6 The changing Earth

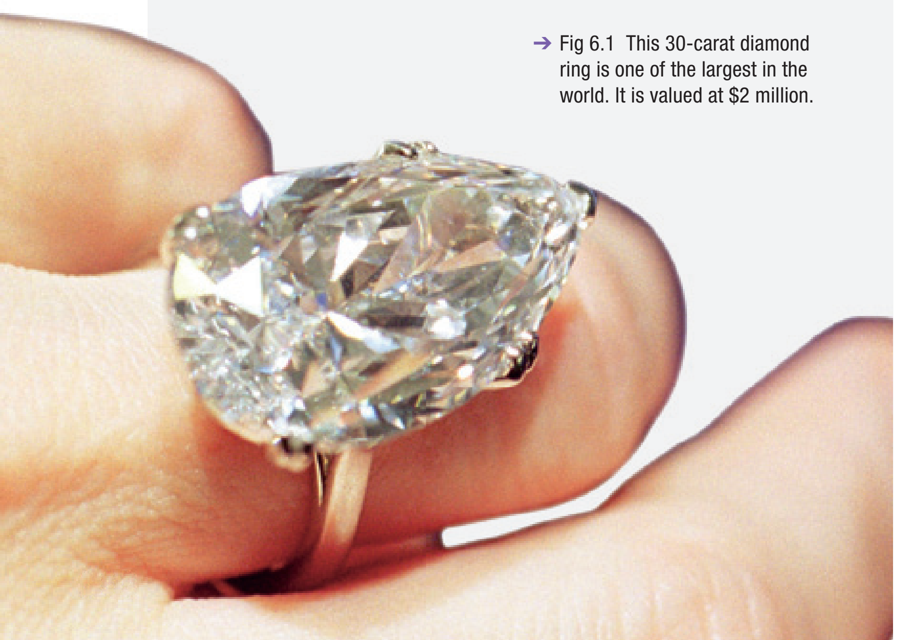
Uluru is a sandstone island mountain—a remnant of a mountain range that was slowly eroded away. Originally formed from sand deposited from fast-flowing streams in a fan shape, the horizontal layers of sand were then tilted vertically by extremely large forces during an episode of mountain building, possibly 300–400 million years ago. The uniform nature of the rock led to its survival while the surrounding rocks eroded away, as is the nature of our changing Earth.

6.1 What are the properties of rocks and minerals?

Minerals are the basic parts, or the building blocks, of all rocks. Just like buildings are made of bricks and living things are made of cells, so rocks are made of minerals.

Minerals display properties that make them useful to humans, such as their hardness, shininess and their ability to be shaped without breaking.

1 What are rocks made of?
2 Figure 6.1 shows two different minerals.
  - Identify each mineral.
  - Suggest which properties of each of mineral make them valuable to humans.
3 As a class, identify other minerals and suggest how they are used.



→ Fig 6.1 This 30-carat diamond ring is one of the largest in the world. It is valued at $2 million.

→ Fig 6.2 The Great Sphinx in Egypt has been badly weathered by wind and rain.

6.2 How do rocks form?

Rocks look hard and tough. 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 and transported away by water, wind and ice. Even statues and buildings made from rock are worn away. The wearing away of rocks into smaller pieces is called **weathering**.

1 The Great Sphinx shown in Figure 6.2 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 shoal and a coral reef here. What sort of process do you think would have formed the limestone?
2 What has happened now to the Great Sphinx statue?
3 'Stacks on the mill' was originally a schoolyard game where children would pile in a heap on top of someone.
  - If you were the child on the bottom, what would it feel like as more and more children piled on top of you?
  - How is this similar to the force and energy that changes rocks?

6.3 What can we learn from studying rocks?

Studying rocks helps us learn about the Earth, how it was created and how it has changed over billions of years. Scientists who study rocks are known as geologists. There are many different types of **geologists**. Those who study rocks are called petrologists. Petroleum geologists study sedimentary rocks and select the best places to drill for oil. **Palaeontologists** also study sedimentary rocks, but they are geologists who study fossils—the remains of plants and animals from the past—enclosed in the rock. By studying fossils, palaeontologists can help us learn about past life on Earth.

1 What does a petroleum geologist learn from studying rocks?
2 What do you think a mineralogist would study?
3 Look at Figure 6.3. What might these palaeontologists learn from this discovery?

→ Fig 6.3 Palaeontologists observe a 270-million-year-old dinosaur fossil found in Germany.

6.1 What are the properties of rocks and minerals?

Not all rocks look and feel the same. Each rock has characteristics that give clues to its identity, such as its colour or hardness. These are referred to as **properties**. By making careful observations of a rock's properties, geologists can tell where a rock came from and what has happened to it.

<<DISCOVERING IDEAS>>

Rocks in your head!

How do you tell one rock type from another? In your mind, 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 already? What do you know about them? Are there certain words you would use for rocks that wouldn't be used for anything else?

Working in small groups, suggest features that could be used to group rocks.

Find some rocks out in the schoolyard and, using the features you discussed in class, group them.

Did the class end up with the same ideas? If not, how did the properties differ? 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 the hardest 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 (as the name suggests) are rocks made up of individual stones that have become cemented together. Granite is made up of large crystals of the minerals quartz, mica and feldspar.

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

- hardness
- lustre (shininess)
- transparency
- the shape of the crystals
- density
- streak (the colour of the powder of the mineral).

Table 6.1 lists some different types of rocks and how they can be identified. These rocks are shown in Figure 6.4.

→ Table 6.1 Rock identification

Rock	Grain size	Hardness	Usual colour
Quartzite	Coarse	Hard	Light
Obsidian	Fine	Soft	Dark
Conglomerate	Mixed	Hard or soft	–
Coal	Fine	Soft	Dark
Limestone	Fine	Soft	Light
Slate	Fine	Soft	Dark
Granite	Coarse	Hard	Light
Scoria	Fine	–	Dark
Pumice	Fine	–	Light
Shale	Fine	Soft	–
Basalt	Fine or mixed	–	Dark
Marble	Coarse	Soft	Light
Sandstone	Coarse	Hard	Light
Gneiss	Coarse	Hard	Alternating light and dark bands
Schist	Medium to coarse	Medium	Medium
Rhyolite	Fine	Hard	Light

What do you know about identifying and selecting rocks?

1 What type of rock am I?
  - a I am soft with distinctive layers.
  - b I am dark with holes in my surface.
  - c I am soft, shiny and used for jewellery.
  - d I am white with coarse grains. I am used for sculptures.

What are minerals?

Properties of minerals

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. 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 that make up the Earth: oxygen (O) and silicon (Si).


Quartzite
Coarse grain
Hard
Light colour


Obsidian
Fine grain
Soft
Dark colour

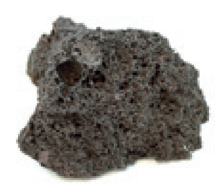

Conglomerate
Mixed grain
Hard or soft
Colour varies


Coal
Fine grain
Soft
Dark colour


Limestone
Fine grain
Soft
Light colour


Slate
Fine grain
Soft
Dark colour


Granite
Coarse grain
Hard
Light colour


Scoria
Fine grain
Dark colour


Pumice
Fine grain
Light colour


Shale
Fine grain
Soft


Basalt
Fine or mixed grain
Dark colour


Marble
Coarse grain
Soft
Light colour


Sandstone
Coarse grain
Hard
Light colour


Gneiss
Coarse grain
Crystals in layers


Schist
Medium to coarse grain
Layers, splits easily


Rhyolite
Fine grain
Often larger crystals
Light colour

→ Fig 6.4 Different types of rocks.

ZOOMING IN

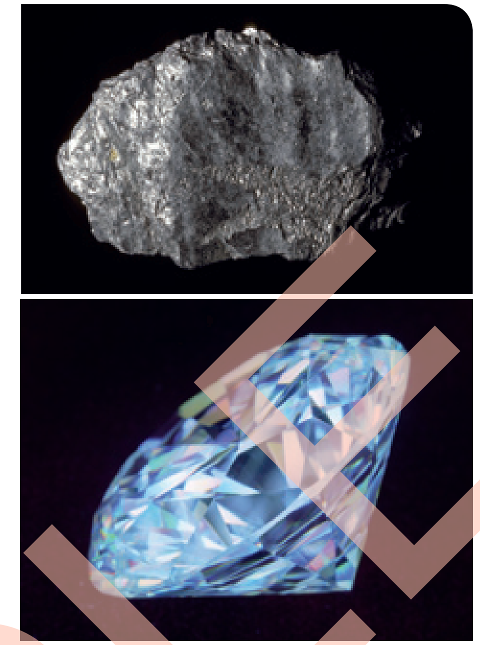
Quartz in watches

Quartz watches use quartz crystals to keep time. A property of the 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.

→ Fig 6.5 Under a microscope, the minerals that make up the rock olivine basalt can be seen as individual crystals.

Minerals are found in shapes called **crystals** (see Figure 6.5).

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 (which is the lead in a pencil) is very soft, whereas diamond is the hardest of all minerals. This difference arises because the carbon atoms in graphite crystals are arranged into sheets that can slide past each other, whereas in diamond crystals the carbon atoms form a strong, interlocking unit (see Figure 6.6).



→ Fig 6.6 The carbon atoms in (a) the mineral graphite are arranged in sheets, whereas in (b) a diamond they are interlocked.

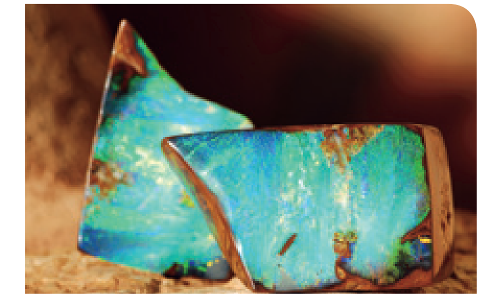
Identifying minerals

To identify minerals correctly, geologists carefully examine the properties of rocks.

The main *colour* of the mineral is not a reliable property with which to judge rocks 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 it cannot be relied on for correct identification.

Lustre is the shininess of the surface of the mineral (see Figure 6.7). 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.



