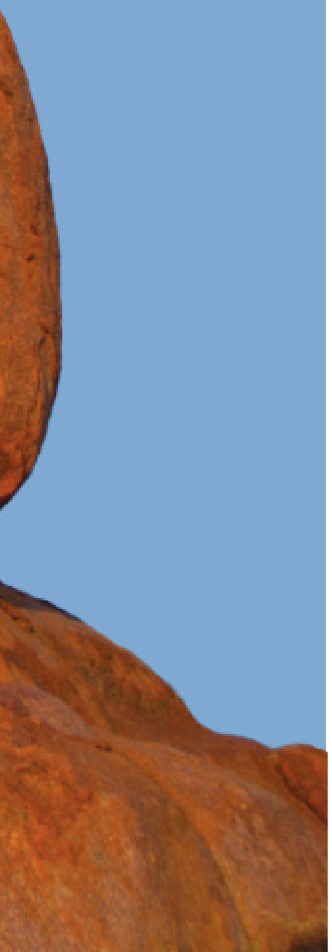
6 THE CHANGING EARTH

The Devils Marbles rocks are an extraordinary landform located in the Northern Territory. Once part of a solid layer of granite and sandstone rock, the processes of erosion and weathering led to the formation of these spectacular granite boulders, which vary in size and are an iconic feature of the Australian outback landscape. The Devils Marbles are an example of how our planet is constantly being reshaped and changed through the rock cycle.



UNDERSTANDING THE EARTH 6.1

The Earth is a rocky planet that formed approximately 4.5 billion years ago. The outer layer of the Earth, the crust, is composed of a thin layer of rock. The ancient rocks that first formed the Earth's crust have eroded and been replaced in an ongoing process called the rock cycle.

Students:

- describe the structure of the Earth in terms of core, mantle, crust and lithosphere
- outline the origins of and relationships between sedimentary, igneous and metamorphic rocks
- relate the formation of landforms to physical and chemical weathering, erosion and deposition
- explain the role of forces and energy in the formation of different types of rocks (additional)

PROPERTIES OF ROCKS AND MINERALS 6.2

Minerals are the building blocks of rocks. Rocks and minerals can be classified according to their properties, such as how hard or soft they are, if they are shiny or dull, or whether they have a distinctive colour. Australia is rich in mineral resources and many people are employed in industries associated with them.

Students:

- identify that sedimentary, igneous and metamorphic rocks contain minerals
- classify a variety of common rocks and minerals into groups according to their properties
- describe examples to show how skills from across the disciplines of science are used in the exploration, mining or processing of minerals

THE EARTH'S GEOLOGICAL PAST 6.3

Geologists are able to determine the history of planet Earth by studying its rocks. Fossils that form in sediments, which later become rock, give scientists important clues about the age of rocks.

Students:

- describe the conditions under which fossils form
- outline how geological history can be interpreted in a sequence of sedimentary layers
- describe some methods used by scientists to determine the age of rock layers (additional)

6.1 UNDERSTANDING THE EARTH

The surface of the Earth, both under the sea and on land, is composed of rocks. Scientists classify rocks according to how they were formed. The three main groups of rocks are sedimentary, igneous and metamorphic. Over time, the surface of the Earth changes as rocks break down, erode and cycle from one form of rock to another. Scientists who study the structure of the Earth, rocks and minerals are called **geologists**.

THE EARTH'S STRUCTURE

Although the Earth is now a solid planet, it began as a ball of molten materials. Scientists believe the Earth and other planets are a result of a massive explosion billions of years ago. According to this theory, planet Earth began as a molten fragment from this explosion called the Big Bang. As the fragment hurtled through space, the outside layers cooled, forming a ball of solid rock and ice. Most of the ice eventually melted and formed the oceans and rivers.

The Earth's surface has continued to slowly change and is still changing – many rocks have worn down to form soil and sand, mountains and valleys have formed, and the land and oceans have changed shape. Some of this change is due to molten rocks moving from deeper down, which in places push their way up to the surface and also move sections of the Earth's crust.

If you could make a journey deep inside the Earth, you would find it is made of several layers.

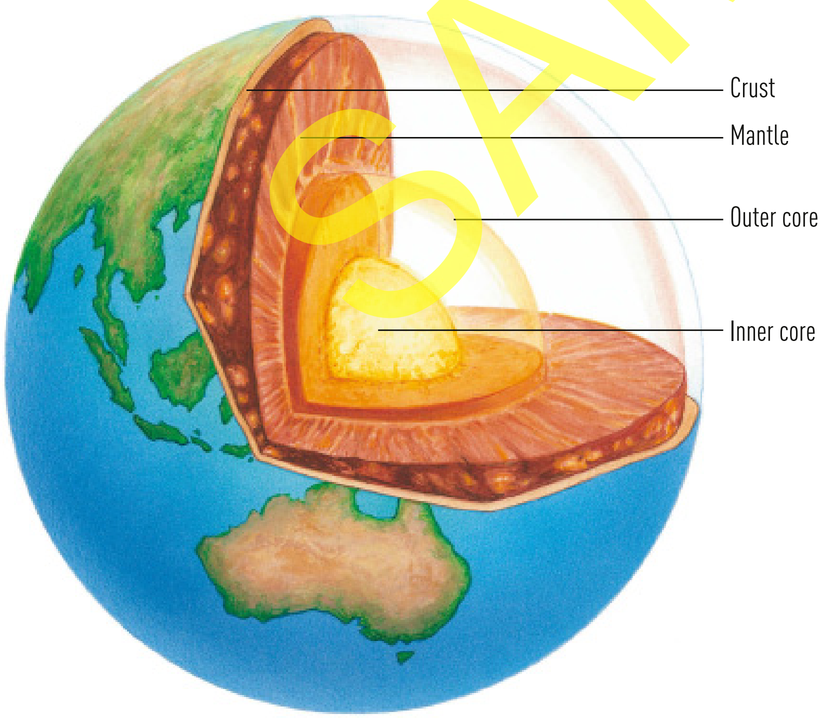


Figure 6.1 Layers of the Earth.

The core

The **core** is the centre of the Earth. It consists of the outer core and the inner core. The outer core is approximately 2200 km thick. The inner core is about 2500 km thick.

The outer core is made mainly of metals (not rock), and the main metal is iron, possibly with some nickel. The outer core is very hot and liquid, with temperatures ranging from 4000°C to 6000°C. The heat comes from nuclear reactions and some of the heat is left over from when the Earth was formed. The outer core gives the Earth its north and south poles and magnetic field.

The inner core has a temperature of almost 10 000°C. The inner core does not melt or boil because of the weight of the rest of the Earth pushing down on it. Of course, no geologist has ever seen the core. Even our deepest mines only penetrate a few kilometres of the Earth's crust.

The mantle

The **mantle** is about 2800 km thick. Temperatures at the top of the mantle near the crust are 500°C and at the bottom of the mantle reach 3000°C. The bottom of the mantle is solid, but nearer to the top the rock slowly moves due to convection currents. Convection currents (see chapter 3) are one type of movement of heat – you have probably heard that 'heat rises'. When heated regions rise, cooler regions move into the spaces left behind. As the hotter regions cool, they move down until they are heated and rise again, forming the cycle of a convection current. The top part of the mantle is more like modelling clay than solid rock. It is the source of volcanoes and earthquakes.

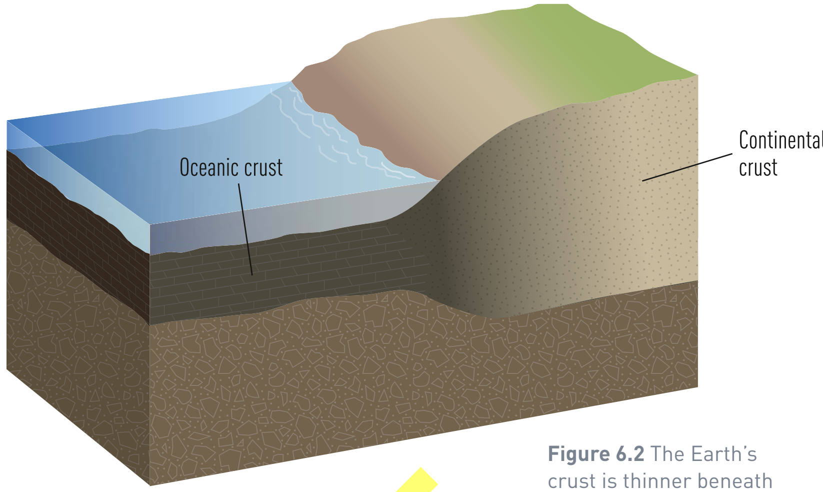


Figure 6.2 The Earth's crust is thinner beneath the oceans than it is beneath the continents.

The crust

The **crust** is the thin outer layer of the Earth on which we live. The crust ranges in thickness from 7 km to 50 km. It is made up of rocks and minerals, and much of the crust is covered by water. Do not think of the crust as just the landmasses; the oceans cover 70% of the crust. The Earth's surface is not smooth. It has hills, mountains, valleys, oceans and deserts. The crust is thickest under the continents and thinnest under the oceans. Compared with the rest of the layers of the Earth, the crust is very thin and brittle.

The lithosphere

The **lithosphere** is the term used by scientists to describe the solid outer shell of a planet. The Earth's lithosphere consists of the crust and the upper part of the mantle, and is approximately 100 km thick. The lithosphere is broken into large sections, which are constantly moving. The speed of movement is similar to fingernail growth: between 1 cm and 10 cm per year.

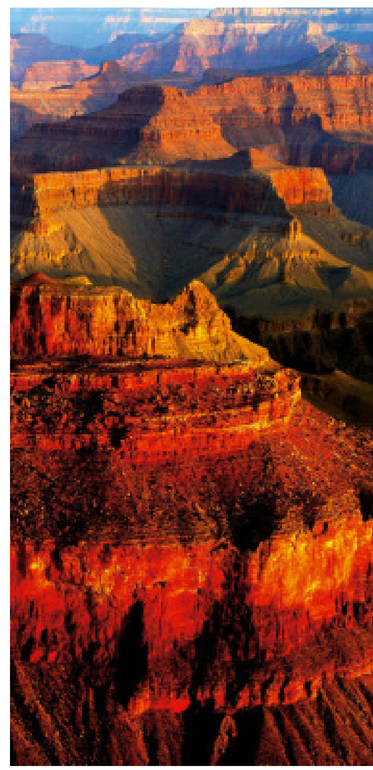


Figure 6.3 The Grand Canyon is part of the lithosphere.

QUESTIONS 6.1.1: THE EARTH'S STRUCTURE

Remember

1 Describe the core of the Earth.
2 Identify where the Earth's crust is thickest.
3 Identify where the Earth's crust is thinnest.
4 Identify the layer of the Earth that is the source of volcanoes and earthquakes.
5 Define the term 'lithosphere'.

Apply

6 '70% of Earth's crust is made of ocean and 30% is made of rock.' Is this statement true or false? Justify your answer.
7 Contrast the core of the Earth and the crust of the Earth. Identify three differences.
8 Propose why no geologist has seen the core of the Earth.

Analyse

9 Propose what feature of the Earth would lead scientists to think that the Earth's core might be made of iron. Hint: You might need to think back to year 7.

HOW ROCKS ARE FORMED

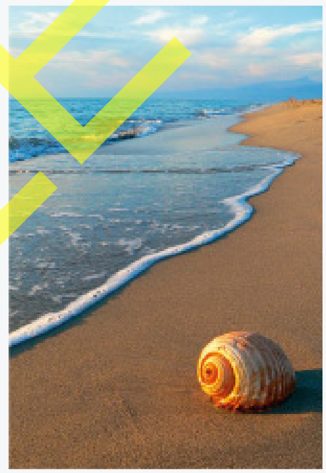
There are hundreds of different rocks on the Earth. Scientists classify rocks into three main groups according to how they are formed. The three main types of rocks – igneous, sedimentary and metamorphic – all form in different ways.

ACTIVITY 6.1.1: MAKING ROCKS

Do you know how rocks are made? In small groups, discuss the following questions.

1 Where are rocks found?
2 How do rocks differ from one location to the next?
3 What conditions might be necessary to make a rock?
4 Could you provide those conditions in a science laboratory?





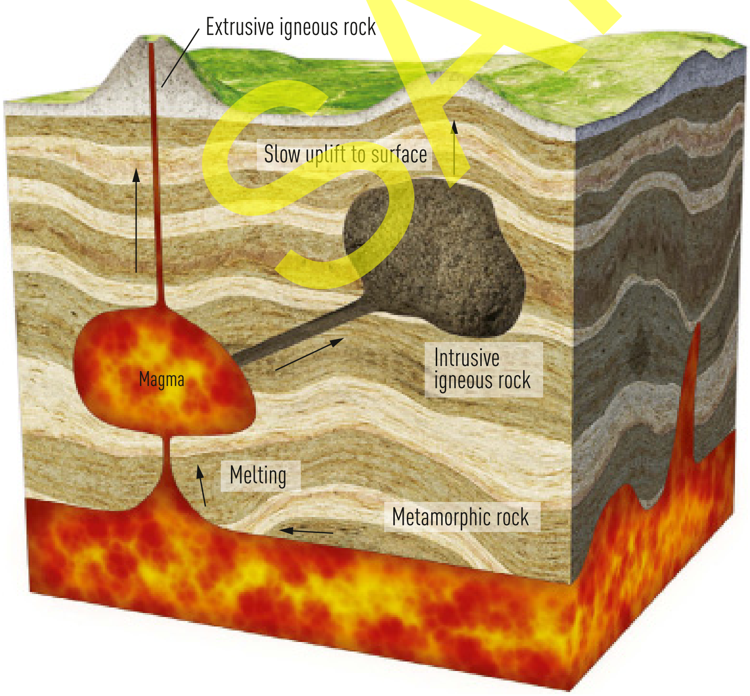


Figure 6.4 Igneous rocks are formed from volcanic magma.

