9 Exploration and mining

HAVE YOU EVER WONDERED…

- how miners know where to dig?
- where all the metals around you came from?
- where oil comes from?
- why gold is found as nuggets, but iron is not?

After completing this chapter students should be able to:

- recall that rocks are a collection of different minerals
- recall that some rocks and minerals, such as ores, provide valuable resources
- describe how the location and extraction of mineral resources relies on expertise from across the disciplines of science
- outline the role of forces and energy in the formation of different types of rocks and minerals
- outline strategies implemented to maintain the environment
- describe how knowledge of the environment and ecosystems is important in a number of occupations.

9.1 Resources in the rocks

This gold nugget was found in Western Australia's goldfields in 1995 and has a mass of 25.5 kg! It is one of the largest nuggets ever found. There are many other valuable things that come from the Earth, such as oil. Without oil, there would be no petrol or plastics. Materials from the Earth are very important to Australia's economy.

Resources and the economy

Humans have been digging up substances and using them for their own purposes for thousands of years. These substances are generally known as resources. Some, such as gold, only need a little cleaning before they can be used. Likewise, most coal can be used straight away with little or no processing. Other resources, such as iron and aluminium, are not found in their pure, element state but are found as compounds such as iron oxide and aluminium oxide. The pure metals then need to be extracted from these compounds. Oil is a mixture of chemical compounds and it too needs to be processed. The processing of oil separates it into its components of petrol, aviation fuel, diesel, kerosene and bitumen.

Resources can be classified as:

- minerals
- petroleum (oil and natural gas)
- coal.

Figure 9.1.1

These ships are loading up with iron ore from the Pilbara region of Western Australia.

The importance of resources to the Australian economy varies greatly as economic conditions in the world change. At present, mining and petroleum contribute about 5.6% of the value of goods and services made in Australia in a year. This is the highest amount for any developed country in the world. Minerals, coal and petroleum exports currently contribute around 35% of Australia's exports.

Australia is among the world's largest exporters of coal, iron ore (like that being loaded in Figure 9.1.1 on page 315), lead, diamonds, rutile, zinc, zirconium, gold, uranium and aluminium. Australia is a significant exporter of titanium, nickel, copper, tin and silver. Our natural gas production is also increasing greatly. Australia's position in the world as a supplier of various minerals, coal and petroleum varies as mines and wells open and close. This is affected by changing mineral prices and the 'life' of the mine or well. Mines and wells only continue while they are profitable or until the mineral or petroleum is used up.

Minerals

Rocks are made up of chemical substances called minerals. A **mineral** is a naturally occurring liquid or solid in the Earth's crust, but oil, coal or natural gas are not minerals. While some minerals are pure elements such as gold and silver, most minerals are chemical compounds made up of different elements. Examples are iron oxide, copper sulfide and aluminium oxide. Other examples are shown in Table 9.1.1.

The rocks containing these minerals are known as **ores**. For example, copper is found in copper ore. Three types of copper ores are shown in Figure 9.1.2

Figure 9.1.2 'Native copper' is found as pure copper. More commonly, copper is found as an ore. Three copper ores are bornite, azurite and malachite.

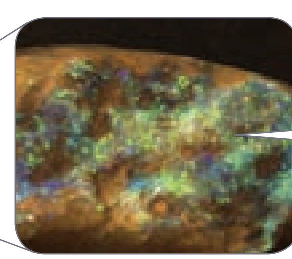
Sometimes the whole mineral is extracted from the ore and used. For example, the mineral titanium oxide can be:

- used to colour paints white
- separated into titanium metal and oxygen. The titanium can then be used in making steel alloys.

At other times, the metallic element needs to be extracted from its compound within the ore.