→ Fig 6.7 The lustre of a mineral describes its shininess.

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 is able to scratch a soft mineral and not get scratched itself. The hardness of a mineral is described by a number according to a scale invented by the Austrian geologist Friedrich Mohs. Mohs gave a hardness number to 10 common minerals (See Table 6.2): the softest mineral, talc, has a hardness of 1, whereas the hardest mineral, diamond, has a hardness of 10. These minerals can be used to find the hardness of any other mineral. A piece of copper (hardness 3.5) will be scratched by fluorite (hardness 4), but not by calcite (hardness 3). Copper will scratch calcite. This is 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 microscope slide.

→ Table 6.2 Mohs hardness scale

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

PRACTIVITY 6.1

Testing the hardness of common substances

What you need

5-cm long iron nail

Glass microscope slide

Plastic disposable Petri dish

2 cm × 5 cm piece of copper sheet

Half a stick of chalk

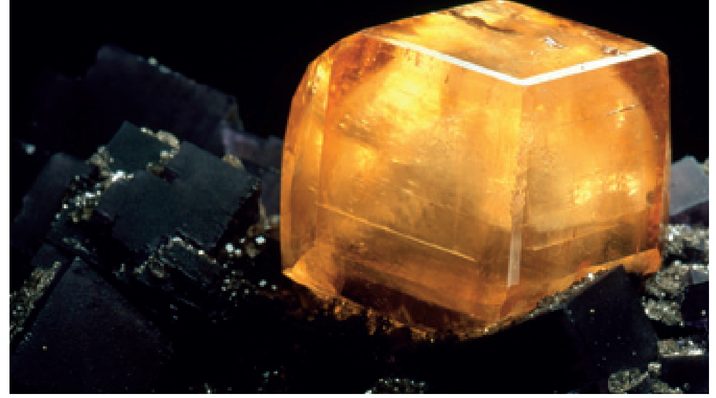
What to do

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. A 5-cm long scratch is all that is needed.
   - Which sample is the hardest?
   - Which sample is the softest?
2. Collect some mineral samples. Arrange them in order of hardness. Minerals such as feldspar, quartz and calcite are listed in Table 6.2.

Cleavage is the number of smooth planes that minerals break along.

Mica breaks into flat layers, like the pages in a heap of papers. Calcite has three cleavages because it breaks with three smooth surfaces: left and right; front and back; top and bottom.

→ Fig 6.8 Mica has one cleavage. Minerals that demonstrate cleavage look like thin slabs stuck together.



→ Fig 6.9 Calcite is a transparent mineral.

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

A key to identifying minerals is given in Table 6.3.

Identifying rocks

EXPERIMENT 6.1

Aim

To identify a range of common rocks.

Materials

Rock samples (unnamed, perhaps labelled A, B, C, D etc.)

Hand lens

Table 6.3 (page 207), as well as a rock key from the Internet or the one supplied with your rock kit

Method

1 Find a rock identification key on the Internet or use the one that came with your rock kit.
2 Examine each rock sample with the hand lens and 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, but 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 and small grains are only visible with a hand lens or magnifier.

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.

→ Table 6.3 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
			Vitreous lustre Breaks along cleavage planes to give smooth faces Often transparent	Gypsum
			Shiny lustre Breaks along one cleavage plane giving flat sheets that are flexible Transparent	Muscovite mica
		Hardness similar to that of a fingernail	Vitreous lustre Cleaves into tiny cubes Salty taste	Halite (rock salt)
	Increasing hardness	Scratched by a knife blade, scratches a fingernail	Pale colour, white or yellow, 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 Sometimes shows two cleavages at 90°	Plagioclase feldspar
			Pink or flesh coloured Cleavage same as plagioclase feldspar	Orthoclase feldspar
		Easily scratches a microscope slide	Vitreous lustre, transparent or milky No cleavage Forms six-sided crystals Conchoidal fracture sometimes seen	Quartz
Non-metallic lustre	Coloured minerals	Scratched by a fingernail	Black, shiny lustre Breaks along cleavage plane giving thin flexible sheets	Biotite mica
			Orange–red, earthy lustre, orange or red–brown streak	Bauxite
		Scratched by a knife blade	Orange–brown, earthy lustre, yellow–brown streak	Limonite
			Bright green, green streak	Malachite
		Scratches a fingernail	Bright blue, blue streak	Azurite
			Bluish purple, white streak, vitreous lustre Four cleavages giving pyramid shape in good specimens	Fluorite
			Greenish colours, white streak, greasy looking Poor cleavages	Apatite
	Increasing hardness	Hardness similar to that of a knife blade	Black Sometimes two cleavages Short, thick crystals, eight-sided, vitreous lustre	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 in colour, brown streak, vitreous lustre, sometimes metallic Often shows cleavage	Sphalerite
			Yellow–brown in colour, yellow to brown streak Dull lustre	Limonite
		Approximately the same hardness as a steel blade	Red or grey colour, 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 colour, tarnishes to purple	Chalcopyrite
		Scratches a steel blade	Pale brass colour 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 form tiny cubes	Galena

Fig 6.10 Different types of minerals.

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 6.4.

Australia is rich in mineral resources. It is the world's leading producer of lead, bauxite and alumina, diamonds (by volume), ilmenite, rutile and zircon (and synthetic rutile) and tantalum. It is the second largest producer of uranium, zinc and nickel, the third largest producer of iron ore, lignite, silver, manganese and gold, the fourth largest producer of black coal and copper and the fifth largest producer of aluminium. Demand for mineral resources worldwide is high, particularly due to increased demand from China as it becomes more and more industrialised.

Table 6.4 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'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, during which the economy of the nation boomed. Because gold is chemically stable, it is almost always found as pure gold. This means that it can be collected without having to be smelted or refined. Gold is not only used in jewellery, but is also used in fine wires in electronics, as fillings for teeth and, because of its reflective properties, to protect satellites and spacecraft from solar radiation.

Australia is an old continent that is 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 (or bought) little glass jars of mineral sands that are often 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 doesn't corrode easily.

However, mineral resources are finite. One way to overcome this 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.

What do you know about minerals?

1. What is a mineral?
2. What is an ore?
3. What is the difference between a mineral and an ore?
4. What are five of Australia's most important minerals?

Fig 6.11 Coloured sands reflect the concentrations and types of minerals they contain.

6.1 What are the properties of rocks and minerals?

Remember and understand

1 Copy and complete:

a An ______________ is a mineral with a large amount of useful metal in it.

b ______________ is the most common metal.

c Minerals are found in shapes called ______________ .

d Rocks are selected for particular purposes because of their ______________ .

2 What is the meaning of:

a lustre?

b streak?

c hardness?

3 Make a ‘rock dictionary’ of 20 rock words that you have learned so far.

4 How do geologists identify minerals?

5 Why is colour not a reliable guide for identifying minerals?

6 What properties of gold made it so valuable to early civilisations, such as the Incas of South America?

7 How are minerals different from rocks?

Apply

8 What is the lustre of these objects?

a a shiny new nail

b a rusty nail

c a newly polished car

d a mirror

e bricks used for building a wall

Analyse and evaluate

9 Why is the hardness of fingernails, copper, iron and glass given half numbers?

10 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.

11 Investigate why recycling aluminium uses only 5% of the energy needed to produce new aluminium.

12 Why do we need to recycle minerals? What minerals can be recycled? What forms can they be used in once they have been recycled?

13 Some famous works of art found in galleries around the world are made of marble. What are the properties of marble that make it ideal for sculpture? What are some of the properties of marble that may not make it appropriate for all works of art?

Critical and creative thinking

14 Some people say that Australia is a huge quarry. This is because Australia mines so many minerals and sells them. Working on your own, list the advantages and disadvantages of mining and selling minerals. Join with a classmate and combine your lists. Then join with another group and prepare another list containing the three best reasons for mining and the three best reasons against mining.

15 Find three small rocks from your backyard, school grounds or local park.

a Take a digital photo of your rocks (or carefully draw them). Create a rock fact card for each rock like the ones on page 204.

b Divide the class into small groups. Create a game using your group’s fact cards.

c Evaluate the success of your game. Did it help you learn more about the properties of rocks and minerals?

<<CONNECTING IDEAS>> Dynamic Earth

16 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. What items should go into your test kit to allow you to test for streak, hardness and so on?

6.2 How do rocks form?

Dead coral and broken shells can accumulate in the sea near reefs. The rock that forms from them is called limestone. Limestone made from broken shells is called shelly limestone. Limestone made entirely from coral is called coral limestone. If you find coral limestone in a quarry, like where the Great Sphinx is found in the desert in Egypt, you know that, long ago, this was a warm, tropical area near a coral reef.

<<DISCOVERING IDEAS>>

Making rocks

Do you know how rocks are made? In small groups, consider the different types of rocks you have already explored.

- What conditions would have been necessary to create them?
- Could you provide those conditions in a science laboratory?
- Where do you find rocks?
- How do rocks differ from one location to the next?

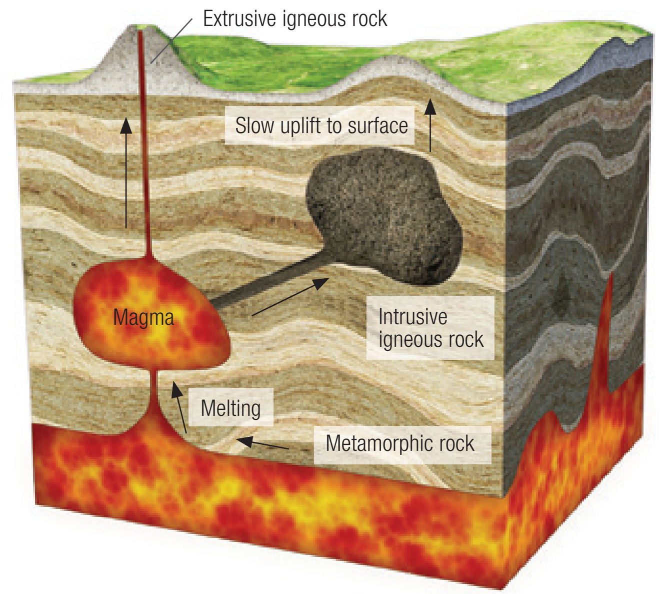
Rock formation

Rocks are broadly classified according to how they are formed. The three main types of rocks—igneous, sedimentary and metamorphic—all form in different ways.

