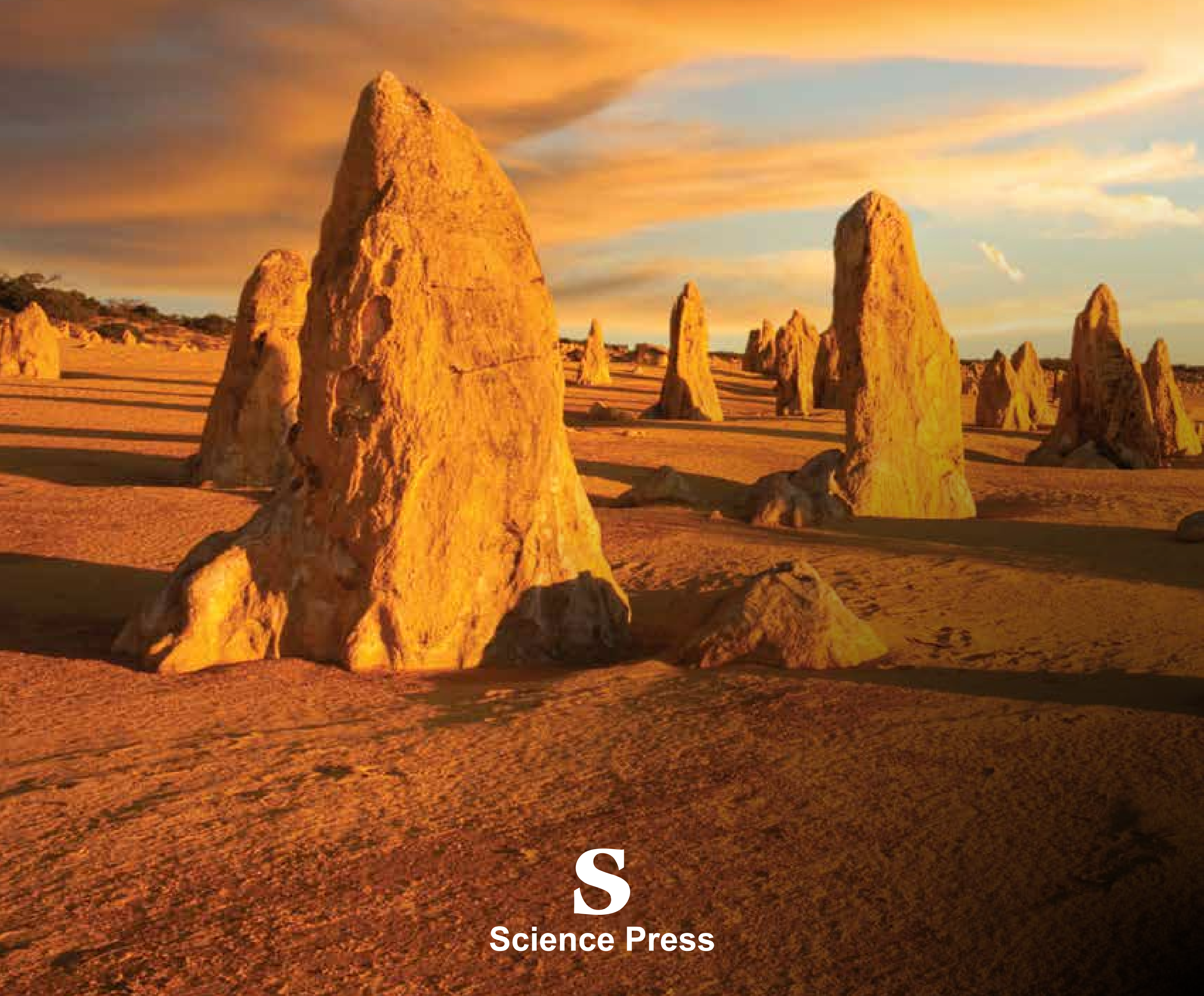
SPOTLIGHT

WACE

UNITS 3 and 4

Earth and Environmental Science

• David Heffernan • Rob Mahon •



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Contents

Words to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Chapter 1

THE USE OF NON-RENEWABLE ENERGY RESOURCES

Figure 1.1 Mining coal This open pit mine efficiently removes coal for export.

Fossil fuels today are mainly used as a source of energy – electrical power generation and transport are both powered by fossil fuels. Extensive efforts are being made to find alternative sources of energy. That will not only allow remaining fossil fuels to be used in areas where alternatives are difficult to find but also help reduce the environmental costs of using fossil fuels. Mining causes the destruction of environments, while burning fossil fuels generates greenhouse gases.

As this textbook was being written, the Australian mining industry was in decline due to a fall in overseas demand for fossil fuels and minerals. However, Australia's mineral resources will continue to be an important part of the economy of Australia for decades to come. Although mining activities only occupy a very small area of Australia, they contribute a large part of export earnings. The Australian mining industry explores, extracts and processes the ore. Some is sold as ore for refining overseas, but much is refined in this country.

However, there are increasing concerns about the impact of mining on the environment in the long term. State and local governments have laws to protect the environment and to allow access to land for exploration. Such laws are designed to minimise environmental damage during and after the mining process, and in the light of national strategies for a sustainable future.

1.1 Non-renewable resources

The welfare of all Australians depends on our many **natural resources** – things we use from the Earth, such as food, building materials, clothing fibres, minerals, water and sources of energy. Our lifestyle depends on the supply of these natural resources. We need fertilisers to increase crop yields so that only a relatively few farms can feed a whole country. We need water for agricultural and domestic purposes. We need metals to build machines and fuels so that they can do work for us. We use oil for transport and to make nearly all plastics and synthetic fibres.

To provide an idea of our reliance on natural resources, consider the minerals produced in Australia in 2013-2014.

- Bauxite: 80 million tonnes.
- Iron ore: 678 million tonnes.
- Gold: 274 tonnes.
- Uranium: 5710 tonnes.
- Black coal: 433 million tonnes.
- Coal seam gas: 7789 million cubic metres.
- Plus smaller quantities of many other ores.

As you can see, mining plays a vital role in maintaining our lifestyles.

Earth resources

Natural resources can be classified in a number of ways, one of which is from an environmental perspective. Water and such living resources as food, natural fibres and wood are **renewable resources** – they can be replaced over a relatively short period of time, like months, years or decades. Non-living resources, such as mineral and energy resources (coal, oil, uranium, metals and fertilisers), are not renewed quickly and are therefore called **non-renewable resources**. For instance, petroleum can take ten million years to be produced.

We can also classify resources according to their economic value. Earth's non-renewable resources fall into two groups – they can be high or low value resources. Metals are good examples of **high value resources**. They are produced wherever they are found. Worth hundreds or thousands of dollars per tonne, they may be transported all over the world.

Figure 1.2 Low value resource Low value resources, such as earth fill, occur near to where they are used.

Two vital terms are commonly used in mining geology. A **resource** is a substance humans need for some use(s) and a **reserve** is an amount of a resource that can be extracted at today's costs and selling prices. The total resource may be much larger than a reserve but may not become a reserve until well into the future. A good example can be seen in the Victorian brown coal resource at Yallourn and Loy Yang, in Gippsland. The brown coal is close to the surface and can be mined by relatively cheap open pit methods.

These reserves are only part of the entire brown coal resource. It may be possible in the future to mine the deeper coal but this is not presently economical.

Sand and gravel are good examples of **low value resources**. They are vital to cities and other construction projects (Figure 1.2). At only a few tens of dollars per tonne, their price means it is not economical to transport them very far – very few sand trucks would carry their loads more than 100 kilometres. Table 1.1 summarises the differences between high and low value mineral resources. Table 1.2 lists many high and low value resources.

Table 1.1 Distinguishing between high and low value resources.

Feature	Low value Earth's resources	High value Earth's resources
Size of deposit	Large	Small
Value per tonne	Low	High
Importance of where it is found as to whether it is extracted or not	High	Low
Import/export trade	Few	Many
How common?	Common	Rare
Processing needed	Little	Complex
Geology of deposit	Simple	Complex

Table 1.2 High and low value resources.

Value of the resource	Metallic	Non-metallic
High	Aluminium, titanium, copper, iron, uranium, lead, gold, silver, platinum, zinc	Phosphates, sulfur, coal (certain types), petroleum
Low		Cement, sand, clay, gravel, gypsum, coal (certain types), water

A resource is **economic** if the cost of mining is less than the price received so that a profit can be made; it is **subeconomic** when the cost of mining is too high to make a profit. The process of classifying resources as economic or subeconomic can be quite expensive and time consuming (Table 1.3). Useful resources are normally found evenly distributed throughout the crust. If we are to mine them, they have to be **concentrated** in some way. Thus a fossil fuel resource must contain a high enough concentration of a useful material to make it economical to mine.

Modern technology has dramatically increased the size, accuracy and amount of detail with which geologists can work. Resources such as minerals and fossil fuels have to be found by modern aerial, seismic and other geophysical surveys (Figure 1.3). More traditional on the ground sampling is involved as well. Eventually, drilling allows the extent of the resource to be determined and the mine or oil well can be evaluated for its economic potential. Unfortunately, all of the easy to find resources have already been located by this process.

Figure 1.3 Geophysical survey These vehicles are used to create vibrations by hitting the ground. The vibrations are detected by sensors and the patterns produced used to create a view of the geology beneath.

Locating the mineral or fossil fuel and proving it is economical to mine is only part of the problem. There are also legal considerations. Who owns the land on which the resource is found? What level of royalties will need to be paid? If the ore is discovered in a national park or on Aboriginal land, there are other legal hurdles to cross.

Environmental considerations are also vital. Can the resource be mined without destroying the local environment? Can mine wastes be contained so that they do not pollute the atmosphere or local waterways? Will transport links cause environmental problems?

If the geology of a region is well known, it is sometimes possible to infer the presence of other sources of minerals or fossil fuel that are not readily visible from the surface. Without drilling, the extent of the resource is only **hypothetical**. What about areas where exploration has never been carried out? Any estimates in such regions tend to be highly **speculative**. Part of the process used is based on history – how the rate at which estimated fuel reserves have changed over time. By extrapolating this history, geologists can speculate about future discoveries.

Table 1.3 Classifying mineral reserves and resources.

Value	Identified reserves and resources that have been measured	Undiscovered	
		In known districts	In undiscovered districts or forms
Economic	Reserves – can be mined at current costs and prices	Resources – hypothetical as their presence can only be inferred	Resources – speculative resources
Subeconomic	Resources – cannot be mined at current costs and prices		

Extending the life of resources

Satellite imagery can give views of remote regions of the world where little or no exploration has taken place (Figure 1.4). Combined with a knowledge of plate tectonics, the possibility of mineral resources can be assessed. Mining companies tend to produce much higher estimates than conservationists!

If we are using more and more of a non-renewable resource, will we run out? That is a difficult question to answer because we have not investigated the geology of the entire Earth in detail. That means we do not really know what is there. The answer also depends on the price we are willing to pay for the fossil fuel.

Figure 1.4 Satellite imagery Can be used to help find mineral reserves.

There are several ways we can meet our future fossil fuel needs.