Table 9.1.1 Common minerals

Mineral	Chemical compound in mineral	Element, compound or material used
Haematite	Iron oxide	Iron
Bauxite	Aluminium oxide	Aluminium
Galena	Lead sulfide	Lead
Azurite	Copper carbonate	Copper and gemstones
Chalcopyrite	Copper sulfide	Copper
Rutile	Titanium oxide	Titanium oxide, or titanium
Cassiterite	Tin oxide	Tin
Chromite	Iron oxide and chromium oxide	Chromium
Pentlandite	Nickel sulfide	Nickel
Opal	Silicon oxide	Gemstones



Beauty in the rocks

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Some people collect rocks and minerals because of their beautiful crystal shapes and colours. A good sample of some rare minerals can be worth tens of thousands of dollars and gem shows are held regularly around the world for enthusiasts. Some geologists chose their career because they were attracted by the beauty in the rocks.

Figure 9.1.3

This rhodochrosite (manganese carbonate) sample is called 'The Alma Queen'. It is one of the most famous mineral samples ever discovered.

Properties of minerals

The main physical properties used to identify minerals are:

- hardness
- lustre
- colour
- streak colour.

Hardness

Hardness is assessed by comparing minerals using Mohs scale. The scale is given in Table 9.1.2. A set of minerals is used to try to scratch the surface of an unknown mineral to determine its hardness.

Table 9.1.2 Mohs hardness scale

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

Another way of testing for hardness is shown in Table 9.1.3. It uses a range of commonly available materials to compare hardness. This is useful as a rough guide if a geologist is in the field and does not have a set of minerals to perform a Mohs test.

Table 9.1.3 An alternative test for hardness

Test object	Will scratch materials of hardness less than
Fingernail	2.5
Copper washer	4
Cast iron	4.5
Window glass	5.5
Steel knife or nail	6

SKILL BUILDER

Using Mohs scale

To determine the hardness of an unknown mineral, you need to try to scratch it with the different minerals or objects listed in Tables 9.1.2 and 9.1.3. If the unknown mineral can be scratched, then it must be softer than whatever you scratched it with. If you can scratch something with the unknown mineral, then the unknown mineral is harder.

WORKED EXAMPLE

Using Mohs scale

Problem 1

On testing, topaz scratched an unknown mineral, but feldspar did not. State the hardness of the unknown mineral and identify what the mineral could be.

Solution

Topaz must be harder than the unknown mineral, so the hardness of the unknown mineral is less than 8 on Mohs scale. The unknown mineral scratched feldspar, so it is harder than feldspar (6 on the scale). The unknown mineral therefore has a hardness of between 6 and 8. It might be quartz, but could also be another mineral with similar hardness to quartz.

Problem 2

An unknown mineral was tested by a geologist in the field. Window glass scratched the unknown mineral but the mineral scratched a lump of cast iron. State the approximate hardness of the unknown mineral and identify what it could be.

Solution

The unknown mineral's hardness lies between cast iron (4.5) and window glass (5.5). The mineral could be apatite (5 on Mohs scale).

Lustre, colour and streak tests

The appearance of a mineral can give a good idea of what it might be. The way a mineral looks can be analysed in three ways.

- Colour is very useful when prospecting (looking) for minerals. For example, gold shows up as a yellowish colour in rock and soil.
- **Lustre** is how shiny a mineral is. Lustre can be useful when you are out prospecting for minerals. For example, gold has a bright shiny surface when clean or wet.
- **Streak** is the colour left behind when you try to scratch an unglazed white tile with the mineral. The streak is often different from the colour of the mineral itself. For example, iron pyrites (commonly known as 'fool's gold') looks very similar to real gold. They both have a similar golden colour. However, fool's gold has a greenish black streak, while real gold has a gold streak. A streak test is shown in Figure 9.1.4.

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Figure 9.1.4 Haematite is the mineral form of iron oxide, which is found in much of Australia's iron ore. The red form and the black form both show a rust-red streak. This helps to show that they are the same mineral.

Flame tests

Flame tests are chemical tests that provide another way of identifying a mineral. In these tests, minerals are ground into powders and heated to a high temperature in a flame. If the mineral is soluble, then it can be dissolved and squirted into the flame as a liquid instead. The mineral glows and gives the flame a characteristic colour that may be used to identify the mineral. Though many minerals have similar colour flames, a flame test may help distinguish between two samples when used with the other tests. You can see a flame test in Figure 9.1.5.

