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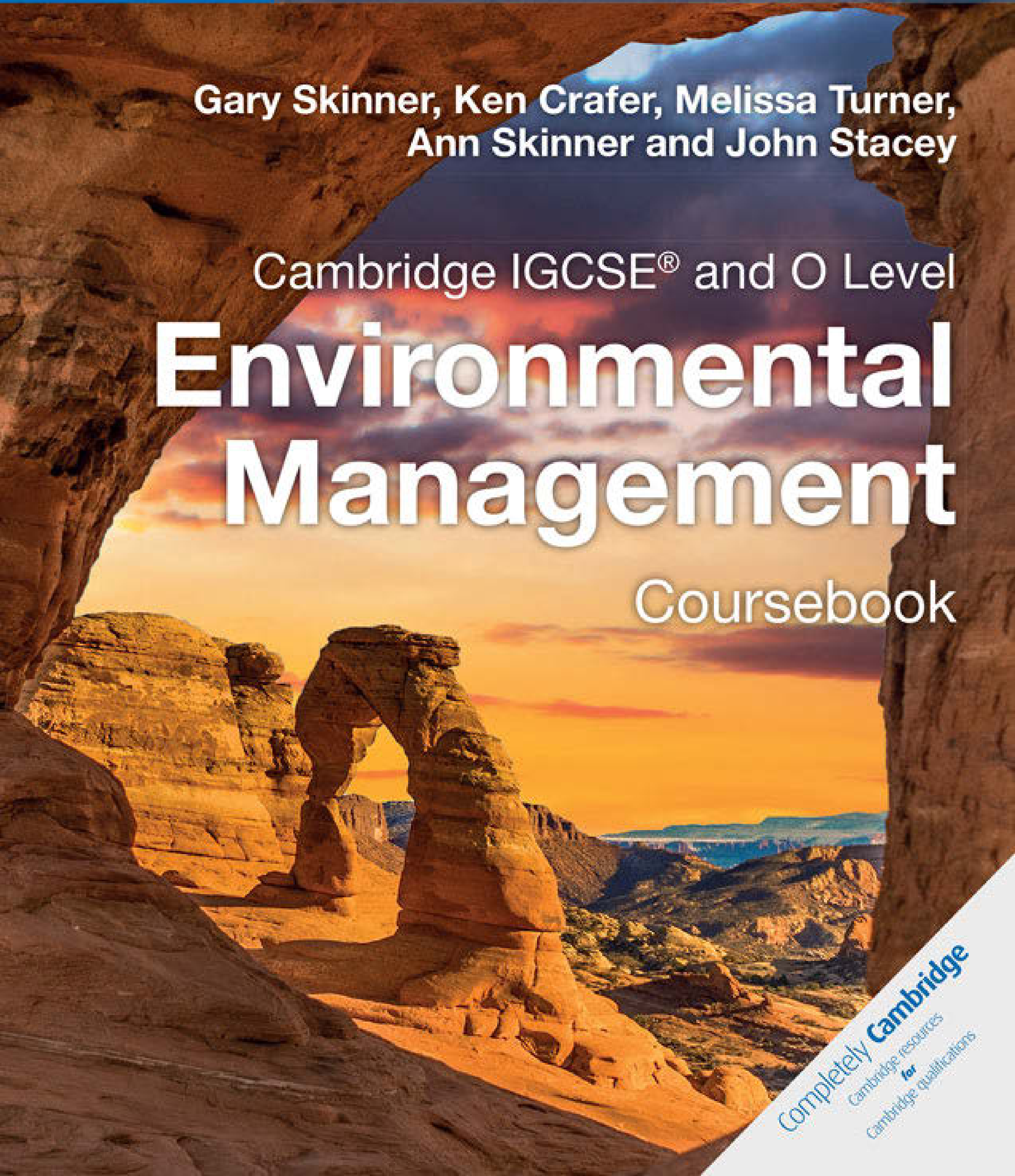
Gary Skinner, Ken Crafer, Melissa Turner,
Ann Skinner and John Stacey

Cambridge IGCSE® and O Level

Environmental Management

Coursebook



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Contents

How to use this book

Learning outcomes – These statements set the scene of each chapter, help with navigation through the book and give a reminder of what's important about each topic.

Chapter 1
Rocks and minerals and their exploitation

Learning outcomes

By the end of this chapter, you will be able to:

- describe, with examples, the characteristics of igneous, sedimentary and metamorphic rocks
- explain the formation of igneous, sedimentary and metamorphic rocks
- explain the rock cycle
- describe surface and subsurface mining
- describe the reasons for extracting rocks and minerals
- describe the impact of rock and mineral extraction on the environment and human populations
- discuss methods of landscape restoration after rock and mineral extraction
- explain the terms sustainable resource and sustainable development
- discuss how rocks and minerals can be used sustainably.

Key terms and definitions - Clear and straightforward explanations of the most important terms are provided for each topic.

KEY TERMS

Rock: a combination of one or more minerals

Mineral: a naturally occurring inorganic substance with a specific chemical composition

Igneous rock: rock made during a volcanic process

Magma: molten rock below the surface of the Earth

Solution: formed when a solid is dissolved in a liquid

Precipitates: when a substance comes out of solution

Ion: an atom in which the number of positively charged protons is not equal to the number of negatively charged electrons

Sedimentary rock: a rock formed from material derived from the weathering of other rocks or the accumulation of dead plants and animals

Practical activity – Opportunities for developing practical skills are provided throughout the book.

PRACTICAL ACTIVITY 8.1

Seven billion and counting

The world population is assumed to have reached 7 billion in October 2011. Danica May Camacho of the Philippines was designated as the 7 billionth human.

Materials

- Access to the internet
- A3 or larger sheet of paper
- Marker pens

Method

- If you go to the BBC website (www.cambridge.org/links/scspenv4002) you can find out what number in the world's population you were when you were born.
- On a large sheet of paper (at least A3), draw the world population size from 1500 to the present day. You can get help with this on the website.
- Mark your birth number on the world population time line.
- Choose five historical world events and five events from your country's history. Mark these events on your poster.

Question

1 Estimate the world's population at the time your chosen historical events happened. For example, when the Second World War ended, the world population was about 2 300 000 000.

Opening discussion – An engaging discussion to bring each chapter topic to life, encouraging you to read around the topic and sparking discussion in class.

Cambridge IGCSE and O Level Environmental Management

The third rock from the Sun

The Earth is a rocky planet, compared with, for example Jupiter, which is a gas giant. This means that the Earth is made from rocks and metal ores. The Earth weighs 5 973 600 000 000 000 000 000 000 kg (5.97×10^{26} kg) and has a density of 5.2 g cm^{-3}, which makes it the densest planet in the solar system. This is mainly because the core consists of iron surrounded by a mantle of rock. However, it is only the very outside part of the Earth, above the mantle, that humans can use. The material that makes up this region is what we call **rocks** and **minerals**. Although this represents a vast amount of material, the quantity of it, like everything else, is limited. What is more, extraction and use can cause environmental and other problems. We are in danger of using up the available sources of many rocks, the most well known of which is probably coal.

Peak mineral is a concept that provides a date after which there will only be less extraction of a mineral. Peak coal, for example, is the date at which it is calculated that the most coal is being extracted, after which it will decline. Because we do not know exactly how much coal exists, estimates of peak coal vary. Some say it is 200 years away, others say it could be soon, maybe 2020. This unpredictability because of future unknowns is illustrated by the situation with oil. In 1956, the originator of the peak mineral idea, M. K. Hubbert, predicted that the peak oil date for the USA would be 1970. This did not happen, and in fact the production of oil in the USA is still rising today. However, it is true that the resources of all these commodities, such as coal, oil and phosphorus (current estimated peak date 2030), copper (current estimated peak date 2040) and uranium (current estimated peak date 2030s), are finite. It is therefore important that we limit the use of these resources, and reuse and recycle them whenever we can.

Figure 1.0 A giant bucket wheel excavator in use in an open-pit mine.

Self-assessment questions – Check your knowledge and understanding, and track your progress by answering questions throughout each chapter. Answers are provided at the back of the book.

SELF-ASSESSMENT QUESTIONS

1.3 What factors need to be considered before starting up a new mine?

1.4 Suggest reasons why developing surface mines is easier than developing mines underground.

Case study – A variety of examples of real world scenarios are included in every chapter to illustrate relevant aspects of the syllabus, with questions to develop your higher order thinking skills. Answers are provided at the back of the book.

CASE STUDY

Acid rain in China

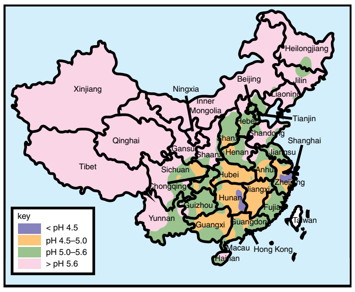

Figure 7.5 The distribution of acid rain in China.

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China is experiencing rapid industrialisation. In 2011 China's government published a report that claimed that 258 Chinese cities were suffering from the effects of acid rain. The acid rain falls in the south and east of the country, where the majority of the population, industry and power stations are located (Figure 7.5). In 2014 China was the world's largest energy consumer, accounting for 23% of all global energy consumption, and the dominant fuel is coal, providing 66% of the country's energy consumption. When the coal is burnt in factories and power stations, it releases sulfur dioxide and nitrogen oxide, which form acid rain. Expanding car ownership is also leading to high emissions of these gases.

The effects of acid rain in China are numerous. Lakes and rivers have become more acidic, killing fish, crop yields are lower and commercial timber is being lost as trees die. Structural damage to buildings is being caused by chemical weathering. The 71 m high and 28 m wide Leshan Giant Buddha, which has stood for more than 1000 years, has been badly affected (Figure 7.6).

China first attempted to reduce sulfur dioxide emissions in 2007, before the 2008 Beijing Olympics. In 2011, as part of the government's Five-Year Plan, ambitious targets for emission reductions were set. Several

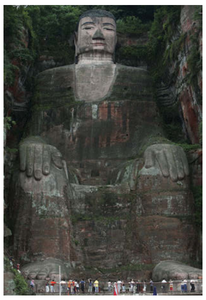

Figure 7.6 The Leshan Giant Buddha is starting to show the effects of acid rain.

End-of-chapter questions – Use the questions at the end of each chapter to check your knowledge and understanding of the whole topic and to practise answering questions in a similar style to those you might encounter in your exams. Answers are provided at the back of the book.

End-of-chapter questions

1 **a** Name the four components of soil. **[4 marks]**

b How would a drought affect the balance of these four components? **[1 mark]**

2 How might changing the pH of the soil affect the growth of a crop? **[1 mark]**

3 Give three ways the 'Green Revolution' has helped feed a growing world population. **[3 marks]**

4 Explain how crop rotation can help increase the yield of a crop. **[2 marks]**

5 Describe three ways farmers can improve the efficiency of their water use. **[3 marks]**

6 Describe the impact of applying too much fertiliser to a crop. **[2 marks]**

7 Intercropping is identified as a useful way of helping prevent soil erosion in certain soil conditions. In addition to the prevention of erosion, what other benefits might this technique have? **[3 marks]**

Summary – A brief summary is included at the end of each chapter, providing a clear reminder of the key themes discussed.

Summary

After completing this chapter, you should know:

- the components of soil
- where the soil components originate
- how to evaluate the proportions of these components
- the availability of nutrients and the impact of deficiencies
- the relative merits of different soil types
- different types of agriculture
- techniques used to increase agricultural yield
- methods of controlling pests, diseases and weeds
- the techniques of selective breeding and genetic modification
- methods for controlling the growing environment
- the impacts of poor agricultural management
- different approaches to maintaining soil fertility.

Extended case study – Longer case studies related to more complex real world settings provide opportunities to practise higher order thinking skills and prepare for this element of your examinations. Answers are provided at the back of the book.

EXTENDED CASE STUDY

Controlling pests naturally: a flawed decision

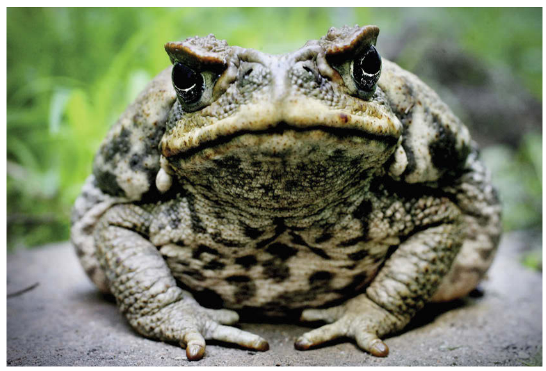

Figure 3.22 The cane toad: introduced into Australia with a huge environmental impact.

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Sugar cane plants were introduced into Australia as the country became populated by Europeans. Records show that there were plantations in the Brisbane area as early as 1862. Plantations were densely planted, tended to be grown as monocultures (only the one crop grown in an area) and today are highly mechanised.

As the numbers of sugar cane plantations grew, so did the incidence of pests. Two native beetle species cause major problems: the adults eat the leaves of the crop and their larvae eat the roots. These beetles have proved to be difficult to control because the adults have a tough skin that repels pesticides and the larvae are buried in the soil so are not easy to spray. When pesticides are used, not only are they not very effective on the pests but they also kill many other insects and upset the natural ecosystem. Australian scientists looked at other areas of the world and read reports of increased yields in plantations in Hawaii, the natural location of cane toads. Cane toads are relatively large in size and eat a wide range of different insects (Figure 3.22).

A small number of cane toads were imported into Australia in the 1930s, bred successfully and released into the local plantations. Unfortunately, it was then discovered that the cane toad was not particularly effective at controlling the beetles on the Australian sugar cane, but preferred to eat other insects and animals in the area. It has been estimated that there are now over 200 million cane toads in Australia. They have bred rapidly because:

- they outcompete native animals for food
- they outcompete native animals for habitat space

Introduction

Managing the environment might be the most important thing humanity has to do over the next century and beyond. But what is the environment and how can we manage it? In its broadest sense, the environment is everything around us. Your environment includes the room you are sitting in, the air in that room, the people in the room next door, the aeroplane flying overhead and the atmosphere it is flying through, among many other things. But how do we go about managing all of this? It is clear that we need to break things down so that the tasks become manageable. That is what the syllabus and this book attempt to do.

The environment can be split into four major categories: the lithosphere, hydrosphere, atmosphere and biosphere. Chapter 1 deals with the lithosphere: the rocks that make up our planet Earth, on which all life is found. Chapters 4 and 5 deal with the hydrosphere: the ceaseless cycle of water and what we do with it in its various forms. Chapter 7 looks at the atmosphere: the air around us, which contains vital oxygen and carbon dioxide and is the place where weather occurs. Chapters 8 and 9 look at the living world, or biosphere: the people and all the animals, plants and other organisms with which we share the Earth. Weaving through all of this is the use we make of energy, without which nothing much of what we regard as our modern world could occur. Chapter 2 considers how we acquire the energy we need and the problems we create in using it.

The environment is not necessarily well-meaning, although this might seem difficult to believe on a warm sunny day with the birds singing and soft wind blowing. Chapter 6 looks at the natural hazards that human and other life is constantly exposed to, from high winds and heavy rain that might cause problems for a few weeks, to the effects of earthquakes and volcanoes, which are the result of the incredibly slow movement of the tectonic plates on which we live.

Finally, Chapter 3 covers that most vital of human activities: farming. Recent studies have shown that nearly half of the Earth's land area is used to produce food, and this is almost certain to increase over the next few decades.

However, having said all this, it is important to realise that every aspect of the environment affects every other. This is the nature of environmental science and ecology; they are sciences that deal with interactions. You are a part of the biosphere and each time you take a breath, you affect the atmosphere by adding carbon dioxide and water vapour and removing oxygen. Every time you eat, for example vegetables, you are taking in minerals that have passed round and round a mineral cycle for millions of years. This is at the heart of the difficulty of managing the environment: anything and everything we do, either by design or by accident, may affect any aspect of the environment. This is known as the law of unintended consequences.

Food webs provide a good example of this law. In the complex interactions between species, feeding relationships make it almost impossible to predict what will happen if just one of species increases or decreases in number. Take Barro Colorado Island, formed when the Panama Canal was constructed in the early twentieth century. Some decades after this area of tropical jungle was isolated from its surroundings, it was observed that many species had been lost. These included birds such as the curassow, the wood quail and the ground cuckoo. The reason for this loss is thought to have been a medium-sized racoon, called a coati, becoming abundant. (Figure 0.1)

Figure 0.1 A coati family looking for food.

Coatis eat the eggs and young of birds like the curassow, wood quail and ground cuckoo. But why was there a big increase in coatis? In their jungle habitat, coatis are preyed upon by jaguars and pumas (Figure 0.2); the new island, with an area of under 15 km^2, was simply too small to support these large cats.

Figure 0.2 A female puma.

Figure 0.3 Two great curassows.

The cats would have died out in this isolated habitat and the coatis would escape being eaten. This would not have been predicted at the time: an unintended consequence of the construction of the Panama Canal was the extinction of the curassow in a 15 km^2 patch of tropical jungle, now an island (Figure 0.3).

An even more dramatic example comes from the story of rabbits in Australia. This European mammal was introduced into Australia in 1788 on the so-called First Fleet (the first fleet of ships that left Great Britain to found a penal colony in Australia). However, it was not until the deliberate release of just 24 individuals in October 1859 that the numbers began to soar. By 1869 hunters were killing 2 million rabbits every year with no effect on the population. The huge numbers of rabbits in Australia have caused massive species loss and even geological changes, such as extensive gully erosion.

The story of the cane toad, again from Australia (see Chapter 3's Extended case study), is another example of the important principle of unintended consequences in environmental management.

We all have an environment around us and we are all part of everybody else's environment. This simple fact makes managing the environment one of the most important challenges for humans in the future.

Key skills in Environmental Management

When thinking about an investigation in environmental management you need to find out about a problem and how it is affecting the environment. An investigation has a sequence of stages:

1. planning the investigation
2. identifying limitations of the methods that were used and suggesting possible improvements
3. presenting reasoned explanations for phenomena, patterns and relationships that you have observed in your data
4. making reasoned judgements and reaching conclusions based on qualitative and quantitative information.