Igneous rocks

In a volcanic eruption, red-hot molten rock called **magma** rushes out onto the surface of the Earth. Once magma is on the Earth's surface, it is known as **lava**. Magma from inside the Earth and lava from volcanic eruptions cool and solidify to form **igneous rocks**. The term 'igneous' comes from the Latin word *ignis*, which means 'fire'. The lower temperatures on the Earth's surface help the lava to solidify quickly. Igneous rocks that form from magma under the ground look quite different from those formed on the Earth's surface because they cool much more slowly.

Intrusive igneous rocks

Intrusive igneous rocks form slowly beneath the surface of the Earth when magma becomes trapped in small pockets.

These pockets of magma cool slowly underground (sometimes for millions of years) to form igneous rocks. Although formed underground, intrusive igneous rocks reach the Earth's surface when they are either pushed up by forces in the Earth's crust or uncovered by erosion. Granite is an example of an intrusive igneous rock (see Figure 6.5).

Extrusive igneous rocks

Lava cools much more quickly on the Earth's surface to form **extrusive igneous rock** such as pumice (see Figure 6.6). Pumice forms when hot, gas-filled lava cools very quickly. Pumice has many tiny holes that are formed by volcanic gases escaping from the cooling lava. Because there are so many holes, pumice is extremely light and can float on water. Pumice stones are used to scrub hard skin from our feet and powdered pumice is found in some abrasive cleaning products.

Figure 6.6 Pumice is an extrusive rock that is so light that it floats on water.

Crystals in igneous rocks

It is hard to understand how the same magma can solidify into both extrusive and intrusive igneous rocks and why the two types of igneous rocks behave quite differently. The answer is in how igneous rocks form and what they are made of. All rocks are made of **minerals** that are found in shapes called **crystals**. The longer it takes for lava to cool, the bigger the rock crystals that grow. Intrusive igneous rocks (such as granite) have large crystals. Lava cools much more quickly on the surface of the Earth, so extrusive igneous rocks have small crystals. Sometimes the lava cools so quickly that no crystals are formed.

Basalt is the most common type of rock in the Earth's crust. Most of the crystals in basalt are microscopic or non-existent because the magma cools so quickly that large crystals are unable to form. We commonly think of basalt as the building product bluestone. However, basalt can look different depending on the type of volcanic eruption it came from and how quickly it cooled. Scoria is a type of basalt full of bubble holes. The lava was filled with gases when it began to cool and the holes in the scoria are where the gas bubbles once were. Scoria is a light rock often used for garden paths and as fill in drainage trenches.

Obsidian is a smooth, black rock that looks like glass. It is formed when lava cools almost instantly and forms no crystals. Obsidian is used to make blades for surgery scalpels; the resulting blades are much sharper than those made from steel.

Figure 6.5 Granite is an intrusive igneous rock.

Figure 6.7 Basalt comes in different forms: (a) bluestone, (b) scoria and (c) obsidian.

EXPERIMENT 6.1.1: FACTORS THAT AFFECT CRYSTAL SIZE

Aim
To grow crystals and determine what affects their size.

Materials
- Bunsen burner
- Matches
- Heatproof mat
- Tripod
- Gauze mat
- Alum powder
- 2 Petri dishes
- Evaporating dish
- Safety glasses
- 250 mL beaker
- Tablespoon

WARNING

> Wear safety glasses while heating the alum solution.

Method
1. Prepare a solution of alum by mixing 2 1/2 tablespoons of alum with 1/2 cup of hot water. Stir until dissolved.
2. Pour roughly equal amounts of alum solution into the evaporating dish and the two Petri dishes.
3. Put one of the Petri dishes in the refrigerator.
4. Put the other Petri dish on a windowsill.
5. Place the evaporating dish on the gauze mat.
6. While wearing safety glasses, gently heat the evaporating dish containing the alum solution over an orange (safety) flame. The orange flame is cooler and will allow for gentle boiling.
7. Continue heating the solution until nearly all the water has evaporated.
8. Observe the size of the crystals formed in the evaporating dish.
9. After two days, observe the size of the crystals formed in the two Petri dishes.
10. Observe the crystals formed in the refrigerator again after four or five days.

Results
Draw a labelled diagram of the crystals formed in the evaporating dish and in the two Petri dishes. Your diagram should show the different sizes of the crystals in the different dishes.

Discussion
Each of the crystals grew over a different time span. How does the time allowed for the crystal to form affect the size of the crystals?

Conclusion
What do you know about the factors affecting crystal size?

Figure 6.8 Crystals form in different shapes, colours and sizes.

Sedimentary rocks

Sedimentary rocks are formed when sediments (loose particles) are pressed together over a long period of time. Sediments are rock particles, such as mud, sand or pebbles, that are usually washed into rivers and eventually deposited on the riverbed or in the sea. Sediments can also come from the remains of living things, such as plants and animals.

Over thousands or even millions of years, these sediments form thick layers on the riverbed or sea floor. Pressure from the sediments and water above squeezes out the air and gaps in the bottom layer. Over time, the compacted sediments become sedimentary rocks. Chemicals that are dissolved in the water can soak into the sediments. The chemicals help cement the grains together once the water has evaporated.

Figure 6.12 Sandstone is a popular building material. The Art Gallery of NSW in Sydney is one of many sandstone buildings in the CBD (central business district).

Figure 6.9 Coal is formed from dead plant material.

The names of some sedimentary rocks give clues to the sediments that formed them. Sandstone, mudstone, siltstone and conglomerate are all types of sedimentary rock. Sandstone, for example, is made up of sand deposited in environments such as deserts and beaches. Conglomerate (as the name suggests) is a mixture of all sizes of rocks that have become cemented together.

Sedimentary rocks are not always formed from the sediments of minerals or other rocks. Living things also break down and their remains are deposited as sediments. Shells and hard parts of sea organisms break down and are deposited in layers on the ocean floor. Eventually they cement together under pressure to form limestone.

The compaction of dead plant material can also help form sedimentary rocks. For example, **coal** is formed from dead plants that were buried before they had decayed completely. Pressure from the layers above may change the plant material into coal or oil.

Chemical sedimentary rocks form when water evaporates, leaving behind a solid substance. For example, when seabeds or salt lakes (such as Lake Eyre) dry up, they leave a solid layer of salt behind. If the layer of salt is compressed under the pressure of other sediments, it may eventually form rock salt.

Figure 6.14 Lake Eyre is a very large inland salt lake in South Australia that is rarely filled with water. It is usually a large salt pan.

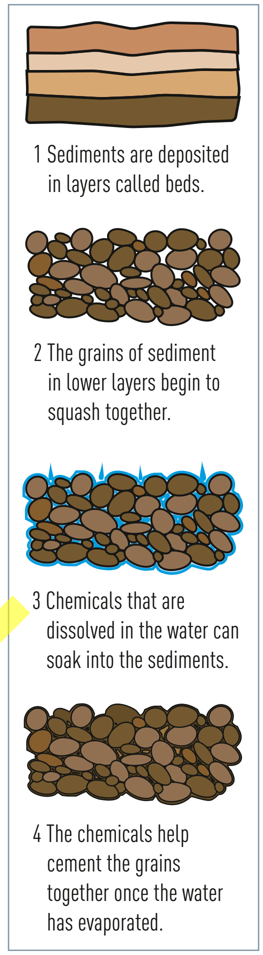


Figure 6.10 The formation of sedimentary rocks.

Figure 6.11 Conglomerate rocks have grains of different sizes. The sediments for these rocks were deposited in fast-flowing rivers during flooding or by glaciers.

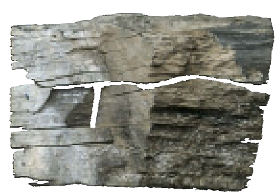


Figure 6.13 Shale (or mudstone) is the most common sedimentary rock. Shale is a fine-grained sedimentary rock made up of clay minerals or mud.

EXPERIMENT 6.1.2: MAKING SEDIMENTARY ROCKS

Aim
To make small samples of sedimentary rocks and compare them with real samples.

- Dry clay
- Mortar and pestle
- Dry sand
- Small, smooth pebbles
- Plaster of Paris
- Teaspoon
- 4 empty matchboxes (or similar small cardboard boxes)
- White tile
- Photos of sandstone, shale and conglomerate

Method
1 Grind a lump of dry clay with a mortar and pestle until it is fine and powdery.

2 Using the teaspoon, mix the dry ingredients for each rock sample on a white tile according to the recipes below, but do not add the water just yet. You will need to prepare two shale samples so they can be used later in Experiment 6.1.3.

Rock	Dry clay	Sand	Plaster of Paris	Pebbles	Water
Sandstone	1/2	4	1/2	0	2
Shale	5	1/2	0	0	2
Conglomerate	1/2	1	1/2	4	2

(All measurements are in teaspoons)

3 Pile your ingredients into a little hill and make a small dip in the centre for the water.

4 Slowly add the water and stir until the ingredients are uniformly mixed. Be careful not to make the mixture too wet.

5 Press your mixture into an empty matchbox, label it with the rock type and your name, and leave it to dry for two days.

6 When your 'rock' is dry, peel off the matchbox and examine your sample. Take digital photos of your samples and photos of the 'real' rocks for comparison. Keep your two shale samples for Experiment 6.1.3.

Results
Include images of your rocks, along with any statements about the process or products.

Discussion
1 How do your sedimentary rock samples compare with the real samples?

2 What were the differences between your samples and the real rocks?

Conclusion
What have you discovered about sedimentary rocks?

Metamorphic rocks

Metamorphic rocks are formed when other types of rocks are changed by extreme heat and pressure inside the Earth. When igneous, sedimentary or even metamorphic rocks are heated to extreme temperatures by magma, or when they are placed under extreme pressure from the layers of rocks above them, they can change into a different type of rock. For example, basalt can be changed into hornfels, granite can be changed into gneiss, shale can be changed into slate (see Figure 6.15) and limestone can become marble (see Figure 6.16).

Metamorphic rocks are stronger than the original rocks they came from because the particles have been fused together under great pressure or heat.

Bands can sometimes be seen in metamorphic rocks. The bands tell us that the crystals inside the rock were squeezed together under immense pressure. For example, when granite is squeezed under high pressure, the crystals change and the rock gneiss is formed (see Figure 6.17).

Figure 6.15 Slate is the metamorphosed form of shale. It is a useful material for floor and roof tiles and as the base for billiard tables.

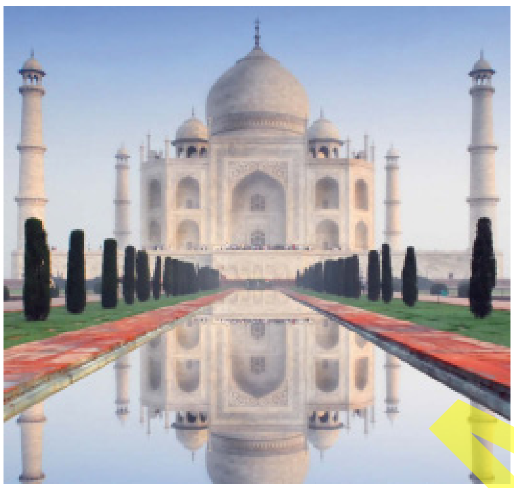


Figure 6.16 The Taj Mahal in India is made of marble, the metamorphosed form of limestone. Marble is also a popular material for sculptures and kitchen bench tops.

Figure 6.17 When granite (a) is subjected to high heat or pressure, it can change into the metamorphic rock known as gneiss (b). The bands on the gneiss show that the crystals have been squeezed together under immense pressure.

EXPERIMENT 6.1.3: MAKING A METAMORPHIC ROCK

Aim

To make a sample of a metamorphic rock.

Materials

- 2 shale rock samples from Experiment 6.1.2
- Bunsen burner
- Tripod
- Pipe clay triangle
- Gauze mat
- Evaporating dish
- Tongs
- 2 × 250 mL beakers

WARNING

> Never leave a Bunsen burner unattended during an experiment.
> Wear safety glasses and a lab coat.
> The apparatus will be very hot at the end of this experiment. Leave it to cool before packing it away.

Method

1 Allow your shale samples made in Experiment 6.1.2 to dry for approximately one week.

2 Place one of the shale samples on a pipe clay triangle on top of a gauze mat and heat it strongly over a blue Bunsen burner flame for about half an hour. If an evaporating dish is placed upside down over the shale, more heat will be retained.

3 After about half an hour of heating, carefully pick up the shale sample using the tongs and drop it into a beaker of water.

