of a dichotomous key.
  - b State the characteristics that would help you to distinguish an intrusive igneous rock from a clastic sedimentary rock while using a dichotomous key.
- 8 If a limestone rock is exposed to acid rain, which type of weathering will occur, and what will be the result?

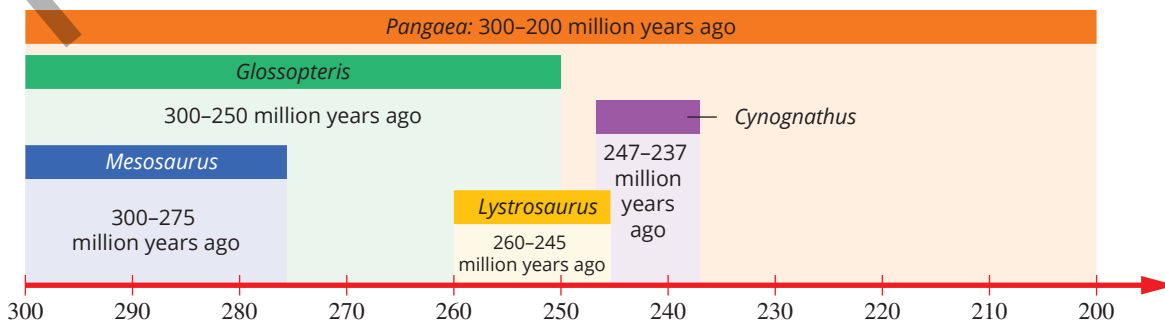
- 9 Refer to the diagram below.



- Identify the type of geographical evidence for the theory of plate tectonics illustrated by the colours in this diagram.
- State which of the bands represents the rocks that are the youngest. Identify a technique that can be used to establish that these rocks are the youngest.
- Identify the type of plate boundary that is shown in this diagram.
- Name two processes that are occurring as the oceanic crust moves away from the mid-ocean ridge in both directions.
- Would earthquakes be expected to occur along this boundary?
- Name two geological features that can form at a convergent plate boundary.

## Apply

- 10 Deep-Earth imaging has found a possible coal deposit. The mining company needs to consider if mining the resource could be profitable. Name four deep-Earth imaging technique that could be used to locate this resource below the ground.
- 15 Fossils of four types of organisms have been identified as biological evidence supporting the theory of plate tectonics. These are the seed fern *Glossopteris*, and the reptiles *Mesosaurus*,

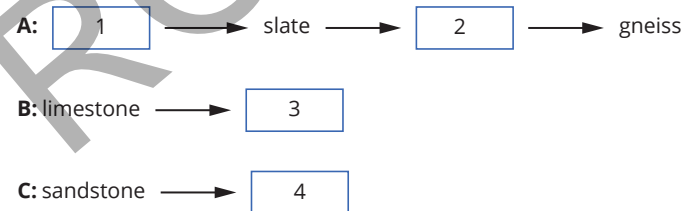


- Name the organism that had the longest period of existence in Pangaea.
- Name the organism that had the shortest period of existence.

- 11 Australia has a very extensive coastline with a variety of landforms.
- Name three landforms you might see on the coast.
  - List two environmental factors that contribute to the weathering of rocks in a coastal area.
- 12 Consider a crystal of quartzite. Draw a rock cycle diagram to show the geological processes required for quartzite to form:
- starting with lava forming the extrusive igneous rock rhyolite, then
  - the sedimentary rock sandstone, then
  - metamorphic quartzite.
- 13 Compare the formation processes of the Himalayas and the Mariana Trench.

## Analyse

- 14 You have been given a number of metamorphic rocks that have been organised into three metamorphic sequences (A, B and C). Some of the rocks' labels are missing.



- Identify the unlabelled rocks numbered 1 to 4 that belong to the metamorphic sequences.
- Identify the parent rock in each sequence.
- Describe a feature you would expect gneiss to have that Rock 1 would not have.

*Cynognathus* and *Lystrosaurus*.

The timeline below shows the periods of their existence and how this aligns with the existence of the supercontinent Pangaea.