All these stages involve certain skills and techniques, all of which are explained below and in the following chapters.

Planning investigations

Planning an investigation involves formulating an aim and one or more hypotheses. An **aim** identifies the purpose of your investigation and you should have a suitable aim in mind when planning. 'To investigate the effects of coal mining waste on soil pH' is an example of an aim. From the aim, the hypothesis or hypotheses arise.

A **hypothesis** is a statement on the topic that you are investigating. It is a testable prediction that proposes a relationship between two variables:

- the **independent variable**, which is not changed by other variables you are measuring e.g. the age of a person
- the **dependent variable**, which is what you are measuring.

In research, the hypothesis is written in two forms: the null hypothesis and the alternative hypothesis (called the experimental hypothesis when the method of investigation is an experiment).

The **null hypothesis** states that there is no relationship between the two variables being investigated (one variable does not affect the other). Results are due to chance and are not significant in terms of supporting the aim being investigated.

The **alternative hypothesis** states that there is a relationship between the two variables being investigated (one variable has an effect on the other). The results are not due to chance and they are significant in terms of supporting the aim being investigated.

A hypothesis can be accepted or rejected by testing. This is achieved through data collection and analysis.

A good hypothesis should:

- be a statement not a question
- be a prediction with cause and effect
- state the independent and dependent variables being tested
- be short in length.

An example of a good hypothesis is 'There will be a decrease in soil pH with increasing distance from a site of coal mining waste'.

KEY TERMS

Aim: identifies the purpose of your investigation

Hypothesis: a statement on the topic that you are investigating

Independent variable: the variable that is deliberately changed in an experiment

Dependent variable: the variable that is measured in an experiment

Null hypothesis: a hypothesis stating that there is no relationship between the two variables being investigated

Alternative hypothesis: a hypothesis stating that there is a relationship between the two variables being investigated

Collecting data

When planning an investigation, you need to plan how to collect your data. There are two types of data: qualitative and quantitative.

Qualitative data is non-numerical, descriptive data.

Quantitative data can be either discrete or continuous:

- discrete data: numerical data that have a finite number of possible values and can only take whole numbers, e.g. the number of trees or 1, 2, 3, 4
- continuous data: numerical data that have infinite possibilities and can take any value, e.g. temperature, time, speed or 1.5, 1.51, 1.512.

Both qualitative and quantitative data can be either primary or secondary:

- Primary data is data collected by you or a group doing the investigation.
- Secondary data is data that has already been collected by people unconnected with the investigation but that are relevant and useful. Examples include data from the internet, newspapers, books or past investigations.

Sampling

It is often unnecessary and sometimes impossible to carry out your investigation on the whole of the target population as it would be too expensive or time consuming. For example, it would be impossible to ask everyone in a large town for their views on the effects of air pollution or to count all the plants in a big field. For this reason a sample must be taken.

A sample should be representative of the target population. If it is, then a larger sample size tends to yield more reliable results. The target population is the subset of people or organisms to which the conclusions of the study can be applied. For example, if only women were questioned about their views on air pollution the conclusions could only be applied to women, which would be the target population.

Before deciding on the sampling method you need to think about how you are going to take the sample.

This could be by:

- point sampling: data collection is done at an exact point, e.g. a pedestrian count
- line sampling: data collection is done along a line (Figure 0.4) or transect, e.g. changes in plant height
- area or quadrat sampling: data is collected within quadrants, e.g. vegetation cover surveys.

Figure 0.4 Students carrying out a line sample across a dry river valley.

Once you have decided on the type of sampling to use, you then have to decide on a suitable sampling method. There are three types of sampling methods.

- random sampling: sample points are selected using random numbers to avoid **bias**. Tables of random numbers can be used or generated by calculators (see Chapter 9).
- systematic sampling: sample points are selected using a regular pattern or order, e.g. conducting a questionnaire on every tenth person or surveying vegetation cover every 5 metres.
- stratified sampling: when a population is divided up into groups, e.g. different ages or gender, taking a stratified sample ensures that each group is asked in the correct proportion.

KEY TERM

Bias: encouraging one outcome over another

Figure 0.5 summarises the different types of sampling methods.

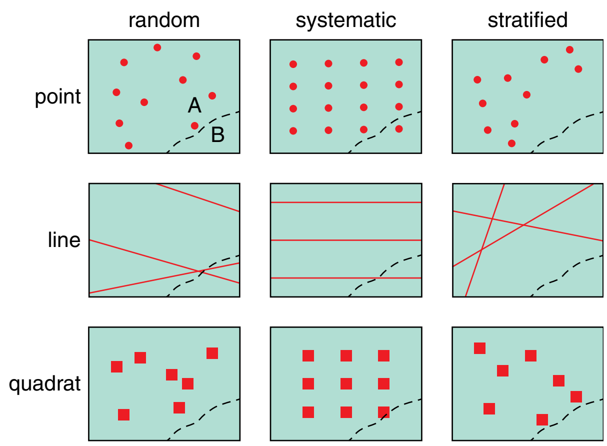


Figure 0.5 Different types of sampling methods.

For example, imagine you wanted to give a questionnaire to a sample of 50 people from a farming area. The area has three villages. How many people should be given a questionnaire from each village?

Village 1	Village 2	Village 3
356 people	233 people	426 people

Table 0.1 Population of the three villages.

a The total number of people is 356 + 233 + 426 = 1015

b To find the number of people from each village to be given the questionnaire, we multiply each village population by $\frac{\text{sample size}}{\text{total population}}$ which in this case is $\frac{50}{1015}$

	Village 1	Village 2	Village 3
Sample size	$365 \times \frac{50}{1015}$ = 17.5	$233 \times \frac{50}{1015}$ = 11.4	$426 \times \frac{50}{1015}$ = 20.9
Rounded numbers of people to be questioned	18	11	21

Table 0.2 Sample size calculations.

A further example of stratified sampling is when soil types are being investigated in an area where 70% of the area consists of rock type A and the remaining 30% consists of rock type B. 70% of the soil samples should be taken on rock type A and 30% of the soil samples on rock type B.

Questionnaires and interviews

This data collection method is used when trying to obtain people's opinions. Stratified sampling is used for questionnaires and careful consideration should be given to the day, time and location when the data are collected to avoid bias.

Questionnaires can be carried out by approaching people in the street, knocking on people's doors, posting questionnaires or, if applicable, placing them on the internet. Each method has its own advantages and disadvantages. Can you think what they are?

Questions should be pre-planned and it is always important to do a **pilot survey** to ensure that the people interviewed understand the questions (five respondents would be sufficient), and the answers provide the information you want to analyse. Always explain the aim of the questionnaire and be polite when asking people to complete them. Stress that the answers will be anonymous and although you should record the age and gender of the respondent, remember these are sensitive questions and should not be asked directly.

A good questionnaire should:

- be carefully worded so people understand the questions and questions are not ambiguous
- be quick to complete and therefore have a limited number of questions in a logical order
- have closed questions at the beginning. Closed questions are those which can be answered by a 'yes' or 'no', or by a definite answer to the question being asked. Open questions are those which require more thought and require more than a simple one-word answer. They take longer to record but are useful if more information is required. However the answers might be difficult to record and analysis.

Always thank the respondent once the questionnaire has been completed.

An interview involves talking to a small group of people or an individual. You should have pre-planned questions and the answers are usually longer than those from a questionnaire.

Risk assessment

To collect data safely, you must be aware of potential health and safety issues relating to the equipment you are using (e.g. sulfuric acid or a Bunsen burner) or to the location of the investigation. You need to decide what equipment you might use and then ensure that the equipment is tested and, if necessary, **calibrated** before the investigation starts. You should always carry out a pilot survey.

KEY TERMS

Pilot survey: a trial run of a survey, which aims to discover any problems with the survey

Calibrated: to check and make any necessary adjustments to a piece of equipment to ensure its accuracy

Recording data

It is useful to record data in a table format. The table should be created before data collection. When drawing up a table, remember the following guidelines:

- When two or more columns are used, the first column should be the independent variable (i.e. the variable chosen by you, the experimenter) and the second and other columns should contain the dependent variable(s) (i.e. the readings taken for each change in the independent variable).
- Columns should be headed with the name of the variable and the appropriate unit.
- Numerical values inserted in the table should just be numbers, without units.

Practical activity 9.1 in Chapter 9 involves estimating plant coverage using quadrats. Table 0.3 is an example of a results table for this activity.

Independent variable/ units	Dependent variable 1/units	Dependent variable 2/units	Dependent variable 3/units	Dependent variable 4/units
Distance/m	Species 1/% cover	Species 2/% cover	Species 3/% cover	Species 4/% cover
1	53	0	3	0
2	45	3	4	2
3	23	17	4	11
4	12	25	5	25
5	0	37	3	12

Table 0.3 Distribution of plant species along a transect line, following a standard layout for tables.

The first column shows the distance along the transect line (in metres), the second column shows the percentage coverage for a named species of plant, the third column shows the percentage coverage for a second species of plant, and so on.

One option in Practical activity 9.1 is to compare estimated plant coverage in two areas. Figure 0.6 shows a results table suitable for recording data for four species of plants, from two areas (A and B) using five quadrats in each area.

area A

	quadrat number / percentage cover					
species	1	2	3	4	5	average
1	19	23	18	25	14	19.8
2	0	3	4	2	1	2
3	67	75	54	49	52	59.4
4	0	0	0	0	0	0

area B

	quadrat number / percentage cover					
species	1	2	3	4	5	average
1	0	1	0	2	0	0.6
2	6	2	3	3	1	3
3	12	14	21	11	16	14.8
4	1	3	0	2	2	1.6

Figure 0.6 Data of the results of a comparison of two areas using five randomly placed quadrats.

Identifying limitations of methods and suggesting possible improvements

The chosen methods for collecting data for an investigation should be achievable and realistic, but you may still encounter limitations to your methods. The quantity and quality of data collected will be determined by available resources such as time, money, equipment, ICT, possible transport requirements and the number of people needed to collect the data.

Relying on other people to gather data can add a random element to the investigation so it is better if the same individual does the measuring. Your choice of sampling, in terms of type and size, is important and you should select a suitable sampling method at the planning stage. For example, you might think of choosing a systematic sampling method for an investigation into vegetation change along a transect but then realise that some of the sampling sites might be inaccessible.

Conditions in which data is collected, such as the weather when conducting a questionnaire, must be considered. Timing and location of data collection can also affect results, as can the sample size, so these factors should be considered too. Questionnaires should ideally be done at regular intervals as well as being timed to maximise respondents. The use of questionnaires can have other limitations, for instance some age groups can be reluctant to answer and not all age groups will be available if the questionnaire is conducted during work time.

Some data collection methods are subjective, for example visually estimating sediment shape and size. You can often use digital equipment in order to collect more objective information and limit human error. If the method involves the use of measuring equipment, ensure that it is calibrated before the investigation starts. By repeating the measurements, or using another piece of equipment, you can increase the reliability of your results.

If you use the internet for data collection, you must consider whether the websites you use are biased or if the information is inaccurate or outdated. Government websites usually provide reliable data.

Presenting explanations for phenomena, patterns and relationships

There are a wide variety of presentation techniques that can be used to display collected data. The skill is choosing the technique that is most suitable for the data. It is important that all techniques used should have a title and that axes are labelled. If you use a key, it should also be labelled. Tables of data are simple to design but when data are presented visually it is often easier to see patterns and trends, so graphs and diagrams can be a better choice.

There are many different types of graph, such as line graphs, bar graphs, histograms, pie graphs and scattergraphs. More specialised types of graph include climate graphs and population pyramids.

Line graphs

A line graph is used when there is a continuous change in the data, often over time (Figure 0.7). The points are plotted as crosses or encircled dots and are connected with a clear straight line. The axes of a line graph begin at zero and the independent variable is put on the horizontal or *x* axis (e.g. time) and the dependent variable on the vertical or *y* axis. A suitable scale is important as it will influence the appearance of the line graph.

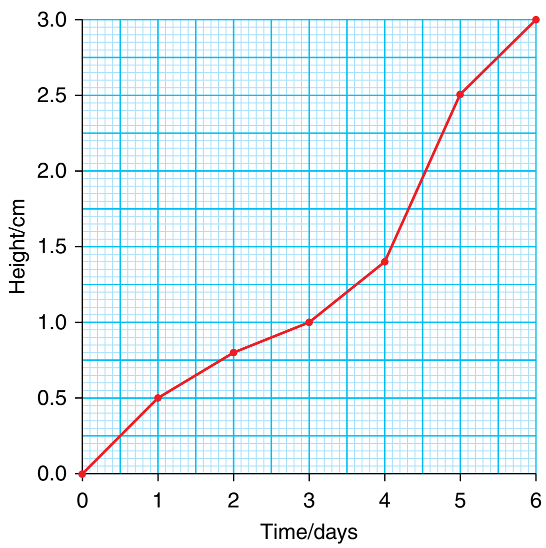


Figure 0.7 A line graph to showing the growth of a bean plant over time.

Bar graphs

Bar graphs are used to show data that fit into categories, e.g. the total number of plant species at different sites.

A bar graph has two axes. The bars should be drawn with equal width and with equal spaces between them (Figure 0.8).

A divided bar graph can be used to show a set of data that is represented by percentages and is an alternative technique to a pie graph. A single bar representing 100% is subdivided into the different data categories.

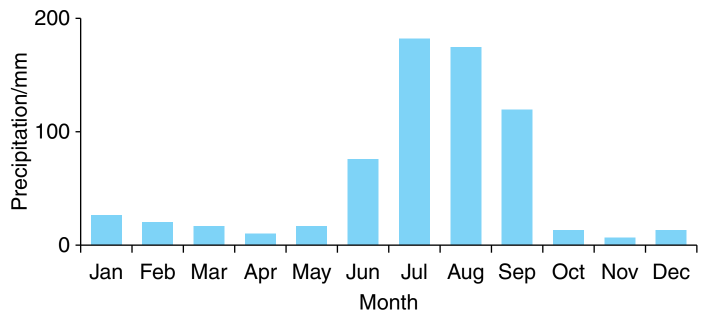


Figure 0.8 A bar graph showing the average precipitation in Agra, India.

Histograms

A histogram may look like a bar graph without the spaces between the bars, but it is different. Histograms are used to show frequencies of data in different categories (Figure 0.9) or change over a period of time. On the *x* axis the range of values is divided into intervals, e.g. 0–99, 100–199 etc. It is a continuous scale and the values do not overlap. The *y* axis shows the frequency or percentage of the collected data falling into each of the intervals. A vertical bar represents each interval and the bars are continuous with no gaps between them.

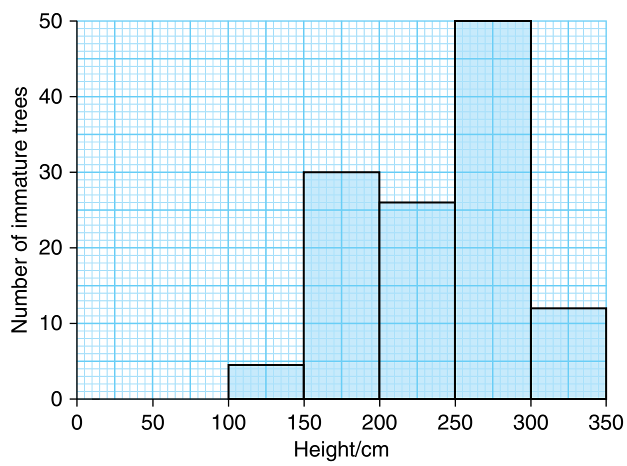


Figure 0.9 A histogram showing the height of immature trees in a plantation.

Pie graphs

Pie graphs are circular charts divided into sectors which show proportions that relate to the data in each category (Figure 0.10). There should be no more than six and no fewer than two sectors in a pie graph. The data used are often in the form of percentages and can be converted into degrees by multiplying each percentage by 3.6 to give a total of 360°. The sectors are plotted in rank order. The largest sector is plotted first starting at '12 o'clock' or 0° and drawn in a clockwise direction. The second sector is then plotted from where the first one ends.

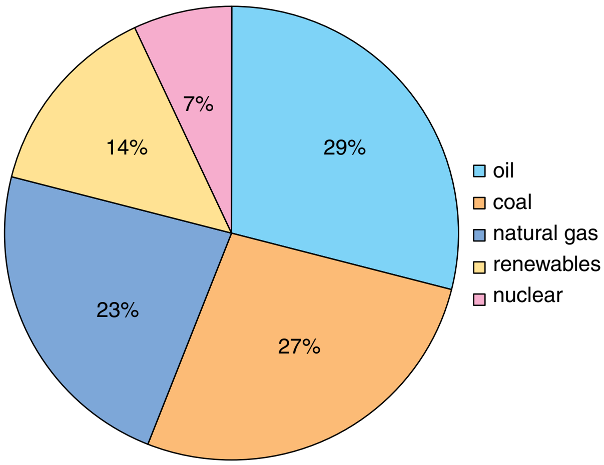


Figure 0.10 A pie graph showing the projected world energy use in 2035.

Scattergraphs

Scattergraphs are used to see if a relationship exists between two sets of data and whether that relationship is positive or negative (Figure 0.11). A scattergraph helps us to see if one set of data is likely to change in relation to a second set of data in a sytematic way. This change (called a correlation) doesn't necessarily mean that one variable *causes* the other to change.

Scattergraphs are plotted in a similar way to line graphs but the points are not joined with a line. The data set that is likely to cause the change is called the independent variable and is plotted on the *x* axis. The dependent variable is plotted on the *y* axis. If the scattergraph shows a likely linear relationship, it is then appropriate to plot the line of best fit (trend line) by eye with an equal number of points above and below the line. The best-fit line does not have to pass through the origin of the graph and should be a single, thin, smooth straight line. There is more information on scattergraphs in Chapter 6.