- Find **more sources**. Even though new technology is making geologic exploration more efficient, this is becoming harder because the easy to find resources are already known.
- We can mine **lower grade deposits**. With better technology and higher prices, it may be possible to mine minerals or coal, or extract petroleum that is not economic at present. Perhaps oil shales can be mined.
- We can make use of **new technology** and mine in new ways. For example, pumping water into oil reservoirs increases the amount of oil extracted.
- We could conserve our minerals and fossil fuels by **reducing the amount we use** by doing without or making **more efficient use** of what we have left. We can do without oil resources by walking. We can reduce the need for fuel by riding a bicycle or using public transport. We can recycle plastics and metals.
- We could find **substitutes** by making use of renewable sources of energy such as solar power, wind power, geothermal power and power from waves and tides. As prices of minerals, coal and petroleum rise, conservation becomes more and more attractive.

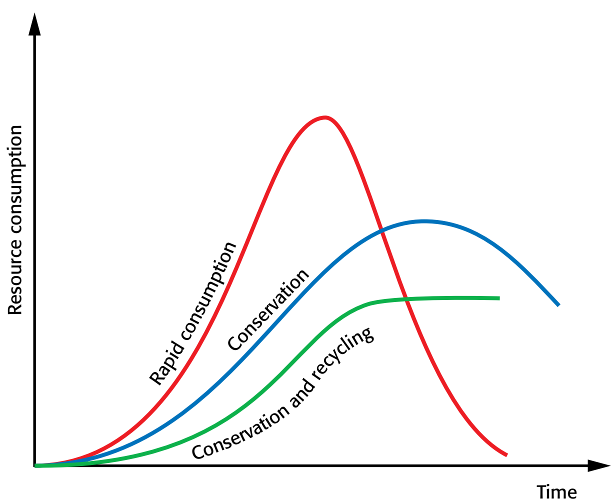


Figure 1.5 Depletion curves Three ways we can use our resources.

Just how long a given resource will last depends on what actions we take in the future. A particular resource can be used in a number of ways – there are economic, political and social factors working in each case (Figure1.5).

- **Rapid consumption.** Historically, this is what has happened with most resources. They are mined rapidly and are soon depleted. The world's fisheries are a classic example as more and more species are becoming endangered. With resources such as minerals and fossil fuels, their continued availability depends on finding and exploiting resources from other parts of the world. Eventually, they will all be gone.
- **Conservation.** More efficient mining and extraction techniques can extend the lifetime of resources. Improved technology allows for better extraction or more efficient use by industry. Wherever possible, renewable resources can be substituted for non- renewable resources.
- **Recycling.** This will lengthen the lifetime of the resource even further. There is already extensive recycling of such metals as copper, lead and aluminium.

The physics of recycling
http://qr.w69b.com/g/mTb9l3YA0

With extensive conservation and recycling it may be possible to use resources **sustainably**. This means the resource can continue to be used indefinitely by present and future generations.

However, there is always some loss of materials during manufacturing and recycling that will need to be replaced by mining or substitution. The sustainable use of fossil fuels will require extensive use of renewable energy resources in the long term.

ACTIVITY 1.1
RENEWABLE AND NON-RENEWABLE RESOURCES

Table 1.4 lists some of the materials used in a typical Australian home. Find out what each is made from and use a table to classify the original resource as renewable or non-renewable.

Table 1.4 Materials in a typical home.

Group	Materials
Building materials	Sand, gravel, stone, brick (clay), cement, steel, aluminium, bitumen, glass
Plumbing and wiring	Iron, steel, copper, brass, lead, cement, glass, ceramic pipes, plastics
Insulating materials	Rock 'wool', wool, fibreglass, gypsum (paster; wallboard)
Paint and wallpaper	Mineral pigments (e.g. iron, zinc, titanium compounds); fillers such as talc; synthetic polymers (paint); paper
Floor coverings	Rock (e.g. slate); plastics (lino and other coverings); wool (carpet)
Appliances	Iron, copper, plastics, a number of rare metals (e.g. manganese and titanium in alloys)
Eating and cooking utensils	Aluminium, iron, copper, plastics; porcelain; china
Furniture	Wool and synthetic fibres in coverings, steel in springs, wood or plastic frames
Clothing	Wool, cotton and the fertilisers and pesticides used to produce them; synthetic fibres from petroleum
Food	Grown with the help of mineral fertilisers and often synthetic pesticides; packaged in plastics by a machine made from metals
Medicines and cosmetics	Mineral and synthetic chemicals; natural chemicals
Other items	What have we missed?

SCIENCE SKILLS

1. **Evaluate** means to make a judgement of value, quality, outcomes, results or size. You need to 'weigh up' a particular situation in a balanced way. Point out the strengths and weaknesses or arguments for and against a proposition. In conclusion, state your judgement clearly. For example, **evaluate** estimates of known reserves of a named non- renewable resource in light of technological innovation.

   Answer:

   There are several possible answers. For petroleum, points you may wish to include are:

   - In past years a number of predictions have been made that petroleum reserves were about to run out.
   - Since that time, improved technology has been able to find new reserves of petroleum.
   - Improved technology has allowed reserves that were too difficult to extract to be reached, such as petroleum in arctic regions and in deeper ocean waters.
   - New technology such as pumping water and carbon dioxide down depleted oil wells has increased the recovery rate of oil from known reserves.
   - Increased prices for petroleum also mean that resources can become reserves that are economic to extract.
   - However, even if known reserves increase, petroleum is anon-renewable resource that will one day be depleted.

Table 1.5 Australia's identified mineral resources (Geoscience Australia, 2011).

Commodity	Resources that can be mined economically	Mine production
Bauxite	5665 million tonnes	69.98 million tonnes
Black coal	50656 million tonnes	461 million tonnes
Brown coal	34150 million tonnes	66.73 million tonnes
Copper (Cu)	86.7 million tonnes	0.96 million tonnes
Diamond (C)	272.5 million carats	7.6 million carats
Gold (Au)	9112 tonnes	258 tonnes
Iron ore	37762 million tonnes	488 million tonnes
Lead (Pb)	35.9 million tonnes	0.62 million tonnes
Nickel (Ni)	20.4 million tonnes	0.215 million tonnes
Phosphate rock	945 million tonnes	2.49 million tonnes
Silver (Ag)	87 900 tonnes	1730 tonnes
Uranium (U)	1.082 million tonnes	5967 tonnes
Zinc (Zn)	68.3 million tonnes	1.51 million tonnes

TO THINK ABOUT

Set 1

1. **List** five natural resources that you have already used today.
2. **Classify** the following as renewable or non-renewable: air; bauxite; coal; wood; fresh water; petroleum; salt; iron ore.
3. **Classify** the following as high or low value resources: sand for building; diamonds;iron ore; timber for building; gravel for roads; bauxite; uranium.
4. **Distinguish** between a resource and a reserve.
5. **Explain** why mineral resources need to be concentrated.

SET 2

6. Use Table 1.5 to answer the questions below.
   (a) **Identify** the biggest and smallest resource by weight.
   (b) **Identify** the biggest and smallest mine production by weight.
   (c) **Explain** why mine production is only a tiny fraction of the resource available.
   (d) **Predict** the metal whose mine production is most valuable.
7. **Describe** three ways in which modern technology is an advantage to the mining industry.
8. **Explain** why sustainable use of resources is so vital.
9. **Outline** possible legal problems that may face a mining project.
10. **Evaluate** the available methods to overcome the problem of running out of a named valuable resource.

1.2 Fossil fuels

Figure 1.6 Black coal Coal occurs in beds, with thickness ranging from less than a millimetre to many metres thick.

The fossil fuels we use today represent energy stored by the Sun hundreds of millions of years ago. Photosynthesis trapped the Sun's energy and incorporated it into plants. When the plants were part of the terrestrial ecosystem, they were sometimes buried and became coal (Figure 1.6). The plants in marine ecosystems were often microscopic in size and preyed on by equally small animals. These microscopic plants and animals are called plankton. When some of this plankton was buried, it became petroleum.

Coal

Coal is a rock produced from once living plant material. Coal is a rock that can be burnt. It is composed mainly of carbon (50 to 98 per cent), hydrogen (3 to 13 per cent) and oxygen, with smaller amounts of nitrogen, sulfur and other elements. Some water is always present, together with grains of inorganic matter, such as sand and clay. Sand and clay form an incombustible residue known as **ash**.

Coal is formed from thick layers of plant matter that have been altered by decay and various amounts of heat and pressure. Between the layers of coal are beds of other sedimentary rocks. Coal forms beds that range from less than a millimetre to many metres thick (Figure 1.6). Such a bed, or several beds separated by thin layers of shale, siltstone or sandstone called dirt bands or partings, makes up a **coal seam**.

Figure 1.7 Brown coal Brown coal occurs in beds which can be tens of metres thick.

Coal is classified by **rank**, which is a measure of the amount of change the vegetation has undergone during formation. It gradually changes as it increases in rank, from an initial **peat** stage to **brown coal**, **sub-bituminous coal**, **bituminous coal** and **anthracite**. An increase in rank is caused by a gradual rise in temperature and pressure that results in a decrease in water content and therefore a rise in carbon content. The properties of coal change gradually between these ranks. Table 1.6 summarises the properties of the different ranks of coal.

Black coal derives its name from its colour (Figure 1.6). It varies from having a bright, shiny lustre to being very dull and from being relatively hard to soft. It has higher energy and lower moisture content than brown coal. Economic resources of black coal occur in most Australian states, particularly New South Wales and Queensland, and most of those mined commercially are of Permian age (about 250 million years old). Permian black coal from New South Wales and Queensland is exported in large quantities to China, Japan, Europe, South-East Asia and the Americas. It includes the ranks of sub-bituminous coal, bituminous coal and anthracite.

Sometimes called **lignite**, **brown coal** is a relatively soft material whose heating value is only about one quarter of that of black coal (Figure 1.7). Brown coal also has a much lower carbon content and a higher moisture content. When found near the surface in thick seams, it is economical to mine it on a large scale by open pit methods. Australian brown coal deposits are Tertiary in age and range from about 15 million to about 50 million years old. Victoria is the only state that produces brown coal.

In the Latrobe Valley of Gippsland, 165 metre thick seams provide coal for Victoria's electric power industry.

Table 1.6 Coal and its properties (approximate values).

Rank/grade	Description	Typical water content (weight per cent)	Carbon (weight per cent)	Inorganic material (ash) (weight per cent)	Typical content of volatile matter (weight per cent)	Energy value (MJ/kg)
Peat	Fibrous decomposed material	40	20	5	35	15
Brown coal or lignite	Still contains woody material	35	30	5	30	25
Sub-bituminous coal	Hard blotchy appearance; dark material; slight lustre	20	40	10	30	30 to 35
Bituminous coal	Black; lustrous; strongly banded appearance	5	65 to 45	10	20 to 40	35
Anthracite	Metallic lustre; bands absent	5	80	10	5	35

Petroleum

Petroleum is a complex mixture of organic compounds divided into crude oil and natural gas. It occurs naturally in the ground and was formed hundreds of millions of years ago. Trapped in sediments, the remains of plants and animals were transformed by heat and pressure of the Earth to produce oil and gas.

Crude oil varies from oil field to oil field in colour and composition from a pale yellow, low viscosity liquid to heavy, black ‘treacle’ consistencies. It is immiscible with and less dense than water; hence it floats. Crude oils are generally classified as **tar sands**, **heavy oils** and **medium** and **light oils** on the basis of their density and relative ability to move between the grains of sediments. Tar sands contain oil that does not flow into a well drilled into the sands. Heavy oils are able to move slowly so that, given time, they can be obtained through a well if given some help (enhanced recovery methods). The medium and light oils are able to move freely through sediments and are recoverable through production wells.