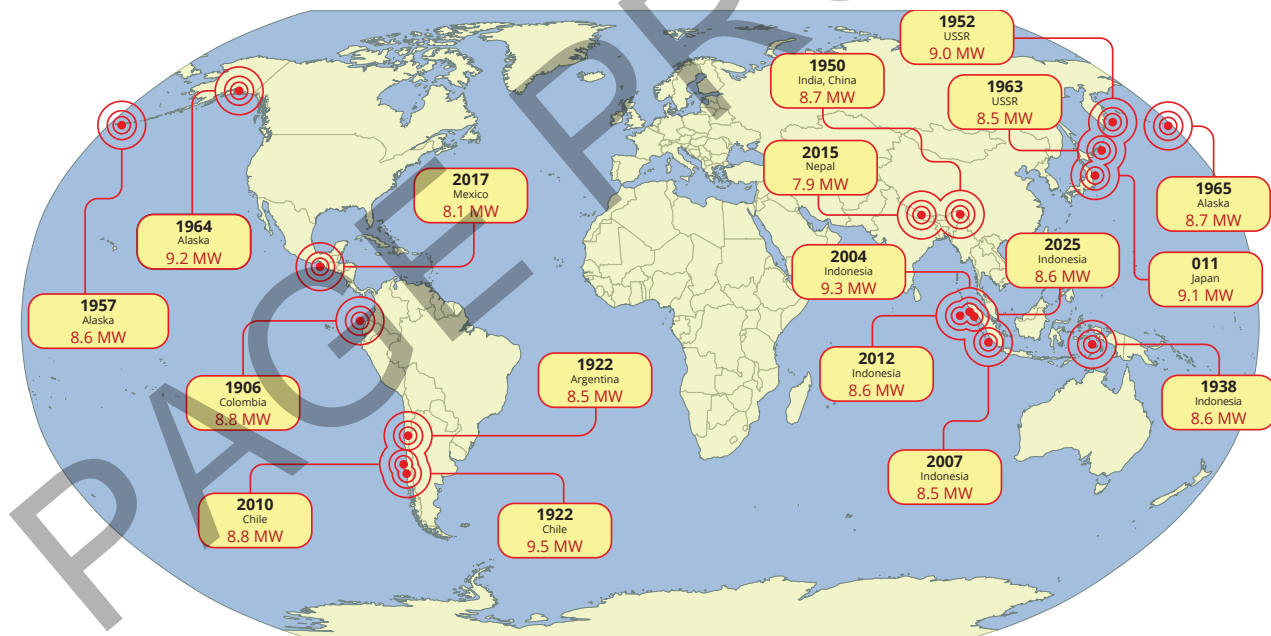
- c Identify the organisms that occurred at the same time as *Glossopteris*.
- d Determine which reptiles existed at the same time as each other.
- e The Permian–Triassic extinction event occurred about 252 million years ago. State the organisms that appear to have become extinct at, or shortly after, this time.

## Extension: Research task

**16** Your task is to use live data to determine the locations of higher magnitude seismic activity in the world in the last 30 days. You will then compare your findings with the locations of the Great earthquakes (earthquakes of magnitude 8.0  $M_W$  and above) on the map below to determine if there is a correlation.

- a Go to one of the following sites that show live earthquake data and investigate current seismic activity in the world. Select settings that look at earthquakes of magnitude 4.5 or more for the last 30 days.

- Geoscience Australia Earthquakes



- Unites States Geological Survey (USGS)
  - ArcGIS Online Live Earthquakes and World Volcanoes
- b Write a paragraph to describe where most of the earthquakes are concentrated. Use the names of tectonic plates in your descriptions.
  - c Refer to the map below, which shows the largest earthquakes of the twentieth and twenty-first centuries. Consider the following questions to work out if there is a correlation between the Great earthquakes and current seismic activity:
    - Did the Great earthquakes occur where earthquakes are currently concentrated?
    - Are there any Great earthquakes that occurred outside of current areas of concentration?
    - Are there any current areas of concentration that are not included on the map of Great earthquakes?
    - Are there tectonic plates or particular plate boundaries with more than their fair share of Great earthquakes?

- d Write a second paragraph to describe the correlation between Great earthquakes and current seismic activity. Also indicate if there

are any particular tectonic plates or plate boundaries that appear to be particularly active in the generation of Great earthquakes.

## Topic reflection

The learning intentions for this topic are given in each lesson and at the beginning of the topic. Consider how well you have achieved them. Note down any particular

areas that you are confident in, and others where you are not so sure.

# 13 Glossary

**asthenosphere** near the top of the mantle, just below the solid lithosphere, and it contains rock that can move very slowly

**biogenic sedimentary rock** sedimentary rock formed mainly from dead organisms

**biological weathering** living organisms that break rocks down into smaller pieces through the action of roots, organic acids, and enzymes

**biosphere** the place where all life exists; consists of Earth's surface and its atmosphere

**cementation** the binding together of sediments as part of the formation of sedimentary rock

**chemical sedimentary rock** sedimentary rock that forms when dissolved materials precipitate from solution

**chemical weathering** reaction processes that break rocks down into smaller pieces, like acid rain, and oxidisation

**clastic sedimentary rock** sedimentary rock formed mainly from small rock particles

**continental crust** the less dense part of the crust that forms the continents

**convection** the transfer of heat through movement of particles in a liquid or gas

**convergent boundary** tectonic plate boundary where plates are colliding with each other

**compaction** the squeezing of layers of sediments caused by pressure from layers above

**contact metamorphism** a type of metamorphism where rock is altered mostly by heat

**crust** the outermost layer of Earth, composed of solid rock

**crystallisation** evaporation of a solvent from a solution, leaving solute behind as crystals

**deposited** the settling of broken rock material to form sediment

**deposition** the settling of broken rock material to form sediment

**dichotomous key** a classification key with two choices at each stage

**divergent boundary** tectonic plate boundary where plates are moving apart from each other

**dynamic metamorphism** a type of metamorphism where rock is altered mostly by pressure

**earthquake** the rapid movement of the ground, usually back and forth and up and down in a wave motion, due to the movement of tectonic plates