Igneous rocks

Magma 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 hot, molten rock inside the Earth is called **magma** and its temperature may be over 1200°C. The magma chamber under a volcano is the source of molten rock for the volcano.

→ Fig 6.12 Igneous rocks are formed from volcanic magma.



In a volcanic eruption, the red-hot magma rushes out onto the surface of the Earth as **lava**. The cooler temperatures on the Earth's surface help the lava to solidify quickly. Igneous rocks also form from magma under the ground. These igneous rocks look quite different from those formed on the Earth's surface because they cool much more slowly.

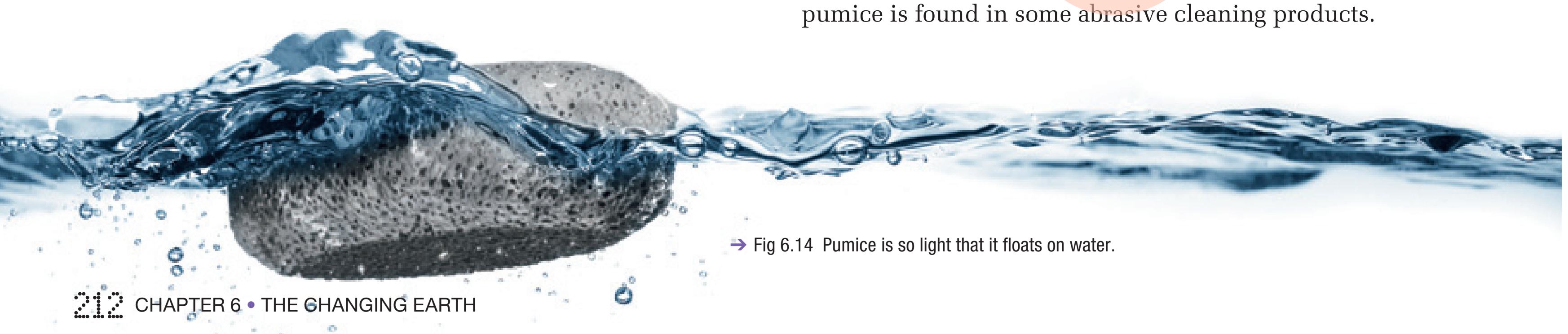
→ Fig 6.13 Granite is an intrusive igneous rock.

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. The longer it takes for lava to cool, the bigger the rock crystals that grow. Intrusive igneous rocks have large crystals interlocked together. Granite is an intrusive igneous rock in which the crystals can be seen with the naked eye (see Figure 6.13). Although formed underground, intrusive igneous rocks reach the Earth's surface when they are either pushed up through forces in the Earth's crust or uncovered by erosion.

Extrusive igneous rocks

Lava cools much more quickly on the Earth's surface to form **extrusive igneous rock**. Because the lava is cooling much more quickly, small crystals are formed in extrusive igneous rocks. Sometimes the lava cools so quickly that no crystals are formed at all. For example, pumice has no crystal structure. 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 (see Figure 6.14). It is so full of holes that it is extremely light and can float on water. Pumice stones are used to scour hard skin from our feet and powdered pumice is found in some abrasive cleaning products.



→ Fig 6.14 Pumice is so light that it floats on water.

EXPERIMENT 6.2

What affects crystal size?

Aim

To grow crystals and determine what affects their size.

Materials

Bunsen burner
Matches
Heat-proof mat
Tripod
Gauze mat
Alum solution
Two Petri dishes
Evaporating dish
Safety glasses
250-mL beaker
Tablespoon

Method

1 Prepare a solution of alum by mixing 2½ tablespoons of alum with ½ 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 window sill.
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 2 days, observe the size of the crystals formed in the two Petri dishes.
10 Observe the crystals formed in the refrigerator again after 4 or 5 days.

Results

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

Discussion

Each of these 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?

ZOOMING IN

The different looks of basalt

It is hard to understand why the same magma can solidify into different rocks. Or why two rocks that are not quite the same have the same name. The answer is in how igneous rocks form and what they are made of.

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 we know as 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 that's 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 that is often used for garden paths and as fill in drainage trenches.

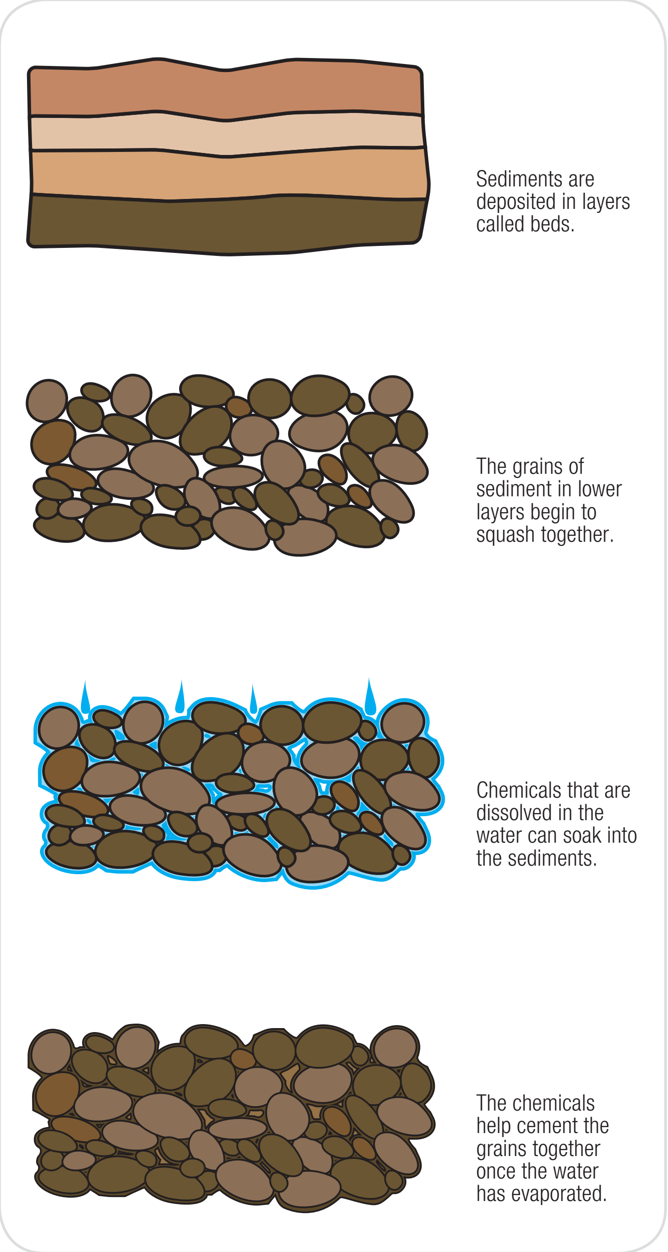
Obsidian is a smooth, black rock that looks like glass. It is formed when lava cools almost instantly and forms no crystals. Obsidian is used to make blades for surgery scalpels; the resulting blades are much sharper than those made from steel.

→ Fig 6.15 Basalt comes in different forms: (a) bluestone, (b) scoria and (c) obsidian.

Sedimentary rocks

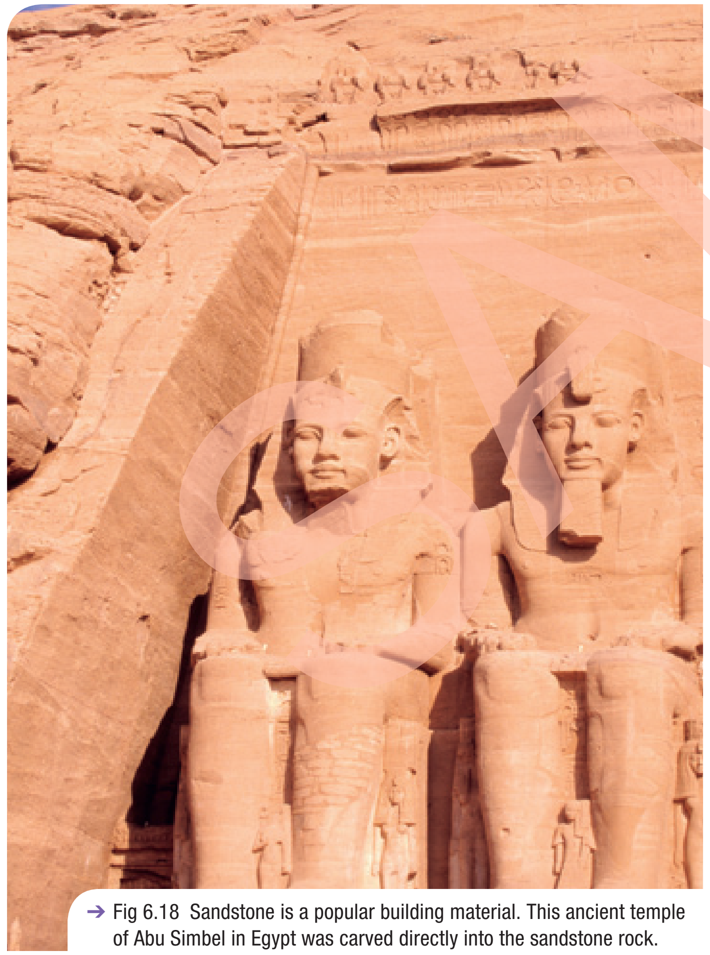
Sedimentary rocks are formed when loose particles are pressed together (compacted) by the weight of the overlying sediments. Sediments are rock particles, such as mud, sand or pebbles, that are usually washed into rivers and eventually deposited on the riverbed or in the sea. Sediments can also come 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 overlying sediments and water squeezes out air and gaps in the bottom layer. Over time, the compacted sediments become sedimentary rocks.

→ Fig 6.16 The formation of sedimentary rocks.