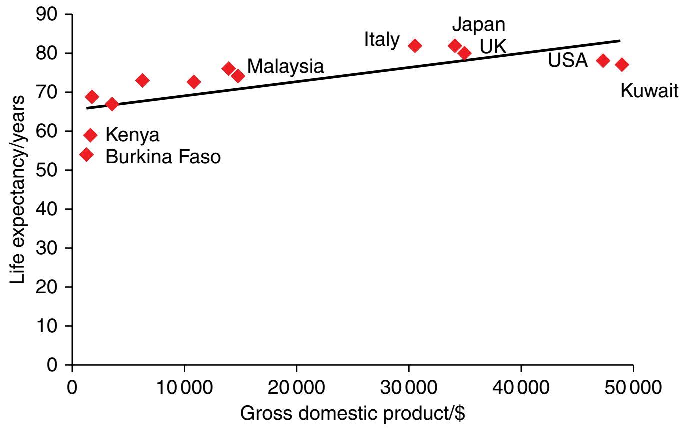


Figure 0.11 A scattergraph showing the relationship between life expectancy and GDP for selected countries.

Analysing your data

Once the data have been presented in a table, graph or diagram, it should be possible to analyse it by describing and explaining what you can see. For example, can you see any trends or associations and explain them? Simple statistical techniques can also be helpful in analysis. These include working out the range (the difference between the largest and smallest values) and the average. There are three kinds of average: mean, median and mode:

- The **mean** is the total of all values divided by the total number of values. It is used when there are no extremes of values, which would distort the mean.
- The **mode** is the value with the highest frequency.
- The **median** is the value in the middle after the data has been sorted into ascending order. It is not affected by extreme values.

KEY TERMS

Mean: the total of all values divided by the total number of values

Mode: the value with the highest frequency

Median: the value in the middle after the data has been sorted into ascending order

The median, range and interquartile range (the range of the middle 50% of the data) can be shown on a box-and-whisker plot. In Figure 0.12 the range of the data is 17–100 and the median is 68.

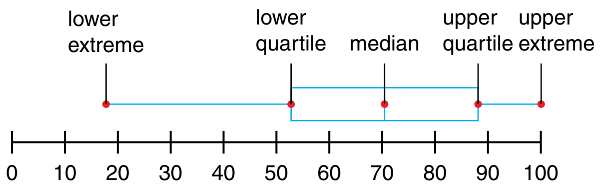


Figure 0.12 A box-and-whisker plot to show range and median values.

Making judgements and reaching conclusions

The conclusion is a summary of the investigation. Using evidence from your data analysis you should now be able to state whether you can accept or reject your hypothesis, giving reasons for your decision. For example the results for the hypothesis from the start of this chapter: 'There will be a decrease in soil pH with increasing distance from a site of coal mining waste', may show exactly that: soil pH does decrease as the distance from a coal mining waste site increases. If so, your conclusion should state this and your hypothesis can be accepted. As well as accepting or rejecting your hypothesis, the conclusion should set out the main findings and discuss if the aim has been achieved. You should also suggest reasons for your findings. For example, if you found that in some cases the soil pH remained the same at different distances, you would need to explain these findings further. Think about whether your findings relate to any previous studies you read about before you carried out the investigation or any theories you have studied.

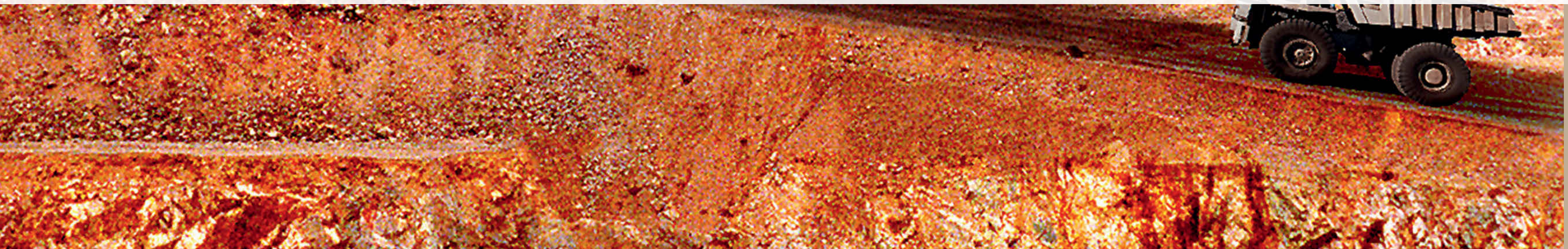
However interesting your results, your investigation could probably be improved by identifying any areas of weakness. This is called evaluating your investigation. Was the sample, size too small? Was your investigation affected by bias? Did you have difficulty collecting your data? For example, if you were investigating how plant biomass changes in a saltmarsh you may have had an incomplete set of results if the tide came in and prevented you reaching some of the sampling sites. Which variables led to inaccuracy or unreliability of the data you collected? Also, think about how your investigation could be extended: could you test further hypotheses?

Chapter 1
Rocks and minerals and their exploitation

Learning outcomes

By the end of this chapter, you will be able to:

- describe, with examples, the characteristics of igneous, sedimentary and metamorphic rocks
- explain the formation of igneous, sedimentary and metamorphic rocks
- explain the rock cycle
- describe surface and subsurface mining
- describe the reasons for extracting rocks and minerals
- describe the impact of rock and mineral extraction on the environment and human populations
- discuss methods of landscape restoration after rock and mineral extraction
- explain the terms sustainable resource and sustainable development
- discuss how rocks and minerals can be used sustainably.



The third rock from the Sun

The Earth is a rocky planet, compared with, for example Jupiter, which is a gas giant. This means that the Earth is made from rocks and metal ores. The Earth weighs 5 973 600 000 000 000 000 000 000 kg (5.97×10^{26} kg) and has a density of 5.2 g cm^{-3}, which makes it the densest planet in the solar system. This is mainly because the core consists of iron surrounded by a mantle of rock. However, it is only the very outside part of the Earth, above the mantle, that humans can use. The material that makes up this region is what we call **rocks** and **minerals**. Although this represents a vast amount of material, the quantity of it, like everything else, is limited. What is more, extraction and use can cause environmental and other problems. We are in danger of using up the available sources of many rocks, the most well known of which is probably coal.

Peak mineral is a concept that provides a date after which there will only be less extraction of a mineral. Peak coal, for example, is the date at which it is calculated that the most coal is being extracted, after which it will decline. Because we do not know exactly how much coal exists, estimates of peak coal vary. Some say it is 200 years away, others say it could be soon, maybe 2020. This unpredictability because of future unknowns is illustrated by the situation with oil. In 1956, the originator of the peak mineral idea, M. K. Hubbert, predicted that the peak oil date for the USA would be 1970. This did not happen, and in fact the production of oil in the USA is still rising today. However, it is true that the resources of all these commodities, such as coal, oil and phosphorus (current estimated peak date 2030), copper (current estimated peak date 2040) and uranium (current estimated peak date 2030s), are finite. It is therefore important that we limit the use of these resources, and reuse and recycle them whenever we can.

Figure 1.0 A giant bucket wheel excavator in use in an open-pit mine.

1.1 Formation of rocks

The planet Earth was formed about 4.5 billion years ago. The force of gravity pulled the heavier elements together first, forming the core. The lighter elements then formed the Earth's crust about 3–4 billion years ago. The mantle developed as a layer between the dense core and the light crust. This structure still exists today (Figure 1.1).

Igneous rocks

When molten rock from the crust and upper mantle cools, **igneous rocks** are formed. The molten rock is called **magma** when it is still below the surface and lava when it reaches the surface.

Magma is found in the outer mantle; it is hot, liquid rock that is under pressure from the rocks above it. When it

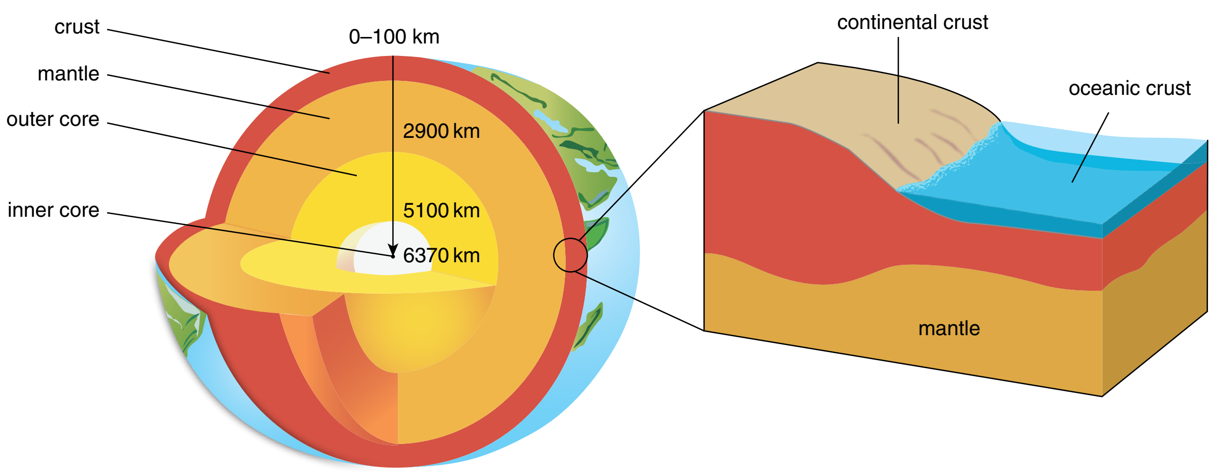


Figure 1.1 The structure of the Earth.

cools it turns to solid rock. When liquid magma rises to the surface from volcanoes the cooling occurs quickly and forms lava. Igneous rocks are made of material that was once molten; they usually contain crystals that are formed as the molten material cools.

The crystals found in rocks are formed when **solutions** of minerals cannot absorb any more dissolved minerals. Some of each mineral type **precipitates** out of solution to form the centre of a crystal. This then provides a surface for more mineral **ions** to precipitate onto. The crystal becomes larger until the solution disappears.

If the rock cools quickly, only very small crystals can form before the rock becomes solid. Rapid cooling occurs when magma is released from volcanoes onto the surface of the Earth's crust.

If magma rises from the mantle into the crust without reaching the Earth's surface, then the magma cools more slowly, allowing the formation of larger crystals. Many of these crystals contain valuable minerals that are used for a wide range of industrial processes.

Heat and pressure are the usual reason for minerals becoming dissolved; a reduction of heat and pressure usually leads to the formation of crystals.

Examples of igneous rocks are granite and basalt (Figures 1.2 and 1.3).

Figure 1.2 A piece of granite.

Figure 1.3 A piece of basalt.

Sedimentary rocks

Sedimentary rocks are formed by the weathering of existing rocks at the Earth's surface, the accumulation and fossilisation of living material, or the precipitation of dissolved materials out of solution in water. Weathering processes release small mineral particles that accumulate to form sediment. Over time, layers of sediment build up to form sedimentary rock.

The sediments include different-sized mineral particles. The smallest particles are clays, followed by silts and then sands. These particles are important in the formation of soils (see Section 3.1). Larger particles of gravels and small boulders can also be found in sediments.

KEY TERMS

Rock: a combination of one or more minerals

Mineral: a naturally occurring inorganic substance with a specific chemical composition

Igneous rock: rock made during a volcanic process

Magma: molten rock below the surface of the Earth

Solution: formed when a solid is dissolved in a liquid

Precipitates: when a substance comes out of solution

Ion: an atom in which the number of positively charged protons is not equal to the number of negatively charged electrons

Sedimentary rock: a rock formed from material derived from the weathering of other rocks or the accumulation of dead plants and animals

The particles are transported by streams and rivers and then deposited as sediment. Each layer of sediment becomes more compact and harder because of the pressure created by the newer deposits above them.

Examples of sedimentary rock are limestone, sandstone and shale (Figures 1.4, 1.5 and 1.6).

Figure 1.4 A piece of limestone.

Figure 1.5 Sandstone.

Figure 1.6 A piece of shale.

Metamorphic rocks

Metamorphic rocks are created from existing rocks when the heat (above 150 °C) or pressure (above 1.5×10^8 Pa or 1480 atm), or both heat and pressure, causes changes in the rock crystals without melting the existing rock. The existing rock therefore changes in structure, becoming a metamorphic rock. The changes in structure can be chemical or physical or both.

Sedimentary and igneous rocks can become metamorphic rocks, and a metamorphic rock can become another metamorphic rock. Metamorphic rocks are usually harder than sedimentary rocks.

Examples of metamorphic rocks are marble and slate (Figures 1.7 and 1.8).

When the Earth's crust first formed, all the rocks were igneous. These rocks were slowly eroded, releasing small particles that formed sediment, and these sediments built up over time to form sedimentary rocks. The rocks that make up the Earth's crust are always moving, which creates the heat and pressure needed to form metamorphic rock. All rock types are constantly eroded and formed in the **rock cycle** (Figure 1.9). Table 1.1 compares the characteristics of the different rock types.

KEY TERMS

Metamorphic rock: a rock formed from existing rocks by a combination of heat and pressure

Rock cycle: a representation of the changes between the three rock types and the processes causing them

Igneous	Sedimentary	Metamorphic
Made from liquid magma	Made from other rock fragments	Made from existing rock
Magma cools to form solid rock	Rock fragments become buried and increased pressure forms a rock	The original rock is changed in form by heat and pressure
Mineral crystals sometimes present; the size of the crystals depends on the speed of cooling	Crystals absent	Mineral crystals present
No fossils present	Fossils may be present	No fossils present

Table 1.1 Characteristics of the different rock types.

Figure 1.7 A piece of marble.

Figure 1.8 A piece of slate.

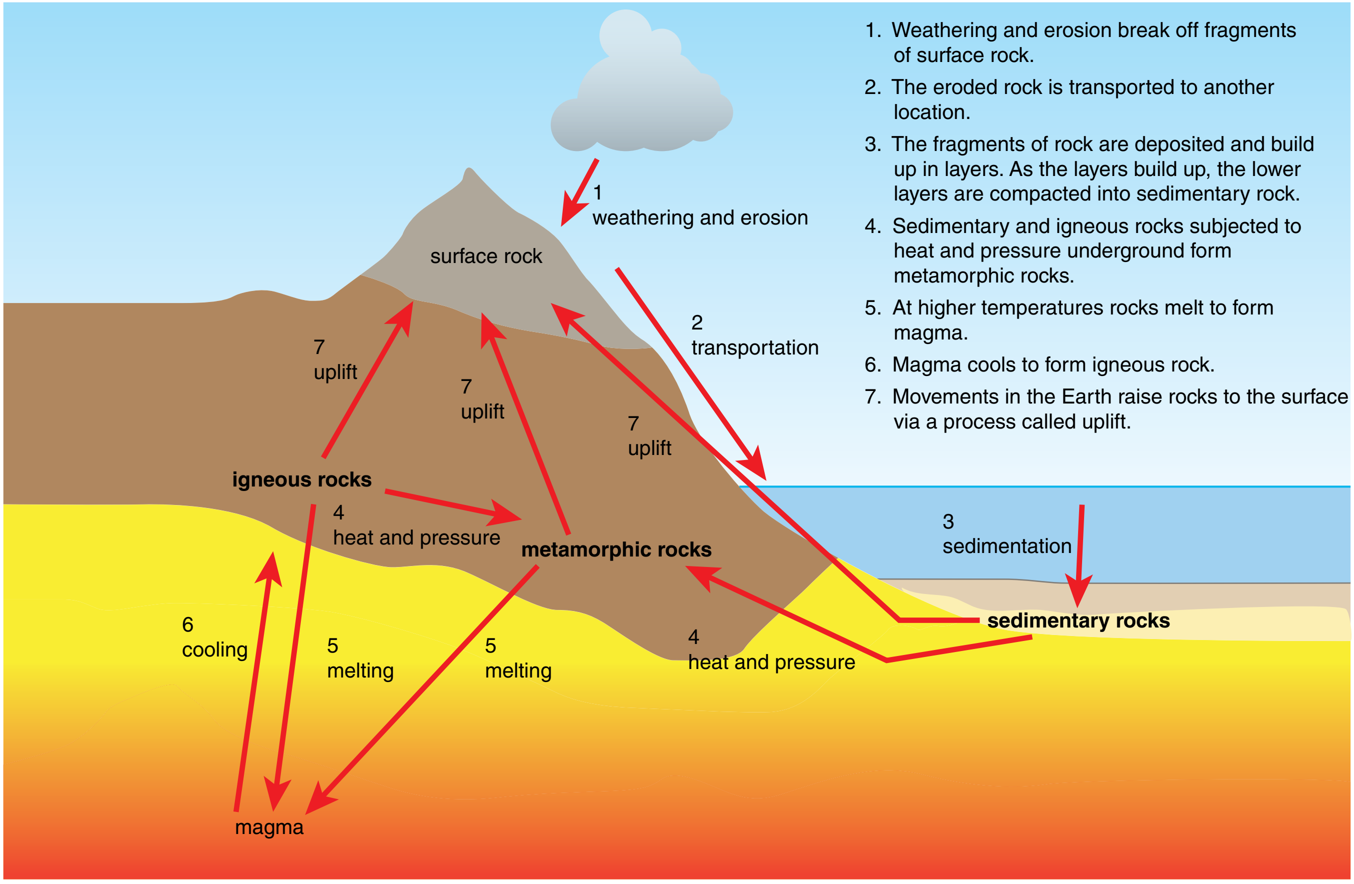
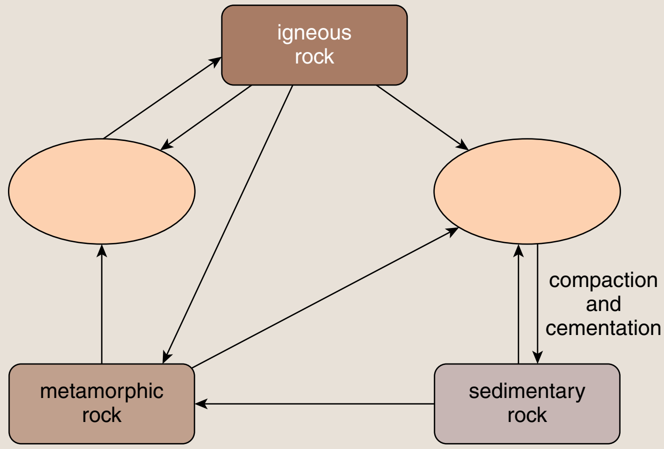


Figure 1.9 The rock cycle showing the relationship between the three rock types, sedimentary, metamorphic and igneous. The diagram also shows the interactions between these types, their origins and the processes by which they are interconverted.