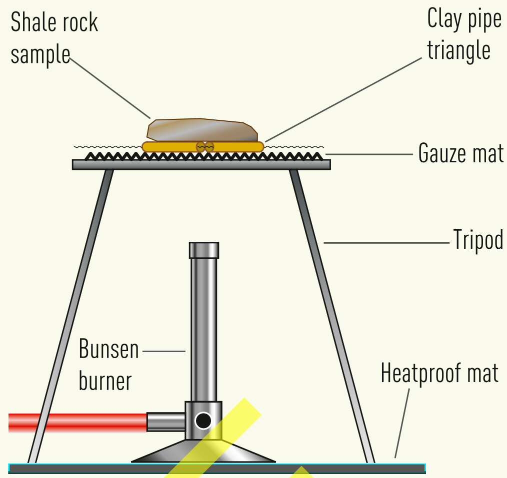


Figure 6.18 Experimental setup.

4 Drop the second, unheated shale sample into another beaker of water and observe what happens to the two rock samples.

Results

Record your observations in a table.

Discussion

1 What differences do you notice about the two rock samples when they are dropped into the water?

2 Can strong heat change the properties of rocks over time?

3 How different was your new metamorphic rock sample from the original shale sample? Was the method successful?

Conclusion

What do you know about the formation of metamorphic rocks?

QUESTIONS 6.1.2: HOW ROCKS ARE FORMED

Remember

1 Identify the sediments that the following sedimentary rocks are made from:
   - **a** sandstone
   - **b** conglomerate.

2 Recall why pumice floats on water.

3 Explain how metamorphic rocks form.

4 Explain how sedimentary rocks form.

5 Explain how igneous rocks form.

Apply

6 Explain what plants have to do with coal.

Analyse

7 The ancient civilisations that discovered obsidian had a competitive advantage over those who did not know about obsidian. Propose why this might have been the case.

FORMATION OF LANDFORMS

The Earth's crust is not flat – it is covered in landforms such as cliffs, valleys, canyons, caves and plateaus. Rocks are gradually broken down and sculpted through both physical and chemical processes. The gradual breaking down of rocks is a process called **weathering**.

Weathering

Rocks look indestructible and permanent. They are used to make roads, important buildings and monuments. Large rocks can be used to hold back the surf and ocean waves. Rocks seem to last forever, but they don't. They are slowly worn down into smaller pieces by weathering. The causes of weathering are either physical or chemical.

Physical weathering

Physical weathering refers to the breakdown of rocks by non-living things. It includes the effects of heat and cold on rocks, the formation of ice, and the effects of wind and water.

In desert areas, the processes of **onion-skin weathering** and **frost shattering** are common. The days are very hot and the nights are freezing cold in the desert. This daily heating and cooling affects only the outside of the rock because rocks do not transmit heat very well. Sometimes the outside of the rock can peel off, just like onion skin. The round rocks produced in this way are called tors.

Frost shattering involves an unusual characteristic of water: when water freezes, it takes up more space. When water freezes in a crack of a rock to form ice, it expands and pushes hard against the rock around it. This can make the crack larger. The next day, the ice melts and water fills the crack again. That night, ice forms again and makes the crack even larger. This process is repeated many times until part of the rock is split off.

Living things also help to break down rocks. Tree roots can grow within small cracks in rocks and exert forces that can eventually break the rocks apart. This is called biological weathering.

Figure 6.19 A frost-shattered rock.

Figure 6.20 The Devils Marbles in the Northern Territory's hot desert have been formed by onion-skin weathering.

ACTIVITY 6.1.2: BIOLOGICAL WEATHERING

Figure 6.21 shows trees growing in the cracks in the rocks of Mount Remarkable National Park in South Australia. Using only this image, and your knowledge of physical weathering, prepare a three-stage diagram to show how trees such as those pictured might cause biological weathering in rocks. Try to imagine what will happen as the trees grow. Add labels and captions to your diagram to explain what is happening.

Figure 6.21 Mt Remarkable National Park, South Australia

Chemical weathering

Sometimes chemicals in the environment cause the weathering of rocks. This is called chemical weathering. The chemicals in air and water can react with the chemicals in rocks. The most common chemicals involved in weathering are water, oxygen and acids.

There are many natural acids. Natural acids come from the decay of dead plants and animals, and also from chemicals dissolved in rainwater that form naturally by the effect of lightning. These acids are not as strong as the acids in a science laboratory but can dissolve some rocks slowly. Limestone is commonly dissolved by rainwater and acids. Amazing features, called stalagmites and stalactites, are formed in this way when a solution containing limestone drips from the roof of caves and evaporates (see Figure 6.23).

In areas of the world where air pollution is very bad, acid rain is a problem. You learnt about the chemical reaction of acid rain in chapter 5 on page 233. Acid rain can form when raindrops dissolve pollution in the air and carry it to the ground. If the pollution is acidic, then the rain will be too. Winds can also carry acid to other regions.

Acid rain destroys forests and makes lakes and rivers so acidic that fish and plant life die. Acid rain is also a problem because it can dissolve the limestone and marble often used in statues and buildings (see Figure 6.22).

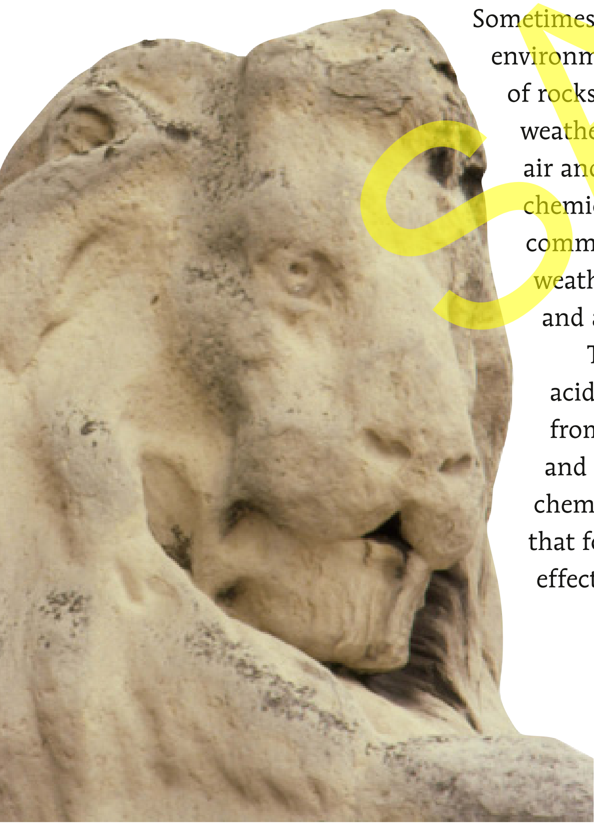


Figure 6.22 Acid rain is a form of chemical weathering that has worn away the features of this statue.

DEEPER UNDERSTANDING

Limestone caves

The amazing long strands of rock found on cave floors and ceilings are composed of calcium carbonate from the limestone ceiling of the cave. A stalagmite grows from the floor towards the ceiling (they 'might' reach the ceiling one day) and a stalactite grows down from the ceiling (they hold on 'tight'). If these formations meet in the middle, a column is formed.

Stalagmites and stalactites form when acids in water dissolve the limestone rocks above the cave. The acid and dissolved limestone makes a solution that drips through the ceiling of the cave and is deposited on the stalagmites and stalactites, gradually increasing their width and length. When touring inside limestone caves with stalactites and stalagmites, do not touch these rock formations because they are generally still forming. Oil from our skin can interfere with their formation.

Figure 6.23 Striking limestone formations at the Jenolan Caves in New South Wales.

EXPERIMENT 6.1.4: THE EFFECTS OF CHEMICAL WEATHERING

Aim

To investigate the action of acids on limestone.

Materials

- 4 small lumps of limestone
- Dilute sulfuric acid
- Soda water
- White vinegar
- Tap water
- 4 test tubes

WARNING

> Safety glasses and lab coats should be worn when handling acids.

Method

1 Carefully place a piece of limestone into each of the four test tubes.

2 Pour some sulfuric acid into one test tube, soda water into another, vinegar into the third and ordinary tap water into the fourth. The fourth test tube, with tap water, is the control.

3 Carefully observe what happens to each piece of rock.

Results

Draw a labelled diagram of the four test tubes.

Discussion

1 Are bubbles produced in each test tube?

2 What do you think is causing any bubbles that are present?

3 Are all the pieces of limestone reacting? If not, why not?

4 Why was tap water used as the control in this experiment?

Conclusion

What can you conclude about the action of acids on limestone?

Figure 6.24 The Twelve Apostles rock formation near the Great Ocean Road in Victoria were formed by water erosion. The soft limestone stacks are prone to further erosion by the ocean waves.

Erosion and deposition

Once rocks have weathered and been broken down into smaller pieces, they are moved and carried away by wind or water. This process is called **erosion**. The weathered rock moved by erosion is deposited on the land, in rivers, and on the floors of lakes and oceans to form sediments. The key agents of erosion are wind, ice and water.

Wind erosion occurs when the wind blows grains of sand and dust. Ice erosion occurs when ice in glaciers (frozen rivers) carries away earth and rock. Water erosion occurs when moving water washes away stones, sand and mud. Surf and ocean waves remove sand from beaches and wash it along the coast or out to sea. Rivers carry sand, gravel and smaller particles. As rivers slow, these particles are deposited in a process called **deposition**.

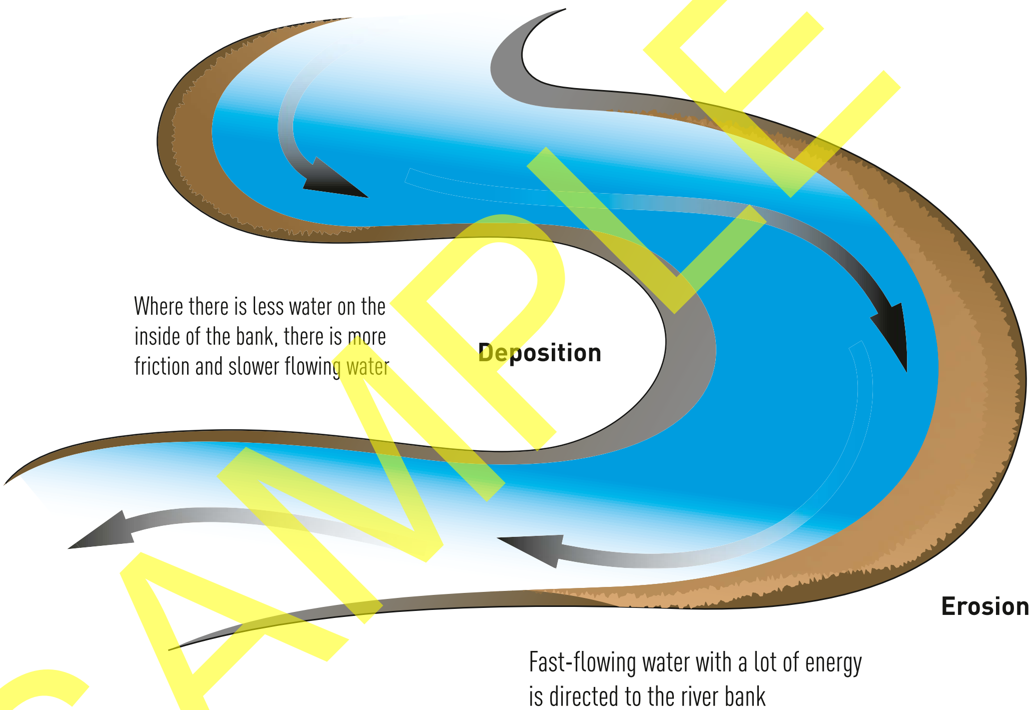


Figure 6.25 The process of water erosion by a river.

QUESTIONS 6.1.3: FORMATION OF LANDFORMS

1 Identify the two types of weathering.
2 Describe the process of onion-skin weathering.
3 Identify the most common chemicals involved in the process of chemical weathering.
4 Explain where natural acids come from.
5 Explain how stalagmites and stalactites are formed.
6 Identify three different types of erosion.

Apply

7 Compare the process of weathering with the process of erosion. What is the key difference?

THE ROCK CYCLE

The **rock cycle** is a model used by scientists to describe the formation and destruction of sedimentary, igneous and metamorphic rocks. It also describes the relationships between the different types of rocks, as geological processes act to recycle one type of rock into another. Erosion and forces within the crust are the main drivers involved in the rock cycle.

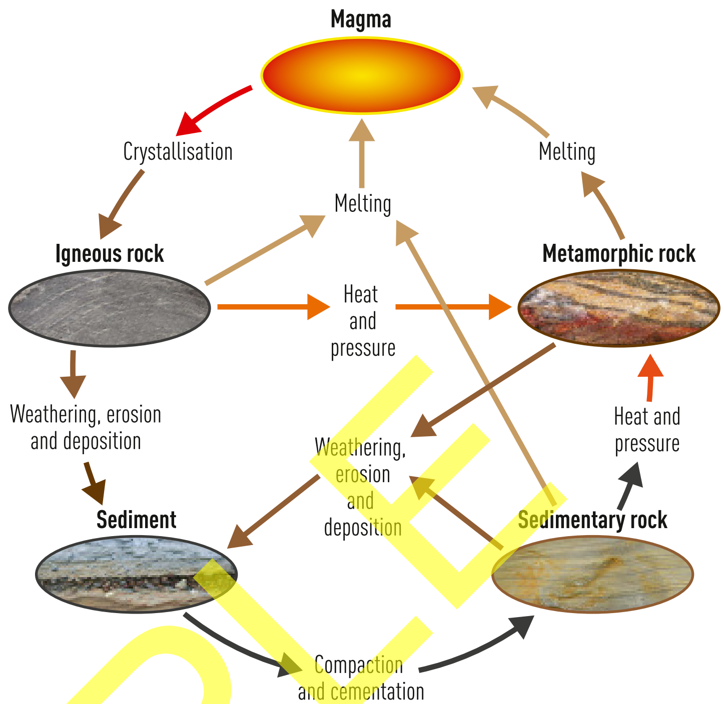


Figure 6.26 The rock cycle.