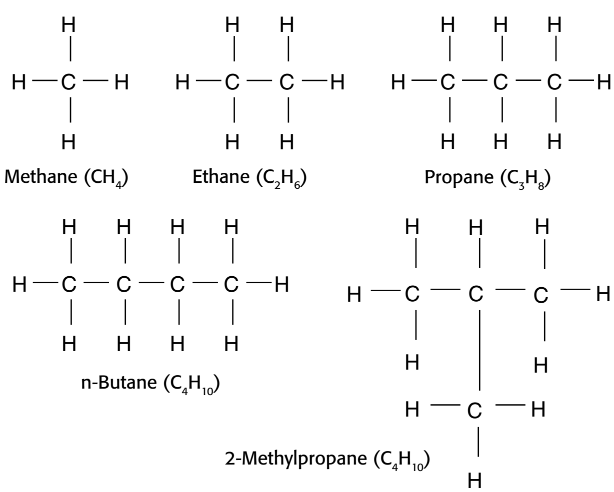


Figure 1.8 Paraffins Only single carbon-carbon bonds are present.

Petroleum consists of three main hydrocarbon groups. **Paraffins** contain straight or branched molecules with only single carbon-carbon bonds (Figure 1.8). The simplest paraffin is methane (CH_4) and, along with ethane (C_2H_6) and propane (C_3H_8), is the main ingredient of **natural gas**. With very few carbon atoms (C_1 to C_4), these have a low density and are gases under normal atmospheric pressure. Paraffins with 5 to around 40 carbons are liquids while those with more than about 40 carbons are solids (Table 1.7). Chemically, paraffins are very stable compounds.

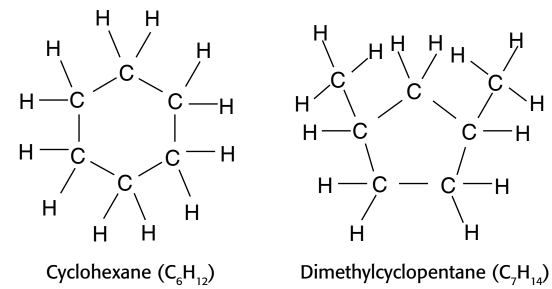


Figure 1.9 Naphthenes Like paraffins, only single carbon-carbon bonds are present.

Naphthenes are made up of carbon rings, sometimes with side chains, with only single carbon-carbon bonds (Figure 1.9). They are chemically stable, occur naturally in crude oil and have properties similar to paraffins.

Aromatic hydrocarbons are compounds that contain a ring of six carbon atoms, with alternating double and single bonds and six attached hydrogen atoms (Figure 1.10). This structure is known as a benzene ring. Aromatic hydrocarbons occur naturally in crude oil and can also be created by the refining process. The more carbon atoms a hydrocarbon molecule has, the higher its molecular weight and boiling point.

Small quantities of a crude oil may be composed of compounds that contain oxygen, nitrogen, sulfur and metals. Sulfur content ranges from traces to more than five per cent. If a crude oil contains appreciable quantities of sulfur, it is called a **sour crude**. If it contains little or no sulfur, it is called a **sweet crude**.

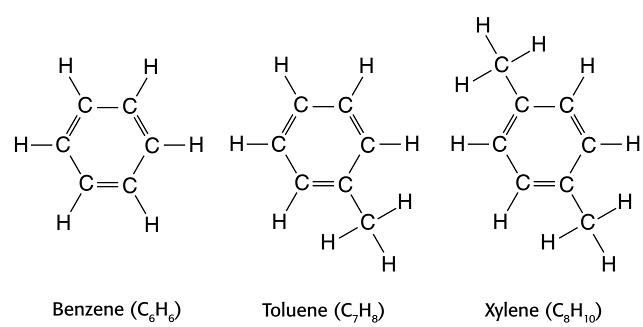


Figure 1.10 Aromatic hydrocarbons Compounds that contain a ring of six carbon atoms, with alternating double and single bonds.

Energy from gas

There are two major sources of gas that can be used as a fossil fuel. The gas can come from sources associated with coal or with petroleum. In each case, there are natural sources and synthetic sources.

Table 1.7 Petroleum and its properties.

Component	Name	Molecule	Volume (%)	State	Energy value (MJ/kg)
Natural gas	Methane	C_1	Greater than 80%	Gas	55.5
	Propane	C_3	Less than 20%	Gas	50.5
	Butane	C_4	Less than 20%	Gas	49.5
Crude oil	Petrol	C_5 to C_{10}	27	Liquid	48.0
	Kerosene	C_{11} to C_{13}	13	Liquid	52.5
	Diesel	C_{14} to C_{18}	12	Liquid	53.5
	Heating oil	C_{19} to C_{25}	10	Liquid	54.0
	Lubricating oil	C_{26} to C_{40}	20	Liquid	N/A
	Bitumen	Greater than C_{40}	18	Solid	N/A

Gas from coal

In the past, gas supplies were obtained from coal. Coal was processed to produce **Syngas**, a mixture of carbon monoxide and hydrogen. Syngas, however, has a very low energy density of around 9 kJ of energy per cubic metre of gas burnt.

Figure 1.11 Coal seam gas Coal seam gas is extracted from mines beneath and used to supply energy to power stations.

A much better source of gas is **coal seam gas** (also called **coal methane**). Australia has considerable resources of methane in the black coal seams of the east coast coal basins and is already used in some power stations. It is estimated that the amount of methane contained within these coal seams is several times greater than the current reserves for conventional natural gas. It has an energy density of around 40 kJ of energy per cubic metre of gas burnt.

Gas from petroleum

Natural gas normally occurs in association with crude oil (although some natural gas in Australia may have come from nearby coal beds). Sometimes the amounts are relatively small compared to the amounts of crude oil. At other times, there is more natural gas. It is these supplies that are piped from the Moomba fields to Sydney and from Bass Strait to Melbourne. Natural gas produces about 39 kilojoules of energy per cubic metre of natural gas burnt.

The other source of gas is the refinery process. When petroleum is refined, significant amounts of methane, ethane and propane are produced. Some of this is used to make plastics while the rest becomes part of **liquefied petroleum gas** (LPG). LPG produces about 105 kilojoules per cubic metre burnt.

ACTIVITY 1.2 EXPERIMENT: COMMON RESOURCES

Aim: To identify and classify a variety of commonly used resources and compare their properties and functions.

Apparatus

- A variety of fossil fuels, organic and inorganic compounds, metals and non-metals
- Balance, multimeter, Bunsen burner with tongs and evaporating basin, litmus paper, test tubes, etc.

Risk assessment: Medium. Wear safety glasses. Perform combustion tests in a fume cupboard. Treat acids and alkalis with care. Treat balances and multimeters with care.

Method

1. Your teacher will give you a variety of unknown resources to test. Your task is to classify them as organic compounds (such as fossil fuels), inorganic compounds, metals or non-metals. Apart from appearance and odour, you can carry out these tests.
   - Multimeter or similar to test for electrical conductivity when solid, liquid or in solution.
   - Bunsen burner to test for the ability to burn or decompose.
   - Litmus paper to test for acidic or basic properties.
   - Balance to measure density.
   - Other tests of your own devising.

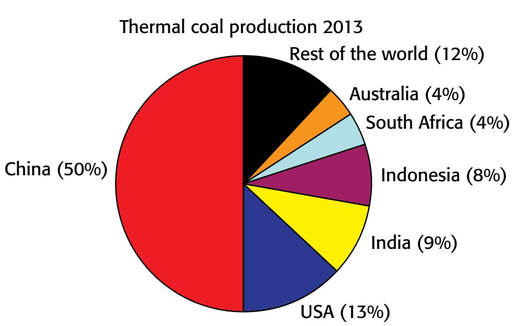
   Record your results in a suitable table, with two extra columns headed 'Uses' and 'Explanation'.
2. Refer to your library, the internet or other resources to find uses for the resources you have tested. Then explain how their properties make them suitable for the use.

ACTIVITY 1.3 FOSSIL FUELS

Use the data in Table 1.6 to produce a column graph, showing the variation of water content for the different types of coal.

SCIENCE SKILLS

1. Thermal coal is mainly used for the production of electricity. Figure 1.12 compares worldwide production and export of thermal coal.



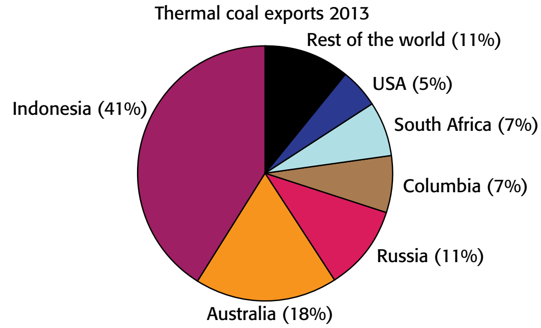


Figure 1.12 Thermal coal Graphs comparing worldwide production and export of thermal coal.

   (a) Place the identified producers in order, from smallest to largest producer.

   (b) Identify the world's largest producer and exporter of thermal coal.

   (c) Explain the differences found in Question 2.

2. Gas produced from oil wells is often called natural gas, not to be confused with coal seam gas. Figure 1.13 shows the amount of natural gas already extracted from Bass Strait and nearby areas, and the amount of gas remaining.

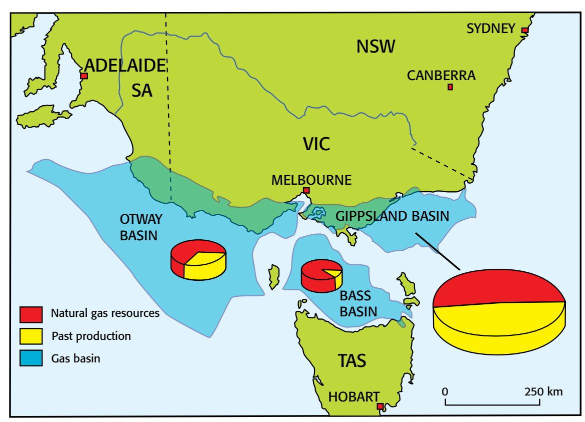


Figure 1.13 Natural gas Gas used and still remaining in Bass Strait and nearby oil fields.

   (a) Place the regions in order, from the largest to smallest producers.

   (b) Explain why one region has a much greater percentage of gas already produced compared to the other areas.

TO THINK ABOUT

SET 1

1. **Explain** why coal and petroleum are called fossil fuels.
2. **Describe** what is meant by a bed of coal.
3. **Identify** the main ranks of coal and how the percentage of carbon changes by rank.
4. **Describe** the main differences between black and brown coal.
5. **Explain** why the best coals leave only a small amount of ash when burnt.

SET 2

6. **Describe** how petroleum differs from coal.
7. **Compare** sour and sweet crude.
8. **Distinguish** between natural gas and coal seam gas.
9. **Identify** the main gas present in natural gas and coal seam gas.
10. Tar sands need large amounts of heat to be supplied so the oil can be extracted. **Explain** why.

1.3 Formation of fossil fuels

Geologists know a lot about the origins of coal. The presence of both plant remains in low rank coal and plant fossils in sedimentary rocks above and below high rank coal indicate that coal has been formed from vegetation.

Figure 1.14 Can coal or oil form here? Swamps like these in Canada form large amounts of peat.