→ Fig 6.17 Shale (or mudstone) is the most common sedimentary rock. Shale is a fine-grained sedimentary rock made up of clay minerals or mud. This specimen clearly shows the layers of sediments that were compacted to form this rock.

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.



→ Fig 6.18 Sandstone is a popular building material. This ancient temple of Abu Simbel in Egypt was carved directly into the sandstone rock.

→ Fig 6.19 Conglomerate rocks have grains of different sizes. The sediments for these rocks were deposited in fast-flowing rivers during flooding or by glaciers.

Biological rocks

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.

→ Fig 6.20 Coal is formed from dead plant material.

Chemical rocks

Chemical sedimentary rocks form when water evaporates, leaving behind a solid substance. 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. When groundwater passes over limestone, it can pick up calcium carbonate from the limestone. When the water evaporates, it leaves behind the calcium carbonate once more. Various rock formations in caves are formed by this method.

ZOOMING IN

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 together in the middle, a column is formed.

Stalagmites and stalactites form when limestone rocks above are dissolved by acids in water. The acid and dissolved limestone make 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 the skin can interfere with stalagmite and stalagtite formation.

→ Fig 6.21 Stalagmites and stalactites in a limestone cave.

EXPERIMENT 6.3

Making sedimentary rocks

Aim

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

Materials

Dry clay
Mortar and pestle
Dry sand
Small, smooth pebbles
Plaster of Paris
Teaspoon
Four empty matchboxes
White tile

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 don't add the water just yet. You will need to prepare two shale samples so they can be used later in Experiment 6.4.

Rock	Dry clay (teaspoons)	Sand (teaspoons)	Plaster of Paris (teaspoons)	Pebbles (teaspoons)	Water (teaspoons)
Sandstone	½	4	½	0	2
Shale	5	½	0	0	2
Conglomerate	½	1	½	4	2

3 Pile up 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 2 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 6.4 later.

Results

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

Discussion

1 How do your sedimentary rock samples compare with the real thing?
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 incredible heat and pressure inside the Earth. When igneous, sedimentary or even metamorphic rocks are heated to extreme temperatures by magma, or when they 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 transformed into gneiss, shale can be changed into slate (see Figure 6.22) and limestone can become marble (see Figure 6.23).

Fig 6.22 Slate splits easily into flat sheets because of its flat, parallel crystal structure. This makes it a useful material for floor and roof tiles and as the base for billiard tables.

Fig 6.23 The Taj Mahal in India is made of marble, the metamorphosed form of limestone. With its dense composition and beautiful patterns, marble is also a popular material for sculptures and kitchen benchtops.

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

Bands can sometimes be seen in metamorphic rocks formed under high pressure. The bands tell us that the crystals were squeezed together to form new crystals in the new rock. Sometimes the crystals are squeezed together so tightly that they melt partially and form fewer, but larger, crystals. For example, when granite is squeezed under high pressure, the crystals change and the rock gneiss is formed (see Figure 6.24).

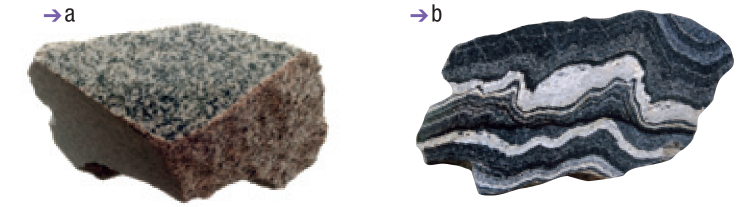


Fig 6.24 When granite (a) is subjected to high heat or pressure, it can change into the metamorphic rock known as gneiss (b). The bands on the gneiss show that the crystals have been squeezed together under immense pressure.

EXPERIMENT 6.4

Making a metamorphic rock

Aim

To make a sample of a metamorphic rock.

Materials

Two shale rock samples from Experiment 6.3
Bunsen burner
Tripod
Pipe clay triangle
Gauze mat
Evaporating dish
Tongs
Two 250-mL beakers

Method

1 Allow your shale samples made in Experiment 6.3 to dry for approximately 1 week.
2 Place one of the shale samples on a pipe clay triangle on top of a gauze mat and heat 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.
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?

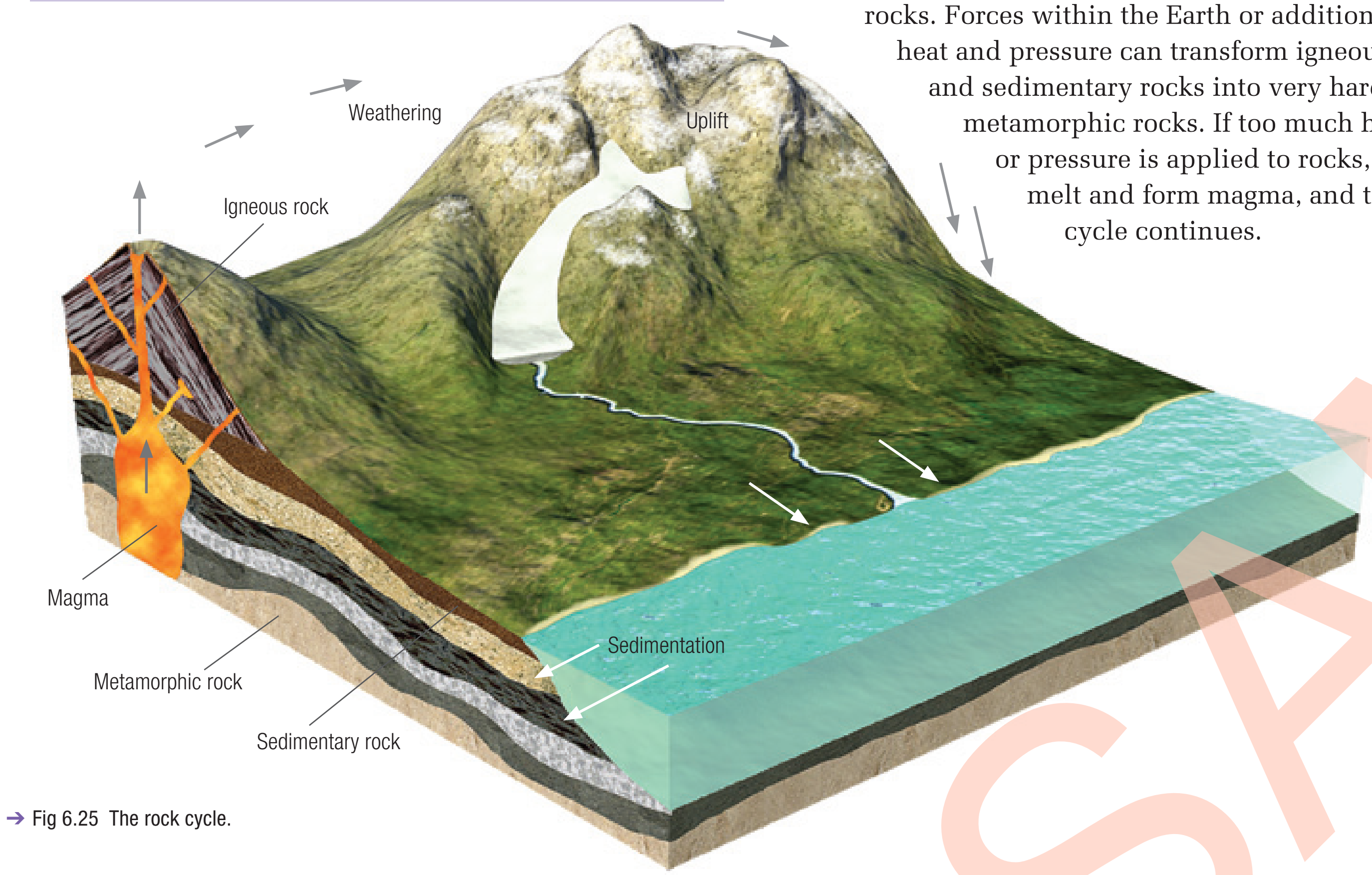
What do you know about rock formation?

1. How do stalactites and stalagmites form?
2. How do metamorphic rocks form?
3. How do sedimentary rocks form?
4. How do igneous rocks form?
5. Explain why pumice floats on water.
6. The ancient civilisations that discovered obsidian had a competitive advantage over those who didn't. Explain why.
7. What do plants have to do with coal?

The rock cycle

The **rock cycle** is an ongoing process that describes the formation and destruction of the different rock types. Magma and lava cool and solidify to form igneous rocks. Rocks are brought to the Earth's surface through the uplifting forces acting on land when tectonic plates collide. (Tectonic plates are the pieces of the Earth's crust.) On the surface, rocks are weathered (broken down into smaller pieces) by water, ice, wind, chemicals and biological forces.

The weathered particles are then removed by erosion, transported and eventually deposited. 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.



→ Fig 6.25 The rock cycle.

What do you know about the rock cycle?

1. List the different stages in the rock cycle as sentences that describe what happens. Use Figure 6.25 of the rock cycle to assist you.
2. Write a creative story of the 'life of a rock'. 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' nor do they 'die'. What life does your rock experience?

6.2 How do rocks form?

Remember and understand

1. Copy and complete:
   a. ______________ rocks are formed when loose particles are pressed together by the weight of overlying sediments.
   b. ______________ rocks are formed when other types of rocks are changed by heat and pressure inside the Earth.
   c. ______________ rocks form when magma and lava from volcanic eruptions cool and solidify.
2. Which rock can be dissolved to make caves?
3. What is the difference between *magma* and *lava*?
4. Cave systems in limestone rocks follow the course of underground rivers. Why is water necessary to make caves?
5. How would you tell the difference between intrusive and extrusive igneous rocks?
6. What is meant by the term *sediment*?

Apply

7. Why does pumice have no crystal structure even though it is a rock?
8. Why do sedimentary rocks form at the Earth's surface?