SELF-ASSESSMENT QUESTIONS

1.1 Figure 1.10 shows the rock cycle.



heat and pressure   weathering and erosion   heat and pressure

melting   melting   cooling   magma   sediment

Figure 1.10 The rock cycle.

Copy and complete Figure 1.10 with processes on the arrows and intermediate stages in the ovals. The processes should be chosen from the list provided; one has been done for you.

1.2 Add the names of the correct rock type to Table 1.2.

Description	Rock Type
Rocks formed in the sea from particles of eroded rock	
Rocks changed by heat	
Rocks formed from the cooling of other molten rock	

Table 1.2 Rock types.

PRACTICAL ACTIVITY 1.1

Rocks and the rock cycle

Materials

- For the first part you will need to be able to access the Interactives Rock Cycle website (www.cambridge.org/links/scspenv4000).
- For the second part, which can be done on a different day, your teacher will provide you with a selection of rocks.

Method

- For the first part of the practical, go to the web page and look at the interactive diagram.
- For the second part of the practical, choose one of the rocks.
- Observe and describe your chosen rock, thinking about things like shape, colour, weight, softness or hardness.
- Return your rock to the table, and put a letter by it. Each rock should end up with a different letter by it.
- Working on your own, select another rock but this time do not pick it up.
- Spend about five minutes writing a description of your rock, without anyone else knowing which one it is.
- Swap your description with someone else and take it in turns to work out which rock has been described.

Questions

1 Test yourself on what you have learnt about the rock cycle using another version of the interactive diagram on the web page.

2 Answer the questions provided on the web page.

1.2 Extraction of rocks and minerals from the Earth

Minerals provide us with a wide range of materials that we use in everyday life. Coal and oil provide energy and many chemicals used in industry. Metallic **ores** provide us with the metals and alloys needed to make products such as computers, mobile phones, cars, wires and nails. The demand for minerals continues to increase, both from developed and developing countries.

Searching for minerals

People have searched for minerals for thousands of years. The simplest way to find mineral deposits is to look carefully at the surface of rocks. This process of **prospecting** has found nearly all the surface deposits of minerals worldwide.

Deposits on the Earth's surface can also be found using a range of **remote sensing** methods. For example, an area of land can be photographed from the air and the images carefully analysed for signs of minerals. Aerial photography can cover much more ground than a person walking over the surface of rocks (Figure 1.11). Images and other data from satellites can also be used to analyse very large areas.

KEY TERMS

Ore: a rock with enough of an important element to make it worth mining

Prospecting: a process of searching for minerals

Remote sensing: a process in which information is gathered about the Earth's surface from above

Geochemical: the chemical properties of rocks

Mineral deposits are weathered at the Earth's surface, producing mineral oxides. These can be detected by their unique radiation pattern, which is recorded by a satellite and downloaded to a computer for analysis.

Other satellites operate by sending signals to the surface of the Earth and then collecting reflected signals. The system works in all weathers, through complete cloud cover and at night.

Valuable mineral ores in the rocks below the surface can be located from the satellite images. Computers are used to process the data from a region of interest to see whether any minerals are present in the area. The satellite's positioning system records the exact location, and the geologists then visit the location to confirm the minerals have been identified correctly. Once in an area identified from satellite data, the geologists can check further locations to see whether the minerals of interest are present nearby as well. Using satellites means large areas can be geologically mapped quickly and at low cost.

Field surveys on the ground are used to take samples. These are sent to a laboratory for **geochemical** analysis, so that the chemicals in the samples can be identified. The samples can be taken from stream sediments, soil or rocks (using shallow drilling). The points where the samples are taken are usually selected by overlaying a grid on a map of the survey area. The location of the sample points in the field can be found accurately using the Global Positioning System (GPS).

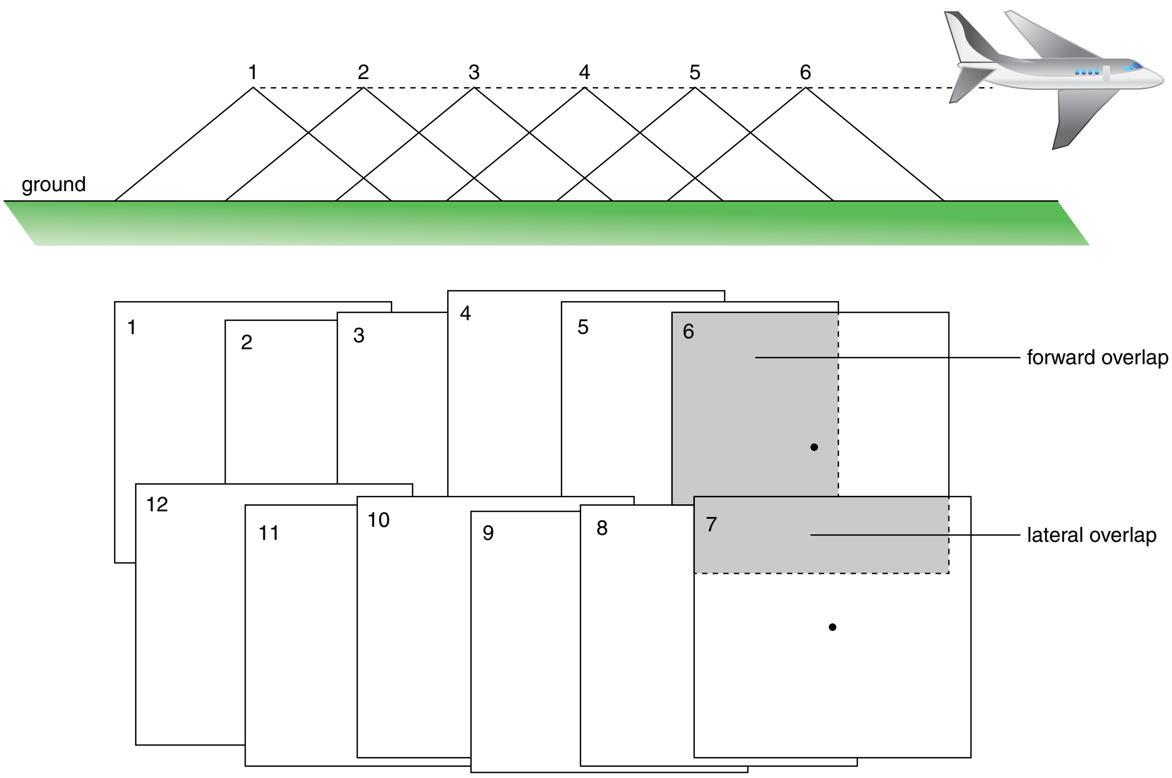


Figure 1.11 Aerial photography used for mineral prospecting. Photographs are taken with an overlap both front to back and side to side. If the overlap is sufficient, three-dimensional views can be generated, which makes the prospecting easier.

Another method used to identify the mineral ores present in rocks is **geophysics**. A series of vibrations (seismic waves) are sent through the Earth's surface. Several sensors at different distances from the source of vibrations are laid on the ground. The vibrations create shock waves that travel down into the rock layers and are reflected back to the sensors on the surface. The shock waves record different patterns depending on what minerals are present in the rock layers. Explosives can be used instead of vibrations but this is potentially more dangerous (Figure 1.12).

Mining rocks and minerals

To make sure that the deposits of mineral ores are large enough to be extracted, a resource evaluation is carried out. The aim of the evaluation is to estimate the grade and tonnage of the mineral of interest present in a deposit. Drilling to collect rock samples must be done to carry out a resource evaluation. For small deposits, only a few samples are needed. For larger deposits, more drilling is required, following a grid pattern on the ground. The aim is to identify the size of the deposit as well as the mixture of mineral ores present.

From the information collected, the deposit may be classified as a mineral ore reserve. Classifying the deposit as a reserve takes into account the amount of material that it is practical to extract. Finally, a feasibility study is carried out to evaluate all the financial and technical risks of any proposed mining project (see below). The final decision may be to develop a mine straight away or wait until conditions change in the future.

Methods of extraction

There are two main types of mining. **Surface mining** includes **open-cast**, **open-pit**, **open-cut** and **strip mining**. **Sub-surface mining** includes **deep** and **shaft mining**.

KEY TERMS

Geophysical: the physical properties of rocks

Surface mining: a type of mining used when the mineral is either exposed on the surface or overlain by only small amounts of **Overburden**

Overburden: the rock and soil overlying an economically viable mineral deposit

Open-pit mining: a type of surface mining

Strip mining: a type of surface mining

Sub-surface mining: a type of mining used when the deposit is covered by a deep layer(s) of unwanted rock

Deep mining: a type of sub-surface mining

Shaft mining: a type of sub-surface mining

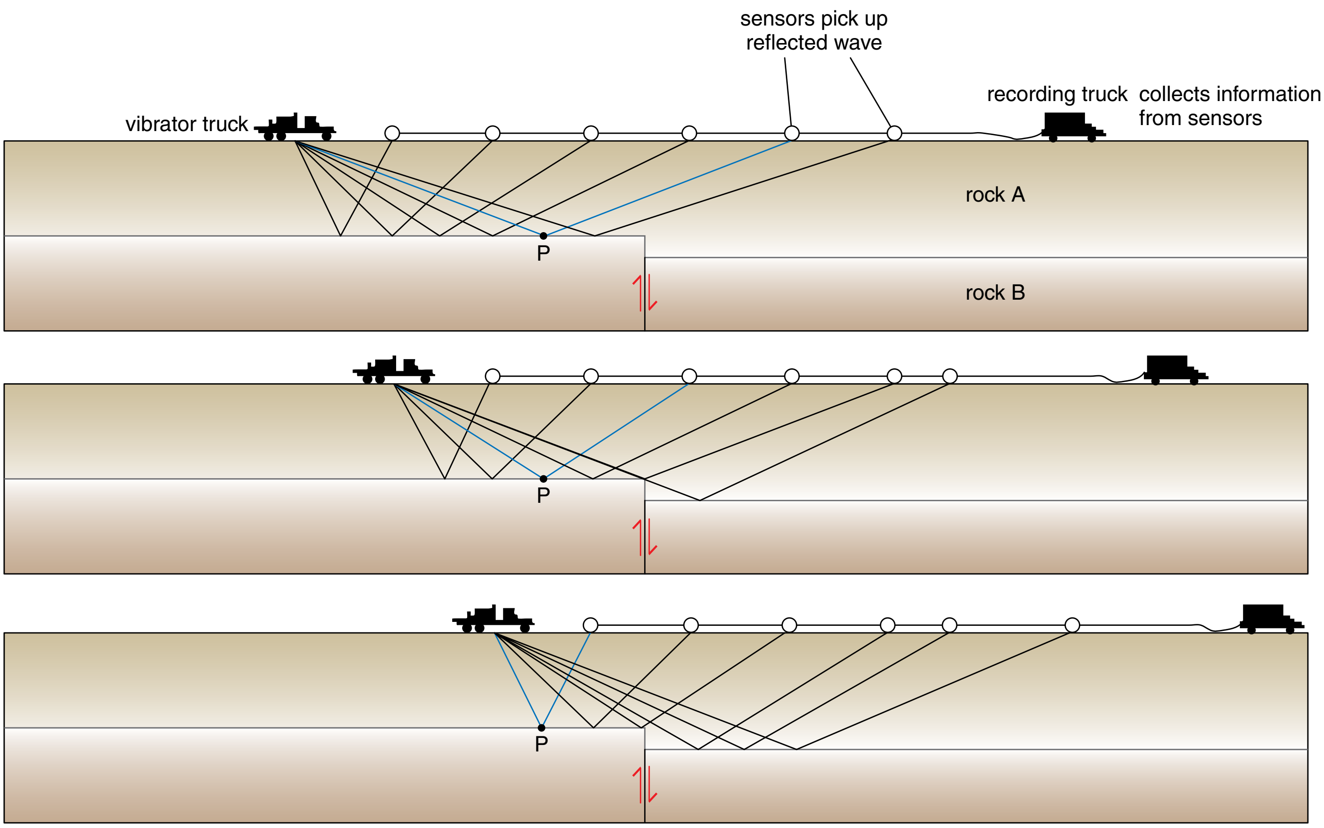


Figure 1.12 Seismic shock waves being used to locate rock or mineral deposits.

Surface mining

Open-pit mining is also called **open-cast** or **open-cut** mining. This type of mining is used when a valuable deposit is located near the surface, often buried below a thick layer of worthless material. The material above the deposit is called overburden. The overburden has to be removed first to expose the deposit, and is stored nearby to be used later for mine restoration (Figure 1.13).

Open-pit mines are carefully dug in sections called benches. The walls of the benches are kept at an angle to reduce the risk of rock falls. The safe angle of these walls depends on the type of deposit and overburden. Roads have to be made as the digging progresses to allow the removal of the mineral deposit and overburden. Building materials such as sand, gravel and stone are removed from open pits called quarries. The process of extraction from pits always uses similar methods.

There are two main reasons why open-pit mines eventually stop being worked. In some cases, as much valuable deposit as possible has been removed. In other cases, the amount of overburden that needs to be removed has increased to an extent that the mine is no longer profitable.

Strip mining is used to mine a seam of mineral. First of all the overburden, which consists of the overlying rock and soil, is removed. Strip mining is mainly used to mine coal near the surface. Figure 1.0 shows a very large bucket wheel excavator, which is often used in strip mines. These machines can move thousands of tonnes of material every hour.

Sub-surface mining

Sub-surface mining (Figure 1.14) involves digging tunnels into the ground to reach mineral deposits that are too deep to be removed by surface mining. Sometimes horizontal tunnels are dug directly into the coal seam in the side of a hill or mountain: this is a drift mine entered by an **adit**. These tunnels produce waste rock as well as the mineral ore.

A sloping tunnel is dug to reach deeper deposits. Mining machinery can be lowered down the sloping tunnels while waste rock and mineral ore are hauled up to the surface.

The deepest deposits are reached by digging a vertical shaft. Horizontal galleries are then dug into the mineral deposits. This type of mining is more expensive and technically challenging than either horizontal or slope tunnelling. Only large deposits of valuable minerals are mined in this way.

Most of the material is removed from mines by machine. The miners' job is to make sure all the machinery is working correctly and safely. Compared with open-pit mining, any form of shaft mining is more difficult because a supply of fresh air and water drainage has to be provided. There are also the dangers of collapsing tunnels as well as the risks of poisonous gas, explosion and underground fire.

KEY TERMS

Open-cast mining: a type of surface mining

Open-cut mining: a type of surface mining

Adit: the entrance to a horizontal (drift) mine

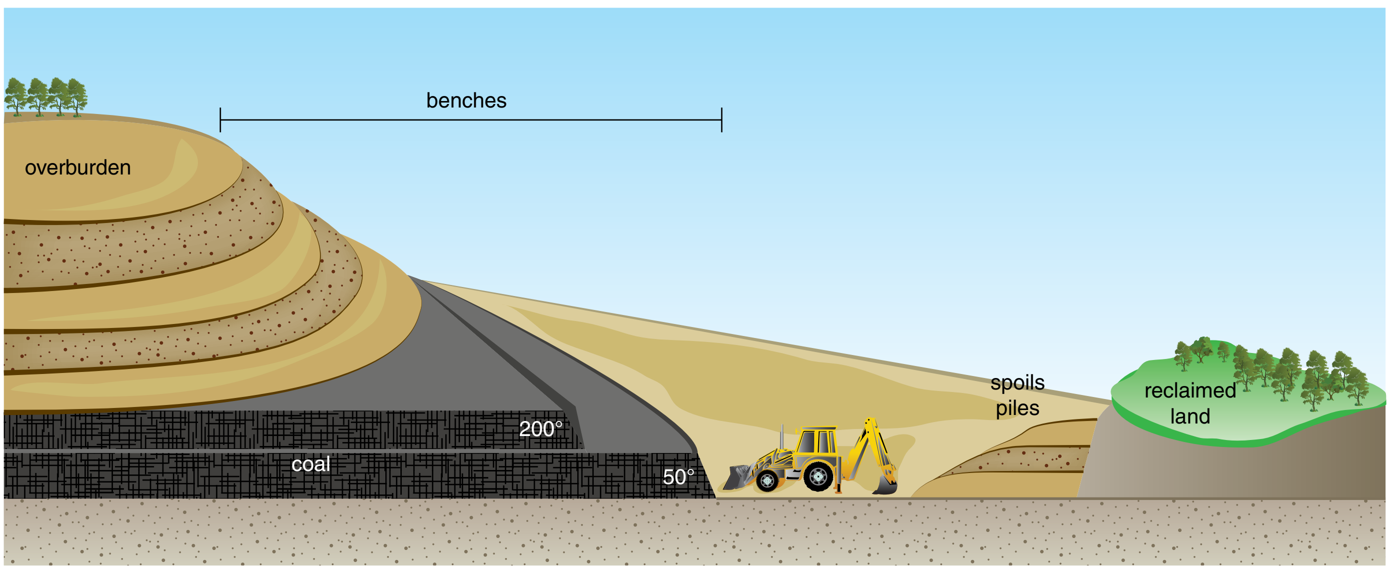


Figure 1.13 An open-pit mine.