The rock cycle: step-by-step

1. Magma and lava cool and solidify to form igneous rocks. These rocks are brought to the Earth's surface through volcanic activity, through the uplifting forces acting on land when tectonic plates collide, or through erosion.
2. On the surface of the Earth, rocks are weathered by water, ice, wind, chemicals and biological forces.
3. The weathered particles are then removed by erosion, transported and eventually deposited.
4. As the deposited sediments become covered with additional eroded sediments, layers form and are cemented together under pressure to form sedimentary rocks. Forces within the Earth or additional heat and pressure can transform igneous and sedimentary rocks into very hard metamorphic rocks. If too much heat or pressure is applied to rocks, they melt and form magma, and the cycle continues.

QUESTIONS 6.1.4: THE ROCK CYCLE

Remember

1 Summarise the different stages in the rock cycle as short bullet points. Use Figure 6.26 to assist you.

Apply

2 Analyse the importance of sedimentary rocks in the rock cycle.

Create

3 In a similar way to humans, rocks change with time. However, unlike humans, rocks don't always head in the same direction – they may move through the rock cycle, covering the same phase many times in many different ways. Rocks are never truly 'born'. Write a creative story about the 'life of a rock'.

6.1 CHECKPOINT

UNDERSTANDING THE EARTH

Remember and understand

1 Match each word with its meaning. [4 marks]

mantle	central part of the Earth
lithosphere	layer of hot, semi-molten rock below the crust
core	outer layer of the Earth on which we live
crust	solid outer shell of the Earth comprising the crust and the upper part of the mantle

2 Identify the rocks formed when:

a loose particles are pressed together by the weight of sediments above them [1 mark]

b other types of rocks are changed by heat and pressure inside the Earth [1 mark]

c magma and lava cool and solidify. [1 mark]

3 Explain the difference between magma and lava. [2 marks]

4 Define the term 'sediment'. [1 mark]

5 Identify the type of rock that can be dissolved to make caves. [1 mark]

6 Identify the three chemicals in the environment that help weathering. For each chemical, explain where it can be found. [3 marks]

7 Identify the model used to describe the relationships between sedimentary, igneous and metamorphic rocks. [1 mark]

8 Identify the features of pumice that make it useful for removing dead skin. [1 mark]

Apply

9 Compare intrusive and extrusive igneous rocks. [2 marks]

10 Explain why sedimentary rocks form at the Earth's surface. [2 marks]

11 Cave systems in limestone rocks follow the course of underground rivers. Explain why water is necessary to make caves. [2 marks]

Analyse and evaluate

12 Predict where you would expect to find a black sedimentary rock that is formed from carbon. Explain your answer. [2 marks]

13 Propose why old buildings and monuments are weathering faster than ever before. [3 marks]

Critical and creative thinking

14 Figure 6.27 shows the Three Sisters in the Blue Mountains in New South Wales. Use this image to propose how these rocks were formed. Prepare a poster to show how the rocks were formed and how they would have changed over time. [5 marks]

Figure 6.27 The Three Sisters at Katoomba in the Blue Mountains, New South Wales.

15 Explain the role that forces play in the formation of sedimentary, igneous and metamorphic rocks. [3 marks]

Making connections

16 It can be said that the Earth's history is written in our rocks. Explain how learning about the rock cycle can help us to understand the history of our planet. [5 marks]

TOTAL MARKS [/40]

PROPERTIES OF ROCKS AND MINERALS

6.2

Scientists classify rocks into three major groups according to how they are formed – sedimentary, igneous or metamorphic. But within these three major groups there are many different rocks, each with their own name. Each rock has characteristics that give clues to its identity, such as its **colour** or hardness. These characteristics are referred to as **properties**. Rocks display properties that make them useful to humans, such as their hardness, shininess or ability to be shaped without breaking. By making careful observations of a rock's properties, geologists can tell where a rock came from and what has happened to it.

ACTIVITY 6.2.1: ROCKS IN YOUR HEAD!

How do you tell one rock type from another? There are probably certain properties you look for to identify objects around you. What properties would you use to identify rocks? Do you know any particular types of rocks already? What do you know about them? Are there certain words you would use for rocks that wouldn't be used for anything else?

1. Working in small groups, suggest properties that could be used to group rocks.
2. Find some rocks out in the schoolyard and group them using the features you discussed.
3. Share your results. Did the class end up with the same ideas? If not, how did the properties differ?
4. Would you consider the properties identified by your group as 'scientific'?

IDENTIFYING AND SELECTING ROCKS

Humans select rocks for particular purposes because of their properties. Granite, for example, is selected for kitchen benchtops because it is a hard building stone, it is not porous (it doesn't let liquid through), it does not change with temperature and it is resistant to damage from chemicals.

Rocks can first be identified by how they look. Coal, for example, is black or dark brown. The surfaces of pumice and scoria are full of holes. Conglomerates are rocks made up of individual stones that have become cemented together.

Geologists also use a range of other properties to help identify rocks, including:

- hardness
- **lustre** (shininess)
- transparency
- density
- composition (including the minerals that make up the rock)
- size of the grains in the rock.

Figure 6.28 shows some different rocks and how they can be identified by their type of rock, grain size, hardness and colour.

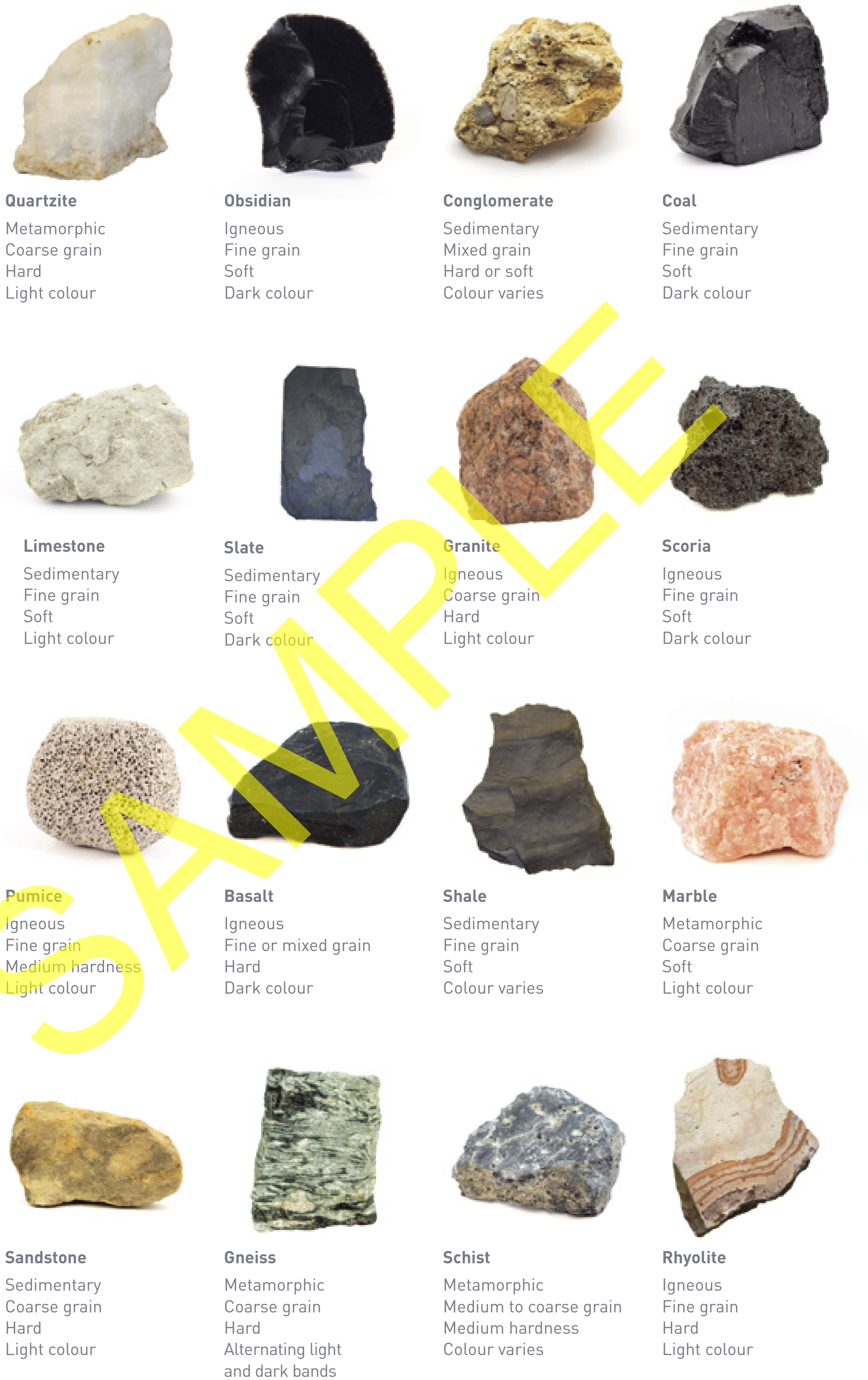


Figure 6.28 Different types of rocks.

EXPERIMENT 6.2.1: IDENTIFYING ROCKS

Aim
To identify a range of common rocks.

Materials
- Rock samples (unnamed, labelled A, B, C, D etc.)
- Hand lens
- Table 6.2 (on page 280), as well as a rock key from the Internet or your rock kit

Method
1 Examine each rock sample with the hand lens.
2 Use the key to identify each of your rocks. Be aware of the following:
   - Crystals in rocks have straight edges and flat, shiny surfaces.
   - Grains are not shiny – they are jagged or rounded, and more like grains of sand.
   - Coarse grains are about the size of a grain of rice. Medium grains are smaller but still visible to the naked eye. Small grains are only visible with a hand lens or magnifier.

Figure 6.29 Rock identification keys are used to identify unknown rock samples. Often a hand lens is needed to see the finer details of the rock.

Results
Display your results in a table that identifies the rock sample (e.g. sample A), lists its main properties and gives its name.

Discussion
1 How hard was it to identify your rock samples?
2 Were there any samples you could not identify?
3 Compare your results with those of another group. Were there any differences between your results?
4 Ask your teacher for the names of your rock samples and see which ones you got right (hopefully all of them!).

Conclusion
Write a comment on the use of a key to identify common rock samples.

QUESTIONS 6.2.1: IDENTIFYING AND SELECTING ROCKS

Remember
1 Identify five properties that geologists use to identify rocks.
2 Use Figure 6.28 to identify three rocks that share the following properties: fine grain, soft and dark in colour.

Apply
3 Explain why the properties of granite make it useful as kitchen benchtops.

Analyse
4 Using the properties listed for sandstone, basalt and limestone, construct a dichotomous key to differentiate between them.
5 Identify each type of rock from the following descriptions:
   a dark with holes in the surface
   b hard with alternating light and dark bands of colour
   c light in colour with coarse grains; used for sculptures

Figure 6.30 Geologists use tools and instruments to examine and identify rocks.

MINERALS

All rocks are made up of one or more minerals. A mineral is a naturally occurring solid substance with its own chemical composition, structure and properties. The minerals that make up a rock determine the properties of the rock. There are more than 4000 minerals known, but only approximately 150 of these are common. Quartz is the most common mineral and it is found in nearly every rock type. Quartz is made up of the two most common elements on the Earth: oxygen (O) and silicon (Si).

DEEPER UNDERSTANDING

Quartz in watches

Quartz watches use quartz crystals to keep time. One property of quartz crystal is that it generates an electric charge when mechanical pressure is applied to it. Depending on the type of quartz crystal, a quartz timepiece can accurately keep time to within 1 second every 10 years.

Figure 6.31 A quartz watch.

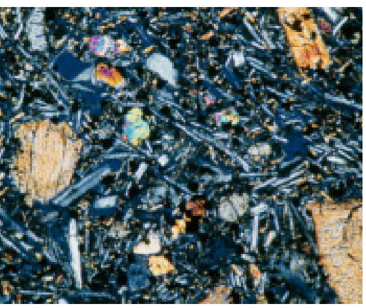


Figure 6.32 Under a microscope, the minerals that make up the rock olivine basalt can be seen as individual crystals.

Mineral crystals

Minerals are found in shapes called crystals (see Figure 6.32). The structure of the crystal greatly influences a mineral's properties. For example, both diamond and graphite have the same chemical composition – they are both pure carbon. Graphite (used as the lead in a pencil) is very soft, whereas diamond is the hardest of all minerals. As you learnt in chapter 4, this difference arises because the carbon atoms in graphite crystals are arranged into sheets that can slide past each other, whereas the carbon atoms in diamond crystals form a strong, interlocking unit (see Figure 6.33).