Analyse and evaluate

9. Where would you expect to find a black sedimentary rock that is formed from carbon? Why?
10. Explain a way to remember which way stalactites and stalagmites grow.
11. What features of pumice make it useful for removing dead skin?
12. An igneous rock has large grains, is hard and is multicoloured. What is it most likely to be?
13. Basalt is the most common type of rock in the Earth's crust. The grains in basalt are microscopic or non-existent. Explain why.

Critical and creative thinking

14. Look at Figure 6.26, which shows the Twelve Apostles. Use this image to describe how these rocks were formed. Prepare a poster to show how the rocks were formed and would have changed over time. How will they look in 1000 years time?

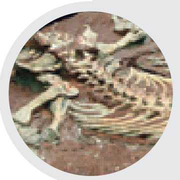
→ Fig 6.26 The Twelve Apostles, located off the coast of Victoria.

<<CONNECTING IDEAS>> Dynamic Earth

15. Imagine you could stop a flooded river.
    - What would you find in the water?
    - If the water was still and then evaporated, describe what the deposit would consist of and what it would look like.

6.3

What can we learn from studying rocks?



One of the richest and most extensive fossil deposits in the world can be found at Riversleigh in north-west Queensland. Some of the fossils date back 15–25 million years ago, when the area was covered in lush rainforest. The mammal fossils, which have been preserved in limestone, have helped palaeontologists understand the story of mammals in Australia and include ancestors and representatives of kangaroos, rat-kangaroos, bandicoots, wombats, marsupial moles, thylacines, koalas, possums, pygmy possums, cuscuses, bats, rodents and platypuses. Fossils of crocodiles, snakes, lizards, turtles, lungfish, frogs, birds, snails, insects and other invertebrates have also been found.

<<DISCOVERING IDEAS>>

Fossil features

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

Fig 6.27 A fish fossil discovered in Australia.

What you need

A selection of fossils

What to do

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.

Questions to consider

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

Learning about the past through fossils

Planet Earth is 4.5 billion years old. The events on Earth are recorded in the rocks. From about 570 million years ago, the ancestors of the different plants and animals that now populate 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 up a picture of Earth's long history.

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 is usually in the form of the hard parts 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 find 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.

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.

Fig 6.28 Broome, Western Australia, is the site of many trace fossils. Can you spot the footprints?

Fig 6.29 If the conditions are just right, soft body parts can be fossilised.

Fig 6.30 This petrified tree trunk looks like a real tree, but its wood has been replaced by minerals to make it as hard as stone.

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.

Steps in fossil formation

After the death of an animal, its body would usually be eaten by other animals. 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 is outlined below.

Step 1 When an animal dies in or near water (see Figure 6.31a), such as a river or a swamp, its remains can be quickly covered in sediment (see Figure 6.31b) 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 6.31c).

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 6.31d). 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.

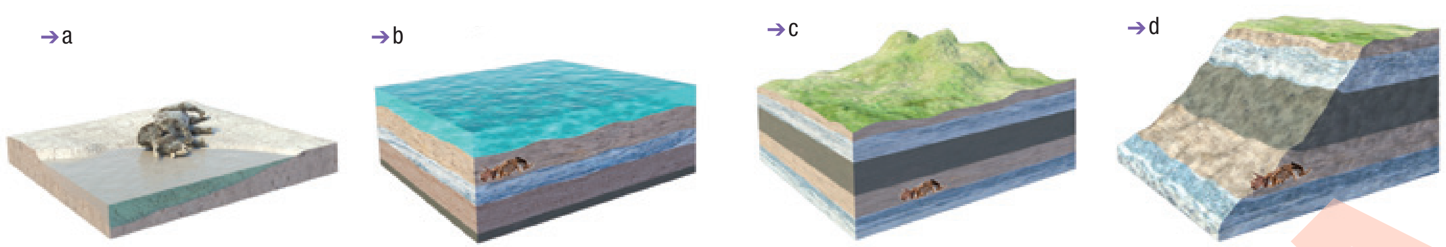


Fig 6.31 Formation of a fossil. (a) If an organism dies near water, it has a greater chance of being covered by sediment. (b) The sediment protects the body from predators and weathering. (c) Over millions of years, more sediment is deposited and the remains are transformed gradually into sedimentary rock. (d) Years of geological movement, weathering and erosion may eventually expose the fossil.

ZOOMING IN

Sabre-toothed tigers

All that we know about sabre-toothed tigers today comes from what we have learned from their fossilised remains. Sabre-toothed tigers are thought to have lived between 2.5 million and 10 000 years ago.

Fig 6.32 Skeletal remains of a sabre-toothed tiger.

These tigers are called sabre-toothed because of their canine teeth, which are extremely long (a 'sabre' is a type of sword). Palaeontologists found many complete skeletons of sabre-toothed tigers from the La Brea tar pits in Los Angeles. Hundreds of the animals became trapped in the sticky tar (asphalt), possibly while trying to feed on mammoths that were already trapped. The asphalt helped keep the fossils intact. By studying the fossils, palaeontologists have discovered that some sabre-toothed tigers had healed injuries that would have normally crippled the animal. Some palaeontologists suggest that this is evidence that the tigers lived in packs and provided food for old or sick members of the pack.

Fig 6.33 Reconstruction of a sabre-toothed tiger.

Building animals from bones

A **palaeontologist** is a person who studies fossils. Usually 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 life-like shape (see Figure 6.34). A palaeontologist's skills cover the areas of zoology, botany, anatomy, ecology and drawing. A palaeontologist also needs a lot of patience to rearrange bones to make a complete skeleton. A job description for a palaeontologist would be as follows:

- To search for the fossil remains of plants and animals and to conserve the sites where they are found.
- To collect as many specimens as possible, noting how and where they were found.
- To make copies of the fossil remains to preserve the original pieces.
- To reconstruct the plant or animal from the pieces of evidence.
- To make inferences about what the environment was like and how the plants and animals were adapted to living in this environment.
- To compare the reconstructed plants and animals with specimens from other places so that a more complete history of life on Earth can be obtained.

From a skeleton, a palaeontologist can make a likeness of an extinct animal. Once the bones are identified, the palaeontologist lays them on a table to get an idea of what the animal might look like. Casts are made of the original, fragile bones using light epoxy resin so that a model can be constructed. The skeleton is then pieced together.

Next, the muscles and internal organs are added. By looking at the shapes of the bones, and the muscle scars on them, palaeontologists can build up an idea of the muscles of the complete animal. The lifestyle of animals can also be deduced (carefully worked out) from their skeleton. Herbivores (grass eaters) have flat, rounded teeth, whereas carnivores (meat eaters) have sharp, pointed teeth. Fast-running animals have long slender bones with large attachments for muscles.

The colour of extinct animals is often deduced from living animals. Most mammals and large reptiles are dull coloured and many are camouflaged within their surroundings. Smaller reptiles and birds are more likely to be brightly coloured. Marine animals are often dark on top and light coloured underneath for camouflage from above and below. Some animals have feathers, fur or scales, whereas reptiles have textured or patterned skins.

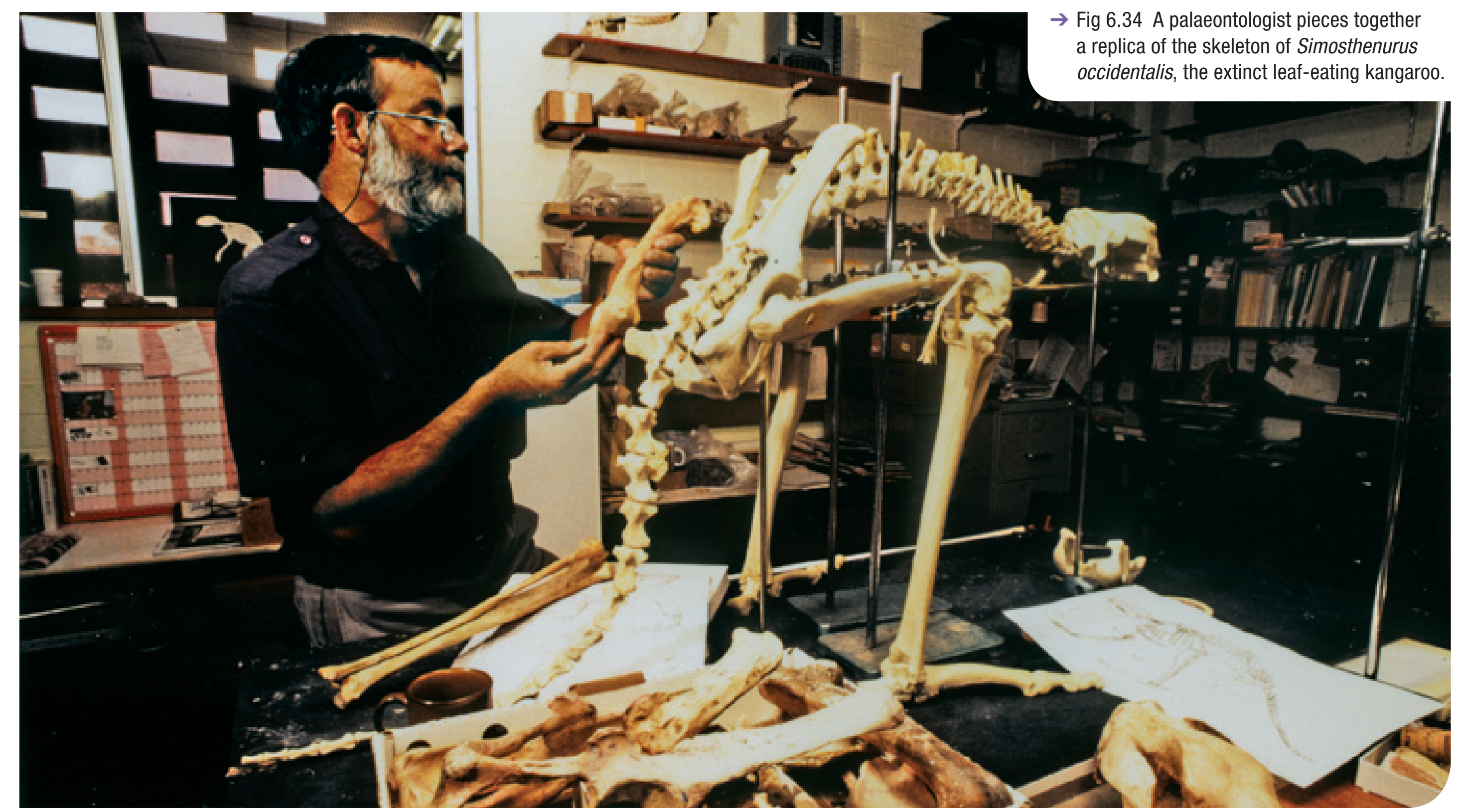


Fig 6.34 A palaeontologist pieces together a replica of the skeleton of *Simosthenurus occidentalis*, the extinct leaf-eating kangaroo.

