Chapter 17 - The planet Earth

Volcanoes

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Volcanoes

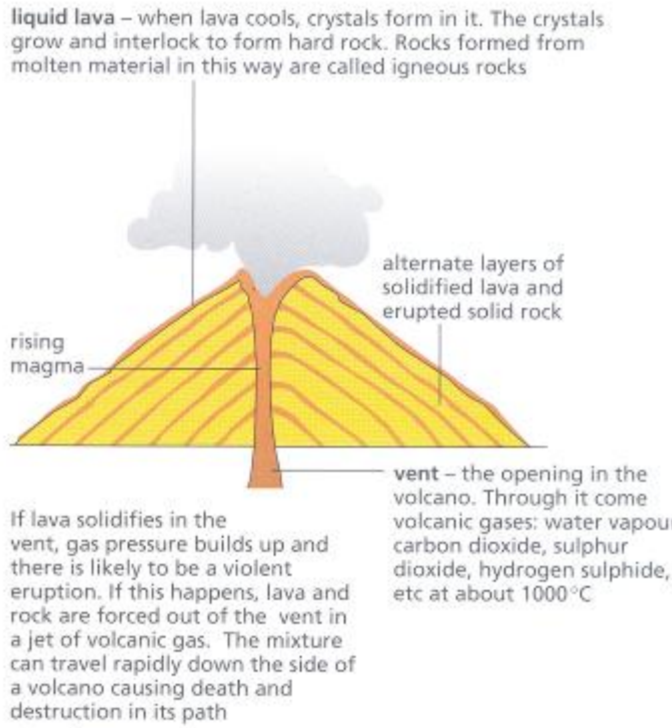
SLEEPER AWAKENS AFTER 100 YEARS

This was the headline which announced the eruption of Mount St Helens in Washington State, USA, in May 1980. When it exploded into life it sent huge amounts of volcanic ash for over 1000 km and left a crater which was over 3 km wide.

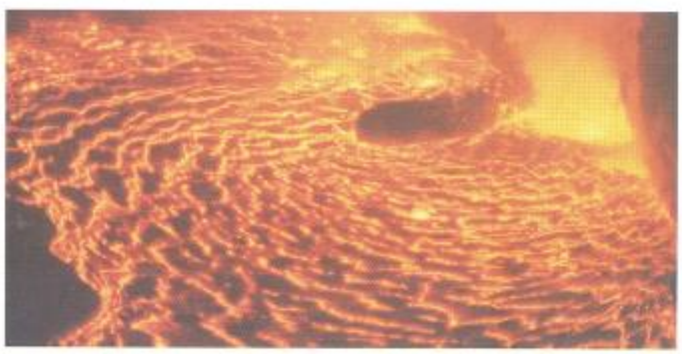
More recently, Europe's most active volcano Mount Etna in Sicily erupted in July 2001 spewing out smoke, ash and lava, threatening nearby villages (Figure 17.1). The last major eruption had been in 1992.

Figure 17.1 The eruption of Mount Etna in July 2001.

Volcanoes are formed when **magma**, the molten rock material containing dissolved gases and water beneath the Earth's crust, escapes to the surface through cracks (**fissures**) or holes (**vents**) in the crust (Figure 17.2a). The magma appears at the surface as **lava** (Figure 17.2b). Lava flow can engulf vast areas of land around the volcano.



a A volcano.



b Molten lava often flows from a volcano and engulfs land about it.

Figure 17.2

Question

1. Explain how a volcano is formed.

The structure of the Earth

How do we know that the Earth has the structure shown in Figure 17.3? In their studies scientists have used sound waves as well as the waves sent out by earthquakes. From the information gathered they have concluded that the Earth consists of the following.

- Core — this is made up of very dense molten metal, which consists mainly of iron and nickel, under great pressure. It is approximately 6930km in diameter.

- Mantle — this surrounds the core and is made up of cooler, less dense rock which contains a lot of iron-rich minerals. It is between 40 km and 2900 km below the Earth's surface.

- Crust — this is the thin, less dense, solid outer layer. The thickness of the crust under the oceans varies from 5 km to 10 km, while that under the continents varies from 6 km to 90 km.

The core has a temperature of about 4300 °C. This temperature drops as you go into the mantle and the temperature just below the crust is only about 1000°C!