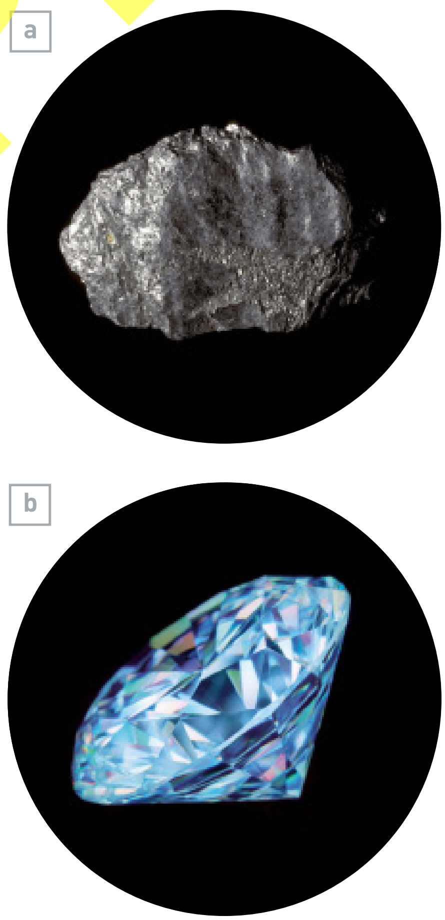


Figure 6.33 (a) Graphite is soft because the carbon atoms are arranged in sheets. (b) Diamond is hard because the carbon atoms are interlocked.

Identifying minerals

To identify minerals correctly, geologists carefully examine their properties. The main colour of the mineral is not a reliable property to identify them by because many minerals are impure. For example, pure quartz is colourless, but impurities can cause it to be many colours, such as purple (amethyst), pink (rose quartz) or yellow (citrine). Even in one sample, the colour may change. The colour of a mineral is a guide to identifying it, but colour cannot be relied on for correct identification. Properties such as lustre, streak, hardness and cleavage are used instead.

Lustre is the shininess of the surface of the mineral (see Figure 6.34). Some types of lustre are:

- metallic – looks like a shiny new coin
- brilliant – very shiny, like a mirror
- pearly – a bit shiny, like a pearl or fingernail
- dull – not shiny at all
- earthy – like a lump of dirt.

Streak is the colour of the powdered or crushed mineral. This colour can be seen by drawing with the mineral on a footpath. The colour of the line that the mineral leaves behind is its streak. Often the streak is different from the main colour of the mineral.

Hardness is how easily a mineral can be scratched. Some minerals are so soft that they can be scratched with a fingernail. Other minerals are so hard that they can scratch glass. A hard mineral can scratch a soft mineral and not get scratched itself. Austrian geologist Friedrich Mohs devised a scale on which the hardness of a mineral is described by a number. Mohs gave a hardness number to 10 common minerals, as shown in Table 6.1. Talc is the softest mineral and has a hardness of 1; diamond is the hardest mineral and has a hardness of 10. These minerals can be used to find the hardness of any other mineral. A piece

Figure 6.34 The lustre of a mineral describes its shininess.

of copper (hardness 3.5) will be scratched by fluorite (hardness 4), but not by calcite (hardness 3). Copper will scratch calcite because copper has a higher hardness number than calcite. The hardness of some common objects are:

- 2.5 – fingernail
- 3.5 – copper metal
- 6.5 – iron nail
- 6.5 – glass in a microscope slide.

Table 6.1 The Mohs scale of mineral hardness.

Hardness	Example
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

ACTIVITY 6.2.2: TESTING THE HARDNESS OF COMMON SUBSTANCES

What you need: iron nail, glass microscope slide, plastic disposable Petri dish, piece of copper sheet, half a stick of chalk.

1. Scratch the samples against each other and rank them in order of hardness from softest to hardest. When testing the hardness, scratch only a small part of the mineral or object. You only need a scratch that is about 5 cm long.
   - Which sample is the hardest?
   - Which sample is the softest?
2. Collect some samples of different minerals and arrange them in order of hardness. Use Table 6.1 to help you.

Figure 6.35 Calcite is a transparent mineral that has three cleavages.

Figure 6.36 Mica has one cleavage. Minerals that demonstrate cleavage look like thin slabs stuck together.

Cleavage is the number of smooth planes that minerals break along. Mica breaks into flat layers, like the pages in a stack of papers. Calcite has three cleavages because it breaks with three smooth surfaces: left and right; front and back; top and bottom.

Several minerals have unusual properties. For example, some minerals shine in ultraviolet (UV) light – these minerals absorb UV light, which we cannot see, and emit it as visible light, which we can see. Calcite is a transparent mineral. When you look through it, you see a double image.

Minerals are usually identified by using a key that outlines the properties of known minerals. A tabular key to identifying minerals is given in Table 6.2.

Table 6.2 Key for the identification of minerals.

Lustre	Colour	Hardness	Description	Mineral
Non-metallic lustre	White or pale	Scratched by a fingernail	• White to pale green • Greasy feel • Often flaky	Talc
	Increasing hardness		• Often transparent, vitreous lustre • Breaks along cleavage planes to give smooth faces	Gypsum
			• Transparent, shiny lustre • Breaks along one cleavage plane to give flat sheets that are flexible	Muscovite mica
		Hardness similar to that of a fingernail	• Vitreous lustre • Cleaves into tiny cubes • Salty taste	Halite (rock salt)
		Scratched by a knife blade, scratches a fingernail	• White or pale yellow coloured, often transparent • Three good cleavages, not at right angles • Forms tiny blocks	Calcite
		Scratches a knife blade, may just scratch a microscope slide	• White or grey coloured • Sometimes shows two cleavages at 90°	Plagioclase feldspar
			• Pink or flesh coloured • Sometimes shows two cleavages at 90°	Orthoclase feldspar
		Easily scratches a microscope slide	• Transparent or milky, vitreous lustre • No cleavage • Forms six-sided crystals • Conchoidal fracture (cleavage that does not follow any natural planes) sometimes seen	Quartz

Lustre	Colour	Hardness	Description	Mineral
Non-metallic lustre	Coloured minerals	Scratched by a fingernail	• Black coloured, shiny lustre • Breaks along cleavage plane to give thin flexible sheets	Biotite mica
			• Orange–red coloured, earthy lustre, orange or red–brown streak	Bauxite
		Scratched by a knife blade	• Orange–brown coloured, earthy lustre, yellow–brown streak	Limonite
			• Bright green coloured, green streak	Malachite
		Scratches a fingernail	• Bright blue coloured, blue streak	Azurite
			• Bluish purple coloured, white streak, vitreous lustre • Four cleavages to give pyramid shape in good specimens	Fluorite
	Increasing hardness		• Greenish coloured, white streak, greasy looking • Poor cleavages	Apatite
		Hardness similar to that of a knife blade	• Black coloured, vitreous lustre • Sometimes two cleavages • Short, thick crystals, eight-sided	Augite
		Scratches a steel blade, but does not scratch a microscope slide	• Glassy green grains, partly transparent	Olivine
			• Pink or flesh coloured • Sometimes shows two cleavages	Orthoclase feldspar
			• Colour variable, vitreous lustre - Amethyst = purple - Rose quartz = pink - Smoky quartz = grey - Conchoidal fracture	Quartz varieties
Lustre is partly metallic, partly earthy	Black or coloured	Does not scratch a steel blade	• Black to brown coloured, brown streak, vitreous lustre, sometimes metallic • Often shows cleavage	Sphalerite
			• Yellow–brown coloured, yellow to brown streak • Dull lustre	Limonite
		Approximately the same hardness as a steel blade	• Red or grey coloured, red streak, red rubs off onto fingers	Haematite
		Scratches a steel blade	• Black magnetic • May be too hard for streak plate	Magnetite
Metallic lustre	Gold colour	Scratched by a steel blade	• Dark brass coloured, tarnishes to purple colour	Chalcopyrite
		Scratches a steel blade	• Pale brass coloured • Crystals may be seen	Pyrite
	Silver colour	Scratched by a copper coin, but not by a fingernail	• Very dense (heavy), grey streak • Three good cleavages to give tiny cubes	Galena

Figure 6.37 Different types of minerals.

QUESTIONS 6.2.2: MINERALS

Remember

1 Define the following terms:

a mineral
b lustre
c streak
d cleavage

2 Identify the most common mineral on the Earth.

3 Identify the term used to describe the shapes that minerals form.

4 Identify an unusual property of calcite.

5 Recall the properties of quartz that make it useful in timepieces.

Apply

6 If a mineral has a hardness of 6, identify if the following minerals will scratch it:

a fluorite
b talc
c topaz
d feldspar

Analyse

7 Explain why the main colour of a mineral is not a reliable property to use for correct identification.

MINERAL RESOURCES

Minerals are important as a source of metals and other materials needed by our society. Some minerals, such as iron ore, have to be treated before they can be used. An **ore** is a mineral with a large amount of a useful metal in it. Some important ores and the metals they contain are listed in Table 6.3.

Table 6.3 Important ores and the metals they contain.

Ore	Metal
Haematite, limonite	Iron
Bauxite	Aluminium
Galena	Lead
Rutile	Titanium
Pitchblende	Uranium
Molybdenite	Molybdenum
Cinnabar	Mercury
Malachite, azurite	Copper
Sphalerite	Zinc
Chalcopyrite	Copper
Pentlandite	Nickel
Cassiterite	Tin

Australia is rich in mineral resources. It is among the world's leading producers of aluminium, gold, iron ore, manganese, rutile, lead and zinc. Australia is also a significant producer of nickel, silver, coal, diamonds and copper. Demand for mineral resources worldwide is high, particularly due to increased demand from countries such as China as they become more industrialised.

Australia's mineral resources have always been in big demand. During the 1850s, after gold was initially discovered in Bathurst, New South Wales, hundreds of thousands of people migrated to Australia to take part in the Gold Rush in Victoria and New South Wales. The Australian economy boomed during this time. Because gold is chemically stable, it is almost always found as pure gold. This means it can be collected without having to be processed. In addition to jewellery, gold has many uses such as in fine wires in electronics and fillings for teeth. Because of its reflective properties, gold can also be used to protect satellites and spacecraft from solar radiation.

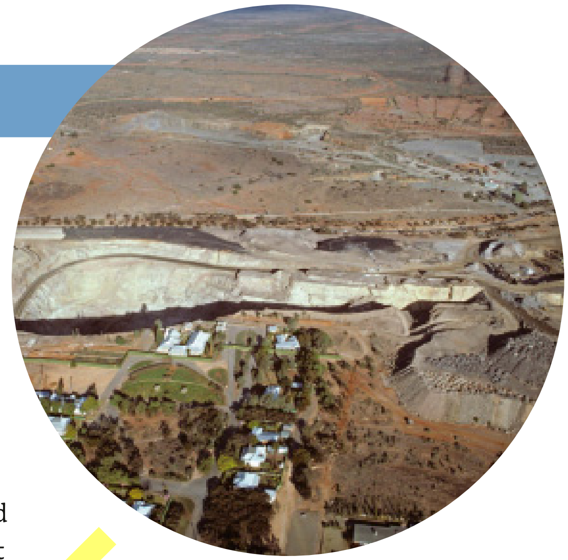


Figure 6.38 The Broken Hill Ore Deposit is the world's richest zinc and silver mine.

Australia is an old continent rich in mineral sands. Mineral sands are old beach sands with significant concentrations of heavy minerals, such as rutile, zircon and ilmenite. Rutile is a rich source of titanium dioxide, which is used as a pigment in paints, plastics and paper. You may have seen little glass jars of mineral sands being sold as souvenirs.

Copper was the first metal to be used by humans. In Australia, copper is found as the mineral chalcopyrite in rocks that are over 250 million years old. Copper is a good conductor of electricity and is used in electrical generators and motors, for electrical wiring, and in electronic goods such as televisions. Copper is also used for water pipes because it does not corrode easily.

Figure 6.39 Gold panning is one of the oldest and simplest ways of extracting gold.

Figure 6.40 Coloured sands reflect the concentrations and types of minerals they contain.

However, mineral resources are finite. One way to overcome this limitation is to recycle materials. For example, aluminium can be recycled over and over again. A lot of energy is used to produce aluminium from bauxite, but once the metal has been made, it can be recycled indefinitely. In fact, recycling aluminium uses only 5% of the energy needed to produce new aluminium. Recycling aluminium saves having to use coal to produce energy in power stations, which reduces the emission of greenhouse gases into our atmosphere. For a sustainable future, the world's mineral resources need to be used wisely.

Locating minerals

Ore deposits are located by mining companies in several different ways. Some of the most common ways are magnetic, gravity, seismic and geochemical surveys.

Magnetic surveys are done from an aircraft carrying a device called a magnetometer. The magnetometer detects changes in the Earth's magnetic field caused by metallic minerals.

Gravity surveys are similar to magnetic surveys as they use a gravimeter attached to an aircraft. The gravimeter detects changes in the Earth's gravitational field caused by large ore deposits.

Seismic surveys are done on the ground and involve sending soundwaves down into the rock and recording the waves that are reflected. Analysis of these waves can detect dense bodies such as ore deposits.

Other methods used on the ground include geochemical surveys where rock samples are drilled out from way below the surface and then analysed to find out what minerals they contain.