Fig 6.35 A cast of a skeleton. This animal had small forelimbs, large, strong hind limbs and a long tail like a kangaroo.

Fig 6.36 Once the skeleton has been put together and the type of animal identified, the other features need to be deduced.

Fig 6.37 Finally, features such as ears and eyes are added, followed by the skin.

Educated guesses

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. An ankle bone found in Inverloch, Victoria, is a good example of this situation. It is a perfect match to 55 Allosaurus ankle bones from North America, but probably one of the smallest. This suggests there were Allosaurus-like animals in Australia and that they were either smaller than their American cousins or that the bone found in Victoria was from a young animal.

Fig 6.38 This fossilised pterodactyl was in the middle of laying an egg when she was killed. This fossil provides valuable information about pterodactyl reproduction.

Fig 6.39 *Allosaurus* is the genus name for a group of extinct predators.

Reconstructing animals

What you need

Copies of bone cut-outs that have been enlarged and are on coloured paper.

What to do

1 Figure 6.40a shows pieces of the skeleton of a human, with some bones held together and some separated. Each bone is shown in front view. Photocopy and cut out the bones and glue them into your notebook in the shape of a person. (You may want to enlarge the photocopy.) Then draw the skin, leaving space for organs and muscles. Use your own body to work out the right and left side arms and legs.

2 Figure 6.40b shows the bones of a frog, with some bones held together and some separated. Each bone is shown in top view. Photocopy and cut out the bones and glue them into your notebook in the shape of a frog. (You may want to enlarge the photocopy.) Then draw the skin, leaving space for organs and muscles. The arms and legs are the most difficult.

3 Figure 6.40c shows the broken skeleton of an extinct amphibian found as a fossil in Queensland. Each bone is shown in top view. Photocopy and cut out the bones and glue them into your notebook in the shape that you believe this animal may have had in real life. (You may want to enlarge the photocopy.) Then draw the skin, making allowance for organs and muscles. Colour the animal and draw in some of its habitat.

Hint: tracing paper could be used for each 'layer' of detail you add.

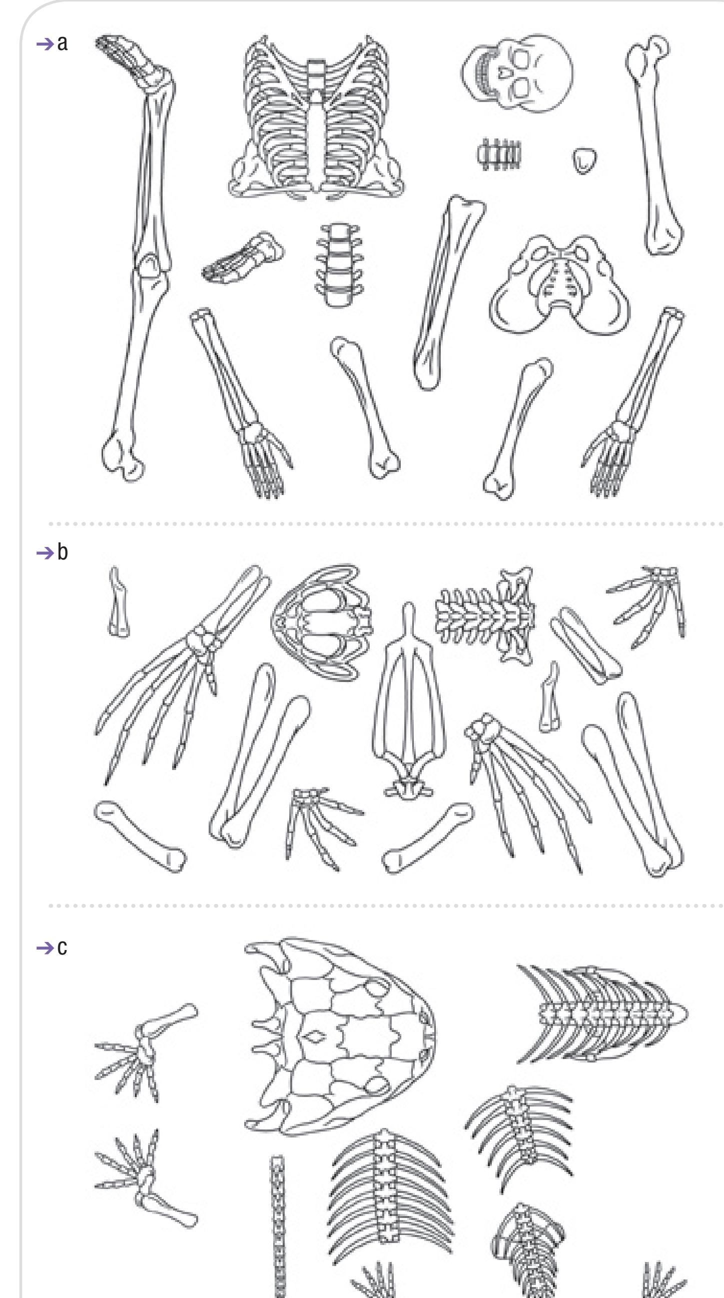


Fig 6.40

What do you know about the past through fossils?

1 What are fossils?
2 How are trace fossils formed?
3 What can fossils show us or tell us about the Earth's history?
4 What are geologists who study fossils called and what sorts of things do they do as part of their job?
5 Why is it important to take accurate and detailed records of all fossils, even if they can already be identified?

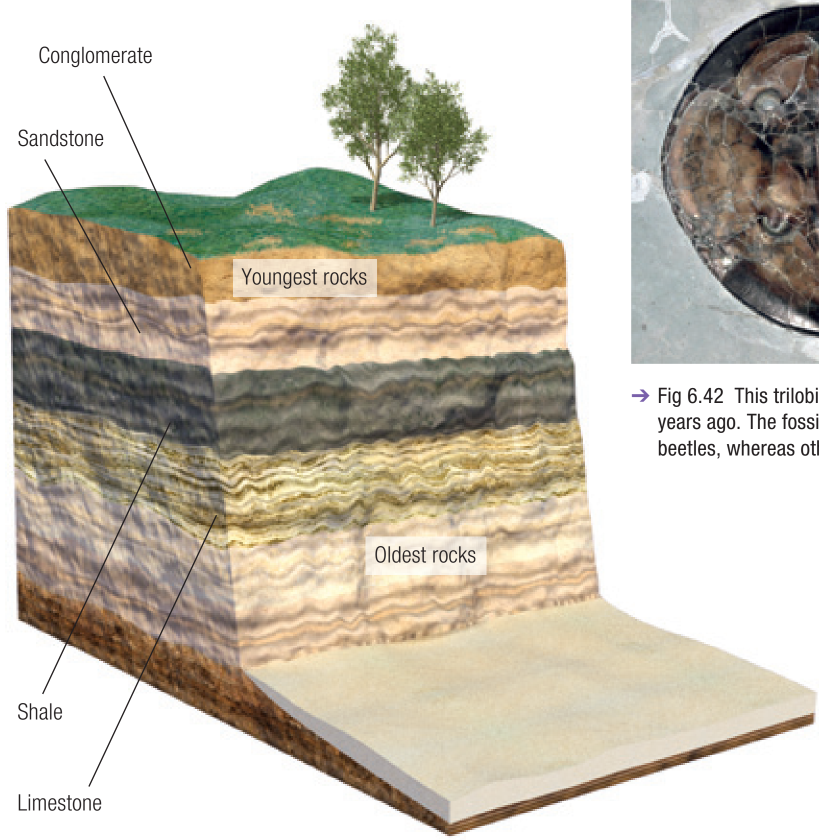
Finding the age of fossils

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.

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 6.41). 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.



→ Fig 6.41 Comparative dating is used to work out the age of rocks and fossils.

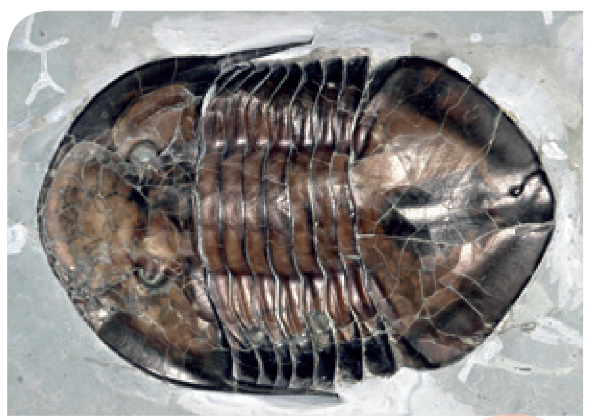
Radioactive dating

The actual age of a fossil, 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 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 Earth, as well as that of Moon rocks brought back to 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 6.42). These are different from the fossils found in the Triassic period, which include the first dinosaurs.



→ Fig 6.42 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.

End of an era

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 absolutely in millions of years using radioactive dating. The names and order of the periods, as well as their absolute age, are shown in the geological time scale in Figure 6.43.

Era	Period (millions of years)	Plant life	Animal life
Cenozoic (recent life)	Quaternary 2	Modern plants.	Development of humans.
	Tertiary 65	Forests of angiosperms.	Mammals dominant over 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.
Palaeozoic (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 the 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 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.	

→ Fig 6.43 Geological time scale.

What do you know about finding the age of fossils?

1 What is *comparative dating*?
2 What radioactive substances are used to date rocks?
3 What are *index fossils*?
4 What are the time periods used by geologists?
5 In what unit are these time periods measured?