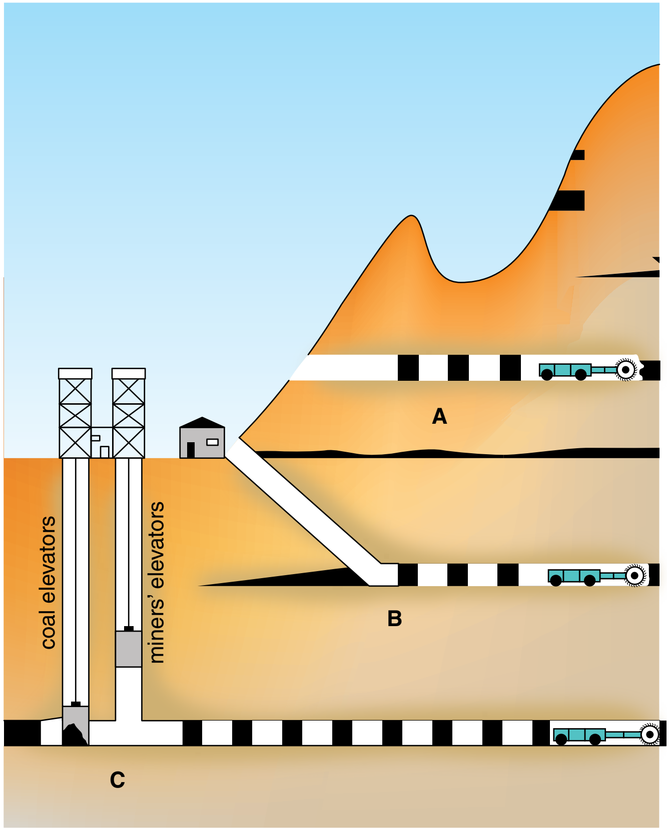


Figure 1.14 A drift mine with a horizontal entrance, called an adit. B Sloping tunnel.

SELF-ASSESSMENT QUESTIONS

1.3 What factors need to be considered before starting up a new mine?

1.4 Suggest reasons why developing surface mines is easier than developing mines underground.

Factors affecting the viability of extraction of minerals

Once a mineral deposit has been located, a mining company has to decide whether it should mine the deposit or not. Mining companies need to consider a range of issues when planning to open a mine, including:

- the costs of exploration and extraction
- geology
- climate
- accessibility
- the environmental impact
- supply and demand.

Greenfield sites are areas that have never been mined for minerals. The chances of finding a deposit there are low. For some metal ores, the **strike rate** ranges from 1 : 50 to 1 : 100. New gold deposits are very hard to find: the strike rate may be as low as 1 : 1000.

Brownfield sites are areas that have already been mined. They usually have a higher strike rate than greenfield sites. Even low-grade deposits that were not extracted in the past may have enough value that they can now be mined for profit.

The probable cost of extracting one tonne of ore has to be calculated. Deposits near the surface can be extracted by open-pit mining. There are usually fewer technical difficulties to mining on a large scale using this method, which leads to a low extraction cost per tonne.

Deeper deposits can only be extracted by shaft mining. This is more costly to set up and maintain, so the cost per tonne will be higher than open-pit mining. Only deposits of high value can be mined economically in this way.

The quality of the mineral deposit is another important factor in deciding to open a mine. High-grade ores will yield more of the required chemical elements than low-grade ores.

The size of deposit that can be extracted is also important. Small deposits of high-grade ore and high-value ores may be worth mining. Small deposits of low-grade ore and low-value ores that cannot be mined at a profit are left as known reserves. In the future they may be mined, either because technical advances make it less costly to do so or because of a sustained increase in world price.

It is possible to estimate the working life of a mine, but many factors have to be taken into account. The main factors are the size of the deposit and the planned rate of extraction. If a mine is projected to have a short working life, then other factors, such as ore value, will be very important in deciding whether work should be started. Mines that are projected to have a long working life are less likely to prevented by other factors.

Transporting the ore from a mine to processing plants may be difficult and expensive. This factor alone could prevent a deposit being mined. The cost of building road or rail links to the processing plants or to the nearest suitable port for export is a start-up cost that has to be considered. These transport links have to be kept in working order, so there will also be maintenance costs. The cost of transporting 1 tonne of ore over 1 km can be calculated.

For large tonnages, such as iron ore, rail transport is the only practical and cost-effective method of moving the ore. If the ore is going to be exported, large ships, called bulk carriers, can be used to keep the transport costs low.

Another way of keeping the transport costs low is to carry out some processing of the ore at the mine. The process used depends on the chemical nature and grade of the ore. The aim of processing is to concentrate the mineral ore and separate it from the waste material. The waste material is stored at the mine. This type of processing produces a higher grade of ore so it has a higher value per tonne. Some ores are high grade when they come out of the ground. For example, some iron ores are called direct shipping ores (DSO) because they have enough iron content that they do not need processing at the mine.

Mining companies can only start work after they have been given a licence to extract a deposit. The government of any country will want to earn some money from the mining activity. This means there will be a tax to be paid to the government for every tonne of mineral ore extracted. From the point of view of the mining company, it is important that a long-term agreement is reached to avoid rapid rises in tax that could make the mining operation unprofitable. From the point of view of the government, the tax needs to generate enough money to be invested in developments for the benefit of the country.

Increase in world demand for any mineral ore will drive the price up. Changes in **supply and demand** can increase or decrease profits from working mines. If the world price remains high, then deposits that could not previously be mined at a profit may become worth mining. The amount of money that needs to be invested in starting up a new mine is considerable. This means that if the world price falls because of a drop in demand, a new mine may not start working at a profit. Only when the world price rises again can a new mine become profitable. The global recession of 2008 stopped some known mineral reserves being mined because of reduced world prices. Recently, the world price of iron ore has dropped because supply is greater than demand.

An example of changes in world price are shown in Figure 1.15.

Mining companies try to predict future demand very carefully so that periods of selling ore at less than the cost of production are kept to a minimum. The profits from periods of high world prices are used to make up for periods of low profitability, as well as to pay for the development of newly discovered deposits.

KEY TERMS

Strike rate: the frequency with which attempts to find a desired mineral are successful

Supply and demand: the relationship between how much of a commodity is available and how much is needed or wanted by consumers of the product

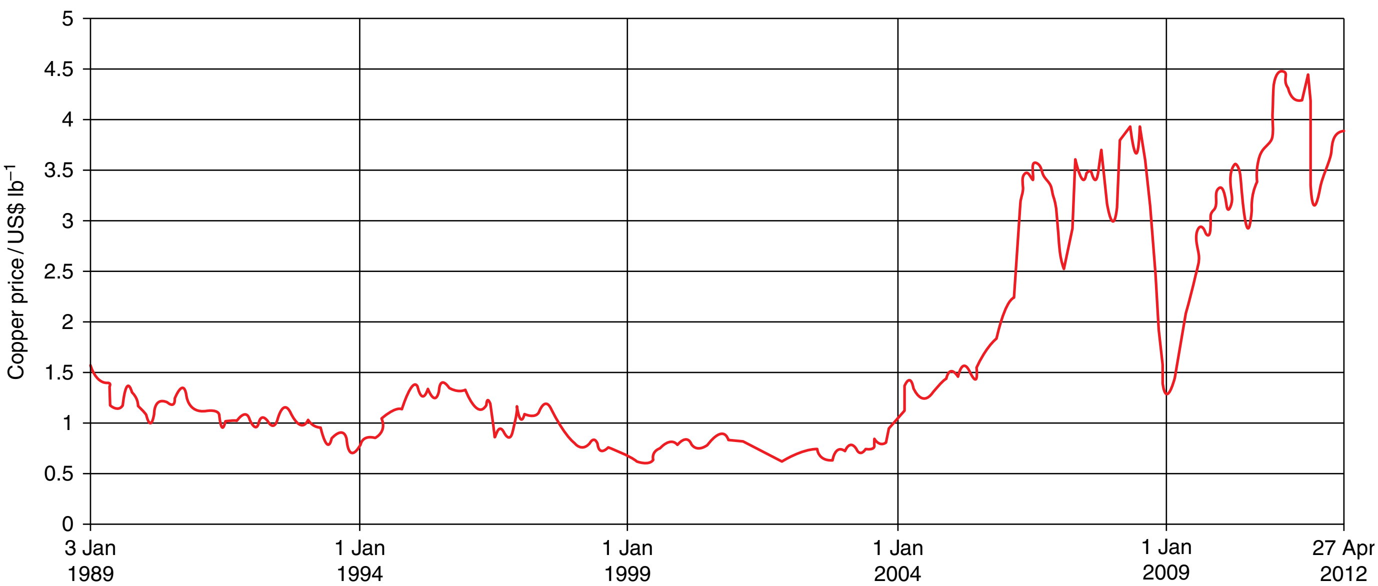


Figure 1.15 Changes in world price of copper, 1989 to 2012.

1.3 Impact of rock and mineral extraction

Environmental impacts

Impacts on the environment from the extraction of rocks and minerals range from large-scale habitat destruction to pollution of the atmosphere, land and water. Those living near the site are also affected by noise and visual pollution.

Ecological impacts

Any mining activity will involve the loss of habitat for some species of plants and animals. Even small-scale surface mineral extraction requires the vegetation to be cleared from an area of land. The plants removed have lost a place to grow, and so have the animals that depend on the plants for food and shelter.

Deep mining means that shafts have to be dug down to the seams of valuable minerals. At the beginning of deep mining operations, only a small area of land is cleared of vegetation. After this type of mine has been working for several years, more habitats will be destroyed as the amount of mine waste stored aboveground increases.

Any form of large-scale surface mining causes the greatest loss of habitat. Large areas of vegetation have to be removed and then large volumes of removed overburden have to be stored. After the seams of valuable mineral have been removed, the overburden is spread over the mined area to restore the land. The new land surface will slowly become covered in some plant species. However, this vegetation will have less biodiversity compared with the original vegetation. This means that some plant and animal habitats will still be lost from an area for many years, even though the land surface has been restored.

When a company applies for a licence to start working, an **environmental impact assessment** is carried out. The licence application is usually approved if the company has a plan to keep the loss of habitat as small as possible and then to restore the land after mining has finished. An environmental impact assessment tries to identify all the possible types of damage to the environment. To have the licence application approved, any mining company must have detailed plans to control the amount of damage to the environment.

KEY TERMS

Environmental impact assessment: a process by which the probable effects on the environment of a development are assessed and measured

Biomagnification: the process in which the concentration of a substance in living things becomes higher at progressively higher levels in a food chain or web

Pollution

The working life of any type of mine will result in some pollution of the environment (Figure 1.16).

This can take the form of noise, water, land, air and visual pollution. Noise pollution is a problem when large-scale surface mining takes place. The overburden is loosened by explosive charges and then removed by large machines. The noise can disturb the behaviour of many animal species near the mine and cause health problems for people. Deep mining usually produces less noise than surface mining. Mining licences set limits on the levels of noise and working hours of a mine.

Water pollution from any type of mine can be a major problem that can continue for many years after a mine has stopped working. The water that drains through mine waste, or comes directly from mine shafts, can cause dramatic changes to the populations of living organisms in streams and rivers. Drinking water supplies may also be polluted by drainage from mines, making it unsafe for people to drink.

This pollution is caused by chemical reactions between water and exposed rocks and mine waste. The water may become acidic and then dissolve toxic metal ions. The combination of acidic water with a high concentration of toxic metal ions kills many aquatic organisms. Some of the metal ions exist only in low concentrations in bodies of water. However, organisms absorb these ions and retain them in their body, reaching concentrations much higher than that in the water. This is called bioaccumulation. The concentrations increase further in organisms that are higher up the food chain. This process is called **biomagnification**, and can cause the death of top consumers. There are other metal ions that are toxic in high concentrations that do not bioaccumulate.

The land surrounding a mine will become polluted by mine waste. In some cases the area will be quite small but the toxic nature of the waste means that only a few plants can grow, even many years after mining has stopped.

Figure 1.16 Pollution and land degradation around a copper mine.

When mine waste is stored above natural water courses, the waste pile may collapse and cover more land. The choice of site for mine waste is an important factor to consider in plans to limit the effects of pollution.

Many mining activities release dust particles, which will settle on the vegetation near the mine. Dust reduces plant growth: the leaves of plants need to absorb light energy to perform photosynthesis. If light cannot penetrate a layer of dust on a leaf surface, then the rate of photosynthesis is reduced.

Dust from mining activities may also have toxic effects depending on the chemical components present in the dust. This can also reduce or stop plant growth, and the particles can be dangerous to human health. The biggest risk is breathing in dust that then remains in the lungs. Long-term exposure can lead to serious lung diseases that can cause death. The lungs of children are very easily damaged by breathing dust particles. Some harmful substances can also be absorbed through human skin. Mining companies provide safety clothing and breathing masks to protect the health of mine workers. However, many people make a living from small-scale mining without a licence. This is often called informal mining and it is illegal. Health problems as a result of toxic substances are common among these miners.

Evidence of mining activity can often be seen because the landscape is damaged. This is visual pollution. Large-scale surface mining will create the most obvious visual pollution during the working life of a mine. This type of pollution may only be temporary because careful restoration of the landscape is possible.

SELF-ASSESSMENT QUESTIONS

1.5 Give reasons why illegal mining without a licence is bad for people and the environment.

1.6 Explain how reduced plant growth can affect an ecosystem.

CASE STUDY

The Antamina Mine in Peru

The Antamina mine is a large open-pit mine located high in the Andes Mountains of Peru at an altitude above 4000 m (Figure 1.17). The estimated reserve is 1.5 billion tonnes of ore. Extraction of copper and zinc ores began in 2001. The mine employs more than 5000 people.

Before mining could begin, more than 100 million tonnes of surface rock had to be removed and placed in waste piles. The ores were then removed and crushed in the processing plant to produce concentrate. Wastes from this process are called tailings. These are stored in a compound to prevent water pollution. The concentrate is then mixed with water and moved in a 300 km pipeline to the coast. After the water is removed from the concentrate it is loaded into ships.

The mine was expected to stop production in 2022. However, more reserves have been found and increased investment in efficient processing machinery has extended the expected life of the mine to 2029.

Questions

1 Suggest why the mine was developed in such a remote location.

2 Water pollution is serious risk at this open-pit mine. Give three reasons why there is a high risk of water pollution.

3 a Suggest how the production from this mine been made more sustainable than originally planned.

b Explain why it is unlikely that the land will be fully restored when this mine stops production.

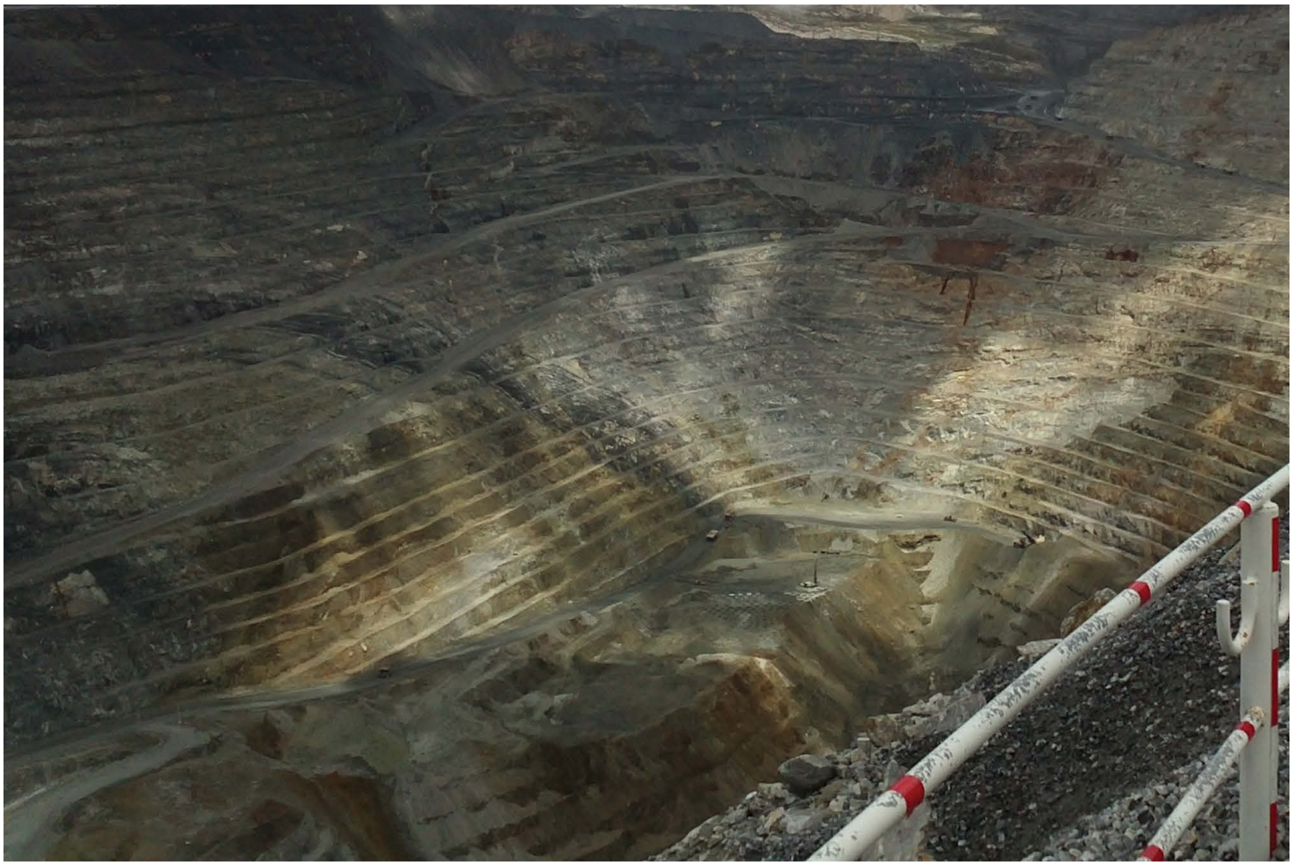


Figure 1.17 The Antamina Copper mine, Peru, showing benches and the sheer size of the mine.

Economic impacts

Extracting valuable minerals provides employment for people and provides taxes for the government. Modern mining is carried out using machines so only a small number of people will be directly employed to extract minerals. However, if the mineral is then refined and processed in the same country, further jobs are created. In many cases minerals are exported from one country to be used in manufacturing processes in another country. This can create jobs in the country importing the mineral. Overall, mineral extraction does provide employment, even if modern methods mean that the total number of mining jobs may only be a few hundred.