No such remains have been left in liquid petroleum. Evidence for its origin comes from a variety of sources. Petroleum contains chemicals similar to pigments, fats and oils found in living organisms. The ratio of carbon-12 isotope compared to carbon-13 is the same as that found in living things rather than the ratio found in the non-living environment. The hydrocarbons found in petroleum have the same effect on polarised light (optical activity) as those in living things. As we will see, however, some puzzles are still left to be solved.

Formation of coal

The Permian coal deposits of Australia began forming around 300 million years ago when lush plants flourished in ideal growing conditions. One environment that has been suggested is a **foreland basin** between the growing Australian continent and an island arc forming above a subduction zone (Figure 1.15). While the island arc eventually formed the New England fold belt, the accumulation of plant matter and sediments left behind produced the massive coal deposits from the Sydney Basin north to the Bowen Basin. Australia was much closer to the South Pole and in the cooler conditions large peat swamps would grow as well as ferns, seed ferns such as *Glossopteris* and the now extinct scale trees.

The Victorian brown coal deposits are much younger. Large amounts of vegetation were deposited into the Gippsland Basin during the Miocene. The plant remains present are much more modern than found in black coal, and include Huon pine and blueberry ash. Because these deposits have only been buried for around 15 million years, they have only progressed to the brown coal stage.

The swamps where coal formed were low in oxygen and very cool, unable to support the normal bacteria that cause decay. As a result, the plant material that fell into the swamps did not rapidly decompose. The mass of plant material was partially decayed by different bacteria to form **peat** – a soft, brown and spongy fibrous material that is the first stage of coal formation. Similar swamps occur today on a large scale across the northern regions of Canada, Russia, Scandinavia and Ireland (Figure 1.14).

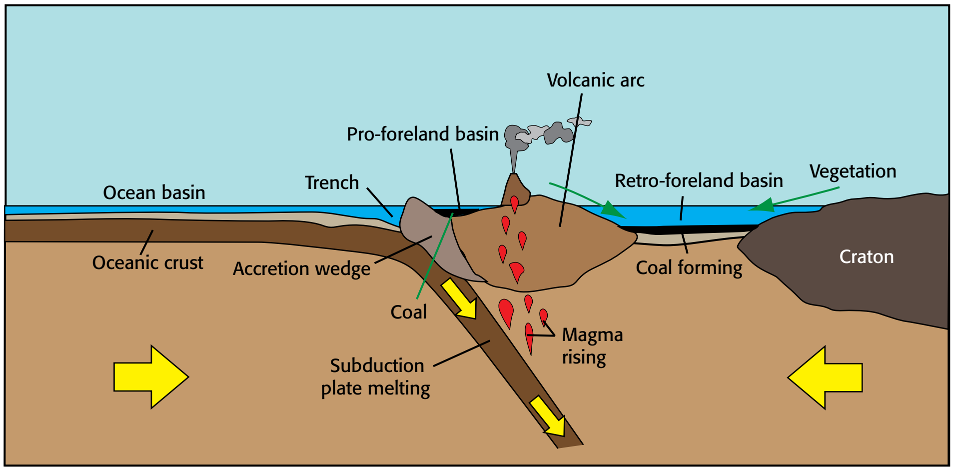


Figure 1.15 Coal forming environment The foreland basin where plant matter collects eventually forms the coal basins of New South Wales and Queensland. The island arc forms the New England plateau and volcanic mounts extending into Queensland.

Coal formation http://qr.w69b.com/g/ryiAvbiSc

Gradually, this peat became buried by sediment such as mud, sand and other material. Since these sediments originate from terrestrial and marine environments, it is believed the swamps existed on a massive scale in the back arc basin. As the weight of accumulated plant materials and sediment caused the coastal regions to sink, the ocean invaded the area and buried it with marine sediment. This eventually silted up and enabled freshwater swamps to re-establish so that alternating layers of coal-forming plants and sediment produced a number of coal seams separated by varying thicknesses of rock.

The initial burial of the plant matter allows bacterial and fungal attack to begin. This plant material thus begins to decompose and emit mainly methane gas but also some carbon dioxide and ammonia. Gases formed biologically in this way are called **biogenic gases**.

As the coal became buried under hundreds and thousands of metres of rock cover (called **overburden**), it was subjected to heat and pressure. The liquid and gaseous contents of the coal, such as water, carbon dioxide and methane, were forced out, leaving behind a material that progressively solidified and became denser. This coal making process is called **coalification** (Figure 1.16).

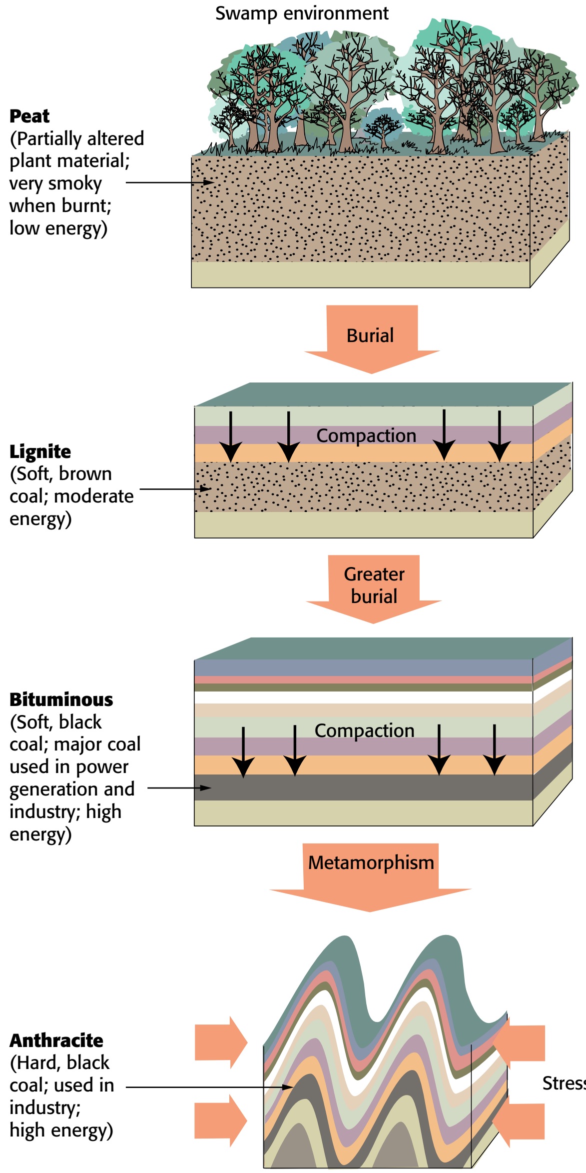


Figure 1.16 Coalification The successive stages in coal formation.

Coalification goes through the following stages of maturity (rank).

- **Peat** develops from partially decomposed plant remains. It is often possible to identify the leaves, bark and wood of the original plants. Peat can be either spongy and light brown or dense and black. It contains up to 90 per cent water, which must be reduced to 30 per cent before it can be burnt. It burns with little smoke or flame.
- **Brown coal** is formed from peat after exposure to heat and pressure over long periods of time (Figure 1.17). It is more compact than peat and dries out and crumbles when exposed to air. Brown coal has a high moisture (up to 60 per cent) and oxygen content, with a corresponding low heating value. It is likely to undergo spontaneous combustion if allowed to dry out. This coal is used widely for power generation in Victoria. It is made into briquettes as a source of solid fuel and can be converted into liquid or gaseous fuels.
- **Black coal** is a solid rock and forms from brown coal after greater heat and pressure have been applied by longer and deeper burial (Figure 1.17). Black coals are distinguished by rank and may be sub-bituminous, bituminous or anthracite.
  - **Sub-bituminous coal** is usually dull black and waxy in appearance. Its carbon content is higher than that of brown coal (71 to 77 per cent), though its moisture content is about 10 per cent. Sub-bituminous coal is a valuable fuel for power generation and can be converted into liquid or gaseous fuels. In Australia there are deposits in Queensland, New South Wales, Tasmania, South Australia and Western Australia.
  - **Bituminous coal** is dense black and solid. It frequently contains bright bands with a brilliant lustre. The carbon content ranges from 78 to 91 per cent, the water content varies from 1.5 to 7 per cent and it burns with a luminous flame. There are many varieties of bituminous coal that, depending on their characteristics, can be used for gas making, steam raising or coke making.
  - **Anthracite** is a jet black coal with a brilliant lustre. Its carbon content is over 92 per cent and its moisture content is very low. Although difficult to ignite, anthracite has a high heating value and burns slowly with a pale blue flame. It conducts electricity and can be blended with bituminous coals to improve coking qualities.

Australia has very little true anthracite – most of the coal mined in New South Wales and Queensland is bituminous coal while brown coal is mined in Victoria.

Figure 1.17 Coal Comparing black and brown coal.

While methane gas is formed biologically in the upper layers, the bacteria that produce *biogenic gases* are killed at greater depths. However, at greater depths gas formed by **thermal cracking** becomes more important. In this process heat and pressure cause chemical bonds in large molecules to break, resulting in smaller gas molecules. Gases created in this way are called **thermogenic gases**. Those made by biogenic and thermogenic means become trapped in the minute pores and form the coal methane studied earlier.

During coalification, changes in appearance and composition take place.

- Colour goes from light brown to black and usually from dull to shiny.
- Texture alters from soft and fibrous to hard and granular.
- Density increases as the coal becomes more compacted.
- Moisture content decreases from about 90 per cent in peat to 1 per cent in anthracite.
- Level of tar and gases given off when burnt lessens.
- Heat released per kilogram rises.

Comparing the formation of petroleum and coal

Coal and petroleum are both formed from the remains of living things. However, no one is totally sure how enough organic matter could have been concentrated to produce the large amounts of oil and natural gas that have been found.

The rocks that hold petroleum are mostly sandstones (60 per cent) and limestones, including dolomites (40 per cent). These are the same typical sedimentary rocks associated with coal. Very little of the world's oil has been found in fractured igneous or metamorphic rocks because they lack the pore space needed to successfully hold petroleum.

Physically, petroleum sources are fluids, whereas coal is a solid. Such a difference has important consequences. As a fluid, petroleum can move and the rocks from which it is extracted are usually *not* the same as those in which it was formed. It also means that, in order to be available for large scale extraction, it must be 'trapped' under impermeable layers of clay, shale or salt.

Chemically, petroleum sources are mainly hydrocarbons, whereas much of the hydrogen in coals has been lost. Both fossil fuel sources are essentially complex mixtures, with no two deposits chemically the same. Coal often has a much higher sulfur content than petroleum – therefore coal has lost favour for domestic use with the increasing concern over air pollution.

Formation of petroleum

Most geologists believe the major source of petroleum was floating plankton – minute marine plant and animal organisms. When they died, their remains sank to the sea floor (Figure 1.18). This debris is rich in organic fats and oils but also contains proteins and carbohydrates. There was a deficiency of oxygen (anaerobic conditions) in these waters, so animal and plant remains were subject to decay caused by methane-producing bacteria.

While correct for many overseas oil deposits, the way in which some Australian deposits have formed differs from the description above. Those deposits off the north-west Australian coast have mainly come from marine sediments as well as contributions from plant sources. However, the major source of petroleum found in Gippsland and western Queensland is land plants.