The dinosaur age

The dinosaur age was between 250 and 65 million years ago. Dinosaurs were the most successful animals on Earth before humans. All we know about dinosaurs today comes from fossil evidence. Many dinosaur fossils have been found in particular rock types or outcrops at a few locations in Australia, such as Dinosaur Cove in southern Victoria and Winton in central Queensland. An almost complete skeleton of *Minmi paravertebrae* (see Figures 6.44 and 6.45) was discovered near Minmi Crossing in north-west Queensland in 1990. Fossils of dinosaurs in Australia have helped palaeontologists deduce how large they were, what they ate and where and how they lived.

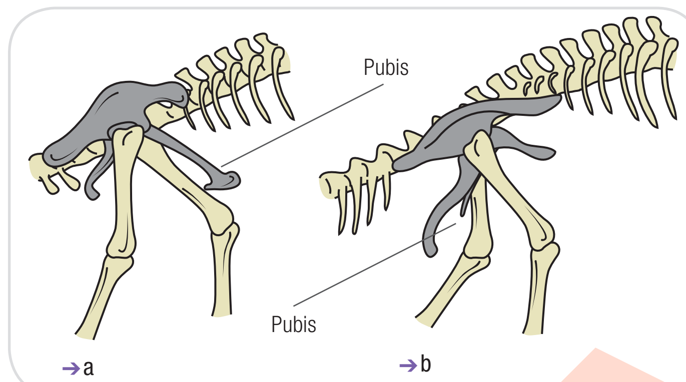
→ Fig 6.44 *Minmi paravertebrae* was a small, armoured ankylosaur. Its armour was more like a shell and was heavy and hard. *Minmi paravertebrae* was a herbivore and its armour was presumably to protect it from predators. Even the belly of *M. paravertebrae* was protected by small bony plates.

→ Fig 6.45 A reconstruction of *Minmi paravertebrae*.

Dinosaur classification

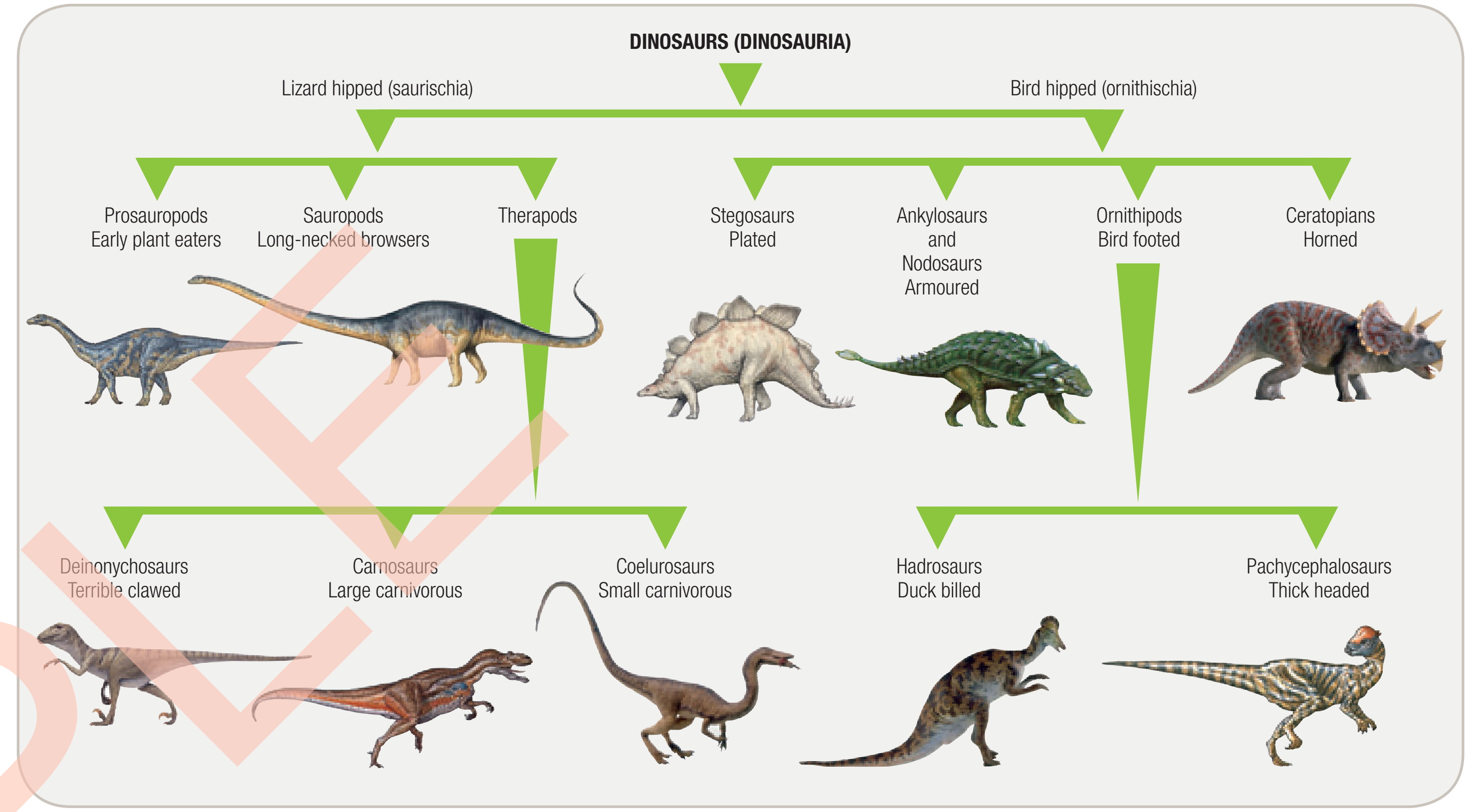
With so many different types of dinosaur fossils, scientists have classified dinosaurs into groups. The classification of dinosaurs is similar to that of other living things, which are normally classified according to their structural features—skeleton, skull shape, teeth, number of legs and the structure of their cells. Unfortunately, not all palaeontologists have agreed on a universal classification system for dinosaurs. The following groupings are those used in the most widely accepted classification system.

The dinosaur family is called Dinosauria and is divided into two main groups: lizard-hipped and bird-hipped dinosaurs (see Figure 6.46). These two main groups are further divided into subgroups, as shown in Figure 6.47.



→ Fig 6.46 Dinosaurs are classified according to hip type. (a) Lizard-hipped dinosaur. (b) Bird-hipped dinosaur.

Scientists have learned a lot about what dinosaurs looked like, how they moved and what they ate. They are still unsure about whether dinosaurs were cold or warm blooded. Until recently, it was thought that dinosaurs were cold-blooded animals (like lizards). The body temperature of cold-blooded animals varies with their surroundings. As the temperature of their surroundings increases, their body temperature increases, as does their ability to move and function. Warm-blooded animals are able to maintain their own body temperature and can function fully in hot and cold temperatures. The discovery of dinosaur fossils at Dinosaur Cove in southern Victoria suggests that dinosaurs may, in fact, have been warm blooded. At the time of the dinosaurs, this part of Australia was located inside the Antarctic Circle: a cold-blooded animal could never have survived the freezing conditions. However, whether dinosaurs were, indeed, cold or warm blooded remains unknown.



→ Fig 6.47 Dinosaur classification chart.

<<OVERARCHING IDEAS>>

Using evidence to deduce

Scale and measurement

The only evidence found worldwide of a dinosaur stampede is near Winton in Queensland. A large Theropod, which had steps of up to 2 m in length and walked at 9 km/h, 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.

1 How would palaeontologists know the species of the dinosaurs involved in the stampede?
2 What information would help palaeontologists work out the weight of the dinosaurs?
3 How could the palaeontologists work out how fast the dinosaurs were travelling?
4 How could the palaeontologists tell that the Theropod slowed down?
5 Why do you think there was a stampede?

→ Fig 6.48 These footprints from near Winton, in Queensland, show a dinosaur stampede.

Dinosaur extinction

Fossil evidence suggests that, 65 million years ago, approximately 70% of all species on Earth suddenly became extinct, including all dinosaurs. The disappearance of the dinosaurs is the most dramatic extinction of animals in the history of the Earth. Scientists argue about whether the extinction of the dinosaurs was sudden or gradual. Many different theories have been put forward, but the real reason for this mass extinction remains unknown.