All these survey methods allow mining companies to form a picture of what is below the ground to help them decide where to mine. Satellite technology has recently started to play a key role in locating new deposits.

Mining minerals

The type of mining used to extract a particular mineral depends on the location and type of deposit being extracted. Open-cut mines are the simplest type of mines and are used for ore deposits that are near the surface. They involve drilling and blasting away rock on the surface to create a deep pit, allowing rock to be shovelled up and transported away for processing.

Figure 6.41 Moreton Island, off Brisbane, is rich in mineral sands.

Figure 6.42 An open-cut mine in Kalgoorlie, Western Australia.

Underground mines are used when the ore deposit is positioned deep underground. Underground mines use tunnels dug down into the Earth to get to the deposits. Rock containing the mineral is then dug away and transported to the surface in lifts, or driven out by vehicles.

Leach mining is another method used to extract minerals from deep underground. Holes are drilled down to the deposit and a solution called a leach solution is pumped into the holes to dissolve the minerals. The solution is then pumped back to the surface and the minerals are extracted.

Mineral jobs

Many Australians are employed in jobs related to the exploration, mining and processing of minerals. These jobs require understanding and skills from across many different areas of science. Some of these occupations are described in Table 6.4.

Figure 6.43 Geologists play an important role in Australia's mineral industry.

Table 6.4 Jobs that relate to the exploration, mining and processing of minerals.

Job and description of role	Areas of science	A day in the life
Underground mine geologist Controls the quality of the ore mined and decides which areas of an ore body should be mined at a particular time. Spends a lot of time mapping and collecting samples underground.	Earth science Chemistry	'Mine geology is a practical application of geology in the field, and will be rewarding to people who love getting outdoors and working as part of a team.' Tim Berryman, Senior Mine Geologist, Kalgoorlie Consolidated Gold Mines
Exploration geologist Completes surveys and fieldwork to determine the geological structure, distribution and age of rocks.	Earth science Chemistry	'I have worked in places that people pay to go on their holidays.' David Bushell, Senior Exploration Geologist, Iluka Resources Ltd
Metallurgist Controls and improves the processes that separate, concentrate and recover minerals and their valuable metals from the natural ores.	Chemistry Physics Mineralogy	'At completion of first year university I landed my first vacation job with Newcrest at Cadia (copper/gold flotation) in NSW. Each year afterwards I completed vacation work with a different company in a different commodity.' Adam Lonergan, Metallurgical Engineer, Rio Tinto

Job and description of role	Areas of science	A day in the life
Geotechnical engineer Identifies and tries to solve problems involving soil, rock and groundwater, and designs structures on and below the ground.	Earth science Engineering	'[I enjoy] Being exposed to different conditions and problems every day – the job/profession is never the same on any two consecutive days.' Steve Webber, Geotechnical Engineer, Consolidated Minerals
Mining engineer Plans and directs the various engineering aspects of extracting minerals from the Earth.	Earth science Physics Chemistry Maths	'I have worked all around Australia and in mines in South America, America and South Africa.' Kate Sommerville, Principal Mining Engineer–Iron Ore, BHP Billiton
Human resources Provides employment and personnel administration services within the mining industry.	Earth science Psychology	'I studied Geology in my final year of high school and went into University studying a Bachelor of Science with a double major in geology and psychology.' Karin Baxter, Resourcing, BHP Billiton
Environmental engineer Assesses and manages the effects of human activity on the natural and built environment.	Environmental science Engineering Biology Chemistry	'Up until year 12 I wasn't sure what I wanted to study. I loved mathematics, science and geography and had a deep love for the outdoors and the environment.' Laura McIlwaine, Senior Environmental Engineer, BHP Billiton

QUESTIONS 6.2.3: MINERAL RESOURCES

Remember

1 Define the term 'ore'.

2 Recall the metal that comes from each of the following ores:

a bauxite

b galena

c sphalerite.

3 Explain the difference between a mineral and an ore.

4 Identify five of Australia's most important minerals.

5 Explain the role of a metallurgist.

Apply

6 There are many different types of geologists. Predict what you think a petroleum geologist would do and what they would learn from studying rocks.

7 Propose what a mineralogist would study.

Create

8 Research a career related to the exploration, mining or processing of minerals that is not mentioned in Table 6.4. Describe the job in detail and the areas of science it covers. Make a set of PowerPoint slides about your chosen job. Merge the slides from your whole class to create a mineral resources job directory.

PROPERTIES OF ROCKS AND MINERALS

6.2
CHECKPOINT

Remember and understand

1 Copy and complete the following statements.

a Rocks are selected for particular purposes because of their ________________ . [1 mark]

b Rocks are made up of one or more ________________ . [1 mark]

c An ________________ is a mineral with a large amount of useful metal in it. [1 mark]

d Australia is rich in ________________ deposits. [1 mark]

2 Match each term to its definition. [4 marks]

lustre	how easily a mineral can be scratched
streak	the number of smooth planes that minerals break along
hardness	the shininess of the surface of the mineral
cleavage	the colour of the powdered or crushed mineral

3 Explain how geologists identify minerals. [1 mark]

4 Explain how a magnetic survey works. [1 mark]

Apply

5 Contrast rocks and minerals and explain how they are different. [2 marks]

6 Identify the lustre of:

a a shiny new nail [1 mark]

b a rusty nail [1 mark]

c a newly polished car [1 mark]

d a mirror [1 mark]

e bricks used for building a wall. [1 mark]

Analyse and evaluate

7 A kitchen scourer can be used to clean stainless steel cutlery, but this type of scourer should not be used to clean silver-plated cutlery. Explain why this is so. [2 marks]

8 Identify the properties of gold that made it so valuable to early civilisations. [2 marks]

9 Research mineral recycling and explain why we need to recycle minerals. What minerals can be recycled? In what forms can minerals be used in once they have been recycled? [3 marks]

Ethical understanding

10 Australia mines many minerals and exports (sells) them to other countries. List three positive and three negative impacts of mining and exporting minerals. [3 marks]

Critical and creative thinking

11 Some famous works of art around the world are made of marble.

a Identify the properties of marble that make it ideal for sculpture. [2 marks]

b Identify some of the properties of marble that may make it unsuitable for all works of art. [2 marks].

12 Make a set of flip cards with the definition of 20 rock terms you have learnt so far. [5 marks]

13 Imagine you are a geologist who is going to discover minerals in a remote part of Australia. You will need to take a test kit to help you identify the minerals you find. Identify the items that should go into your test kit to allow you to test for streak, hardness and other common properties of minerals. [4 marks]

Figure 6.44 The marble Abraham Lincoln statue sits as part of the Lincoln Memorial in Washington D.C.

TOTAL MARKS
[/40]

6.3 THE EARTH'S GEOLOGICAL PAST

Planet Earth is 4.5 billion years old. The events of the Earth's history are recorded in our rocks. From about 570 million years ago, the ancestors of the plants and animals that now populate the Earth came into being. The remains of some of these life forms are captured in the rocks as **fossils**. Fossils allow specialist geologists, known as **palaeontologists**, to build a picture of the Earth's long history.

ACTIVITY 6.3.1: FOSSIL FEATURES

There's no time like the present to jump right in and be a palaeontologist!

What you need: A selection of fossils

For each fossil, write down as many observations as you can about the organism that it holds. Your observations will most likely be of physical features.

- What inferences can you make about the organism's lifestyle?
- Is there any evidence to suggest that this organism lived alone or in groups?
- Is there any evidence to suggest how this organism reproduced?
- Is there any evidence to suggest what this organism ate?
- What other information would you need to support your inferences?

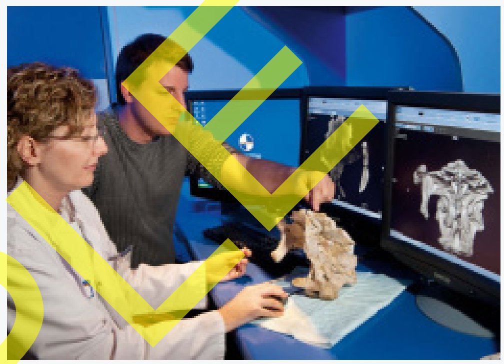


Figure 6.45 Palaeontologists compare MRI scans of a fossilised dinasaur skull with the real thing.

LEARNING ABOUT THE PAST THROUGH FOSSILS

What are fossils?

Fossils are the remains (or imprints) of animals or plants preserved in rock. A fossil is evidence of life in the past. Fossilised evidence may be found in many forms, but it is usually the hard parts of animals that remain after decay – bones, teeth and shells. Sometimes softer parts of an organism are preserved, and even footprints or impressions of organisms are considered fossils. Palaeontologists study these remains to gain clues about ancient life.

Through a process known as **petrification**, wood, bones, teeth and shells can be replaced chemically by minerals dissolved in water. Minerals slowly replace the original material as it decays, leaving a stone replica in the same shape as the original.

Figure 6.46 Broome, Western Australia, is the site of many trace fossils. Can you spot the footprints?

Figure 6.47 This petrified tree trunk looks like a real tree, but its wood has been replaced by minerals to make it as hard as stone.

Figure 6.48 If the conditions are just right, soft body parts can be fossilised.

Sometimes the whole organism may be preserved as a fossil. Animals and plants trapped under frozen ground have been uncovered with flesh, hair and even stomach contents intact. Ancient insects have been found trapped in the sap of ancient trees (amber). Even animal droppings can be petrified – these are called coprolites. The remains of animals or plants sometimes leave an imprint in the rock. Remains can also be broken down by minerals in water, leaving a mould in the exact shape of the organism. **Trace fossils**, such as footprints, can also leave an impression in rocks.

How do fossils form?

Fossils are usually only found in sedimentary rocks. These rocks are formed by the deposition of layers of sediments, such as mud, silt or sand. Any organism caught up in the mud and silt can eventually become part of the rock through the process of fossilisation. The fossils can be uncovered when the rocks are broken apart or weathered away. This process can take millions of years.

DEEPER UNDERSTANDING

Fish fossils

One of the richest and most extensive fossil fish deposits in the world can be found at Canowindra, west of Sydney, near Orange. Some of the fossils date back 360 million years ago from the Devonian **period**. The Wellington Caves in central-western NSW contain famous megafauna fossils – skeletal remains of giant kangaroos, marsupial lions, and even a diprotodon (a three-tonne wombat) have been found at this location. It is one of the world's most significant fossil sites with fossils dating back 30 000 to 4 million years ago.

Figure 6.49 One of the fish fossils at the Age of Fishes Museum at Canowindra.

Steps in fossil formation

After the death of an animal, other animals would usually eat its body. Its bones would be crushed or weathered, leaving no evidence of the remains. However, for fossils to form, parts of the animal must be left behind. This process of fossil formation occurs as follows:

Step 1 When an animal dies in or near water (see Figure 6.50a), such as a river or a swamp, its remains can be quickly covered in sediment (see Figure 6.50b) and thus protected from being eaten. The soft parts of the body eventually decay, leaving behind the bones and teeth.

Step 2 Over millions of years, more and more layers of sediment are deposited. The sediment surrounding the buried remains transforms gradually into sedimentary rock. The bones and teeth may be replaced by minerals dissolved in water, which seeps into the remains. The shape of the animal remains the same, although it is generally flattened by the pressure of the sediments above (see Figure 6.50c).

Step 3 The layers of rock containing the fossilised remains may be pushed upwards and fractured, bent and moved by forces beneath the Earth's surface. Weathering and erosion eventually wear away some of the rock to expose one or more of the bones or teeth (see Figure 6.50d). Fossils can also be uncovered when digging mines or cuttings for roads. If fossilised remains are discovered, palaeontologists may start looking for other remains in the same area.