**epicentre** the point on Earth's surface directly above the focus of an earthquake

**erosion** the movement of weathered rock particles from the site of the weathering

**extrusive igneous rock** igneous rock that forms on the surface of Earth

**focus** the place below ground where an earthquake starts

**fold mountains** mountains formed by crust crumpling upwards as plates collide

**foliated** a process where minerals under pressure realign and the rock develops layers or bands

**force** a push, pull or twist that can change an object's shape or motion

**fossil** the preserved evidence in rocks or soils of organisms that were once alive

**fossil record** a list showing the classification of all the species on Earth that have been found as fossils

**gas giant planet** large planet in the solar system that is mainly composed of hydrogen and helium gas; includes Jupiter and Saturn

**geology** the study of Earth

**geosphere** all the rocks, minerals and landforms that make up Earth

**geothermal energy** the heat energy that comes from within Earth

**hot spot** isolated place away from plate boundaries where a lot of hot magma is collecting

**humus** dark material in soils produced by the decomposition of plant and animal remains

**ice giant planet** large planet in the solar system that is mainly composed of water, ammonia, and methane; includes Uranus and Neptune

**igneous rock** rock formed by the cooling of molten rock, for example basalt

**index fossil** a fossil that can be used to compare the relative age of rock strata in different locations

**inner core** extremely hot, solid ball made of iron and nickel at the very centre of Earth

**intensity** a measure of the effect of something

**intrusive igneous rock** igneous rock that forms below the surface of Earth

**lava** molten rock that reaches Earth's surface

**lithosphere** name for the crust and the upper mantle together

**magma** molten rock below Earth's surface

**magnetic striping** patterns of magnetism trapped in rocks on each side of plate boundaries

**magnitude** a measure of the size or strength of something

**mantle** solid layer of Earth between the crust and the outer core

**metamorphic rock** rock formed when heat and/or pressure alter existing rock

**mid-ocean ridge** a mountain chain on the floor of the ocean along the boundary of two tectonic plates

**mineral** a naturally occurring solid substance that is inorganic, has a characteristic crystalline structure and a fairly constant chemical composition

**oceanic crust** the denser crust that forms the ocean floor

**outer core** a liquid layer of Earth's interior, primarily composed of liquid iron and nickel, located beneath the solid mantle and surrounding the inner core

**P-wave** type of earthquake wave that are longitudinal pressure waves that spread through Earth, they can pass through solid and liquid layers

**parent rock** the original rock that experiences metamorphism, or changes form, to become a new kind of rock

**physical weathering** mechanical processes that break rocks down into smaller pieces, like wind, freezing water, changes in temperature, and crystallisation of salts

**primordial** something that originated during the planet's formation process a very long time ago

**radiometric dating** a technique for determining the age of rocks that measures the radioactive elements in a substance

**regional metamorphism** a type of metamorphism where rock is altered by both heat and pressure over a wide area

**ridge push** older crust is pushed by new ocean crust at mid-ocean ridges, forcing plates apart

**rift valley** a low-lying valley created by the action of a geological rift or split, often at a diverging plate margin

**rock cycle** a model geologists use to explain the endless cycle of change that rocks undergo

**rock** a solid mass of one or more minerals

**S-wave** type of earthquake wave that are transverse shear waves that spread more slowly than P-waves, they can only pass through solid layers

**sediment** solid material that was broken down by weathering, moved to a new location by erosion, and has now settled into layers

**sedimentary rock** rock made by sediments being compacted and cemented together

**seismic data** data about movements of the ground that is used by scientists to study and monitor earthquakes

**seismic wave** the shaking, wave-like movement of the ground in an earthquake

**seismogram** the recorded information from a seismograph

**seismograph** a seismometer that is connected to a recording device

**seismometer** an instrument that detects the seismic waves from an earthquake

**slab pull** pulling force exerted by older, colder and denser oceanic plates sinking down into the asthenosphere due to gravity, dragging the rest of the plate with it

**subduction** when a more dense plate sinks below another less dense plate during a collision

**supercontinent** one of several large land masses that are thought to have divided to form present-day continents

**surface wave** type of earthquake wave that does not penetrate Earth but travels along the ground

**tectonic plate** large section of Earth's lithosphere that moves about on Earth's surface

**terrestrial planet** smaller planet in the solar system that has a similar internal structure and composition as Earth; includes Mercury, Venus, Earth, and Mars

**theory of plate tectonics** scientific theory that describes the existence, and motion, of tectonic plates

**transform boundary** tectonic plate boundary where plates are sliding past each other either in opposite directions or in the same direction but at different speeds

**trench** a depression in the ocean floor

**tsunami** a large and destructive ocean wave or series of waves caused by either a large earthquake on the seafloor, a landslide or a volcanic eruption

**viscosity** the measure of a liquid's resistance to flow

**volcano** a place where extremely hot material from inside Earth erupts at the surface

**weathering** processes that break rocks down into smaller pieces

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