Formation of oil and gas
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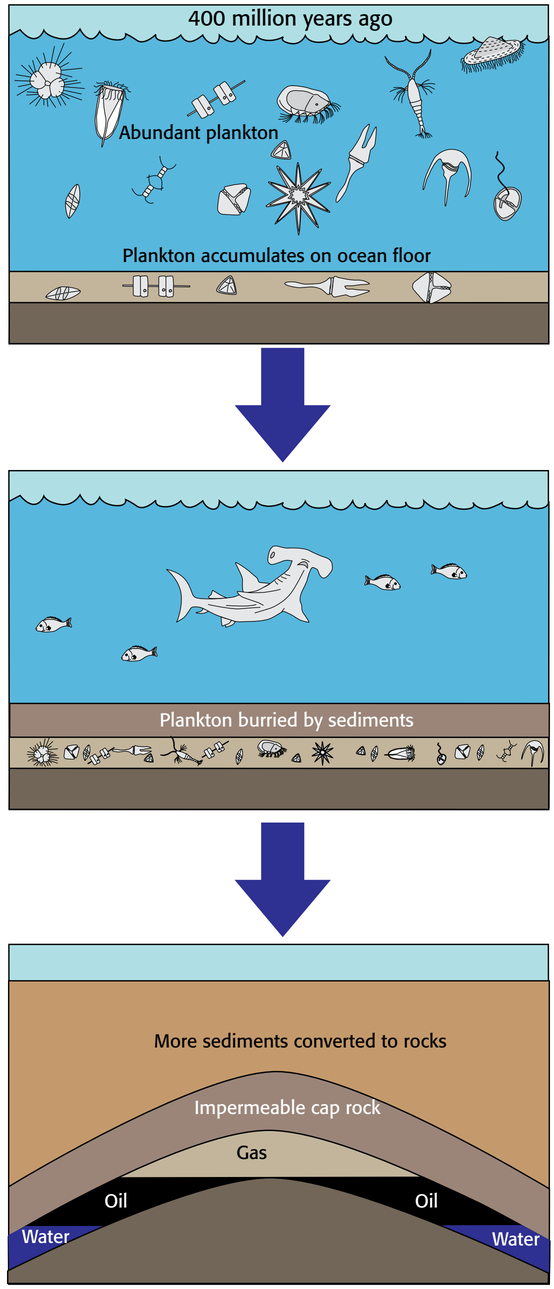

Figure 1.18 Formation of oil The conversion of organic matter into oil and natural gas depends on depth of burial. The natural gas and oil often migrate from where they are formed.

One possible location where this has occurred is in the seas formed when Australia separated from other continents (Figure 1.19). The Western Australian petroleum deposits formed as Australia separated from India during the Cretaceous, a process called **rifting**. Some of these rifts never resulted in separation but still provided deep ocean regions where plant material, plant rich sediments and marine organisms could be deposited. When buried the weight of sediments above as well as heat and pressure from plate tectonics resulted in formation of oil.

The petroleum and gas deposits off the coast of Victoria formed as Australia separated from Antarctica in the late Cretaceous. A large rift developed between the two continents as they slowly drifted apart. In the early stages large amounts of vegetation and plant rich sediments were deposited into the rift and then buried. Subsequent plate tectonics would help provide heat and pressure for the formation of petroleum.

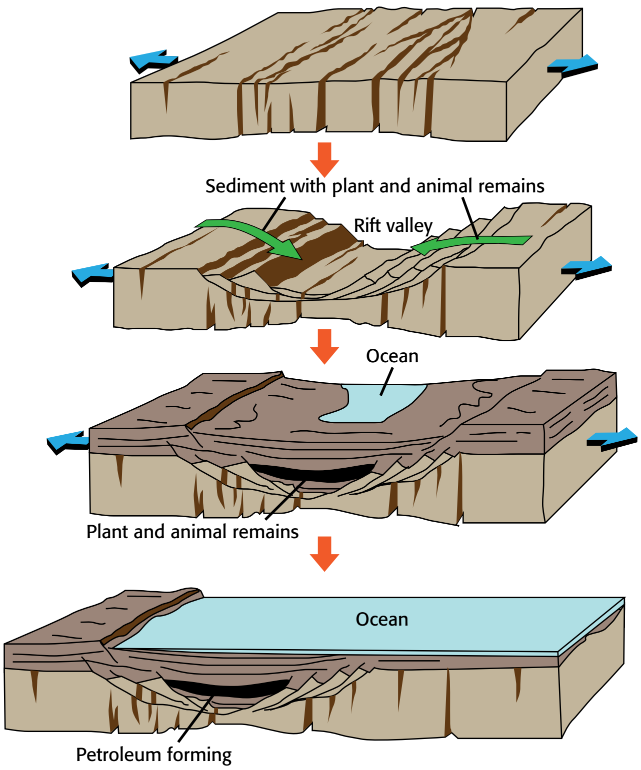

Figure 1.19 Oil-forming environments The Gippsland location of petroleum formation is a deep rift formed as Australia separated from Antarctica. Carbon rich sediments as well as plant and animal remains are deposited in the rift where they were buried.

The process of oil and gas formation in marine sediments is shown in Figure 1.20. The depth scale, which also corresponds to a general increase in time and temperature, is only approximate and may vary with the nature of the original organic matter. The depth of burial has been subdivided into three major zones that correspond to increasing temperature and pressure caused by the weight of rocks above and the heat from the Earth's core.

Diagenesis occurs from the surface of the depositing sediment to depths of a few hundred metres, where temperatures are generally less than 50°C and pressures more than 1000 atmospheres. Some of the organic matter is oxidised by oxygen from the air or consumed by burrowing organisms. Anaerobic bacteria are commonly very active in the upper parts of this zone and are responsible for the conversion of organic matter into a sticky liquid and considerable amounts of biogenic methane and other gases.

Catagenesis occurs at depths to about 3.5 to 5 kilometres, where the temperature range is 50°C to 150°C and pressure rises to 1500 atmospheres. This combination of factors brings about the compaction of rock and the expulsion of water. The organic matter is progressively altered, becoming a thick organic material called kerogen and liquid petroleum.

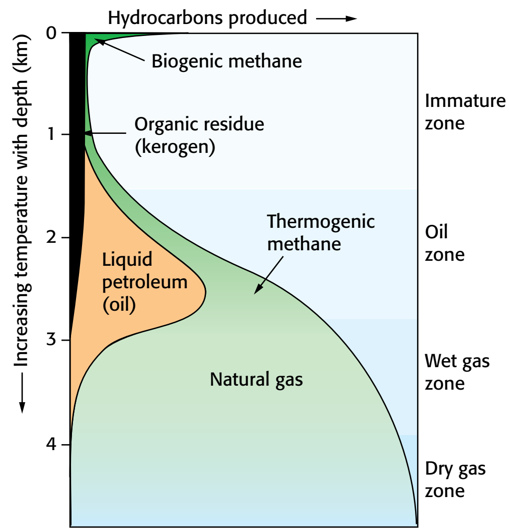

Figure 1.20 Formation of oil The conversion of organic matter into kerogen, oil and natural gas as a function of depth of burial.

Below depths of 3500 to 4000 metres, the temperatures exceed about 150°C and the pressure rises above about 1500 atmospheres. Under these conditions the early stages of metamorphism take place. This process is called **metagenesis** when applied to organic matter. At this point, the leftover organic matter is either converted into gas, which is nearly pure thermogenic methane, or remains as a carbon rich solid residue.

Thus there are a number of factors that will determine if a deposit is mainly crude oil, natural gas or both. Natural gas is mainly produced in shallow and in deep deposits. Crude oil is produced at intermediate levels. However, liquids and gases can migrate from their point of formation. Thus a deposit may end up as a mixture of the two.

ACTIVITY 1.4
FORMING COAL AND PETROLEUM

Figure 1.21 shows a geologic map of Western Australia, indicating the location of sedimentary basins and fold belts. Conduct your own research to find the ages of the major geologic structures in your state, and answer the questions that follow.

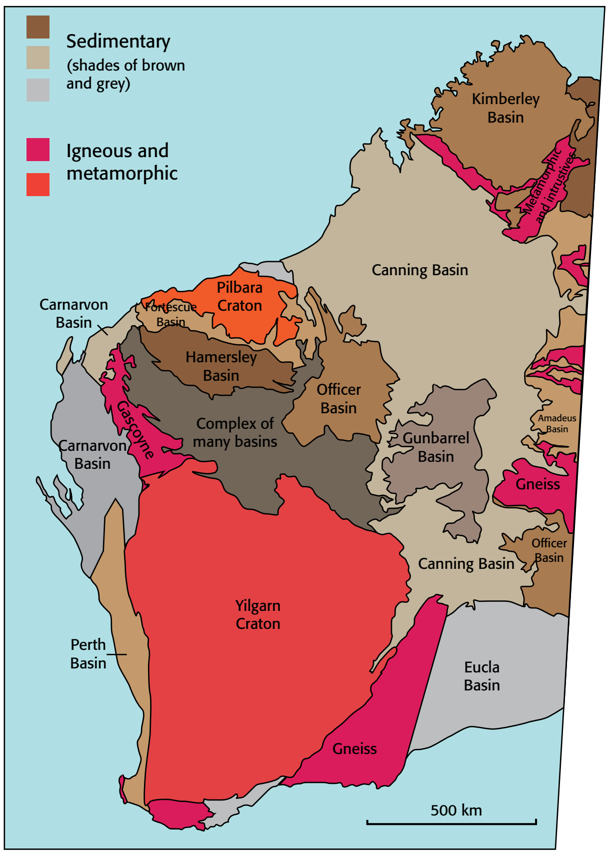

Figure 1.21 Geologic map of Western Australia The locations of the major sedimentary basins and fold belts.

1. Use your knowledge of coal formation to predict the best places to look for coal. Justify your selection.
2. Use your knowledge of petroleum formation to predict the best places to look for petroleum. Justify your selection.

ACTIVITY 1.5
COAL AND PETROLEUM-FORMING ENVIRONMENTS

1. Compare the environments in which coal and petroleum are formed.
2. Use the information above to construct flow charts for the processes used in the formation of:
   - Coal
   - Petroleum

   Align your flow charts to highlight the similarities in the two processes.

SCIENCE SKILLS

1. **Discuss** means to identify issues and provide points for and/or against. Thus you need to present a point of view, that of others and/or your own. The views expressed should be supported by arguments and evidence. For example, **discuss** the process of coalification – transforming vegetable matter into peat and coal.

   Answer:

   Points you may wish to include are:
   - Coalification is the process by which plant remains become coal.
   - Initial bacterial action in anaerobic environments produces gases such as methane.
   - Burial forces out liquids and gases such as water, carbon dioxide and methane.
   - The level of compaction and heating determines the final rank of the coal.
   - Texture alters from soft and fibrous to hard and granular.
   - Density increases as the coal becomes more compacted.
   - Moisture content decreases from about 90 per cent in peat to 1 per cent in anthracite.
   - Heat released per kilogram rises.

TO THINK ABOUT

SET 1

1. **Outline** evidence that coal is a sedimentary rock.
2. **Describe** the environment in which Australia's coal may have formed.
3. **Compare** peat with brown coal.
4. **Outline** the process of coalification.
5. **Explain** why brown coal in Victoria has not become black coal such as in New South Wales and Queensland.

SET 2

6. **Describe** what would happen to vegetation in foreland basins if they were not buried.
7. **Identify** the major source of living things that formed petroleum.
8. **Outline** the process that forms petroleum.
9. **Describe** the environment in which petroleum has formed.
10. **Explain** the importance of rifting in the formation of petroleum.

1.4 Exploration and extraction of coal

Figure 1.22 Mining coal Underground coal mining is highly mechanised (CSIRO).