The asteroid theory

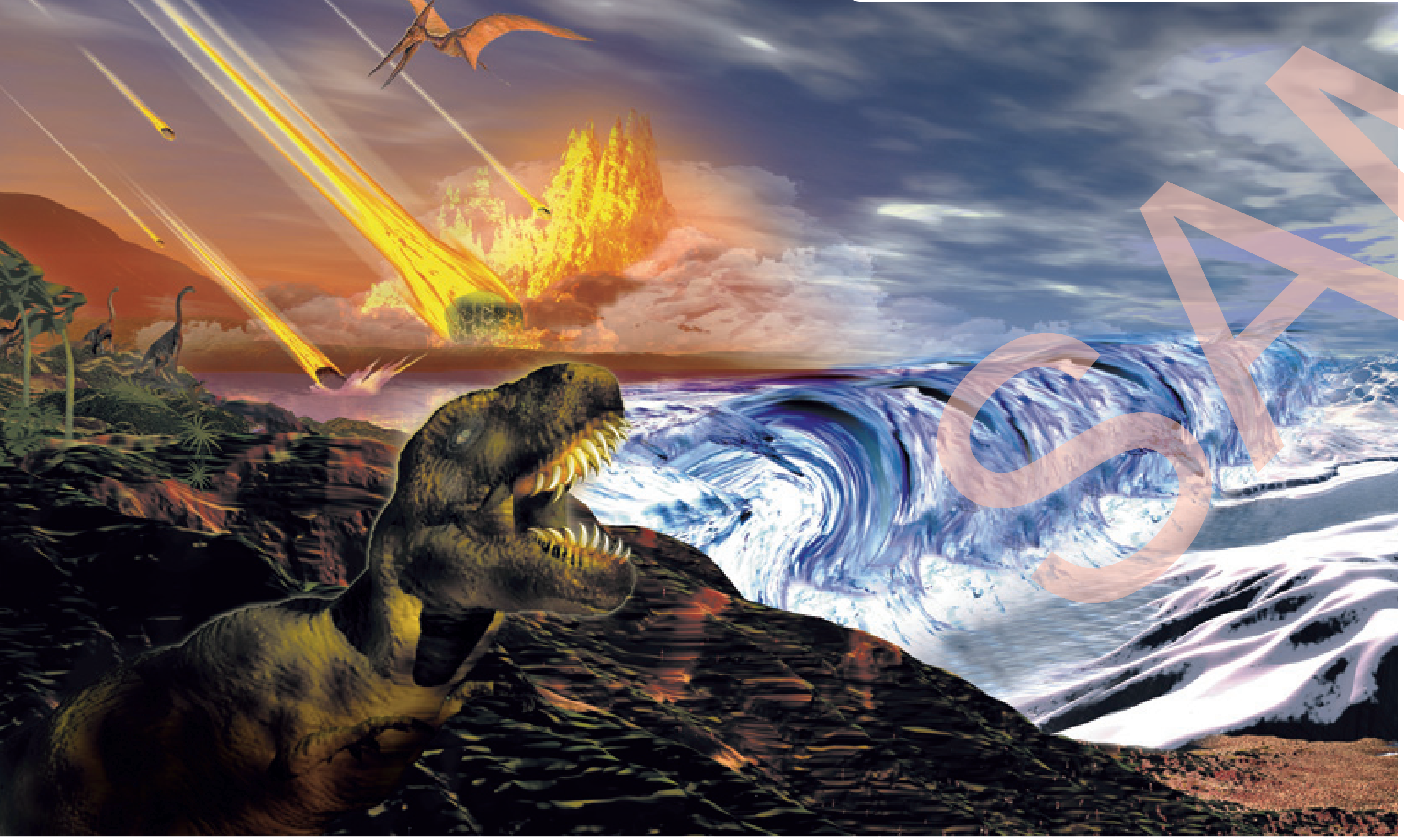
The most widely accepted theory is that an asteroid, approximately 6–15 km in diameter, hit the Earth with the force of five billion atomic bombs. A huge crater, more than 180 km in diameter, was found buried at Chicxulub in Mexico in 1990, giving more support to this theory. The impact of the asteroid would have incinerated all plants and animals in its path, caused fires, generated earthquakes and tsunamis and scattered dust, debris and sulfuric acid into the atmosphere. Sunlight would have been obscured for months or even years and temperatures around the world must have fallen.

With the drop in temperature and lack of sunlight, plants probably stopped growing. Large plant-eating dinosaurs would have starved quickly and the meat-eating dinosaurs who preyed on them would have followed. Smaller nut- and seed-eating animals may have survived. As the dust finally settled and sunlight returned, dormant seeds would have sprouted and the animals that survived the impact would have prospered without dinosaurs to compete with.

The volcano theory

Volcanic eruptions shoot ash and other fragments high into the air. If there had been a large amount of volcanic activity approximately 65 million years ago, this too could have reduced levels of sunlight and dropped temperatures, leading to the extinction of the dinosaurs in the same way as proposed in the asteroid theory.

➔ Fig 6.49 Dinosaurs became extinct approximately 65 million years ago.



Other theories

In 1980, the Nobel prize-winning physicist Luis Alvarez identified a layer of sedimentary rock found all over the world that marked the end of the Cretaceous period. This layer, known as the **KT boundary**, contained iridium, a rare radioactive element, in concentrations far greater than in any other layer of the ground. Iridium is known to exist in large amounts in most asteroids and comets, so Luis Alvarez theorised that an impact from space was the most likely cause of the extinction of the dinosaurs. Others suggested that volcanic eruptions could bring iridium from the Earth's centre, making this another likely explanation for the extinction of the dinosaurs.

This physical evidence makes any other theories for the extinction of the dinosaurs seem far less likely. Climate change, either due to natural cycles or the movement of the continents, has often been proposed as another theory. Yet another, less common, theory is that the seabeds dropped, causing significant changes to the Earth's albedo—its ability to reflect heat and light. However, the effects of such changes would have been very slow and many species would have evolved fast enough to survive. It is possible that the evidence for climate change is correct, but that it happened in addition to a major catastrophic event.

➔ Fig 6.50 The creamy layer of rock is the KT boundary. It marks the end of the Cretaceous period.

What do you know about the dinosaur age?

1. What are the two main groups of dinosaurs?
2. Why could less sunlight and reduced temperatures have led to the extinction of dinosaurs?
3. In what period did dinosaurs live?
4. Why do you think the dinosaurs are so well known, despite representing a tiny snapshot in time?

6.3 What can we learn from studying rocks?

Remember and understand

1 Copy and complete:
  a The geological time scale used is ________________ .
  b ________________ are used to find rocks of the same age.
  c ________________ can leave an impression in rocks.
  d A person who studies fossils is a ________________ .
2 Refer to the geological timescale in Figure 6.43.
  a During what period did dinosaurs become extinct?
  b When did the first land plants appear on Earth?
  c When did insects become common?
  d When did humans appear?
3 How do index fossils help identify rocks of the same age?
4 Explain why only simple fossils are found in the oldest types of rocks, whereas younger rocks have fossils of mammals.
5 Design a flow chart showing the steps in fossil formation.
6 Which dinosaur family do I belong to?
  a I have a long neck and eat by browsing.
  b I have a bill like a duck and people say that I have bird-like hips.
  c I have terrible claws and everyone is scared of me.
  d I have a thick head—but that doesn't make me any less clever than those Hadrosaurs!

Apply

7 Dinosaurs are grouped into lizard-hipped dinosaurs and bird-hipped dinosaurs. What does this tell you about how they moved?
8 Write a list of ten interview questions that you would ask a palaeontologist if you had the chance. Make sure that your questions will help you learn more about this branch of geology.

Analyse and evaluate

9 Why don't most organisms form fossils when they die?
10 A palaeontologist found a dinosaur skull but was not able to find any other bones in the area. Explain why this was the case.
11 If you were a palaeontologist searching for fossils, which types of rocks would you look for? Explain.
12 'Scientific ideas are not fixed—they have changed throughout history and continue to change.' Based on what you have learned in this unit, write a response to this statement. Do you agree or disagree? Make sure you back up your answer with evidence and fact.

Critical and creative thinking

13 In a format of your own choosing, demonstrate different ways that fossils can be formed and the types of fossils that are formed in this way.
14 Imagine that you are a world-famous scientist who is part of the team that has discovered how to reverse the geological timescale and bring dinosaurs back to life. Write a short science fiction story about the day the first dinosaur egg hatches.

CONNECTING IDEAS Dynamic Earth

15 Imagine you are living 10 million years into the future.
  a What might you find in the fossil record for the year 2012 in the area where you live?
  b Do you think there would be any human fossils?
  c What other objects from before 2012 might you find in the rocks?

ZOOMING OUT

Research

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.

- 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

Which gemstones are found in Australia? Which gemstones are dug up by recreational fossickers? What do the gemstones look like?

Extraction of metals

Metals are extracted from their ores using 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 using different chemical or electrical processes? Find out about 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 Earth has changed?

My future

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

Review

Key words

basalt
cleavage
coal
colour
comparative dating
crystal
era
erosion
extrusive igneous rock
fossil
hardness
igneous rock
index fossil
intrusive igneous rock
lava
limestone
lustre
magma
magma chamber
metamorphic rock
millions of years ago
mineral
obsidian
ore
palaeontologist
period
petrification
properties
pumice
quartz
radioactive dating
relative dating
rock cycle
scoria
sedimentary rock
streak
trace fossil
weathering

6

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. Over time, Gondwana broke up, 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 study of the rocks difficult, new techniques have been used to determine the types of rocks and minerals found in Antarctica. The Antarctic Peninsula 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.

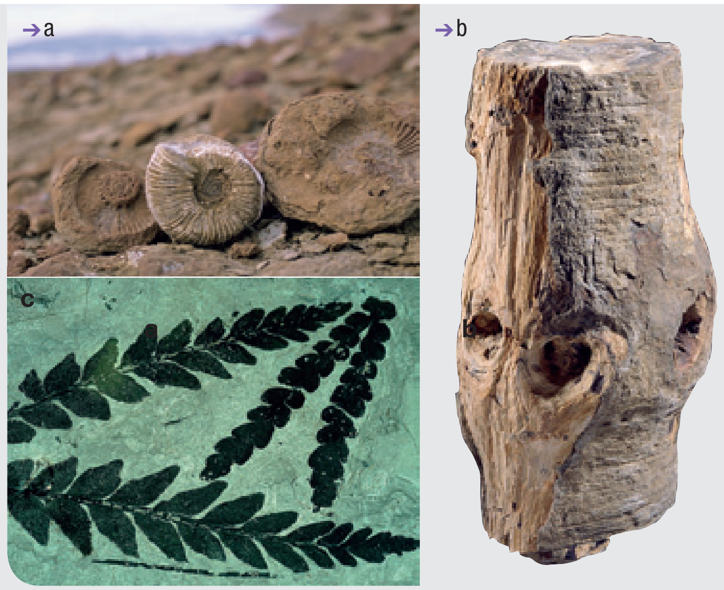
→ Fig 6.51 The Antarctic Peninsula.

→ Fig 6.52 Ash from an Antarctic volcano.

→ Fig 6.53 Transantarctic mountains contain a wealth of valuable minerals.

About 500 million years ago West Antarctica was partially in the Northern Hemisphere with 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 extremeness of the 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. In fact, 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.



→ Fig 6.54 (a) Antarctic ammonite fossil, (b) A petrified conifer tree from Antarctica, (c) 260-million-year-old fossil leaf from Antarctica.

1 What types of rock formation processes have occurred in Antarctica?

2 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 What sort of a climate would have existed on Antarctica for forests of trees and ferns to have existed?

5 Why do you think that mass extinction events such as of the dinosaurs were not as great on Antarctica as in other places in the world?