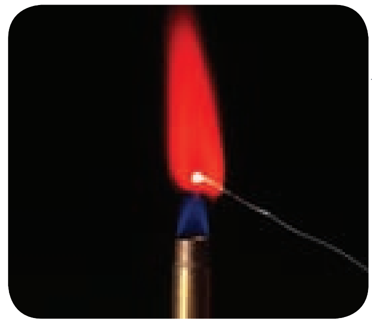

Figure 9.1.5 Minerals glow in a flame, giving out a distinctive colour such as the crimson red of strontium.

INQUIRY science 4 fun

Flaming minerals

No

Do minerals burn with the same colour flame?

Collect this ...

- atomiser bottle
- samples of different minerals in solution
- Bunsen burner and bench mat
- matches
- safety glasses

Do this ...

1. Go to one of the different stations around the room.
2. Squirt the solution found at the station into the blue Bunsen flame and observe the colour of the flame.
3. Repeat steps 1 and 2 for the remaining mineral samples in the room.

Record this ...

Describe what you observed.

Explain how your results could be used to identify a mineral in an ore.

Formation of minerals

Minerals are found in particular locations because they formed there or they were moved there after being formed somewhere else. How minerals form is the subject of much research because this knowledge helps mining companies locate large ore deposits called **ore bodies**.

Some minerals form by crystallisation of magma and are therefore found in igneous rocks. Other minerals form by metamorphic processes, when heat from magma and pressure melts existing rocks to form new ones.

Other minerals are found in sedimentary rocks. These form when solutions of the compound flow through rock and the minerals slowly crystallise as the water evaporates. This may happen in a cave, forming crystals like those in Figure 9.1.6. Stalagmites (which rise from the floor of caves) and stalactites (which hang from the ceiling of caves) of calcium carbonate form this way too. Crystallisation may also happen at the ground surface, such as in a salt lake where halite, gypsum and other chemical sedimentary rocks form. It can also happen inside other rocks or cracks in the rocks.

Figure 9.1.6 These 11-metre-long crystals of selenite (calcium sulfate), the largest crystals ever discovered, formed from hot volcanic fluids inside the Naica Cave in Mexico.

Iron ore

Most iron ores around the world were formed by sediments deposited on the sea floor. The deposits became banded iron formations. These bands of iron oxide occur in a pattern of alternating layers with other minerals in between.

Banded iron deposits can be lifted to the surface by movements in the Earth's crust. Once exposed, the rock starts weathering to form iron-rich layered mountains such as Mt Tom Price and Mt Whaleback in the Hamersley Ranges, Western Australia. You can see these layers clearly in Figure 9.1.7.

Figure 9.1.7 Iron ore deposits in the Pilbara region of Western Australia are sedimentary rocks. The red folded layers of iron oxide rock shown here contain iron oxide.

Some iron deposits in the Pilbara region of Western Australia were formed in a different way. Dissolved iron compounds precipitated from the water that carried them down from surface soils or rocks. The iron compounds solidified around small grains of sand and gradually built up into large gravel-like rocks. This formed the minerals limonite and goethite, found in the Hamersley Basin also in Western Australia.

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Magnetic rock

Magnetite is magnetic iron ore. If a long, thin piece is suspended from a string, the magnetite spins around and once it stops spinning, one end will be pointing north. Ancient seafaring people used magnetite to form simple compasses.

Copper ore

The world's major copper deposits were formed near magma that pushed into existing rocks. This is shown in Figure 9.1.8. The magma superheated (heated to above its boiling point) nearby water, which then dissolved some of the copper minerals in the surrounding rocks. These superheated liquids are called **hydrothermal fluids**. The hydrothermal fluid then flowed further away from the magma and into spaces in surrounding rocks. The fluids cooled and minerals solidified in these spaces, forming a rich copper mineral layer. The copper tends to be in a zone called an 'aura' that surrounds the old magma chambers. Other minerals tend to form in cracks in the rocks called 'veins'.