Coal is one of the most important minerals mined in Australia (Figure 1.22). It is a big export earner and is used locally to produce electricity and steel. Approximately 75 per cent of Australia's electricity requirements are met by coal fired power stations. Coal comes from underground mines and open pit mines. In the past, most came from under ground but today most comes from open pit mines. The current annual rate is around 200 million tonnes mined of metallurgical coal (e.g. for steel making) and around 300 million tonnes mined of thermal coal (e.g. for power stations).

Coal exploration

Coal was first found in Australia in 1791 near Newcastle in NSW and was being mined by 1797.

It was also being mined both at Lithgow and on the south coast near Wollongong by the 1850s. The extent of our coal resources was well known by as early as 1900 even though mining of many deposits may have only begun recently.

Government and industry geologists have carefully mapped Australia (Figure 1.23). As a result they know where the sedimentary basins are located. Seismic studies reveal the depth and thickness of coal seams. A search along the edge of the basins will reveal if coal is close to the surface and can be economically mined. It also helps to have the coal as close to markets as possible to reduce transportation costs.

The next step is to find out the quality of coal by drilling into the seams. This will tell you if the coal seams are thick enough to mine and will also allow samples to be analysed to see if the coal is of a suitable quality. For this to be the case, it needs to have a high rank to produce as much heat as possible per kilogram. Also, the coal should not contain too much sand, clay or dirt because this increases the costs of cleaning up the coal.

Coal needs to be safely transported to where it will be used, in Australia or overseas. Black coal poses little problem in this respect. However, brown coal generates a lot of heat when it dries out on exposure to air and is likely to catch fire if transported over large distances. The use of brown coal is therefore restricted to power stations close to where it is mined.

The amount of ash produced during combustion must be measured. Ash is an inorganic material, such as clay and sand, that has to be removed from smoke or remains after the coal is burnt. Since it has to be disposed of, the less ash the lower the costs of production. The chemical nature of the ash is also important because it can cause boilers to corrode when the coal is used to produce steam.

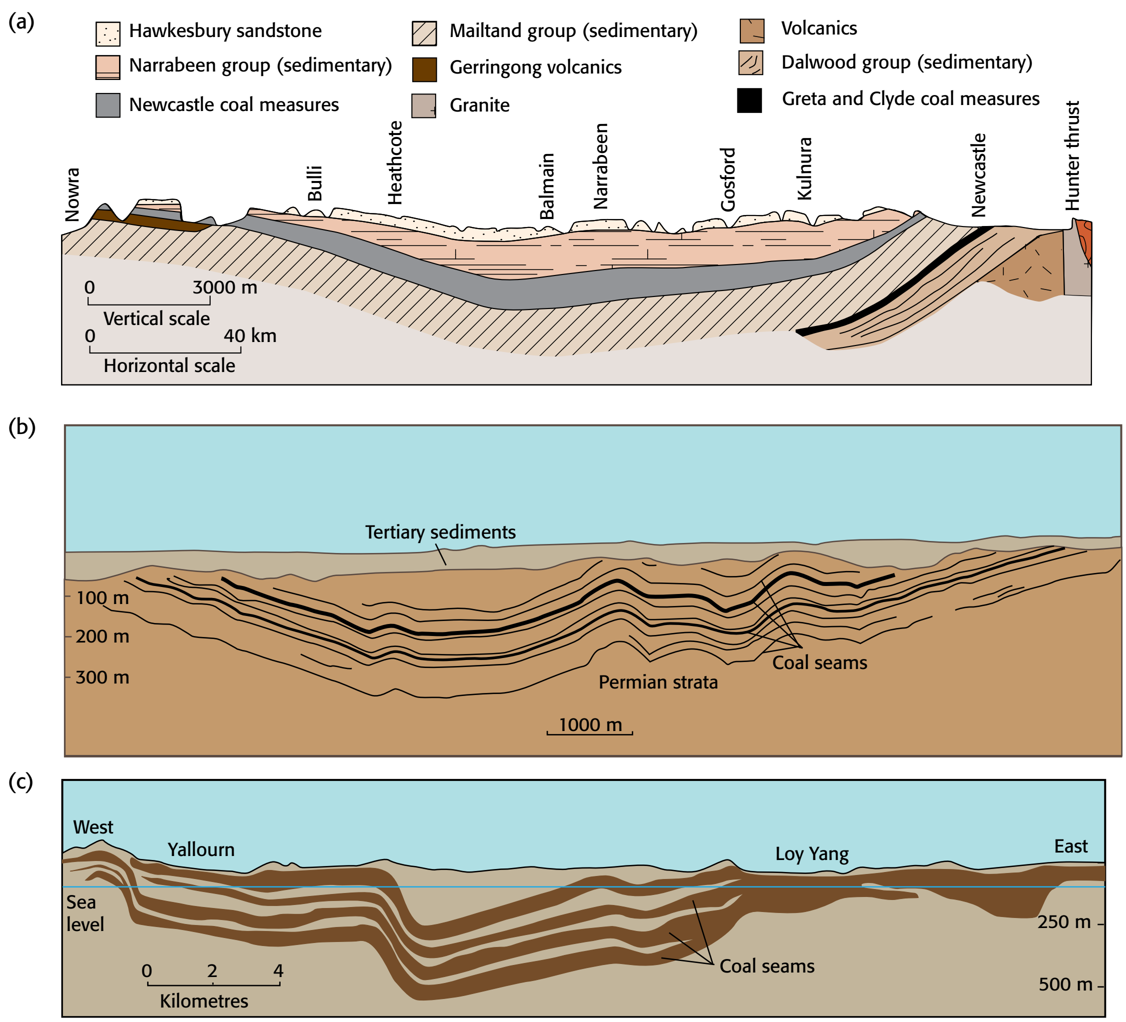

Figure 1.23 Coal deposits (a) The Newcastle coal measures in NSW. (b) Bowen Basin in Queensland. (c) Latrobe Valley, Victoria.

Coal also needs to be low in sulfur. When sulfur burns, it yields sulfur dioxide gas. Since sulfur dioxide is responsible for acid rain, it must be removed from the waste gases produced. The less sulfur, the lower the cost of waste disposal.

The characteristics of rocks above a coal seam are important. If the mine is open pit, the overburden needs to be removed easily. The quality of the rocks in the walls will determine if there is a chance that the walls of the pit will collapse. The location of any igneous intrusions such as dykes and sills need to be determined as well as any faulting.

The quality of those rocks above the coal seam is especially important in underground mining. Their strength will reveal how much roof support is needed. In addition, the presence of methane pockets in the coal seam will determine the danger of underground explosions.

ACTIVITY 1.6
COAL EXPLORATION

Using information in this chapter, as well as other sources of information, **outline** the methods and technologies used to locate coal reserves, including the following.

- Reports of coal by early explorers.
- Mapping of geologic basins.
- Seismic studies to determine the extent and thickness of coal beds.
- Magnetic and other studies to locate faults, sills and dykes that could interfere with mining.
- Drilling to determine the rank of coal, ash and sulfur content and the characteristics of rocks above, below and around the coal seam.

Extracting coal

There are two main methods of mining coal – underground and open pit mining. Open pit mining is sometimes called surface or strip mining. The method to be implemented is determined by the depth of the coal deposit. Open pit mining is employed when the coal seam lies close to the surface (Figure 1.24). Its current limit in Australia is about 120 metres, but studies are under way to increase this depth.

Extracting coal

Open pit mining is more economical than underground mining.

- A greater proportion of the coal seam can be recovered. The supporting columns of coal do not have to be left behind.
- The economical extraction of thin seams becomes possible.
- A 3 metre thick seam can be economically mined if overburden is not over ten times greater in thickness.
- There are lower accident rates as no ceilings collapse.
- There is less exposure to coal dust.
- The average production per shift worked is higher.

With open pit mining, the overburden of soil and rock is first broken up by explosives and then removed by huge mechanical excavators called walking draglines or, if only a small amount of overburden exists, by trucks and shovels (Figure 1.24). Draglines weigh over 3000 tonnes and can remove 100 tonnes of overburden in a few minutes. It would take 20 000 workers with shovels and wheelbarrows to move the daily capacity of one dragline.

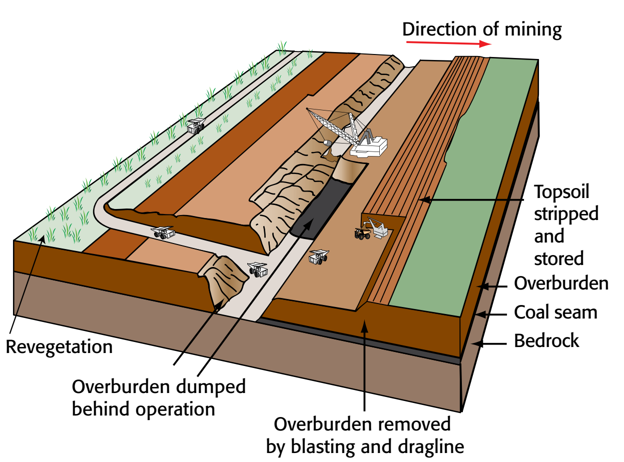

Figure 1.24 Open pit mining The most efficient way to mine coal close to the surface.

Once the coal seam is exposed, it is drilled, fractured and systematically mined in strips. The loosened coal is then loaded by electric power shovels onto a fleet of large trucks for transport to the coal preparation plant, where it is stockpiled.

Open pit mining of coal
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Land disturbed through open pit mining must be rehabilitated, which involves stockpiling the overburden and topsoil. This stockpile must be made into stable slopes to stop soil eroding and polluting streams. After the coal has been removed, the site is reshaped to conform to the surroundings – landscaped, topsoiled, fertilised and sown to pasture.

Underground mining

Most underground coal mines in Australia operate at depths of between 150 and 500 metres (Figure 1.25). The coal seam, usually with a thickness greater than 1.5 metres, can be reached from the surface in two ways. A vertical hole called a **shaft** may be sunk down to the seam or a **sloping tunnel** may be driven from the surface to the seam. Both methods are used to provide access, ventilation, power, water pipes (for spraying the coal face to prevent airborne dust) and for communications. The sloping tunnel is generally preferred because coal can be transported by conveyor straight to the surface in a continuous operation, and miners can walk to the surface in an emergency.

Underground mining of coal
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There are two main methods used to mine the coal – room and pillar and longwall. With the **room and pillar system**, an electrically powered machine about 10 metres long called a continuous miner extracts coal from the face with a rotating cutting head (Figure 1.25 (a)). The coal is automatically gathered by steel arms and dumped into shuttle cars that transport it to a conveyor system for removal from the mine. Pillars of coal are left to support the ceiling. They are sometimes mined later and the ceiling is then allowed to collapse.

In the **longwall system** (Figure 1.25 (b)) two tunnels, or headings, are cut into the coal seams at a distance of 100 to 200 metres and are joined by a third connecting tunnel at the far end. This third tunnel becomes the coal face, and the block of coal lying between the two main headings is mined away. The coal is cut by a rotating shearer that shaves it off the long face. When the shearer has completed a traverse of the entire coal face, all of the longwall equipment – shearer, conveyor and roof supports – moves forward closer to the coal face.