Mineral extraction usually benefits both local and national economies. Jobs are created directly to extract minerals and further jobs to supply transport and mining equipment. More jobs are created when the mineral is refined to make products. If all these activities occur in the same country, this will generate the most income for buying goods and services as well as investing in infrastructure projects.

Some improvements to transport and services, such as healthcare and education, will be required to supply any mining industry as well as support the mineworkers and their families. Some improvements will be paid for by the mining companies as a condition of their mining licence. Taxes paid by mining companies and individual workers can provide a country with enough revenue to invest in infrastructure projects to benefit the whole population of the country.

1.4 Managing the impact of rock and mineral extraction

Management of a mining operation should start with plans for safe waste disposal and end with plans to return the land to its original state when mining is over.

Safe disposal of mining waste

In the past, mining waste was usually been put in piles near the point of extraction. In some cases, stable waste piles were placed on top of water courses, which then become polluted with toxic chemicals. In other cases, waste piles were unstable and collapsed. Apart from the possible loss of life caused by a collapse, collapsed waste piles increase land and water pollution.

Today, safe storage and disposal of mine waste is one of the most important aspects of any mining licence application.

In a well-regulated system, applications must provide a detailed plan to show how mine waste will be stored to prevent collapse. The site of the mine waste must also prevent the possibility of water pollution. The plan must include details of how the waste will be monitored to detect any movement or water pollution.

Land restoration and bioremediation

When mining has finished, the land needs to be restored. Sometimes mine waste can be reshaped to blend in with the surrounding landforms. The waste can then be covered by a layer of soil, which may be enriched with fertiliser. Such an area can then be planted with trees. This will help other plants and animals to colonise the area. As time passes, the soil will be improved by the addition of organic matter from plant and animal wastes. This method of land restoration is often used to manage the waste from coal mining. Planting trees creates habitats fairly quickly even though the trees are only able to grow slowly.

Some mine waste does not allow the growth of tree roots, so other methods of restoration have to be used. Contaminated waste can be treated where it was left (in situ treatment) by **bioremediation**. Alternatively, waste can be removed from a site to a treatment plant (ex situ treatment).

KEY TERM

Bioremediation: a process in which living things are used to remove toxic chemicals from a natural site

Bioremediation is the process of removing pollutants from waste using living organisms. Many organisms are able to break down toxic substances into less hazardous substances. This often happens slowly in natural environments. Some microorganisms, such as bacteria found in soils, are able to absorb pollutants and process them via metabolic pathways into less harmful substances. When bacteria take in pollutants they usually gain either energy or nutrients.

Microorganisms can remove and process pollutants at a faster rate if their environment provides a source of oxygen and nitrogen. Some plants are also naturally able to bioaccumulate toxic metals, and this process can be speeded up with the addition of fertilisers. These plants are grown on contaminated waste. The plants absorb toxic metals, and later the parts of the plant aboveground are removed so the waste left in the ground becomes less toxic.

Figure 1.18 Former granite quarry on Bornholm, Denmark, the steep sides now a paradise for sea gulls.

After this treatment, the land is often turned into a nature reserve as, even though the ground surface is less toxic, it may still not be possible to use it for farming or to build houses on. Several tree and herb species are introduced, and as the plant populations grow they create habitats for many animal species. These nature reserves become valuable green spaces for human recreation, as well as helping to maintain biodiversity (Figure 1.18).

Mineral extraction often creates large holes in the landscape. If the rock lining the hole is impervious to water and non-toxic then it can be allowed to fill with water to form a reservoir. This water could be used for irrigating farmland or processed to provide clean, safe drinking water for humans. Sometimes, these holes are filled with household waste until they are full. The waste is then covered with soil and planted with trees. This is referred to as landfill.

How successful are these strategies? The Society for Ecological Restoration International (SERI) proposed a number of ecosystem-related variables to measure the success of a land restoration programme. In summary, a successful scheme will return the site to as close as possible to the native ecosystem that existed before the mining began. In this respect, although all strategies have a value, some scientists believe that allowing a site to undergo a natural process of recolonisation and slow change to the environment (a process called succession) may actually be the most beneficial method. Active reclamation is important to reduce the incidence of such events as landslides and erosion. However, once this has been done, the natural process of succession can probably be relied on to achieved the ecosystem recovery SERI and others think we should aim for.

1.5 Sustainable use of rocks and minerals

The supply of rocks and minerals that are used as building materials and for industrial production is finite. It is hard to see, therefore, how the use of these materials can meet the definition of sustainability. Sustainable use means use that meets the needs of the present without affecting the ability of future generations to meet their needs. A fully sustainable resource will never run out, and this can be achieved in fisheries, agriculture and forestry where the resource is biological and can be regrown. Unlike these biological systems, such things as rocks and minerals will not last indefinitely.

Human societies need to use any resource with care so that its use is at least more sustainable than it has been in the past. The sustainable development of the reserves of any rock or mineral must take into account environmental, economic and social factors. The aim is a planned and controlled use of any reserve to provide the most benefit to people, maintain economic growth and stability and prevent widespread environmental damage. National laws and international agreements encourage sustainable development of resources.

The term sustainability is now widely used. However, as the world population continues to increase, it is difficult to see how the challenge of complete sustainability can be met. Perhaps the best that can be achieved is the prolonged use of resources with limited environmental damage and the most benefit for human societies.

On the other hand, it may be possible to find substitutes for the use of relatively scarce materials. For example, copper is quite rare and is used for, among other things, the conduction of electricity. When the purpose is to transmit information, copper wire can be replaced by fibre optic cables, which are made from the much more common element silica.

Several strategies can be used to make the exploitation of rocks and minerals more sustainable.

Efficiency of extraction

Increasing the efficiency of extraction seems an obvious starting point. For example, underground coalmines only remove between 55 and 70% of the coal present in the reserve. This is because of the technical difficulties of extracting the remaining coal in a safe and cost effective manner. Open-pit mining is more efficient at extraction than underground mining but some wastage still occurs.

To improve the efficiency of extraction, many mine wastes are now being processed for a second time. This allows valuable materials to be recovered and reduces the risk of pollution from stored mine waste. New extraction methods include chemical treatment of the waste, which extracts much of the valuable mineral still within it. Biological treatment with microorganisms can also be used to extract more product from the waste.

Improvements in the performance of the machines used in mining and processing also increase the efficiency of extraction. Greater use of data analysis by computers is likely to lead to improvements as well. However, surface mining has more potential for an increase in efficiency of extraction than underground mining. This is because it is more difficult to predict geological conditions underground.

Efficiency of use and recycling

Recycling materials makes an important contribution to the sustainable use of rocks and minerals. Many manufactured goods, from cars to steel cans, are recycled in most countries. Most metals can be recovered and refined back to clean metals to be used by industries again. This uses less energy than processing the ores or concentrates to make metals. Many countries still have the potential to recycle far more materials in the future (Figure 1.19).

Attempts to use minerals such as metals more efficiently include engineering solutions. For example, it is possible

Figure 1.19 Scrap metal in a scrapyard.

to design steel beams used in buildings to have the same strength but use less steel. In the 1980s titanium became very expensive and there was an incentive to design products that used less of this metal. Many countries may in the future require car manufacturers by law to take back their products when they are finished with. It is hoped this will encourage them to make more durable products that use less minerals and last longer.

The major way in which governments are trying to encourage a more sustainable use of minerals and rocks is to pass laws that requires manufacturers to become responsible for recycling and reuse. For example, the Waste Electrical and Electronic Equipment (WEEE) Directive of the European Union, was passed in 2002. Although some of the items covered are not mineral rich (for example televisions are only 6% metal) others are: a typical cooker is 89% metal.

SELF-ASSESSMENT QUESTIONS

1.7 Suggest one advantage of *in situ* waste treatment and one advantage of *ex situ* waste treatment.

1.8 Describe three ways in which recycling materials is important for the sustainable use of resources.

Summary

After completing this chapter, you should know:

- the characteristics of named igneous, sedimentary and metamorphic rocks
- how these rocks are formed in the rock cycle
- the features of surface and subsurface mining
- how we decide to extract rocks and minerals
- the environmental, economic and social impacts of rock and mineral extraction
- how landscapes damaged by rock and mineral extraction can be restored and how successful these strategies can be
- the meaning of sustainable resource and sustainable development
- how rocks and minerals can be used sustainably.

End-of-chapter questions

1 An important local fishery exists in Lake Titicaca, Peru. The lake is 100 km from a mercury mine. A study was carried out on the levels of mercury in fish caught in the lake. Some of the data are shown in Table 1.3.

Length of fish / mm	Mercury concentration / ppm
104	0.20
124	0.32
125	0.30
128	0.20
136	0.30
140	0.32
146	0.35
159	0.45
160	0.35
178	0.55
196	0.85

Table 1.3 Fish and mercury levels

The same data are plotted in Figure 1.20.

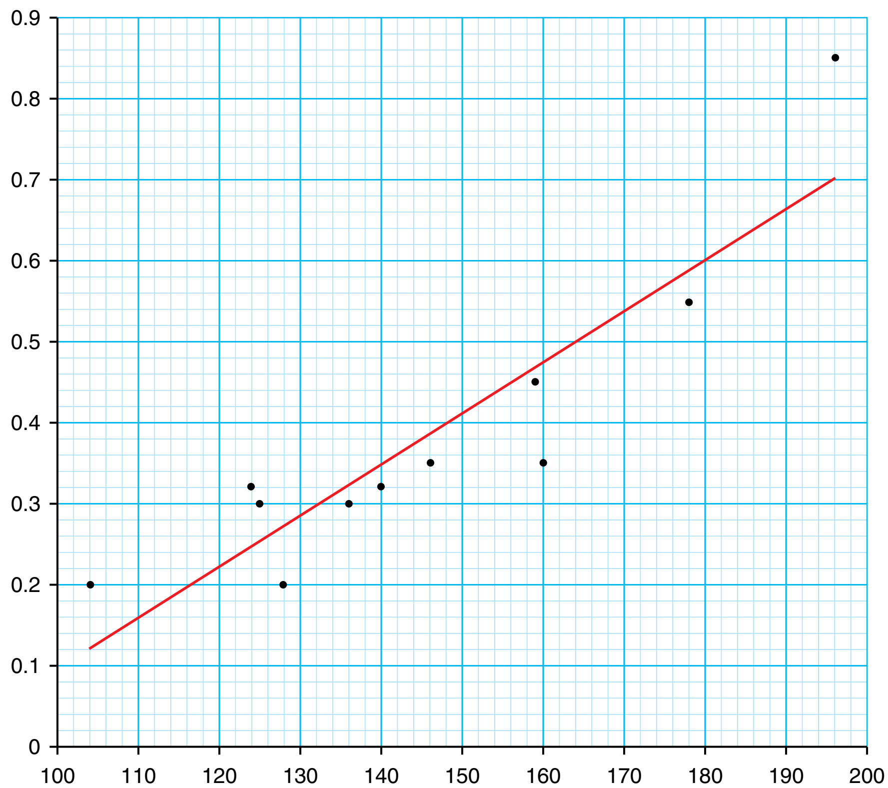


Figure 1.20 Fish and mercury levels.

a Copy and complete the graph by labelling the axes. **[2 marks]**

b Describe and suggest an explanation for the relationship shown by the data in Figure 1.20 and Table 1.3. **[5 marks]**

c The recommended maximum level of mercury in food is 0.30 ppm. Suggest the maximum length of fish that people in this area should consider eating on a regular basis. **[1 mark]**

d It was suggested that the source of the mercury in the fish in the lake was a mercury mine 100 km upstream. To test this, water samples were taken from a river as shown in Figure 1.21. They were analysed to discover the concentration of mercury.

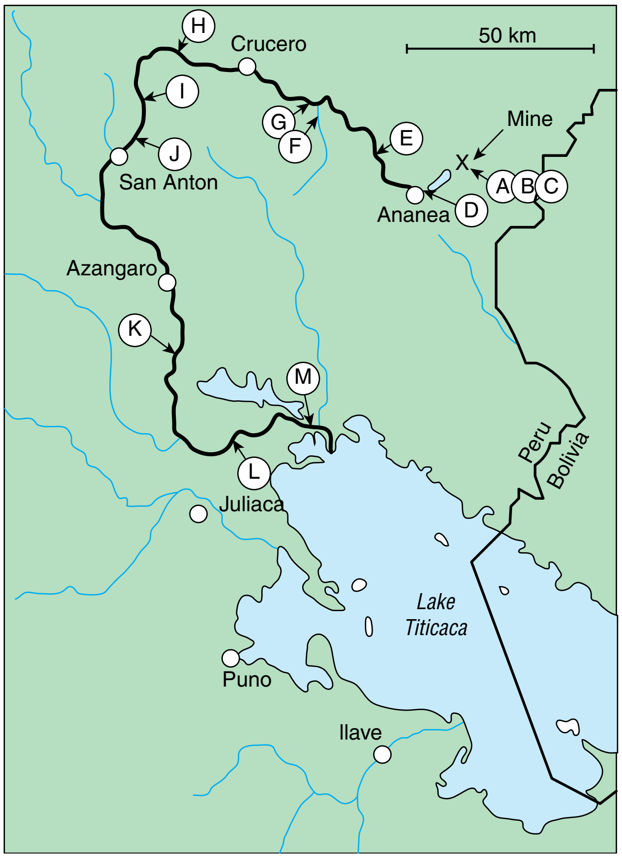


Figure 1.21 Mercury sampling

The data from some of the sites are shown in Table 1.4.

Sampling site	Mercury concentration / microgram per litre of river water
A	0.12
B	0.26
C	0.10
F	0.38
G	0.06
H	undetectable
J	undetectable
K	undetectable
M	undetectable

Table 1.4 Mercury sampling.

State and explain the conclusion you would reach from these data about the source of the mercury in the fish. **[3 marks]**

2 Aluminium is produced from bauxite. Five tonnes of bright red bauxite are made into 2 tonnes of a white powder called alumina (aluminium oxide) in an alumina plant. The bauxite is usually obtained from open-pit mines. Hot caustic soda solution is added to the crushed rock to get rid of impurities. The alumina is then converted into 1 tonne of aluminium in a smelter. An electric current is passed through the alumina and molten aluminium is siphoned off.

- **a** State the name given to any rock that contains a valuable metal. **[1 mark]**
- **b** Calculate the mass of solid waste that would be produced from the processing of 25 tonnes of bauxite. **[3 marks]**
- **c** Calculate the mass of bauxite that would be needed to produce 25 tonnes of aluminium. **[1 mark]**
- **d** Suggest two environmental consequences of aluminium production after the bauxite has been mined. **[3 marks]**
- **e** Explain how the landscape may be restored after bauxite mining is finished.

3 Figure 1.22 shows a deep coal mine and the area around it. **[3 marks]**

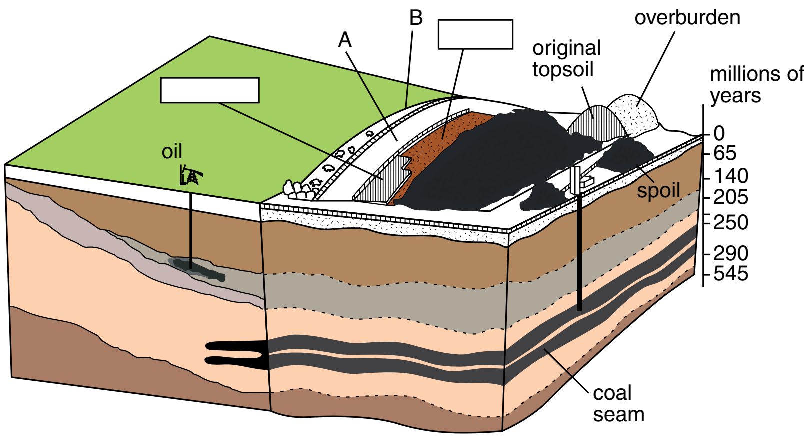


Figure 1.22 A deep coal mine and the area around it.

- **a** State the rock type to which coal belongs. **[1 mark]**
- **b** Explain how the coal is extracted from the location shown in Figure 1.22. **[3 marks]**
- **c** State the age of the coal and oil deposits shown in Figure 1.22. **[2 marks]**
- **d** Copy and complete the labelling of the diagram by adding the correct names to the boxes. **[2 marks]**
- **e** Explain, using the names and letters, how the spoil heap has been reclaimed. **[5 marks]**

4 Figure 1.23 shows how the production of a mineral changed over time.

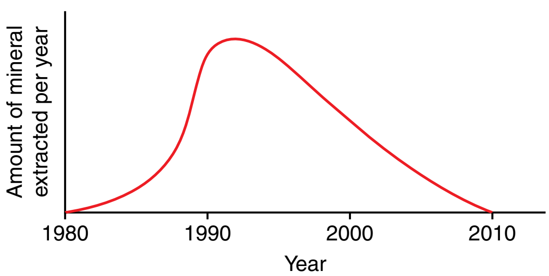


Figure 1.23 The production of a mineral over time.

- **a** Choose a word from the list to describe the situation for this mineral in 1980, 1993 and 2010. **[2 marks]**

  exhaustion   peak production   discovery
- **b** Suggest what might have happened between 1993 and 2010. **[3 marks]**
- **c** Suggest how the mineral could have still been extracted after 2010. **[2 marks]**

EXTENDED CASE STUDY

The Island Copper Mine, Vancouver Island, British Colombia, Canada

The Island Copper Mine started production in 1971. It was finally closed in 1995 because there was insufficient ore left to make further extraction economically feasible. It was an open-pit mine and employed 900 people at its peak. During its lifetime 363 million tonnes of ore were extracted. The ore contained an average of 0.41% copper and 0.017% molybdenum. Extraction involved the removal of a billion tons of material in all, at a maximum rate of 170 800 tonnes per day. The pit produced by the mine was 2400 m long, 1070 m wide and had a depth of 400 m. The waste from the mine, which is called tailings, was disposed of in the sea. Seepage from the mine was restricted by a 33 m deep, 1 219 m long seepage barrier. The final production figures for the mine were 1 299 978 tonnes of copper, 31 000 tonnes of molybdenum, 31 700 000 g (31.7 tonnes) of gold, 335 994 324 g (336 tonnes) of silver and 27 tonnes of rhenium. These materials were exported to many countries around the world (Figure 1.24).