Some copper ores also formed in the ocean, where they became sedimentary rocks. Water flowing through copper-rich rocks on the land dissolved some copper. When the water reached the ocean, the copper precipitated and mixed with the other sediments. Copper carbonate ores can be formed in this way.

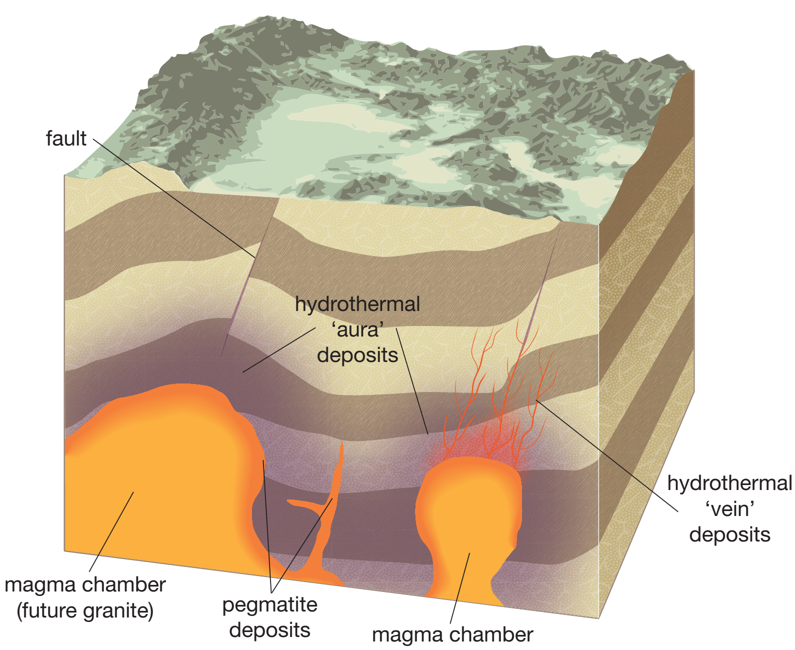

Figure 9.1.8 Hydrothermal fluids can form mineral deposits around magma chambers (aura) and in cracks (veins) in rocks.

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Gold

Gold is formed in a variety of ways. The main way involves hydrothermal fluids, the same as for copper. Some gold is deposited in igneous rocks, but is later dissolved by hydrothermal solutions. These fluids then move through other rocks and deposit the gold in cracks forming veins of gold like those in Figure 9.1.9.

Figure 9.1.9 This gold deposited from hydrothermal fluids that flowed into cracks in granite rock.

Another process forming gold is deposition in gravel rocks containing iron oxide. Gold can be dissolved when it is weathered from a parent rock. Water carrying the dissolved gold flows away and deposits the gold around tiny sand grains elsewhere. The rocks gradually grow in size and may eventually look like gravel, but with fine grains of gold inside them.

Gold can also be found in soils or sedimentary rocks. However, gold is rarely formed there. It has simply been transported there by streams. The gold is deposited when the stream flow slows and there is not enough energy to carry the heavy gold particles. For this reason, gold prospectors like to know where old water courses are located.

9.1

Formation of oil and gas

Oil and gas formed from microscopic animals and plants that lived in the oceans and lakes between 10 million and 160 million years ago. When these ancient plants and animals died, they sank to the bottom of the oceans and lakes and were covered by sediment. This sediment and lack of oxygen changed the way they decayed. Heat from the Earth slowly changed the chemicals making up the plants and animals, turning them into compounds high in carbon. The sediment slowly turned into sedimentary rock. As it did so, the carbon compounds became oil or gas.

Oil can flow through some types of rocks and can accumulate in spaces between the rock particles. Oil is less dense than water and so it often flows upwards from the rock where it was originally formed. It can enter rocks such as limestone and sandstone, which are porous and have large spaces that can hold a lot of oil. The oil can be trapped in these rocks if there are impervious rocks above that do not allow oil to flow through them and block the oil from rising any further. The rocks that block the oil are known as cap rocks. Figure 9.1.10 shows where oil is found.

