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

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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).

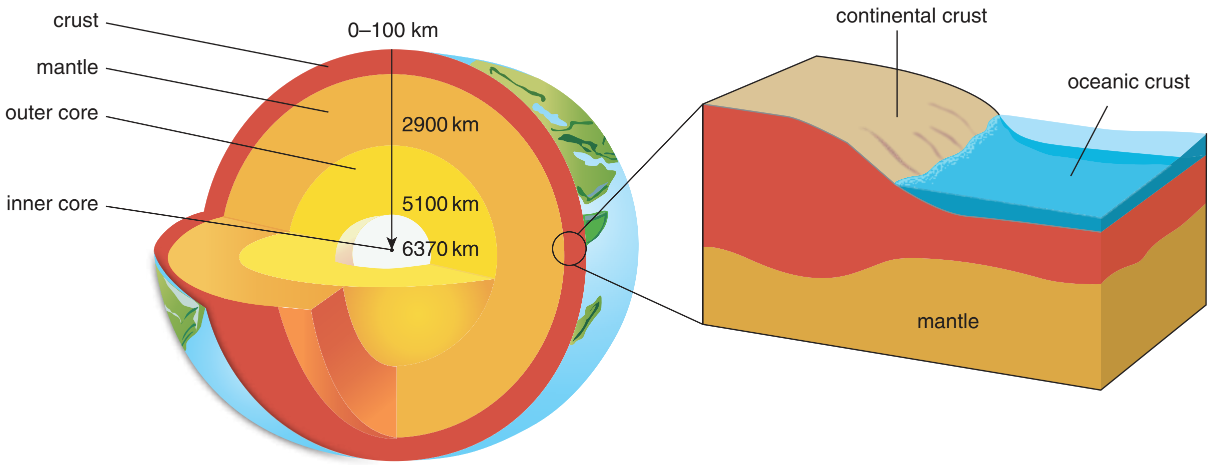

Figure 1.1 The structure of the Earth.

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

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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

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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.

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Figure 1.7 A piece of marble.

Figure 1.8 A piece of slate.