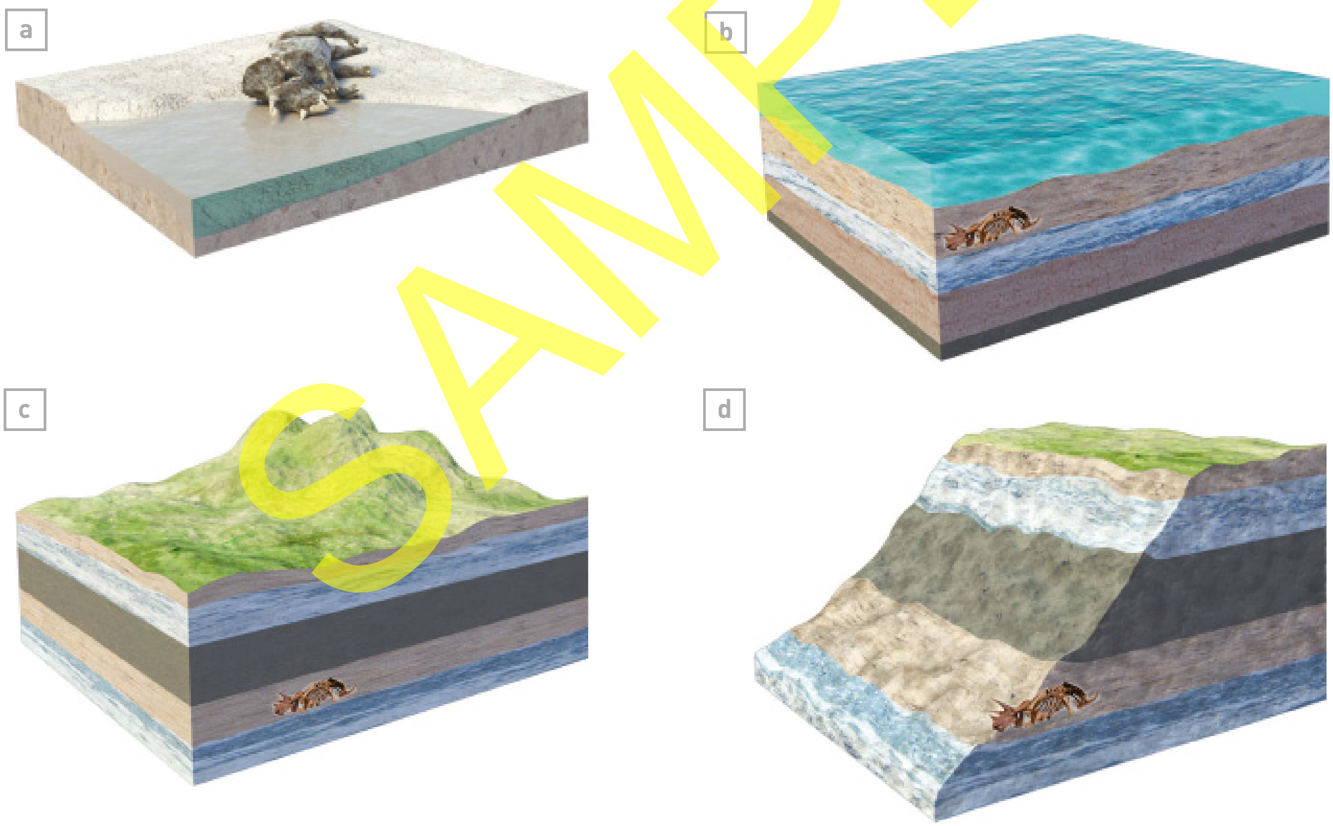


Figure 6.50 Formation of a fossil. (a) If an organism dies near water, it has a greater chance of being covered by sediment. (b) The sediment protects the body from predators and weathering. (c) Over millions of years, more sediment is deposited and the remains are transformed gradually into sedimentary rock. (d) Years of geological movement, weathering and erosion may eventually expose the fossil.

Building animals from bones

In most instances, fossils are the only evidence of life forms that are now extinct. Palaeontologists are skilled in cleaning and preserving fossils, piecing parts of them together and reconstructing them into a lifelike shape (see Figure 6.52). Usually only a few fossilised bones are found, rather than a complete skeleton.

Very detailed observations need to be made of these bones so that they can be compared with other finds. If the bones are a good match, palaeontologists may decide that the bones have come from a similar organism, but further evidence will be required to confirm that theory. A palaeontologist's skills cover the areas of zoology, botany, anatomy, ecology and drawing.

Figure 6.51 This fossilised pterodactyl was in the middle of laying an egg when she was killed. This fossil provides valuable information about pterodactyl reproduction.

Figure 6.52 A palaeontologist applies the final touches to the skull of a dinasaur from southern Africa.

STUDENT DESIGN TASK

Fossil impressions

Challenge

Sometimes when an organism is buried in sediments and the hard parts of it dissolve over time, only an imprint or impression of it remains. This type of fossil evidence is known as a mould. Moulds reveal the size, shape and pattern of the organism.

Your task is to use plaster of Paris and a leaf with a prominent shape or vein structure to create an impression. Imagine your leaf has settled to the floor of a lake or seabed (a white tile can be used for this surface). Over time, it becomes covered with sediment (plaster of Paris can represent this stage). As the leaf itself decays, only the imprint is left.

Figure 6.53 A plant fossil found in a rock.

Questioning and predicting

- What consistency of plaster will work best?
- How will you contain the plaster on top of your leaf so it doesn't spread everywhere?
- How will you prevent your leaf from sticking to the plaster?

Planning

Plan your experiment by drafting an aim, materials list, method and diagram of your setup. Have your plan approved by your teacher before starting work.

Conducting

Carry out your experiment, making any necessary changes to your method as you go.

Processing, analysing and evaluating

Take some digital photos of the different stages of the investigation.

Communicating

Write a full experimental report at the conclusion of your experiment, including a discussion of the following ideas:

- Evaluate the success of the investigation.
- What improvements would you make to your experimental design?
- How does your leaf impression compare with a real fossil impression?

QUESTIONS 6.3.1: LEARNING ABOUT THE PAST THROUGH FOSSILS

Remember

1 Recall the type of geologist who investigates fossils.
2 Define the term 'fossil'.
3 Explain how trace fossils are formed.

Apply

4 Draw a flow chart to outline a series of events or conditions that need to occur, over a period of geological time, for a fossil to be preserved.
5 Explain why fossils are not found in igneous rock.
6 Explain why it is important to take accurate and detailed records of all fossils, even if they can already be identified.

Analyse

7 Describe what fossils can show us or tell us about the Earth's history.

FINDING THE AGE OF ROCKS AND FOSSILS

Extremely old rocks have fossils of simple animals in them, whereas rocks that are slightly younger have fossils of animals with shells. Rocks that are younger still have fossils of fish. Only the newest rocks have fossils of mammals. The variety and complexity of life has increased as the Earth has become older.

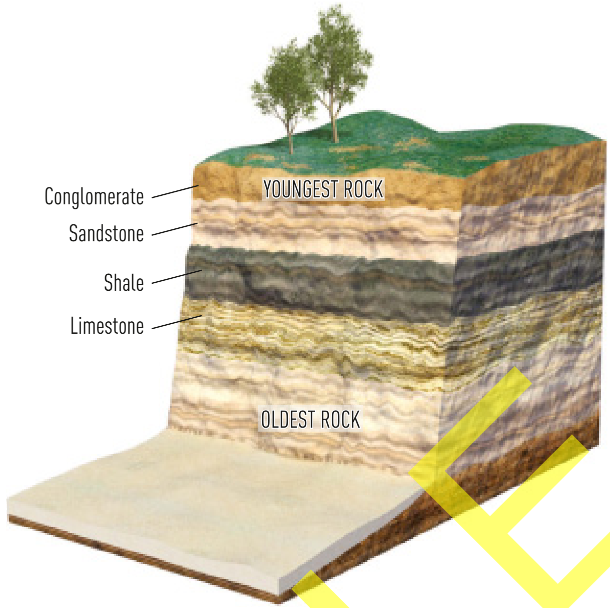


Figure 6.54 Comparative dating is used to work out the age of rocks and fossils.

Comparative dating

Geologists can place rocks and fossils into a date order. They work this out from the different layers of sediment in rocks. When layers of sand or mud are deposited, the oldest sediments are at the bottom. Newer or younger sediments are deposited on top (see Figure 6.54). This is known as the law of superposition. Working out the age of rocks as being younger or older than existing rocks is called **comparative dating** or relative dating. It is comparative because we are comparing the old with the new.

Different rocks that are the same age have the same type of fossils in them. These fossils are called **index fossils**. They are used to find rocks of the same age.

Radioactive dating

The actual age of a rock, measured in millions of years, is found by looking at the amount of radioactivity left in rocks. For example, uranium (U) is a radioactive substance found in many rocks. It decays to lead (Pb) at a known rate. The age of rocks can be calculated by comparing the amounts of uranium and lead they contain. This is called **radioactive dating**.

The oldest rocks found on the Earth have been dated at 4500 million years. This method has been checked using different radioactive atoms. This age is the same as that of meteorites that crash to the Earth, as well as that of Moon rocks brought back to the Earth by astronauts.

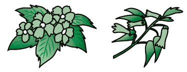
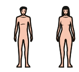
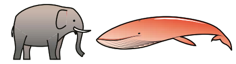
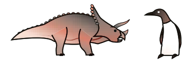
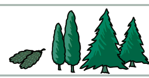
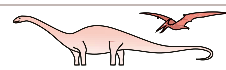
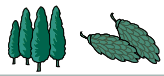
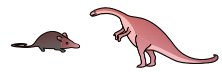
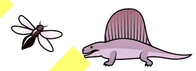
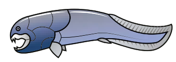
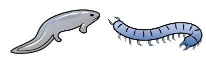
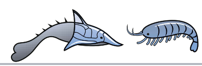
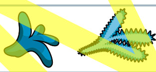
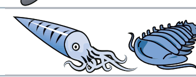
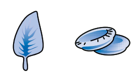
Geological time scale

Geologists and palaeontologists use a similar time scale. Because they are dealing with such huge periods of time, they divide time into eras and periods. The time scale used is millions of years. The eras and periods are based on major events such as ice ages, widespread volcanic activity or the mass extinctions of species.

Each period has particular fossils associated with it. For example, the fossils in the Cambrian period include the first shells and trilobites (see Figure 6.55). These are different from the fossils found in the Triassic period, which include the first dinosaurs. The end of most periods is marked by a large number of extinctions. The most famous of these is the extinction of many plants and animals, including dinosaurs, at the end of the Cretaceous period. All the periods have been dated in millions of years using radioactive dating. The names and order of the periods, as well as their period in millions of years, are shown in the geological time scale in Table 6.5 on page 294.

Figure 6.55 This trilobite fossil has been dated to 500 million years ago. The fossils of some trilobites are the size of beetles, whereas others are the size of dinner plates.

Table 6.5 Geological time scale (not to scale).

Era	Period (millions of years ago)	Plant life	Animal life
CENOZOIC (recent life)	Quaternary 2	Modern plants. 	Development of humans. 
	Tertiary 65	Forests of angiosperms. 	Mammals dominant over the Earth. 
MESOZOIC (middle life)	Cretaceous 142	Angiosperms take over from gymnosperms. 	Dinosaurs become extinct. Mammals develop, birds appear. 
	Jurassic 206	Gymnosperms abundant, first angiosperms appear. 	Age of reptiles, some flying reptiles. 
	Triassic 248	Age of gymnosperms. 	First mammals. Reptiles dominate land. Amphibians decline. 
PALEOZOIC (ancient life)	Permian 290	Early seed plants develop. 	Many land vertebrates. Familiar insects develop. Some invertebrate sea life becomes extinct. 
	Carboniferous 354	First large forests. Rise of gymnosperms. 	Insects become more common. First reptiles appear. 
	Devonian 417	Well-developed land plants. Ferns common. 	Fish and coral reefs common. 
	Silurian 443	First land plants. Many algae. 	Many coral reefs, shells. First animals on the land – amphibians and invertebrates. 
	Ordovician 493	Types of large algae found as fossils. 	Many invertebrates. First vertebrates, fish, found. 
	Cambrian 545	More types of algae. 	Animals with bodies protected by shells. 
PRECAMBRIAN	Ediacaran 600	Algae—the simplest plants, lived in the water. 	Soft-bodied animals. Very few fossils found, except in special locations. Their bodies were jelly-like. 
	2500	Multicellular life develops in the shallow warm seas. Fossils are rarely found because of the great age of the rocks and the soft fragile bodies of these organisms.	
	Archaean 3800	Bacteria are abundant. Some lived in extreme environments; stromatolites were photosynthetic. Fossilised and living mounds are still found on the Earth today. Oldest known sedimentary rocks, and oldest 'fossil' remains. They are chemical traces of living things.	
	Hadean 4500	Solidification of the Earth from a ball of molten rock.	

QUESTIONS 6.3.2: FINDING THE AGE OF ROCKS AND FOSSILS

Remember

1 Describe the process of comparative dating.

2 Define the term 'index fossils'.

Apply

3 On page 289 you read about Canowindra, where some of the fossils date back 360 million years ago from the Devonian period. Outline the Devonian period by writing a description or creating a labelled drawing. Use Table 6.5 to help you. Explain how palaeontologists would have known that the Canowindra fish fossils were from the Devonian period.

THE EARTH'S GEOLOGICAL PAST

6.3

CHECKPOINT

Remember and understand

1 Recall how old planet Earth is. [1 mark]

2 Refer to the geological timescale in Table 6.5 and identify the period in which the following events occurred.

a Dinosaurs became extinct. [1 mark]

b The first land plants appeared on the Earth. [1 mark]

c Insects became common. [1 mark]

d Humans appeared. [1 mark]

3 Explain how index fossils help to identify rocks of the same age. [2 marks]

4 Explain why only simple fossils are found in the oldest types of rocks, whereas younger rocks have fossils of mammals. [2 marks]

Apply

5 Construct a flow chart showing the steps in fossil formation. [4 marks]

6 The fossil records show that some ancient organisms survived on the Earth for only very short periods of time, while others were very long-lived. Propose two possible reasons for this. [4 marks]

7 A geologist finds a rock sample with a fossilised trilobite in it.

a Identify the approximate age of the rock sample. [1 mark]

b Recall the term used to describe a trilobite fossil when it is used to date a rock. [1 mark]

Analyse and evaluate

8 Identify which process gives the more accurate age of a rock: comparative or radioactive dating. Explain your answer. [2 marks]

9 Explain why most organisms do not form fossils when they die. [2 marks]

10 Explain why it is usually quite hard to find fossils. [2 marks]

11 Petrified wood is stone in the shape of a piece of wood.

a Is it classed as a fossil or not? Explain your answer. [2 marks]

b Propose how a piece of petrified wood could have formed. [2 marks]

12 A palaeontologist found a dinosaur skull but was not able to find any other bones in the area. Explain why this was the case. [2 marks]

13 Imagine you are a palaeontologist searching for fossils. Explain the types of rocks you would look for. [2 marks]

Critical and creative thinking

14 Construct a series of diagrams demonstrating the different ways that fossils can be formed and the types of fossils that are formed in each way. [4 marks]

15 The only evidence found worldwide of a dinosaur stampede is near Winton in Queensland (see Figure 6.56). A large theropod, which had steps of up to 2 metres in length and walked at 9 kilometres per hour, approached from the north. After six steps, the animal slowed down and, at the tenth step, it turned right. The smaller tracks show that there was then a stampede by 150 smaller ornithopods and coelurosaurs.