Formation of coal

Australia has large reserves of black coal mainly in the Bowen Basin in Queensland and the Hunter Valley in New South Wales. There are large reserves of brown coal in Victoria's Latrobe Valley. Coal is formed from plants that lived in swampy areas on land. Many of these were species of trees that are now extinct on Earth. They died and fell into the swamps, where they were covered by sediment. High pressure, heat and a lack of oxygen changed and compressed the plant remains to form coal.

Coal is solid and cannot flow into other rocks. A sample of coal is shown in Figure 9.1.11.

Figure 9.1.11 Coal is partly decomposed plant matter, and fossils of ancient plants are often still visible in the rock.

From Earth to final product

The process of obtaining minerals, oil or coal in the form required generally consists of several main steps.

1. *Exploration:* this is the search for the rocks containing the minerals, coal or oil.
2. *Mining:* this is the removal of the resource from the ground. For oil and gas, this involves drilling a deep hole.
3. *Enrichment:* this concentrates the resource, increasing how much there is of it in a particular volume of the mined material. This may involve removing other materials that aren't wanted. The rock may need to be crushed into smaller pieces and then ground down to fine particles like sand.
4. *Extraction:* some metals need to be extracted. This chemical process involves removing the wanted element from the compound in which the metal occurs. For example, iron needs to be extracted from iron ore. Iron ore is iron oxide, and the iron atoms and oxygen atoms need to be separated from one another.

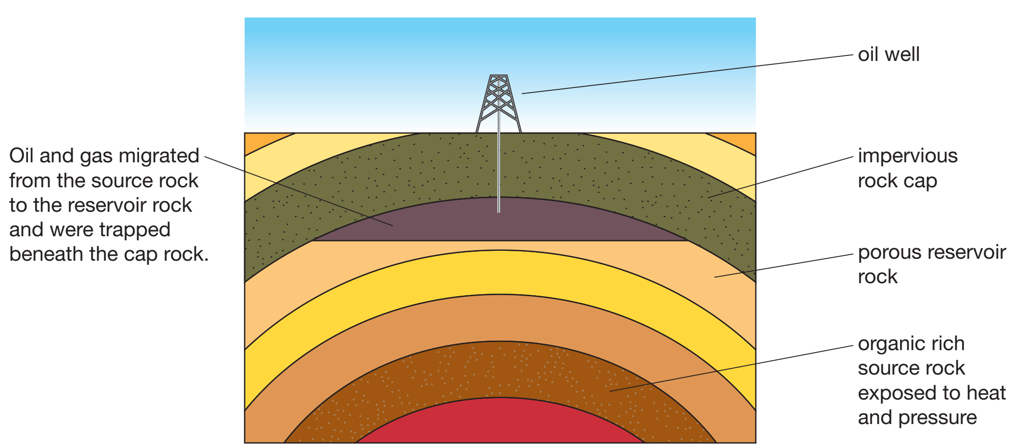


Figure 9.1.10 Oil and gas accumulate in sedimentary rock layers beneath cap rocks. Cap rocks do not allow oil and gas to flow through, trapping them underground.

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Golden bacteria

Figure 9.1.12 Gold accumulated by the bacteria

Australian scientist Frank Reith, from the University of Adelaide, noticed that a bacterium called ***Cupriavidus metallidurans*** occurred on gold grains in southern New South Wales and northern Queensland. He wondered if the bacteria were involved in forming gold.

In 2006, Frank Reith organised an international team of scientists to carry out further research. The team was made up of scientists from the University of Adelaide, CSIRO (Commonwealth Scientific and Research Organisation), the United States, Canada, Germany, Belgium and France. Their experiments showed that the bacteria could accumulate gold compounds from a solution prepared in the laboratory. These gold compounds are toxic to the bacteria, so the bacteria defend themselves by turning the gold compounds into metallic gold. The tiny gold particles are produced inside the bacteria. You can see this in Figures 9.1.13 and 9.1.14.