Figure 1.24 Open Pit Copper Mine, Vancouver Island, British Columbia, Canada

During its lifetime the environmental impact of the mine was carefully managed and monitored. All water run-off from dumps was controlled by a system of water management.

The impacts of the mine can be summarised under four headings.

- Physical: 400 million tonnes of tailings deposited into Rupert Inlet reduced its depth by 40 m. These materials, leading to a reduction in its biodiversity, regularly smothered the bottom fauna. A small rocky beach was formed where once it was sand, and copper-tainted sediment was found many kilometres away.
- Chemical: Over 25 years of monitoring, no trends were seen in any of the variables measured (pH, oxygen and dissolved heavy metals including copper, manganese and zinc).
- Biological: Although there was evidence that the water became more turbid, there was no measurable effect on productivity of the biological systems. The reduction in species diversity on the seabed was the biggest effect. A site near the mine had 15 species in 1995, whereas one unaffected site had 41. Despite early fears, no dead zone, an area with no life, was created.
- Tissue metal: There was very little evidence of an increase in the levels of any metals in the tissues of animals. This suggest that neither bioaccumulation nor biomagnification was occurring.

Port Hardy, a small town near the mine, originally had a population of 700 that grew after the opening of the mine to have a population of over 5000. The company spent over 2.9 billion US dollars (USD) in its 25 years of life. From early on during the life of the mine, tax was paid at a rate of about 3 million USD year^{-1}. The mining company provided 400 houses for its employees, with another 600 being constructed by other developers. All the necessary services, including sewage, roads and water, were paid for and provided by the mining company. The mine's opening also led to the provision of a hospital, a swimming pool, a theatre and some parks.

The plans for the eventual mine closure were in place even when its opening was being prepared in 1969. Nearly 5 million tonnes of overburden were kept and used for land reclamation during the 25 years of the mine and after its closure. The features of the mine covered by the closure plan were the open pit, the waste rock piles, the sea and the buildings.

The open pit was flooded with seawater after closure, creating a 300 m deep lake with an area of 215 hectares. The possibility of using this lake for aquaculture was considered.

A further 200 hectare area was recontoured and over 600 000 alder and lodge pole pine seedlings were planted during the life of the mine. The hope is that a cedar–hemlock forest will eventually result from this, as a result of succession.

Questions

1 Explain why the mine was closed in 1995.

2 Calculate the percentage of the total material extracted that was waste. Quote your answer to two decimal places.

3 One of the biggest concerns about the operation of the Island Copper Mine was the possible effect of disposing the tailings at sea. Various studies were started as soon as the mine opened to monitor this. In one study, a commercially important top predator, the Dungeness crab (*Metacarcinus magister*) was checked for the levels of copper and other metals in its tissues yearly over the life of the mine.

The data from this study are given in Table 1.4

Year	Copper / mg kg^{-1} wet mass
1971	7
1972	6
1973	5.7
1974	8.1
1975	7.7
1976	9.7
1977	11.8
1978	11.6
1979	9.9
1980	8.5
1981	8.5
1982	10
1983	7.7
1984	9.1

Year	Copper / mg kg^{-1} wet mass
1985	6.5
1986	6.6
1987	6.4
1988	8.1
1989	9.9
1990	10.4
1991	9
1992	9
1993	10
1994	11
1995	9
1996	10.3
1997	12.3
1998	9.3

Table 1.4 Copper levels.

a Copy and complete Figure 1.25 using the data in Table 1.4.

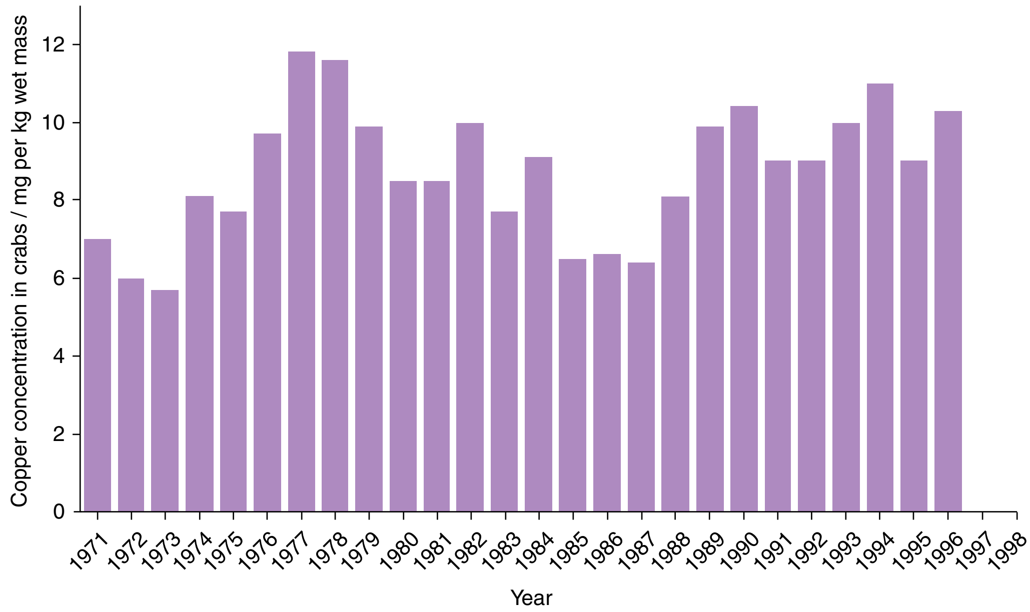


Figure 1.25 Copper levels in crab tissue.

b **i** Describe the trend in copper in crab tissue from the opening of the mine until 1977.

ii In the late 1960s the Society for Pollution and Environmental Control (SPEC) was formed in British Columbia where Island Copper is situated. This organisation was involved in actively campaigning against industrial pollution. Write a brief assessment of the situation with regard to copper in the Dungeness crab as it might appear in a report to SPEC in 1978.

iii Write a new report updating SPEC on the situation for a new report in 1996.

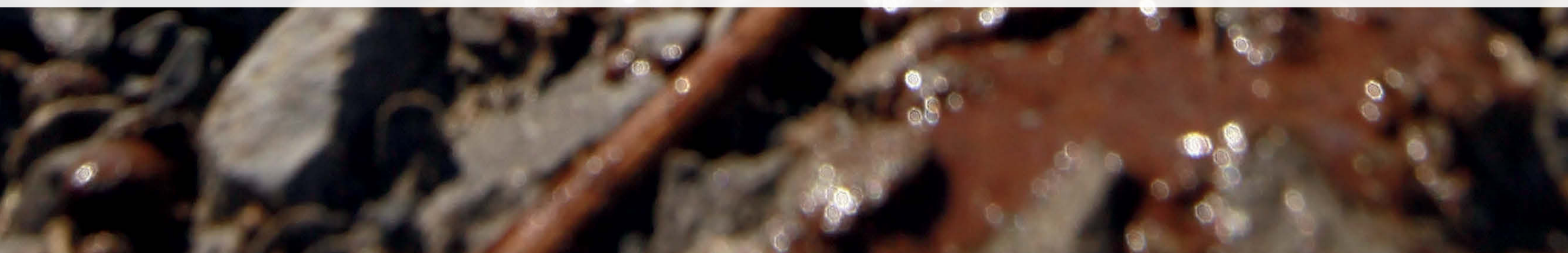
c Suggest why *Metacarcinus magister* was chosen to monitor copper levels in the tissues of living things in this study.

Chapter 2
Energy and the environment

Learning outcomes

By the end of this chapter, you will be able to:

- name fossil fuels and describe how they are formed
- classify energy sources into renewable and non-renewable types
- describe how different energy sources are used to make electricity
- explain the environmental, economic and social consequences of different energy sources
- discuss different demands for energy
- explain how energy sources can be managed efficiently
- discuss the current research into possible new energy sources
- describe the impact of oil pollution
- describe how the impacts of oil spills can be minimised.



The need for power

Many scientists agree there is a link between the burning of oil, coal and gas and climate change. While there are still reserves of these fuels, the decision facing governments around the world is whether we should be using them.

Fuel is enormously useful, very valuable and very important politically, but tackling global warming might mean choosing to leave the untapped reserves in the ground.

While not all scientists will agree on all facts of climate change, the consensus is that human activity is a significant cause. It is also recognised by governments that the rise in global temperature should be halted at 2 °C. While this is not a 'safe' level, it is thought to be enough to prevent the worst impacts of the temperature changes. There also seems to be a link between the amount of carbon products emitted into the air as gases through burning and climate change.

So what are the options? Could the world ignore all the oil, coal and gas that has not been extracted to prevent emission of more carbon? How would vehicles operate without these sources? Could the world cope with using other forms of energy production? Would all governments work together in this way? At the moment, these are questions without answers. As you work through this chapter you will see that many of the potential answers are not straightforward.

Figure 2.0 The human population is using greater amounts of energy; this has impacts on the world around us.

2.1 Fossil fuels

The world population uses energy in a variety of ways, much of it by direct combustion (burning) to produce heat and light. Combustion requires a suitable fuel source, typically something with large amounts of carbon.

While items such as wood contain carbon and are used for burning, there are other sources that are far more 'energy dense', producing a greater amount of heat from a unit of fuel. These sources, natural gas, coal and oil, are often known as **fossil fuels.**

How fossil fuels are made

Despite the name, fossil fuels are not made from fossils, but is it a useful term to reflect upon the amount of time it takes to produce them. Fossil fuels are produced from the decay of plants and animals. These remains formed organic matter that became covered in layers of sediment.

Over millions of years, and buried deep in the ground by the addition of further layers of sediment, the organic material was subjected to great pressure and heat.

KEY TERM

Fossil fuel: a carbon-based fuel, formed over many millions of years from the decay of living matter

The precise conditions, and the type of animal and plant material available, determined whether coal, oil or natural gas is produced.

Figure 2.1 shows how coal is formed. The processes for oil and gas are similar and are shown in Figure 2.2.

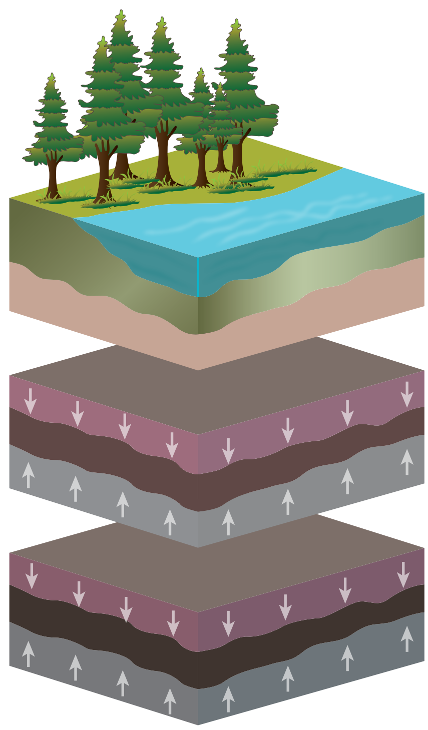


Figure 2.1 The process by which coal is made.

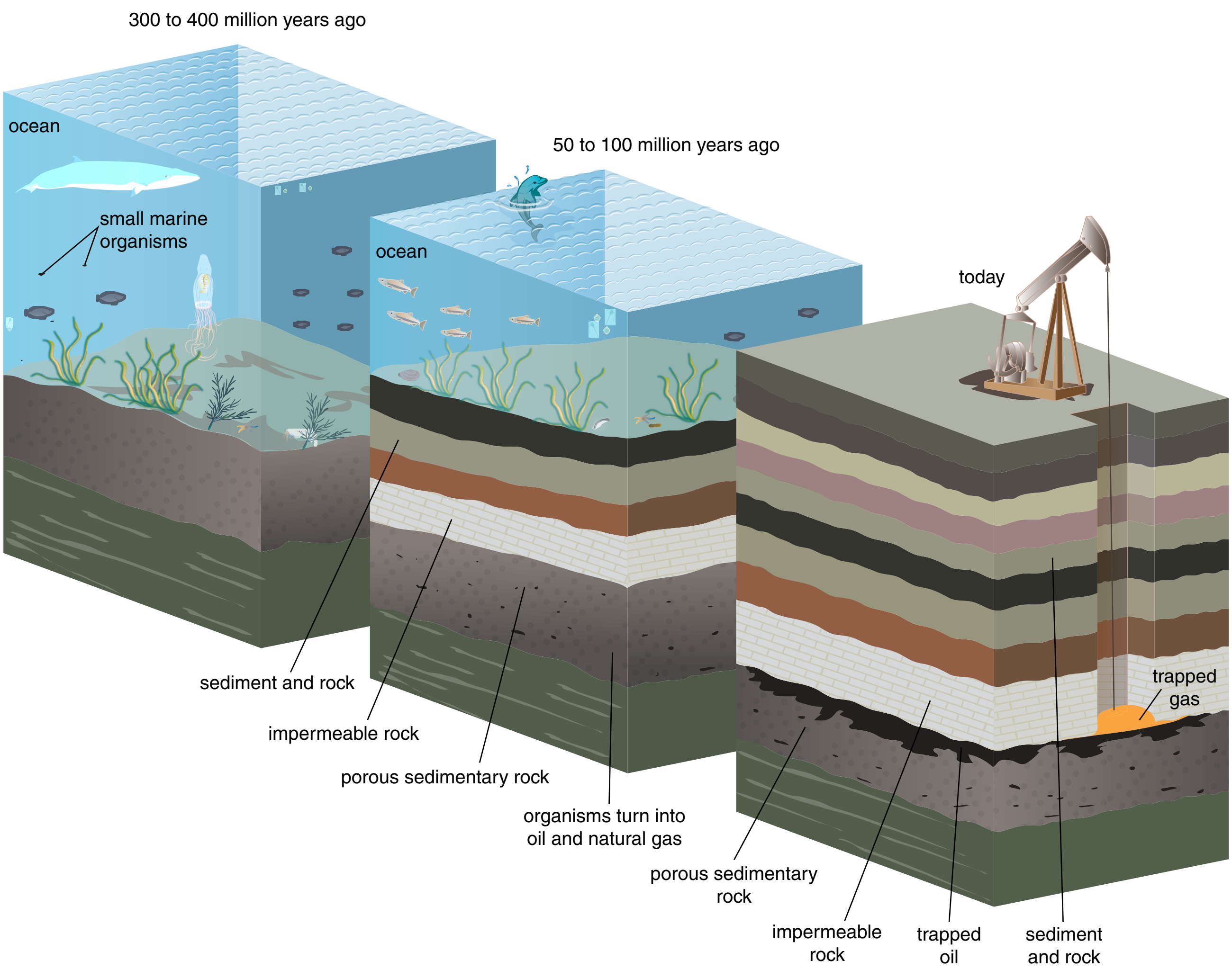


Figure 2.2 Oil and gas were formed in a similar way to coal. They are held in a layer of porous rock, which means they can be accessed by drilling.

In both cases the dead remains from animals and plants are buried under many layers of sediment, so extracting them involves digging or drilling deep underground. The length of time needed to create fossil fuels means that there is only a limited supply.

2.2 Energy resources

The demand for energy is increasing worldwide. There are a number of reasons for this:

- increasing population size
- increasing industrialisation and urbanisation
- improvements in standards of living and expectations.

In order to meet the demand for energy, existing sources need to be used more efficiently and methods that until now have been too difficult or too expensive to use need to be explored further. Improvements in engineering and advances in technology may well reveal new opportunities.

Types of energy sources

Different types of energy sources can be described by whether they are limited resources or available in unlimited supplies.

Limited sources of energy are often described as being **non-renewable**: as they are used they cannot be replaced.

Renewable sources of energy are those than can be replenished and therefore can be used over and over again.

KEY TERMS

Non-renewable: an item or resource that exists in a finite amount that cannot be replaced

Renewable: an item or resource that will not be used up or can be replaced

Table 2.1 provides a list of the most common examples of renewable and non-renewable types of energy. More detailed descriptions and explanations of the different types will follow later in the chapter.

Non- renewable energy sources	Renewable energy sources
Oil	Geothermal power
Coal	Hydroelectric power
Natural gas	Tidal power
Nuclear power	Wave power
	Wind power
	Solar power
	Biofuels, e.g. bioethanol, biogas and wood

Table 2.1 Classification of energy sources.

While some of the energy sources in Table 2.1 are easy to classify, others are more complex. Nuclear fuels, for example, will last for many centuries and are seen by many scientists as a more suitable replacement for fossil fuels. However, the source material (uranium) is only available in limited supply so, although will last a long time, it cannot be replaced.

Biofuels include the burning of wood, of which there is only a limited amounts at any one point in time, but it is possible to replace felled trees with new ones, therefore it is classified as being renewable.

How energy sources are used

While many energy sources can be burnt (combusted) to produce heat or light, the main use for many of them is the manufacture of electricity.

Most electricity is generated by **electromagnetic induction**. This process was discovered in the 1820s by Michael Faraday, and it transforms kinetic energy (the energy from movement) into electrical energy using loops of a conducting material such as copper and a magnet. As the coils are rotated close the magnet, electricity is generated. Over many years the process within this **generator** has been made more and more efficient.

Clearly a power source is needed to rotate the coils. This comes from a **turbine** connected to the generator.

Turbines are designed to provide the rotary motion needed in the generator. This is typically done by passing a stream of gas or liquid over the turbine blades, causing a shaft to move.

Figure 2.3 shows a simple electricity generation system using a turbine.