- **a** Explain how palaeontologists would know the species of the dinosaurs involved in the stampede. [1 mark]
- **b** Propose what information would help palaeontologists work out the weight of the dinosaurs. [1 mark]
- **c** Explain how the palaeontologists could work out how fast the dinosaurs were travelling. [1 mark]
- **d** Explain how the palaeontologists could tell that the theropod slowed down. [1 mark]
- **e** Why do you think there was a stampede? Explain your answer. [2 marks]

Making connections

16 Imagine you are living 10 million years into the future. Predict what you might find in the fossil record for the year 2014 in the area where you live. [4 marks]

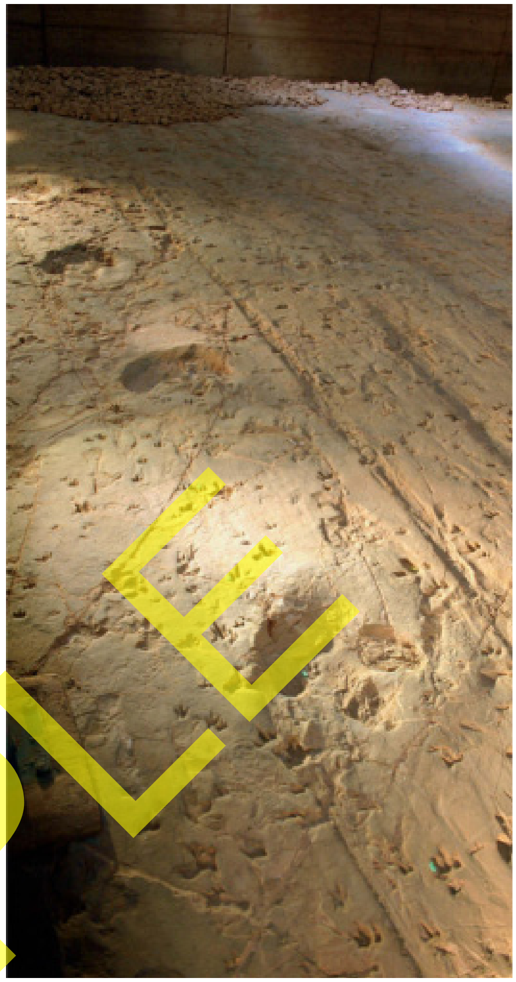


Figure 6.56 These footprints from near Winton, in Queensland, show a dinosaur stampede.

17 Table 6.5 on page 294 shows the geological history of the Earth over 4500 years. If this time scale could be compressed into one calendar year, each day on this new scale would represent approximately 12.3 million years. Since humans and modern plants developed in the Quaternary period, propose which day(s) of the year that would be on this new scale. Identify what other life forms developed around this time and propose where they would fit into the new scale. [3 marks]

TOTAL MARKS
[/50]

6 CHAPTER REVIEW

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

The Earth is made of three layers: the crust, the _________ and the ________. The rocky outer shell of the Earth, which is divided up into tectonic plates, is known as the _____________.

Magma and lava cool to form _________ rocks. Sedimentary rocks are formed when ___________ are compacted together over a long period of time. ___________ rocks are formed when other types of rocks are changed by incredible heat and ________ inside the Earth. ____________ and movement of tectonic plates are the main forces that drive the rock ________. Sedimentary, igneous and metamorphic rocks are made of _________. Minerals can be classified according to their __________, which include lustre, hardness and _________.

_________ are the remains of animals or plants preserved in rock. Fossils can only form under specific ________. Geologists can date rocks by studying ________ of sediment in rocks.

WORD BANK

conditions	erosion	mantle	properties
core	fossils	metamorphic	sediments
crust	igneous	minerals	streak
cycle	layers	pressure	

Describe the structure of the Earth in terms of core, mantle, crust and lithosphere

2 Describe the Earth's crust. [1 mark]

3 Recall the layers of the Earth in order from the centre outwards. [1 mark]

4 Describe the characteristics and features of the lithosphere. [2 marks]

Relate the formation of landforms to physical and chemical weathering, erosion and deposition

5 The Great Sphinx of Giza (see Figure 6.57) was carved in a limestone quarry in Egypt that was formed at the bottom of the sea 50 million years ago. Shells can be found around the embankment and there was once a sandbar and a coral reef here.

   a Identify the process you think would have formed the limestone. [1 mark]

   b Explain what has happened to the Great Sphinx of Giza over time. [1 mark]

6 Describe how the processes of weathering, erosion and deposition are linked. [3 marks]

7 Apply your knowledge of weathering, erosion and deposition to describe how Uluru might have formed. [3 marks]

Outline the origins of and relationships between sedimentary, igneous and metamorphic rocks

8 Explain why sedimentary rocks form at the Earth's surface. [1 mark]

9 Recall the processes that can cause metamorphic rocks to change. [1 mark]

10 Identify if intrusive igneous rocks:

   a are rapidly cooled or slowly cooled [1 mark]

   b contain large crystals or small crystals [1 mark]

   c form on the Earth's surface or beneath the Earth's surface [1 mark]

Figure 6.57 The Great Sphinx of Giza in Egypt has been badly damaged by wind erosion.

6 CHAPTER REVIEW

Explain the role of forces and energy in the formation of different types of rocks (additional)

11 Intrusive igneous rocks are formed deep underground. Explain how they reach the Earth's surface. [1 mark]

12 Recall which two rock types are formed by force and pressure. [1 mark]

Identify that sedimentary, igneous and metamorphic rocks contain minerals

13 Identify what rocks are made of. [1 mark]

14 Recall the shape in which minerals are found. [1 mark]

Classify a variety of common rocks and minerals into groups according to their observable properties

15 Recall the name of a sedimentary rock formed from smaller rocks that have been cemented together. [1 mark]

16 Identify the hardness value of a substance that is scratched by feldspar (hardness of 6) but not by quartz (hardness of 7). [1 mark]

Figure 6.58 A fish fossil found in Australia.

Describe the conditions under which fossils form

17 Explain what is meant by the term 'fossil'. [1 mark]

18 Explain why marine plants and animals are more commonly found as fossils than those that lived on land. [1 mark]

19 A fossil has been dated as 360 million years old. Outline a chain of events that may have led to this fossil being formed, discovered and dated. [3 marks]

Outline how geological history can be interpreted in a sequence of sedimentary layers

20 Recall where the oldest sediments are found when layers of sand or mud are deposited. [1 mark]

21 One rock has a fossil of a trilobite and another rock has a fossil of an early mammal. Based on this information alone, identify which rock is older. [1 mark]

Describe some methods used by scientists to determine the age of rock layers (additional)

22 Explain the process of radioactive dating. [2 marks]

23 Explain the process of comparative (or relative) dating. [2 marks]

Describe examples to show how skills from across the disciplines of science are used in the exploration, mining or processing of minerals

24 There are many branches of geology. Recall the names of three specialist geologists that you have read about in this chapter. [3 marks]

25 Identify two areas of science that a geotechnical engineer would have studied. [2 marks]

26 Identify the type of scientist that would assess and manage the effects of human activity on the natural and built environment. [1 mark]

TOTAL MARKS
[/40]

6 CHAPTER REVIEW

RESEARCH

Choose one of the following topics for a research project. A few guiding questions have been provided but you should add more questions that you wish to investigate. Present your report in a format of your own choosing. Acknowledge the sources of your information in a bibliography.

Formation of oil

Oil is formed from the compression and heating of dead marine plant material in mud over millions of years. Oil is made up of hydrocarbons, which are lighter than rock and water, so it often migrates up porous rock towards the Earth's surface. Research on the Internet to find out the following:

- What is an oil reservoir?
- What conditions are needed for an oil reservoir to form?
- How is an oil field formed?
- In what other forms is oil found?

Gemstones

Find out what types of gemstones are found in Australia. Which gemstones do people sometimes dig up? What do the gemstones look like?

Extraction of metals

Metals are extracted from their ores by a variety of methods. Some are heated, some are purified using electrical energy and some are extracted using chemical processes. Why are different metals extracted by different chemical or electrical processes? Find out how some metals are extracted, such as copper and aluminium, and design a poster that shows the process of extraction.

New discoveries

Fossils are being found all over the world all the time.

- Where are the most recent finds?
- What animals or plants do they represent?
- What do the fossils reveal about these animals or plants?
- How important are these finds?

REFLECT

Me

1 What new science laboratory skills have you learned in this chapter?

2 What was the most surprising thing you found out about studying rocks?

3 What were the most difficult aspects of this topic?

My world

4 Why is it important to understand how the Earth has changed?

5 Why is it important to understand how life on the Earth has changed?

My future

6 What can you do now to make sure that humans do not become extinct like the dinosaurs?

KEY WORDS

cleavage
coal
colour
comparative dating
core
crust
crystal
deposition
erosion
extrusive igneous rock
fossil
frost shattering
geologist
hardness
igneous rock
index fossil
intrusive igneous rock
lava
lithosphere
lustre
magma
mantle
metamorphic rock
mineral
onion-skin weathering
ore
palaeontologist
period
petrification
property
radioactive dating
rock cycle
sedimentary rock
streak
trace fossil
weathering

6

MAKING CONNECTIONS

Evidence from Antarctica

The Earth's landmasses have not always been in the same position. About 200–500 million years ago, Antarctica, South America, Africa, Madagascar, Australia, New Guinea, New Zealand, Arabia and the Indian subcontinent all made up a southern supercontinent called Gondwana. This huge landmass extended from near the South Pole to near the Equator, and mostly had a mild climate. Gondwana broke up over time, and the Antarctica we know today was formed about 25 million years ago. The changing climate and latitude greatly influenced the rocks formed on Antarctica.

Although nearly the entire continent of Antarctica is covered with a thick layer of ice, making studying the rocks difficult, new techniques have been used to determine the types of rocks and minerals found in Antarctica. The Antarctic Peninsula was formed by the uplift of metamorphic rock from seabed sediments. Volcanic activity occurred and intrusive igneous rock also formed. In East Antarctica, some of the rocks formed more than 3 billion years ago. This area is largely made up of a platform of metamorphic and igneous rocks, which form the base for more modern rocks such as limestone, sandstone, coal and shale. Faulting has also occurred in some coastal areas.

Figure 6.59 The Antarctic Peninsula.

Figure 6.60 Ash from an Antarctic volcano.

Figure 6.61 The Transantarctic Mountains contain a wealth of valuable minerals.

About 500 million years ago, West Antarctica was partially in the Northern Hemisphere and had a mild climate. During this time, the rocks formed were largely sandstone, limestone and shale. Over the next 100 million years, as Gondwana moved south and the climate cooled down, sand and silt were deposited in mountain areas.

About 360 million years ago, glaciers formed, thus weathering the rock formations. In areas where fern-like plants grew in swamps, deposits of coal formed. Coal can be found near the Beardmore Glacier and as a low-grade form across many parts of the Transantarctic Mountains. Iron ore has also been found in significant deposits in the Prince Charles Mountains. However, the Protocol on Environmental Protection to the Antarctic Treaty has banned all exploitation of mineral resources by signatory states until 2048.

Although plant life is limited on Antarctica to mostly mosses and liverworts because of the extreme climate, fossils provide evidence of a rich plant life in the past. Fossils of leaves and wood are abundant and indicate the existence of extensive forests in warmer times when Antarctica was part of Gondwana, and even in colder times when it was closer to the South Pole.

Fossils of dinosaurs and marsupial mammals have also been found in Antarctica, indicating that they once roamed across its surface. Marine fossils of invertebrates, including shells with their original mother-of-pearl shell still intact, giant penguins and marine reptiles have also been found. Dinosaur fossil evidence from Antarctica reveals that the extinction of dinosaurs was not as great as it was in a lot of other places around the world, but it still took 300 000 years for shallow marine communities of organisms to reappear. This sort of information has enabled scientists to understand how long it takes for communities of organisms to recover after mass extinction events.

Questions

1 Explain what types of rock formation processes have occurred in Antarctica.

2 Explain what types of weathering processes have dominated in Antarctica.

3 What can you deduce about the past climate if sedimentary rocks such as sandstone, limestone and shale are found?

4 Identify the sort of climate that would have existed on Antarctica for forests of trees and ferns to have grown there.

5 Mass extinction events, such as the extinction of the dinosaurs, were not as great on Antarctica as in other places in the world. Explain why you think this may be.

Figure 6.62 (a) An Antarctic ammonite fossil, (b) a petrified conifer tree from Antarctica, (c) a 260-million-year-old fossil leaf from Antarctica.