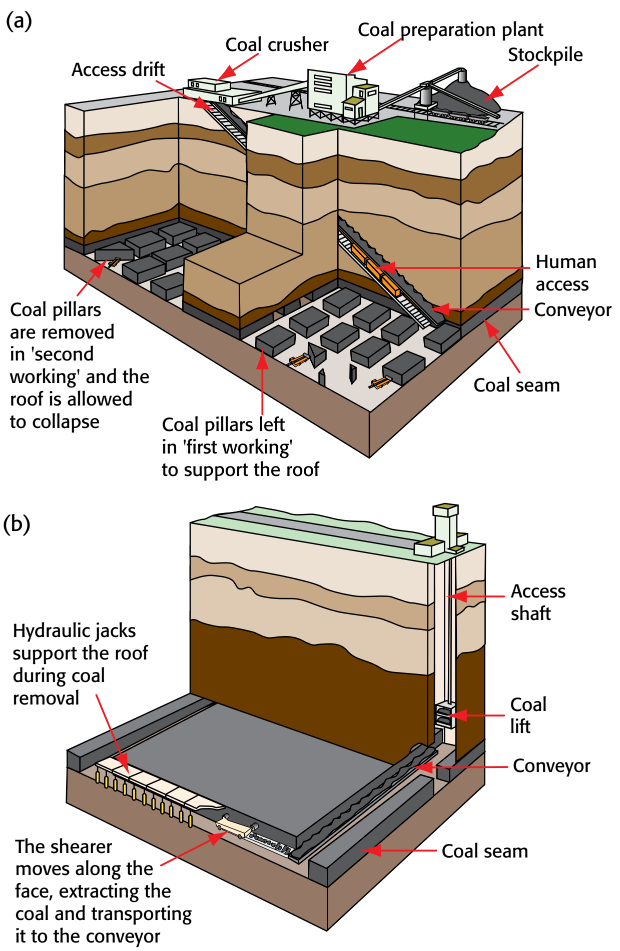

Figure 1.25 Underground mining (a) Room and pillar system. (b) Longwall mining.

Next, the hydraulic steel jacks supporting the ceiling are moved forward with the cutter and the ceiling is allowed to collapse. A steel conveyor running along the whole face takes the coal away. This system is the safest for miners because the hydraulic jacks holding up the face give continuous support to the roof while the coal is removed. Longwall mining achieves very high rates of output and allows for almost total extraction of the seam.

Refining coal

Black coal may be used without any processing other than crushing and screening (a type of filtering) to reduce the rock to a usable and consistent size. However, it is often **washed** to remove pieces of rock or mineral that may be present, cutting ash and improving overall quality.

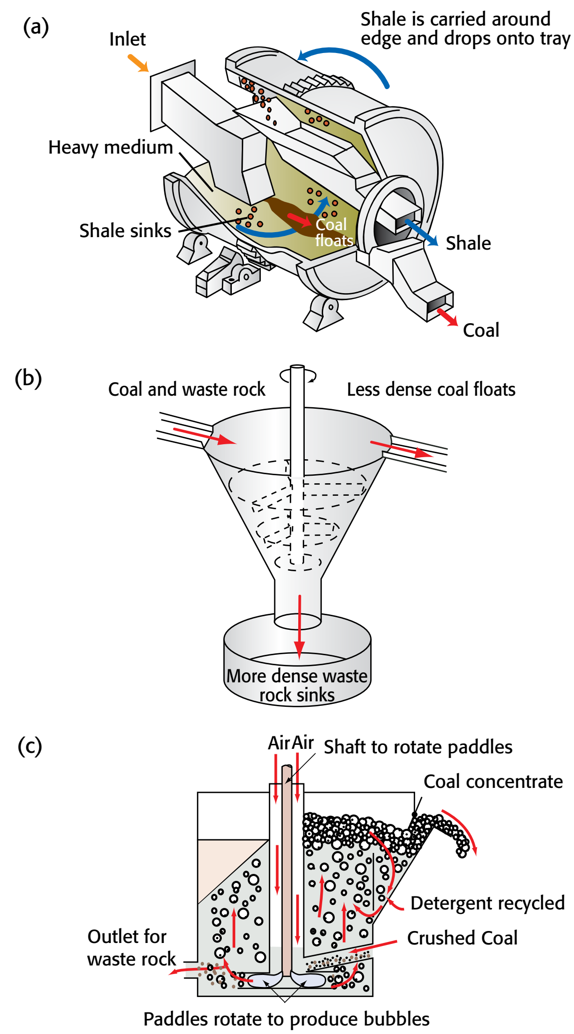

Figure 1.26 Washing coal (a) In the dense medium process, the denser rocks sink while the less dense coal floats. (b) In a dense medium cyclone, the denser rocks move around the outside to the bottom while the less dense coal moves to the middle and leaves through the top. (c) In froth flotation, the finely ground coal sticks to bubbles and floats to the top where it is scraped off.

The methods for washing vary from mine to mine (Figure 1.26).

- Some mines apply the **dense media separation** process (also called **sink float)**, where the crushed coal and waste rock is added to a high density liquid in which the coal floats and can be recovered while the heavier waste rock sinks and is discarded.

- Other mines use **dense media cyclones**, where the crushed coal and waste rock is added to a high density liquid and forced into a cyclone where it rotates around the centre. The denser waste rock moves to the outside and slides to the bottom, while the less dense coal moves to the centre and leaves through the top.
- Other mines with finely crushed coal rely on **froth flotation**, where the coal sticks to bubbles and floats to the surface and is skimmed off. The coal and bubbles are then separated.

Once the coal is separated it must be dewatered ready for shipment to markets.

Making use of coal

The export coal fields of Australia are located relatively close to the coast and the main ports and industrial centres of NSW and Queensland. It is not uncommon to haul coal more than 100 km from mine to port. The three most common methods of transporting coal are conveyor, road and rail.

Conveyors are used extensively for short distance transport within the mine area and from mines to power station stockpiles. **Road transport** is important in some coal fields, for both short distance coal haulage from mines to the railhead and delivery to domestic customers. **Rail** is the most vital and efficient method, particularly for coal destined for export – the rail network servicing the New South Wales and Queensland coal mines are several thousand kilometres long. Coal to be exported is shipped to the ports along the NSW and Queensland coast (Figure 1.27).

Figure 1.27 Exporting coal Coal is exported by ship to all parts of the world (CSIRO).

Steaming coal (usually non-coking coal) is used to provide heat energy. The most widespread use of steaming coal is in a crushed or pulverised form burnt in thermal power stations to provide heat to generate steam. This steam drives turbines that in turn generate electricity.

Coking coal is high quality, high rank black (bituminous) coal, often called metallurgical coal, that is converted into coke for the manufacture of steel. When heated in large, airless ovens, virtually all of the coal's volatile matter is driven off as gases and vapours while the material left behind produces hard, thin walled bubbles called **coke**.

Coke is composed almost entirely of carbon and is used in blast furnaces to provide a consistent, high and clean heat that converts iron oxide (iron ore) into metallic iron. Coke also supplies the carbon required in steel manufacture. The gases and vapours driven off from coke production are finally cooled and treated to separate out the by-products. These include refined coal tar used in plastics, explosives, dyes, pitch and ammonia and other chemicals used in fertilisers, cement, bricks and tiles.

Coal and the environment

The costs of coal mining vary from region to region. The Hunter Valley north of Sydney has been prime agricultural land since the 1800s. It is the home of famous vineyards, horse studs, dairy and other pastoral industries. It has been able to coexist with a coal industry in the region since the 1830s. There are also several power stations generating electricity using the local coal. However, the rapid expansion of coal mining has begun to threaten these local industries.

Figure 1.28 Hunter Valley Mining affects air quality of towns.

Coal mining has been allowed to encroach on towns, covering them with dust for long periods of the year (Figure 1.28). The long term effects of this dust is believed to have contributed towards lung cancer and chronic heart, respiratory and kidney disease related to living near coal mines. Asthma rates amongst children are much higher in this area. However, Australian governments are unwilling to fund health research on this subject, and the evidence comes from overseas studies.

Coal has been mined in several parts of Queensland for some time, including the Bowen and Surat Basins. However, it is the new mines in the Galilee Basin inland from Mackay that are causing most concern. Locally the mine will need 12 gigalitres of water a year. Since the nearby river only flows in the wet season, much of this water will have to come from the Great Artesian Basin. This in turn will affect local farming and its use of water in what is a dry region.

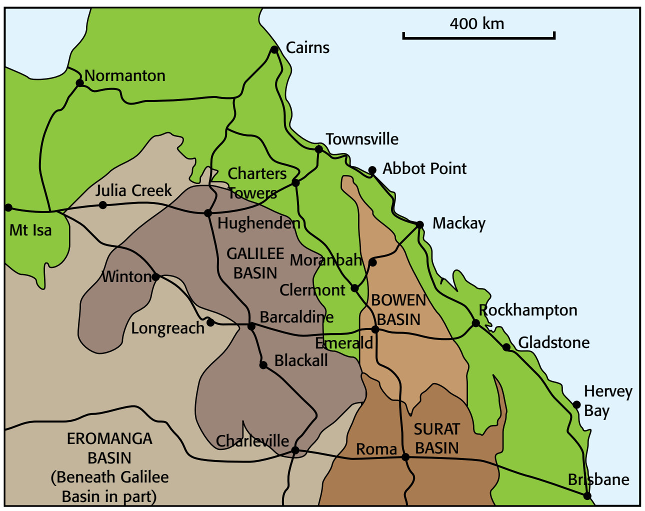

Figure 1.29 Galilee Basin Mining will export much of its coal from Abbot Point.

Of most concern is the building of ports inside the world heritage Great Barrier Reef. Railways will need to be extended to bring the huge quantities of coal to ports along the coast so the coal can be shipped overseas. The two major ports are at Hay Point just south of Mackay while Abbot Point is just south of Bowen (Figure 1.29). While there are plans to expand both coal exporting terminals it is the one at Abbot Point that is causing most concern. The original plan was to dredge the harbour and dump the sediments out near the Great Barrier Reef. This caused outrage around the world and in Australia. Under pressure from Australian voters, UNESCO and other bodies the government relented and agreed to use taxpayer funds, if needed, to dump the sediments on land so they could not reach the reef.

Brown coal is found in the Gippsland Basin east of Melbourne. It fuels 92 per cent of the electricity generated in Victoria, making it a huge contributor to our total greenhouse gas emissions. It creates more pollution than other fuels such as black coal, natural gas and much more than clean renewable energy. This makes Victorians among the most greenhouse polluting people per capita on the planet.

Figure 1.30 Brown coal mining The fire of 2014 (ABC/CFA).

Brown coal readily ignites and burns. That happened in 2014 when embers from a nearby grass fire set one of the open pit mines alight (Figure 1.30). The area had been mined but not completely rehabilitated so that brown coal was exposed at the surface. It was this exposed highly flammable coal that caught alight. The nearby town of Morwell was blanketed in smoke and particles for nearly a month before the fire was extinguished. This was very unpleasant for all residents and very dangerous for some. Many had to leave the town until the smoke cleared.

ACTIVITY 1.7 REFINING COAL

Use the above information to construct **flow charts** for the processes used in the:

- Mining of coal.
- Refining of coal.

ACTIVITY 1.8 EXPERIMENT: DESTRUCTIVE DISTILLATION

Aim: To produce coke and coal gas in the laboratory using destructive distillation of coal.

Coal is heated out of contact with air at a coke oven to produce coke for use in a blast furnace. It also produces coal gas which is burnt to supply heat.