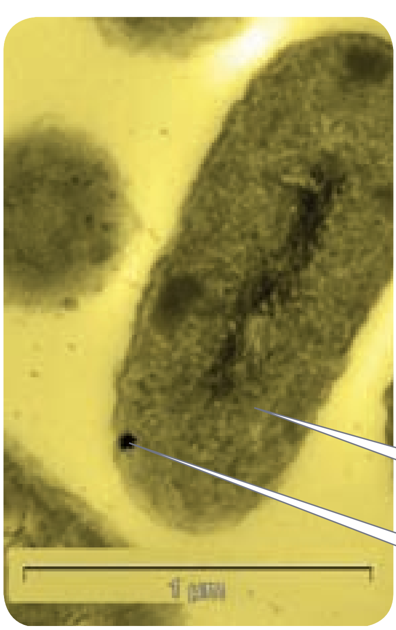


Figure 9.1.13 This is a single bacterial cell with a growing particle of gold inside it.

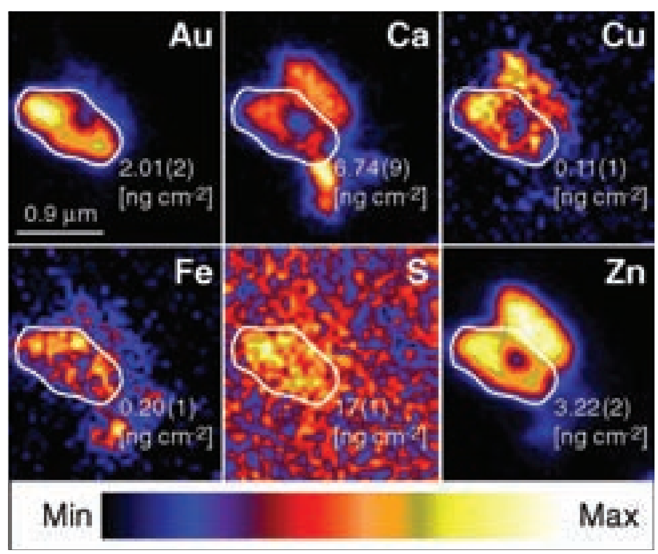


Figure 9.1.14 These X-ray fluorescence maps show the distribution of gold (Au), calcium (Ca), copper (Cu), iron (Fe), sulfur (S) and zinc (Zn) in an individual cell after one minute of exposure to the gold solution. This helps scientists determine how the bacteria react to the gold solution.

Reith has since been investigating whether the bacteria could be used as a 'biosensor'. If it works, they would become part of a biological system for detecting gold sources in rock. This will help companies exploring for gold. Further research is also planned to find the genes that control this unique cell chemistry of the bacteria.

9.2

9.1 Unit review

Remembering

1 a **List** five minerals.
  b **Name** the chemical compound in each of them.
  c **Name** the element extracted from the compound.

2 **List** four physical properties used to identify minerals.

3 **List** the four main steps involved in obtaining a mineral from the Earth.

Understanding

4 **Explain** how lustre and colour can help identify a mineral.

5 **Explain** how a streak test could be used to distinguish between two minerals.

6 **Explain** why minerals are so important to Australia.

7 **Explain** how a mineral may be formed as a result of chemical sedimentation.

8 **Describe** one way in which the following may form.
  a iron ore
  b copper minerals

9 **Describe** where oil and gas are usually found.

Applying

10 **Use** Mohs scale to **identify** minerals that could:
  a be scratched by a fingernail
  b scratch a fingernail.

11 An unknown mineral was scratched by fluorite, but not calcite. **Use** Mohs scale to **state** the likely value for its hardness.

12 One of the minerals in Table 9.1.2 on page 317 was scratched by topaz but not by an iron nail. **Identify** what mineral it probably was.

Analysing

13 **Compare** a rock, a mineral and an ore.

14 **Compare** the formation of coal and oil.

15 **Compare** the formation of gold and copper by hydrothermal fluids.

16 **Contrast** the involvement of water in the formation of iron ore and copper ore.

17 Imagine you are given two large white crystals labelled U1 and U2. Write a method to **compare** these two crystals to decide if they are different minerals or the same mineral.