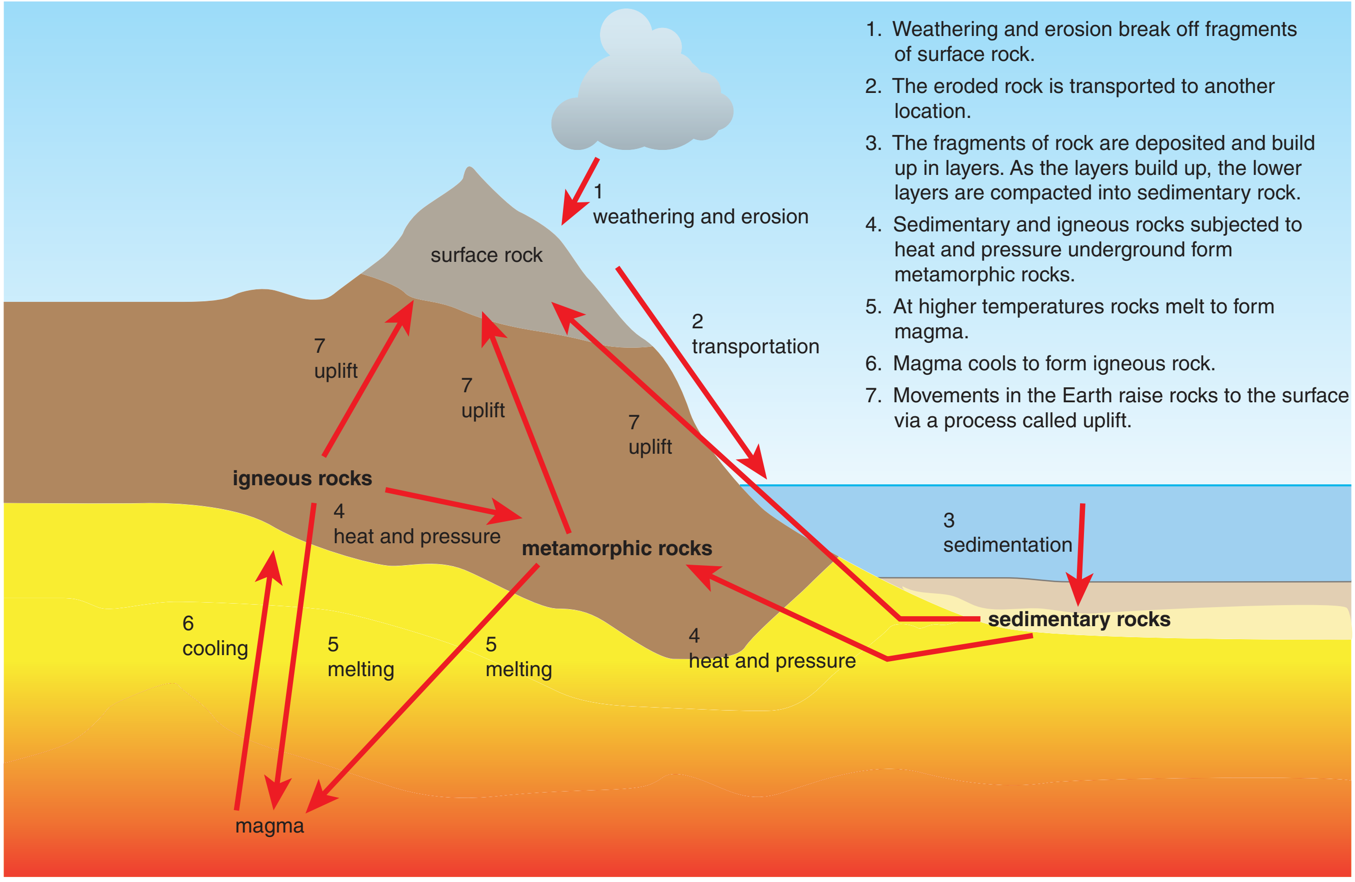

Figure 1.9 The rock cycle showing the relationship between the three rock types, sedimentary, metamorphic and igneous. The diagram also shows the interactions between these types, their origins and the processes by which they are interconverted.

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SELF-ASSESSMENT QUESTIONS

1.1 Figure 1.10 shows the rock cycle.

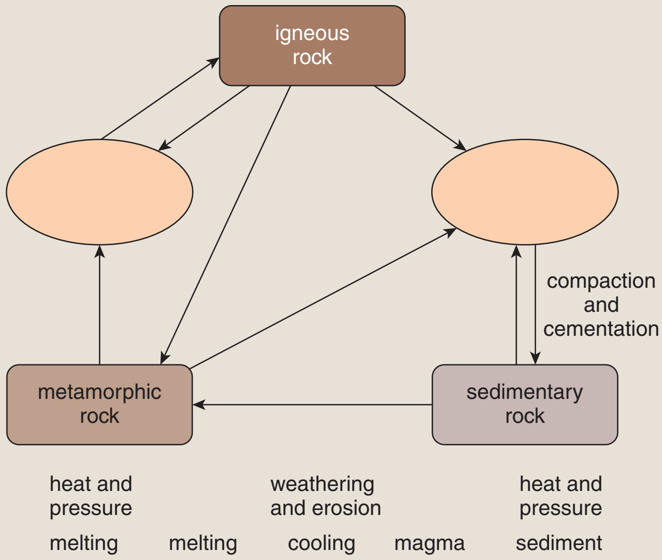

Figure 1.10 The rock cycle.

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

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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).