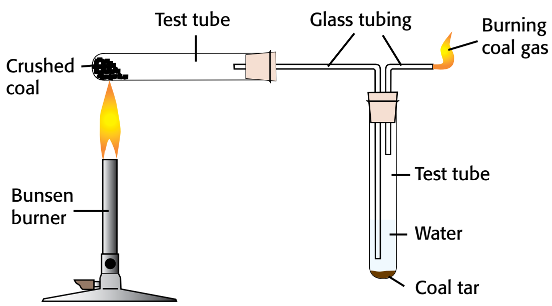

Figure 1.31 Destructive distillation of coal Coal is heated out of contact with air.

Apparatus

- Soft coal sample
- Bunsen burner
- Crushed ice
- Ring stand
- Pyrex or Kimax test tube
- Gas bottle or flask
- Two-hole stopper
- Test tube holder
- Bent glass tubing
- Large beaker
- Wooden splints

Risk assessment: Coal gas is flammable. To make sure you do not inhale the fumes, make sure coal gas cannot escape and perform the experiment in a fume cupboard. Wear safety glasses.

Method

1. Place some small lumps of bituminous coal in a heat resistant test tube and clamp the test tube to a ring stand (Figure 1.31).
2. Use a bent glass tube to attach the test tube to a second test tube. Be sure the glass tube does *not* touch the bottom of the second test tube.
3. Insert a bent tube into the two-hole stopper in the second test tube. The other end of the tube should be drawn to a narrow opening at one end.
4. Place the second test tube in a beaker of crushed ice.
5. Heat the coal slowly by moving a flame back and forth along the test tube.
6. After several minutes, bring a lit wooden splint to the tip of the narrow tube. Does the coal gas produced burn?
7. When no more gas is produced, turn off the flame. Remove the beaker of ice.
8. The bituminous coal in the test tube has been changed to coke.
9. The liquid in the bottom of the second test tube is coal tar.

Questions

1. What happened as you placed a lit splint to the narrow tube opening in step 6 of the procedure.
2. Describe the mixture that remains in the test tube at the conclusion of the experiment.
3. Describe the mixture that forms in the test tube that was submerged in crushed ice.
4. What safety precautions would you recommend to workers near a coke oven? Justify your answer.

SCIENCE SKILLS

1. You will need Figure 1.23 to help answer these questions.
   (a) Identify the coal basin that is the 'odd one out'.
   (b) Use the scales to determine the thickness of coal seams in each basin, and then place them in order from thinnest to thickest.
   (c) In the Sydney Basin, **identify** the coal seam that you would expect to have the highest rank. **Justify** your answer.
   (d) For each basin, suggest the best locations for a mine. **Justify** your answers.

Answers

Chapter 1 The Use of Non-Renewable Energy Resources

1.1 Non-renewable resources

1. Many answers: For example, boiled water in a jug made from glass and aluminium; ate breakfast of meat, egg and vegetables; read magazine made from paper.
2. Renewable: air; wood; fresh water; salt perhaps.
   Non-renewable: bauxite; coal; petroleum; iron ore.
3. High value: diamonds; iron ore; bauxite; uranium.
   Low value: sand; timber; gravel.
4. A resource is a substance humans need for some use(s) and a reserve is an amount of a resource that can be extracted at today's costs and selling prices.
5. Mineral resources are naturally spread through the environment and need to be concentrated by natural means to make mining economic. Once mined, the minerals need to be concentrated even more to allow for cheaper transport and to make extracting the useful part cheaper.
6. (a) Biggest resource by weight is black coal with 50 656 million tonnes; smallest resource is diamonds with 272.5 million carats (1 carat is 0.0002 kg; 54.5 tonnes).
   (b) Biggest mine production is iron ore at 488 million tonnes; smallest resource mined is diamonds at 7.6 million carats (1.52 tonnes).
   (c) The amount of mineral mined depends on current prices which in turn depends on supply and demand. Since it costs money to mine, there is no point mining minerals that you cannot sell.
   (d) At the time of writing gold is selling at around AUD$55 per gram or AUD$55 000 000 per tonne with a total value of $14.2 billion. Iron ore exports total more than AUD$60 billion with coal coming in second.
7. Modern technology speeds the exploration and evaluation of mineral and fossil fuel resources, it makes the mining of the resource more efficient and lowers the costs of refining and transporting the resource.
8. All non-renewable resources have a limited lifetime, with fossil fuels such as gas and oil having some of the shortest lifetimes. Sustainable use means the resources are used in a way that make them available for future generations to use as well.
9. Mining projects can have legal problems with native title and with environmental issues. The environmental issues can involve threatened species, as well as pollution of the air in local communities, and pollution of local waterways and ground water.
10. When a major resource does run out, or the cost of production becomes too high for many uses, there are a number of ways to substitute for the resource that can be evaluated. For example, aluminium cans are widely used for supplying soft drink and beer.
    There are many known bauxite deposits around the world that are not being mined at present. Perhaps there are others to be yet found. Thus one possibility is to use technology advances to mine resources that are too expensive to mine today.
    Another solution already in use in some parts of Australia is to recycle the cans so the metal can be used again.
    We could also substitute cans made from plastic or iron, but iron cans are heavier and can rust, and iron and petroleum are non-renewable resources. They too have a limited lifetime.
    However, one resource is quite massive and effectively has no limit available. That is the sand used to make glass. We could substitute cans with glass that also has the advantage of being recyclable.
    Thus with soft drink cans there are a number of ways the resource can be extended, but glass containers are effectively a sustainable way forward.

1.2 Fossil fuels

1. A fossil is the remains of prehistoric once living things. Both coal and petroleum are the remains of once living things – coal derived from plants and petroleum from microscopic plants and animals.
2. Sedimentary rocks usually occur in layers called beds of rock. Thus a bed of coal is a layer of coal often sandwiched between beds of other sedimentary rocks. Also called a seam of coal.
3. Ranks of coal are peat (20%), brown coal (30%), sub-bituminous black coal (40%) , bituminous black coal (45% to 65%), anthracite (80%).
4. Brown coal is fibrous and brown in colour, containing significant amounts of moisture and formed during the Tertiary period. Black coal is shiny and hard and black in colour, containing only small amounts of moisture and are from the much older Permian period.
5. Ash left in a coke oven or in the boiler of a power station poses disposal problems and may contribute to air pollution if not removed from gases given off.
6. While both are fossil fuels, petroleum is liquid derived from micro-organisms, while coal is a solid derived from plants.
7. Sour crude contains significant amounts of sulfur while sweet crude contains little sulfur.
8. Natural gas is derived from petroleum while coal seam gas is derived from beds of underground coal.
9. Methane (CH_4).
10. The oil in tar sands is very viscous and does not flow readily. The tar sands must be heated to lower the viscosity of the oil so that it flows more easily and can be removed.

1.3 Formation of fossil fuels

1. • The presence of plant remains in low rank coal help show coal is derived from vegetation.
   • Plant fossils in sedimentary rocks above and below high rank coal indicate that coal has been formed from vegetation.
2. Black coal basins are today located west of the New England fold belt. Geologic evidence tells us that in the Permian, there was a subduction zone with a volcanic arc producing what would become the New England fold belt. There was also a basin behind the volcanic arc and this seems to be the location where the deposits collected that formed the coal.
   Brown coal formed from vegetation deposited into the Gippsland Basin.
3. Peat and brown coal are similar in that they are fibrous and consist of plant remains. They differ in that brown coal is more compact than peat and dries out and crumbles when exposed to air. Brown coal contains about 60 per cent water while peat is around 90 per cent water.
4. • Plant remains are converted to peat.
   • Subject to pressure and heat the peat is converted to brown coal, with a reduction in the amount of water and the plant fibres becoming more crumbly.
   • Brown coal is converted to sub-bituminous black coal by further heat and pressure. Water content is further reduced and the coal become black and waxy.
   • Further heat and pressure converts the sub-bituminous black coal into bituminous black coal which is a dense black colour with less moisture and burns with a luminous flame.
   • Anthracite is jet black with a brilliant lustre. It has a high heat value and is the end result of the effects of increasing heat and pressure.
5. Brown coal began to form during the Tertiary some 15 million years ago, while black coal was formed during the Permian some 300 million years ago.
6. Even if the vegetation had been submerged in a anaerobic swampy environment, there is enough oxygen present to allow a slow rotting of the material. The vegetation needs to be buried so that it is out of contact with oxygen. Burial also allows the vegetation to be compressed by the weight of sediment above to begin the process of coalification.
7. In many parts of the world, the main living things buried are planktonic organisms in a marine environment. While there is some marine sediments associated with petroleum in Australia, most petroleum has a major component of material from vegetation.
8. • Diagenesis occurs from the surface of the depositing sediment to depths of a few hundred metres, where temperatures are generally less than 50°C and pressures more than 1000 atmospheres. Anaerobic bacteria are responsible for the conversion of organic matter into a sticky liquid and considerable amounts of biogenic methane and other gases.
   • Catagenesis occurs at depths to about 3.5 to 5 kilometres, where the temperature range is 50°C to 150°C and pressures rises to 1500 atmospheres. Pressure and temperature brings about the compaction of rock and the expulsion of water. The organic matter is progressively altered, becoming a thick organic material called kerogen and liquid petroleum.
   • Metagenesis occurs below depths of 3500 to 4000 metres, the temperatures exceed about 150°C and the pressure rises above about 1500 atmospheres. At this point, the leftover organic matter is either converted into gas, which is nearly pure thermogenic methane, or remains as a carbon rich solid residue.
9. In Australia, most petroleum has formed along the continental margin in deep rift zones. This has allowed the accumulation of vegetation as well as plant rich sediments to accumulate resulting in their burial so that pressure and temperature can convert them into petroleum.
10. Rifting is the formation of a deep depression between landmasses. A major rift developed between Australia and Antarctica which resulted in the separation of the continents. Other rifts formed in the north-west of Australia but these did not result in separation. In each case, large amounts of vegetation and plant/animal rich sediments were able to collect in these rifts and this material was converted to petroleum over time.

1.4 Exploration and extraction of coal

1. Providing energy for electrical power stations; making coke for the manufacture of steel.
2. Governments assist the coal industry by carrying out geologic surveys to assist company geologists to identify possible mine sites.
3. • Identify possible locations from seismic and other data.
   • Determine if the coal is close to the surface.
   • Use drilling to identify the quality of the coal; thickness of beds; rank of the coal; ash content; sulfur content.
   • Determine how the coal will be transported to a market. Brown coal can spontaneously catch fire if transported long distances.
   • Sources of water for washing coal and methods of disposing of this water.
   • Thickness of overburden that needs to be removed for open pit mining.
   • Quality of rocks above the coal to ensure there are no landslides with open pit mining.
   • Quality of the rocks above to lessen the chance of a rock fall in underground mines.
   • Presence of faults or volcanic dykes that could interfere with mining.
4. Ash remains at the bottom of a furnace after the coal is burnt and it has to be removed from smoke. The ash then has to be safely disposed of, all adding to cost. Sulfur in coal burns to produce sulfur dioxide which not only damages the furnaces, it dissolves in water to produce acid rain. This acid rain damages local trees, buildings and the environment in general. Removing the sulfur dioxide costs money.
5. With open pit mining, the rocks above the coal seam are called overburden and have to be removed. They also form the walls of the pit and need to be stable enough not to form a landslide. With underground mines, the rocks above the coal are a matter of life and death. They need to be strong enough not to collapse onto miners beneath at least until they are supported.
6. The quality of coal from underground mines is mostly greater than that of open pit mines, producing metallurgical coal. In a few cases, the presence of existing infrastructure may make it cheaper to continue mining rather than constructing a new mine.