Evaluating

18 Two unknown white, lustrous minerals were tested for hardness and streak. Both had a hardness of 4, and had a white streak. **Draw** a conclusion from these tests.

19 Some gold nuggets that were rounded like sand grains were found by a prospector in dry soil nowhere near a stream. The prospector insisted that the gold was carried there by an ancient stream that disappeared long ago. The land was fairly flat but there were some hills about 1 km away. **Assess** the prospector's argument.

Creating

20 **Construct** a table summarising the ways in which iron ore, copper ore, gold, coal, oil and gas form.

Inquiring

1 Magnetite, cassiterite, tourmaline and haematite are black minerals. Research how you could perform laboratory tests using the physical properties of magnetism, density and streak to distinguish between them.
If your teacher has some of these minerals available, then ask if you can try your experiments.

2 Research where gold, copper, iron, uranium, diamond, coal and petroleum deposits are found in Australia. Construct a map of Australia showing the major mines and wells.

9.1 Practical activities

1 Comparing minerals

Purpose

To compare the properties of different minerals.

Materials

- minerals
- white unglazed tile
- stereomicroscope or hand lens
- steel nail
- copper washer or nail
- cast iron

Procedure

1. In your workbook, copy the table shown in the results section. Draw enough rows for all the minerals.
2. Choose one mineral sample. Record its name from the label or identify it using Figure 9.1.15. Describe its colour and lustre.
3. Use the stereomicroscope or hand lens to observe the shape of any crystals. Describe or draw them in your table.
4. Do a streak test and record the colour in your table.
5. Test the hardness using Tables 9.1.2 and 9.1.3 on page 317 and enter the result in your table.
6. Repeat for all other mineral samples.

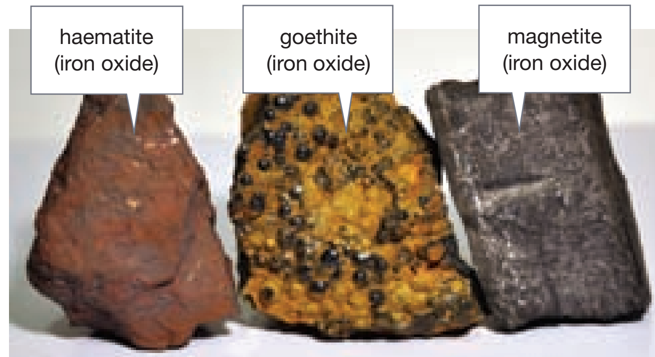
Results

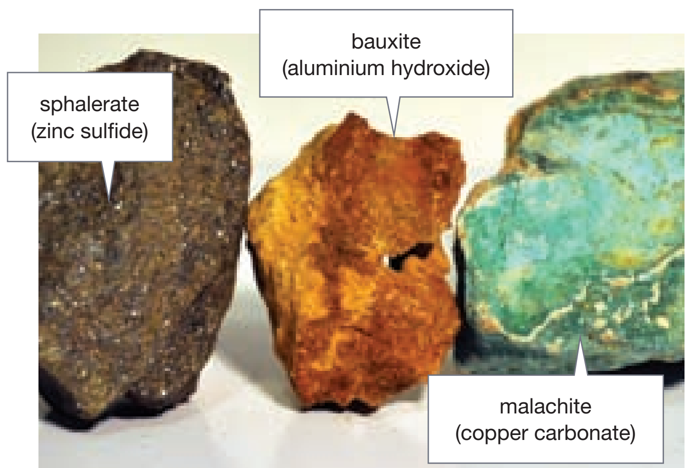
1. Copy and complete the following table for all the minerals you have.

Mineral name	Colour and lustre	Crystal shape	Streak colour	Approximate hardness

Discussion

1. **Describe** any difficulties you had in conducting these tests.
2. **Propose** some difficulties geologists may have if they rely only on these tests to identify a mineral.
3. **Propose** why minerals look different and have different properties.