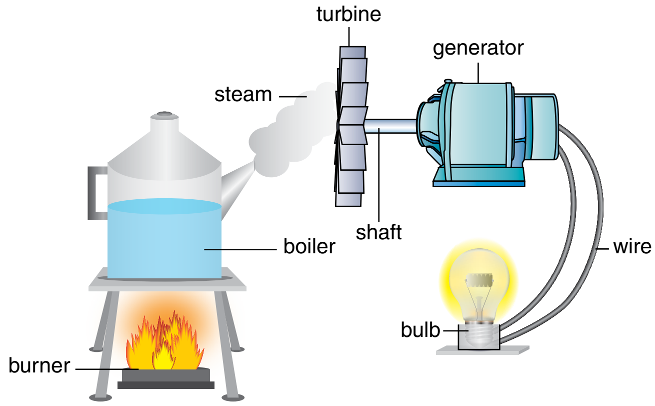


Figure 2.3 A simple electricity generation system.

In this simple system, a heat source (in the **burner**) heats up water (in the **boiler**), which is converted to steam. The steam passes through the blades of the turbine, causing them to move. As a result of the rotation on the shaft, the copper coils in the generator move, producing electricity that is transferred by conductive wires to the light bulb. The efficiency of the turbine can be increased by fitting more blades, or increasing the flow of gas or liquid that causes it to move by pressurising them.

Figure 2.4 shows a simplified diagram for the production of electricity from a geothermal source. In this case, cold water is pumped under pressure into a layer of hot rocks. The rocks heat the water and the hot water then returns to the surface under pressure. The hot water heats up a second supply of water using a heat exchanger. The steam produced in the second supply moves the turbine, which generates electricity in the generator. Water can then be re-used in the system to continue the process.

Energy sources such as fossil fuels, biofuels and nuclear and geothermal power are usually used to heat up water to produce steam. Other energy sources, such as wind, wave, tidal and hydroelectric power, are used to turn a turbine directly without the need to produce steam first.

KEY TERMS

Electromagnetic induction: a process used for generating electricity that uses the movement of a metal coil and a magnet

Generator: a machine that converts mechanical energy (such as movement) into electrical energy

Turbine: a machine, often containing fins, that is made to revolve by the use of gas, steam or air

Burner: a receptacle used to hold fuel as it is burned

Boiler: a vessel used to heat water to convert it into steam

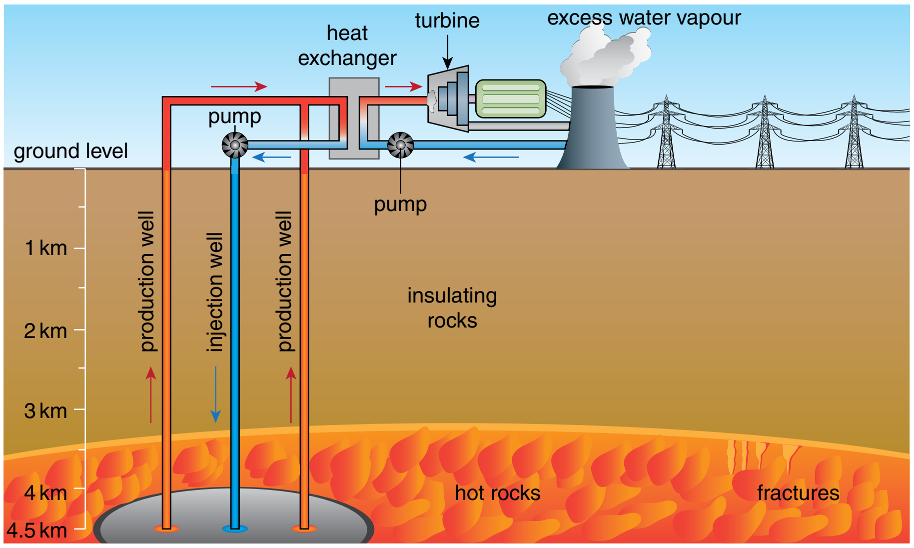


Figure 2.4 Production of electricity from a geothermal source.

Figure 2.5 shows a wind turbine. Note the addition of a gearbox to maximise the rotation of the shaft as it enters the generator. The brake will slow down or stop the rotor blade in very windy conditions to prevent the blade being damaged.

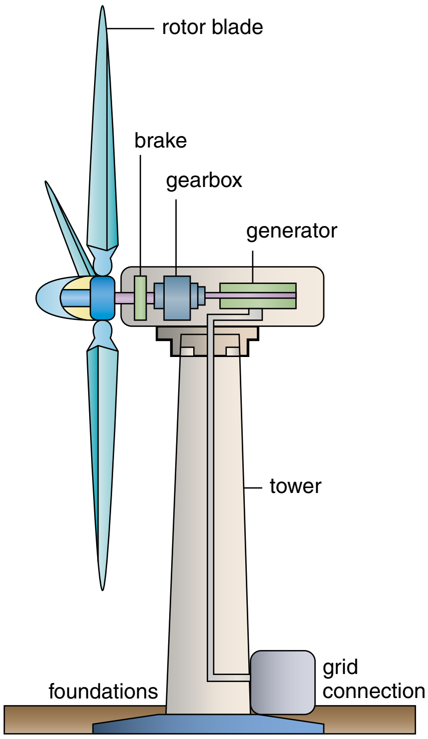


Figure 2.5 A wind turbine.

Solar power is the one main exception in the way that electricity is produced. Most electricity produced by this method uses photovoltaic cells. While the chemistry and construction of photovoltaic cells is quite complex, they all work on the principle that certain materials produce a small electric charge when exposed to light. Even though the electricity produced by one cell is small, a bank of cells organised into solar panels, and a group of panels organised into a solar array, can produce a significant amount of electricity.

Technological advances in the design and manufacture of photovoltaic cells are making them far more efficient, but many of the metals used within them are relatively rare and expensive to obtain.

Wave and tidal power systems both use the sea or large rivers to generate electricity, but the technology and availability of power can be very different.

Tidal power uses the natural rise and fall in the level of water in an area during a day. As the levels drop, water is held back by a tidal barrage – a small dam that releases water back through a turbine. This, in turn, generates the electricity using a generator. The amount of power that is generated is dependent on the change in tide level throughout the day.

Wave power also uses a turbine and generator to generate electricity, but these use the smaller differences in water levels that are caused by wind action. Power is therefore produced by channelling the energy of waves at sea, rather than by tides. Unlike tidal power, wave power is not limited to the regular pattern of the tides; however, electricity generation may stop when calm weather conditions mean that there is little or no wave production in an area.

KEY TERMS

Solar power: harnessing energy from sunlight

Tidal power: the use of tides (the natural change in sea levels) to generate electricity

Tidal barrage: a small dam used to hold back a tide

Wave power: the use of changes in the height of a body of water to generate electricity

Using the different energy sources

Deciding which energy source to use is not always easy because of different economic, social and environmental impacts. One source of power may have both advantages and disadvantages.

Economic factors

The supply of energy is expensive, particularly in a world where the demand is ever increasing and the supply from many sources is limited. If a fuel is in high demand and in short supply, then the price for that item rises. Clearly if a country has its own fuel supply then it can often use this more cheaply than importing other sources from other countries.

It is therefore logical for a country to rely on its local fuel supply, for example the Middle East relies on its own oil, Russia relies on its natural gas and the USA relies on its coal. Some countries have other naturally occurring sources they can take advantage of, such as high (and consistent) amounts of sunlight near the equator or geothermal energy (heat from underground rocks) in areas such as Iceland.

While plentiful supply and ease of access might be good economic arguments for using certain types of fuel, some countries face an economic barrier that prevents them from using certain energy sources. The cost of investing in technology, for example, might prevent a country or region developing solar power even though it has a plentiful supply of sunlight.

Social factors

The impact of different fuel sources will depend on the local area and the industry that it supports: the mining of an area for coal or drilling for oil might mean that the land is no longer available for agricultural use, but the new industries might mean greater local employment. The increase in industry locally might also mean that other businesses are needed to supply the needs of the energy business and its workers. The development of a large-scale project could provide improvements to the local infrastructure such as roads, supply of mains water and electricity, healthcare and schooling.

However, the energy business could also cause the displacement of a whole community, for example if the land in a valley is flooded during the construction of a dam to develop hydro-electric power. The development of new technologies might be a great asset to a community if it brings new manufacturing opportunities to the area, but might be seen as a disadvantage for those working in a sector that then starts to decline.

The development of new energy sources can change the political relationships and trading patterns between two nations. For example, developing a renewable energy source might mean that a country is less dependent on oil from one of its neighbours, reducing the trade in oil.

The investment in certain energy sources might also have health effects for the local population, for example dust from extraction, noxious fumes from combustion, or the risk of radiation from nuclear power.

Environmental factors

Impacts on the environment will vary from region to region. Many renewable sources (such as wind, solar and wave power) do not produce carbon dioxide emissions, which are linked to climate change. Biofuels will produce carbon dioxide when combusted, but the growth of the plants will also use carbon dioxide during photosynthesis. Fossil fuels are a major contributor to carbon dioxide in the atmosphere.

Other environmental impacts may be less obvious, but no less important.

- Pollution: spillage of fuel into the environment, such as oil spills in the ocean, can cause damage to wildlife. Burning fuels can also produce toxic gases and waste products.
- Changes to the ecosystem: extraction of fuels from underground can destroy habitats for a range of animals or their food sources. Even renewable sources can cause problems, for example the damming of a river for hydroelectric power generation can affect the ability of fish to breed.
- Visual impact: the nature of the landscape can be changed, for example large areas of solar panels or wind turbines impact on an area's natural beauty as well as changing the local ecosystem.

Table 2.2 summarises the advantages and disadvantages of different fuel types.

Fuel type	Advantages	Disadvantages
Fossil fuels (oil, coal, natural gas)	Plentiful supply in some locations. Extraction provides jobs Existing technology: the fuel is available for most countries to use	Carbon dioxide and toxic gases when burnt (impacting on climate change) Extraction causes damage to local area Limited supply: prices will rise as the supplies get smaller
Nuclear power (using uranium)	Does not produce carbon dioxide (impact on climate change) Small amount of fuel produces large amounts of energy Power plants employ lots of people	Risk of radiation leakage (impact on human health and environment) Waste products cannot be recycled as radiation active for centuries Limited supply
Biofuels (bioethanol, biogas, wood)	A renewable source: bioethanol and wood are both obtained from growing plants, biogas from the recycling of waste products Growing more plants uses carbon dioxide Potentially a plentiful supply	Carbon dioxide and other toxic gases produced when burnt A lot of land is needed to grow crops for fuel Potential removal of natural ecosystems to grow fuel crops
Geothermal power	Does not produce carbon dioxide Unlimited supply as uses the heat from the Earth as the power source	Can be expensive to install Only certain areas have suitable conditions
Hydroelectric power	Does not produce carbon dioxide Water can be reused for other purposes	Building of dams impacts the natural flow of water Villages and ecosystems may be destroyed when dams and reservoirs are built
Tidal power	Does not produce carbon dioxide Tidal movements not dependent on weather conditions	Limited to specific coastal areas Impacts on the tourist industry and local fishers
Wave power	Does not produce carbon dioxide A renewable source of power	Limited to specific areas Currently not very efficient, so large amounts of resources needed
Solar power	Does not produce carbon dioxide Sunlight is not a limited resource	Only efficient under certain weather conditions Generation only occurs in daylight hours Visual impact and potential damage to local ecosystems
Wind power	Does not produce carbon dioxide Uses a renewable resource	Not all locations are suitable Generation only occurs in certain conditions (at certain wind speeds) Visual impact Uses a large area

Table 2.2 Advantages and disadvantages of different fuel types.

CASE STUDY

Biofuels: the future of fuels or a misguided technology?

Figure 2.6 Aerial view of ploughed land on sugar cane plantation near Ribeirao Preto, Brazil. The crops from this plantation is used for biofuels.

Fuels that are extracted from crop plants are known as biofuels. The three most common types are **bioethanol**, **biogas** and wood: the growing and burning of timber to produce heat.

Bioethanol is a renewable energy that is mainly produced by fermentation of the sugar found in some crops. Crops that can provide this sugar include maize, wheat, corn, willow, Miscanthus and similar tall grasses, sorghum and Jerusalem artichoke. These crops are often grown especially for biofuel production. Bioethanol can be used as a substitute for petroleum (gasoline).

Biogas is the common name for a mixture of gases formed by the decomposition of organic matter in the absence of oxygen (anaerobic decomposition). Biogas's main component, methane, is highly flammable and is therefore suitable as a fuel source. Biogas can be produced from a range of organic wastes such as animal manure, food waste and household waste.

Bioethanol is believed to have great potential as a fuel for cars and trucks; it is already commonly mixed with petroleum or diesel oil to make these finite resources last longer.

Supporters of bioethanol production state a range of benefits.

- Easy to source: crude oil is a non-renewable resource whereas crops can be grown around the world for years to come.
- Reduces greenhouse gases: the burning of fossil fuels causes increased levels of carbon dioxide production. While the same is true of bioethanol, the plants grown to provide the fuel use carbon dioxide to produce sugars via the process of photosynthesis.
- Economic security: not all countries have a supply of oil, but many can grow suitable crops to produce bioethanol. There is less risk of a lack of supply if a country can produce its own fuel.

Those against increasing the use of bioethanol state a range of disadvantages.

- Food shortages: bioethanol is produced from crops with high quantities of sugar that also tend to be food crops. When there are people short of food across the world, it does not seem right to use potential food as fuel rather than feeding the hungry.
- Water usage: the crops need a lot of water, which can lead to a shortage of water in some areas for humans and their livestock.
- Industrial pollution: while the amount of carbon dioxide produced by bioethanol may be less than by fossil fuels, the factories that produce bioethanol do emit pollutants, which can affect the local population.
- Monoculture: the energy crops used to make bioethanol are grown in the same large fields year after year. This means the soil becomes short of nutrients, adding fertilisers can cause water pollution and the crop will also need the application of pesticides, which will affect the local ecosystem.

Questions

1. Why might the production of bioethanol be more attractive to a country with few oil supplies rather than one with large oil reserves?
2. Why, on a worldwide scale, is the growing of biofuels seen to be important, even though there are some clear disadvantages?
3. Why might a farmer choose to grow crops for bioethanol production rather than crops for food production?

KEY TERMS

Bioethanol: the creation of ethanol from fermentation

Biogas: the creation of methane from the breakdown of organic materials in an anaerobic digester

2.3 The demand for energy

All experts predict that human use of energy will continue to increase over the next 40 years, with the challenge of a limited supply of non-renewable resources. Nobody knows exactly how long the supplies with last. Predictions from many years ago have proved to be inaccurate as new deposits have been found and, as the price of the materials has increased, it has made mining or drilling in new areas economic.

What is certain is that the world price of non-renewable energy sources will continue to rise with the increase in demand and there is only a finite amount of these resources.

The demand for energy

A review of the energy use within different countries shows that there is a significant difference in the amount of energy used per person of different populations. There are a number of contributing factors.

Industrial demand

The use of energy per head of population is far lower in a traditional farming community that it is in a community that has become industrialised. Manufacturing requires the use of large quantities of energy in all stages of production.

Iron and steel production, for example, has an extremely large energy demand, using fuel to melt iron ore and refine it (Figure 2.7). Additional heat is also needed to shape the resulting product.

The advance in manufacturing techniques has resulted in technological advances in the products and also made them more affordable. This means that many items are no longer considered as luxuries but instead as necessities: more people want to buy them, and the

Figure 2.7 The production of iron and steel requires the use of very high temperatures, needing large quantities of energy.

increase in demand leads to increasing energy needs for increased production.

Domestic demand

The impact of more efficient manufacturing processes has meant that many goods have become more affordable. Televisions, for example, were once only seen in the homes of high earners in the developed world because they were so expensive to produce. They are now widely available, many households having more than one. The same trend can be seen with cars, computers and mobile phones, to name just a few.

Domestic demand is created by affordability and availability but is also driven by the need to keep up with the neighbours. Items that a decade ago would be seen as a luxury are now considered to be a necessity in many cultures. Most of these purchases increase the demand for energy supplies, most notably the need for a reliable electricity source.

Domestic demand and changing purchasing patterns have resulted in consumers in some countries wanting and expecting to be able to get fruit and vegetables that are not naturally in season locally. This demand can be met by either producing them in controlled conditions such as a glasshouse (see Section 3.4) or growing them in a more favourable climate and transporting them via air freight. In either scenario, the energy cost is significant.

Transport demand

The drive to develop efficient systems of production has meant that in many locations manufacturers are supplying customers across the globe. While this may decrease production costs it has significantly increased the costs of transportation. Some estimates suggest that there has been a fourfold increase in the number of shipping journeys in the past 20 years. There has also been a significant increase in the amount of air transport.

Both modes of transport require large amounts of fossil fuels to operate. Although the cost of transporting goods across oceans is significant, the cost savings in manufacturing still make them attractive to the end customer, albeit the amount of energy used in the process is greater than if produced locally.

Economic factors

Domestic demand for energy (and the purchase of manufactured goods) will be dependent upon the relative affluence of the people within a country. If economic conditions are good, there will be higher employment and more money to spend on luxury items. If economic conditions are poor, families will have less available money and will need to make savings, which could include reducing the use of fuel and the purchase and use of electrical items (which also use energy).

What is seen at a small scale (within a family) can also occur at a national level within the economy of a country. If a country has less income because of a reduction in manufacturing, it will have less ability to import foreign goods.

A poor economy will mean:

- less manufacturing (less energy used)
- fewer goods to transport (less energy used)
- an inability to purchase foreign energy supplies.

Sometimes the impact of a reduction of manufacturing in one country can have an impact on the global economy. A reduction in the economy of China in the mid-2010s meant a worldwide:

- reduction in demand for steel
- a decrease in the amount of manufactured goods transported by ships
- a decrease in the price of oil (because worldwide demand had decreased as a result of the two factors above).

Climate

Comparing the energy usage in one country with another is also complicated by the prevailing weather conditions.

People living in a temperate climate are likely to experience colder winters than those living in a more equatorial climate. The energy demand for heating in colder climates is likely to be far higher. In the winter months, the population also experiences fewer hours of daylight, with a corresponding increase in use electric lighting.

Climate change has resulted in extremes of weather that have not been experienced in over a generation, for example excessive cold and heat to name but two. These have resulted in increased energy consumption, particularly from those living in urban areas, either through the need for additional heating or the installation and operation of air-conditioning units.