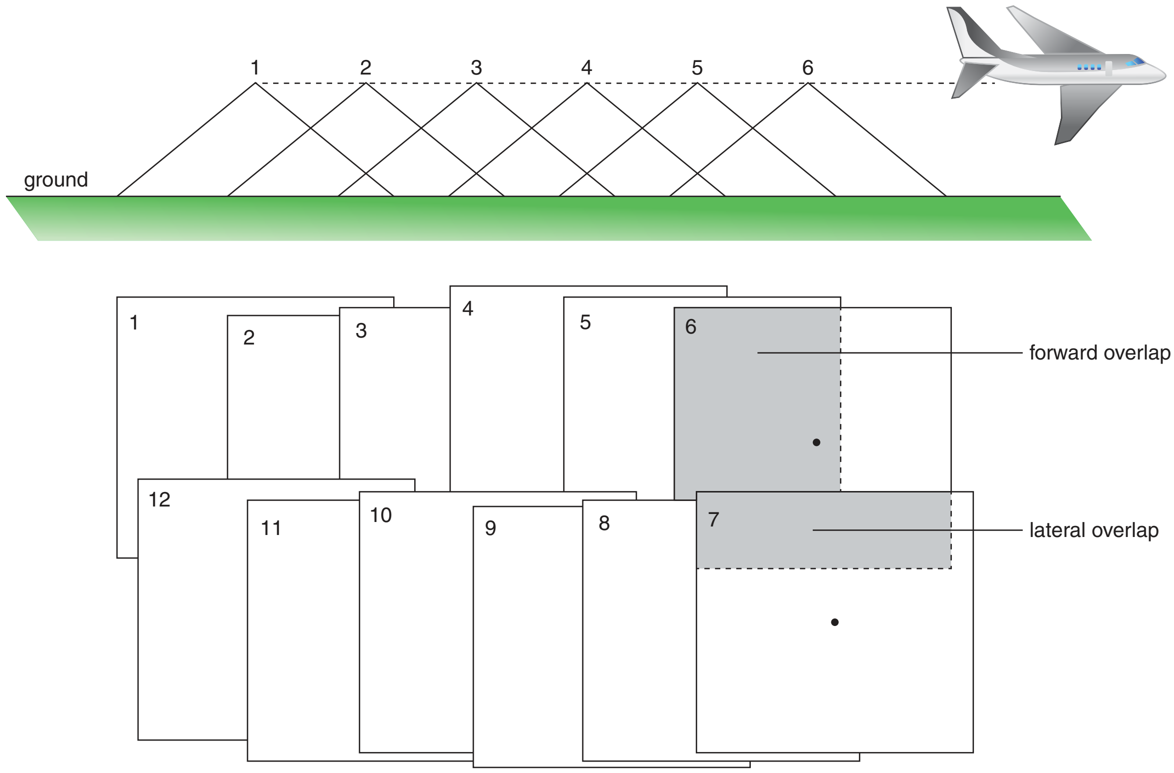

Figure 1.11 Aerial photography used for mineral prospecting. Photographs are taken with an overlap both front to back and side to side. If the overlap is sufficient, three-dimensional views can be generated, which makes the prospecting easier.

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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

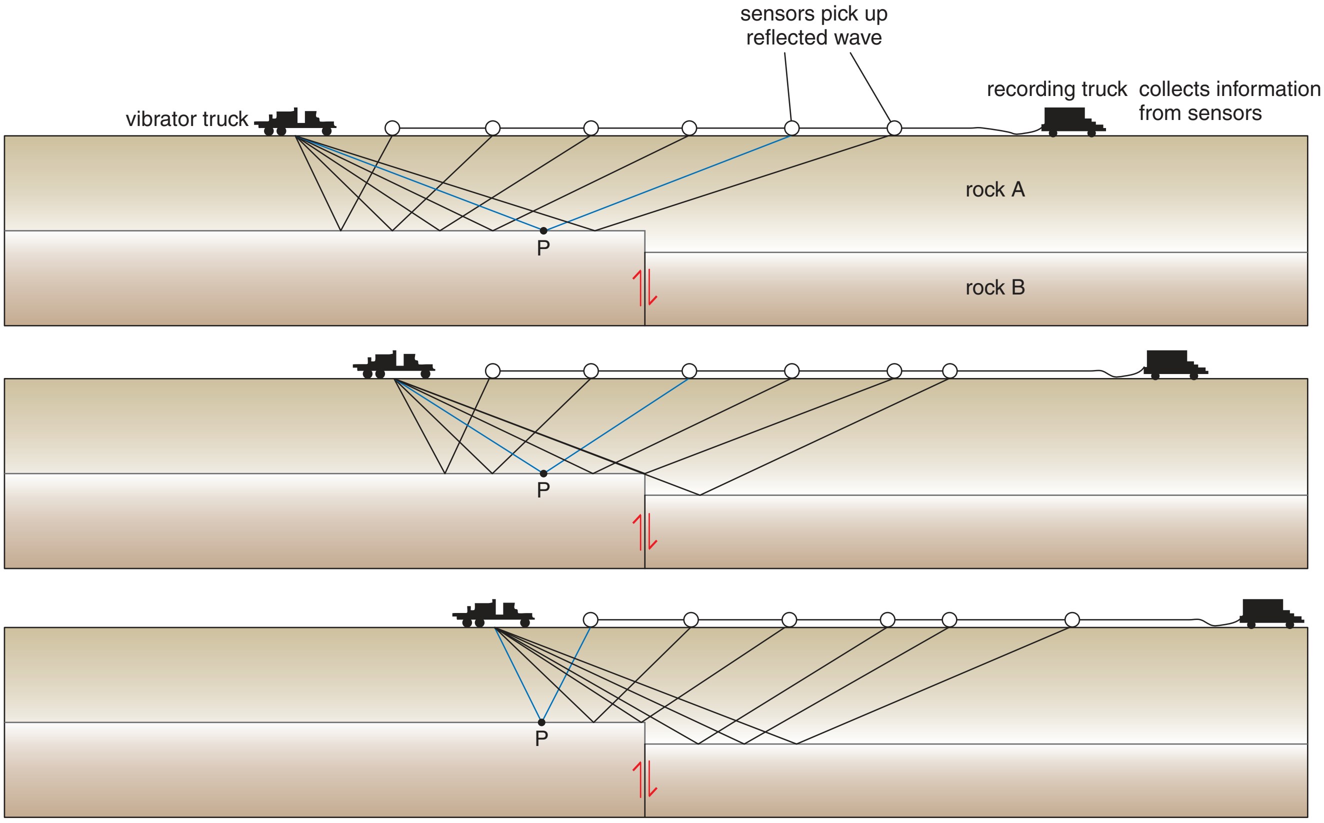

Figure 1.12 Seismic shock waves being used to locate rock or mineral deposits.