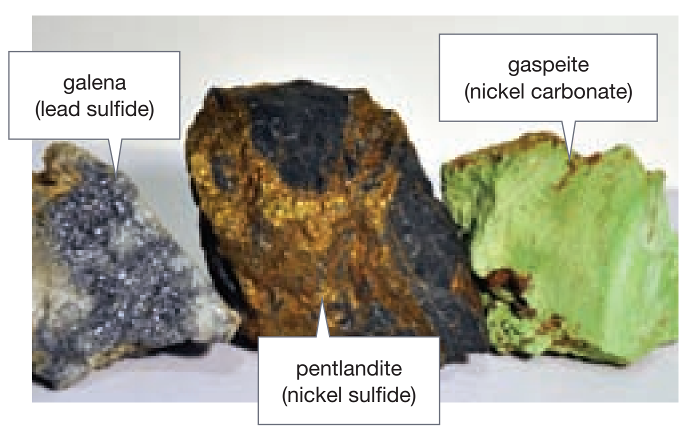


Figure 9.1.15

2 Malachite

Purpose

To investigate the composition of malachite, a green-coloured copper carbonate mineral found in rock.

Materials

- malachite ore or powdered copper carbonate (about 2 g)
- 1 M sulfuric acid (about 10 mL)
- steel wool
- large test-tube with one-hole stopper and delivery tube
- test-tube and test-tube rack
- limewater
- video camera or mobile phone with video function (optional)

SAFETY

1 M sulfuric acid is highly corrosive.

Wear safety glasses at all times.

Wear rubber gloves at all times.

Procedure

1 Place about 2 cm (about 2 g) of the malachite or powdered copper carbonate in the test-tube with the stopper and delivery tube.

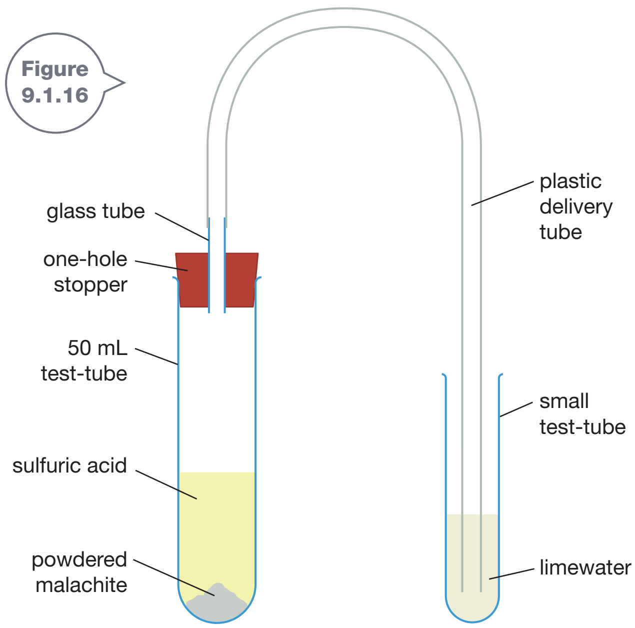
2 Pour about 3 cm of limewater into the other test-tube and place it in the rack.

3 Add about 5 cm of 1M sulfuric acid (approximately 10 mL) to the test-tube containing malachite. Replace the stopper and delivery tube, and bubble the gas through a limewater solution for no more than 30 seconds (Figure 9.1.16). Remove the end of the delivery tube from the limewater.

4 Let the test-tubes stand for a few minutes until a definite colour can be seen in the test-tube containing the malachite. Record your observations of both test-tubes.

5 Place some steel wool into the liquid in the test-tube with the malachite and leave it for 2 minutes.

Figure 9.1.16



Results

1 Record or video your observations.

2 Leave the test-tube until the end of the class and again record your observations.

Discussion

1 **Describe** the changes in the test-tube containing the malachite as the acid was added.

2 Limewater turning milky white is a chemical test for carbon dioxide gas. **Propose** what the acid did to the malachite.

3 In the test-tube containing the malachite, there were two changes that were evidence of a chemical change. **Identify** these changes.

4 **Describe** the changes to the steel wool and the solution in the test-tube.

5 **Identify** the material on the steel wool based on your knowledge of the elements.