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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

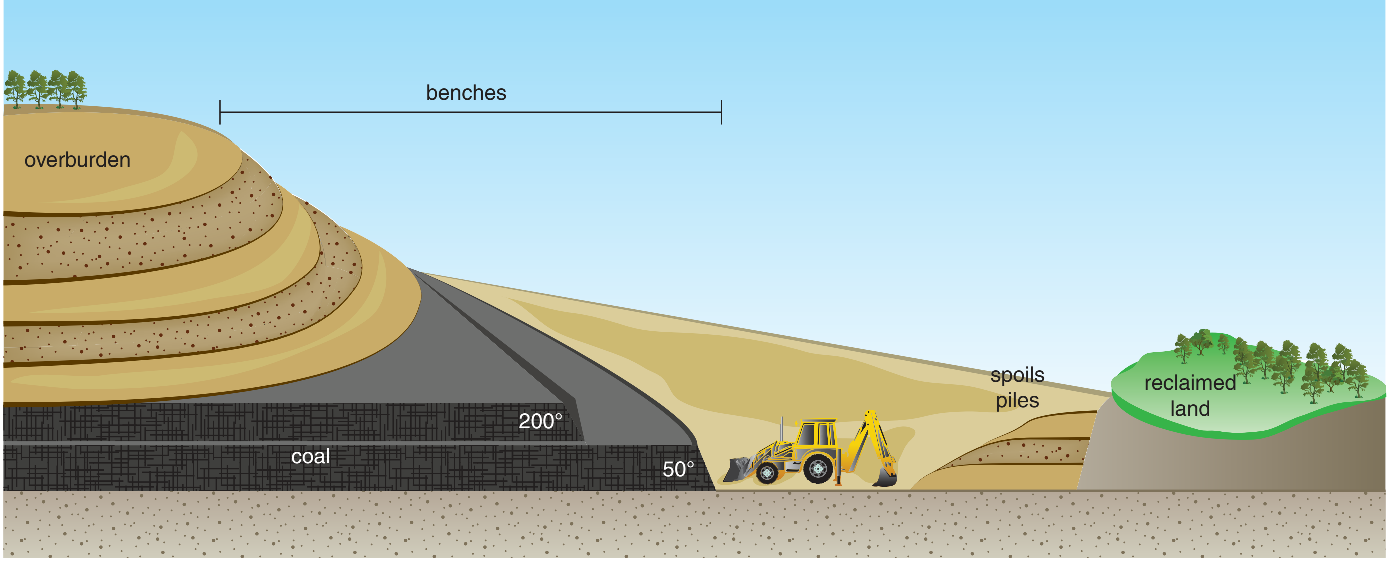

Figure 1.13 An open-pit mine.

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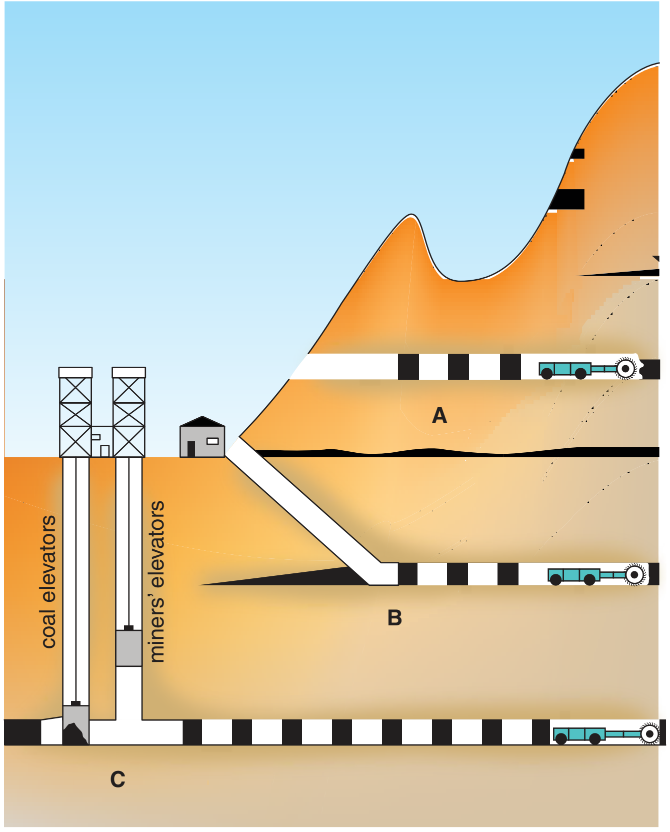

Figure 1.14 A drift mine with a horizontal entrance, called an adit. B Sloping tunnel.

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.

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