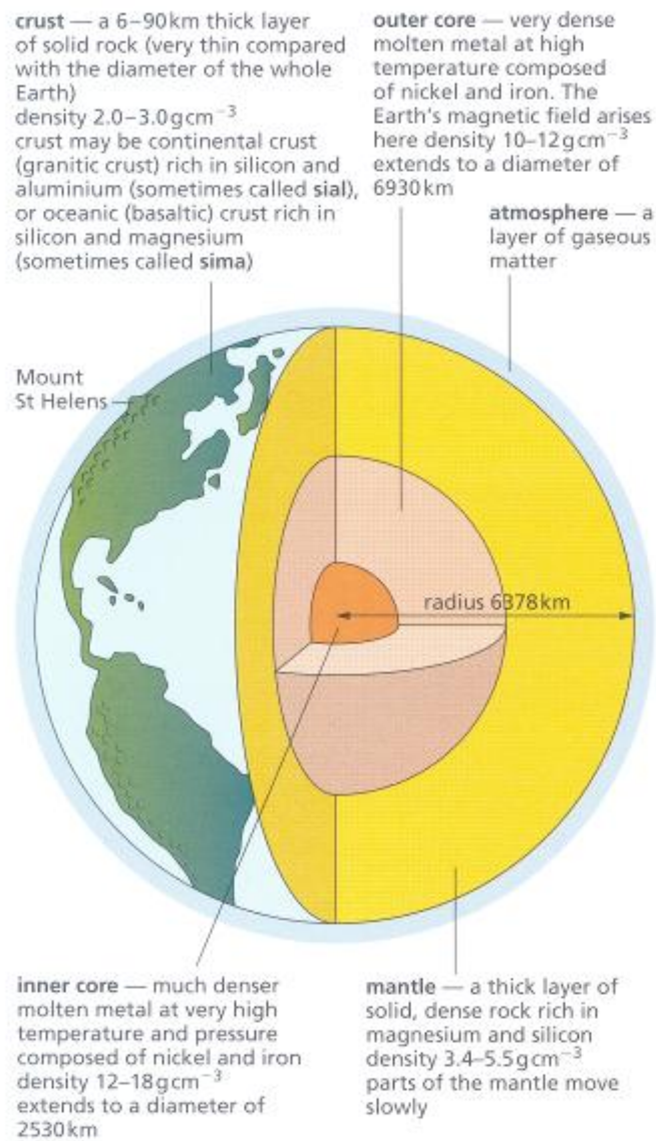


Figure 17.3 The Earth.

These high temperatures are maintained mainly by:

- the inside of the Earth being insulated by the outer layers
- the radioactive isotopes of the elements potassium, thorium and uranium — the nuclei of these isotopes are unstable and break up, giving out large amounts of energy as they change into smaller nuclei.

What is the crust made of?

There are many different rocks in the Earth's crust. These different rocks vary in the minerals they contain and in the shape and size of the mineral grains. Geologists have shown that there are three main groups of rocks — igneous, sedimentary and metamorphic.

Igneous rocks are formed when hot magma from the Earth's mantle or lower crust rises, cools and hardens. Igneous rocks are usually crystalline. There are two main types of igneous rock: intrusive and extrusive.

- Intrusive igneous rocks are formed by crystallisation of the magma underground. Granite is an example of this type of igneous rock (Figure 17.4).

- Extrusive igneous rocks are formed by crystallisation of the magma on the Earth's surface. Basalt is an example of this type of igneous rock (Figure 17.5).

Figure 17.4 A granite erratic moved during glaciation.

Figure 17.5 Vesicular lava, otherwise known as basalt.

Sedimentary rocks cover approximately 75% of the continents. These are formed when solid particles carried in seas or rivers are deposited. Sediment is also carried by wind and moving ice. Dissolved materials may later be extracted from water by plants or animals, or by evaporation to produce sediments. Layers of sediment can pile up for millions of years, and the sediment at the bottom of the pile experiences great pressure; the grains become cemented together, forming the sedimentary rock. Sedimentary rocks have definite layers, or **strata**, associated with them, and you can often see these layers running through the rocks (Figure 17.6a). There is a large variation in their hardness and grain size. Sedimentary rocks often contain fossils (Figure 17.6b).

a Limestone strata.

b Fossils are often found in limestone.

Figure 17.6

Limestone is a sedimentary rock which formed beneath the sea. Although it was formed beneath the sea, it is often found well above sea level due to the movement of the Earth's crust. This happens during the process of **uplift**. Uplift occurs mainly because of the large-scale lateral forces at work on the Earth's crust, resulting in its crumpling, for example at plate boundaries (Figure 17.12, p. 245).

Limestone is composed mainly of calcium carbon-ate, which effervesces when it comes into contact with a dilute acid (Chapter 8, p. 122). This property is often used to show the presence of limestone in a rock sample. Sandstone is also a sedimentary rock.

Metamorphic rocks are formed when rocks buried deep beneath the Earth's surface are altered by the action of great heat and pressure. Marble is a metamorphic rock and is formed by this type of action on limestone (Figure 17.7, top). Slate is another example of metamorphic rock (Figure 17.7, bottom), which is formed from mudstone.

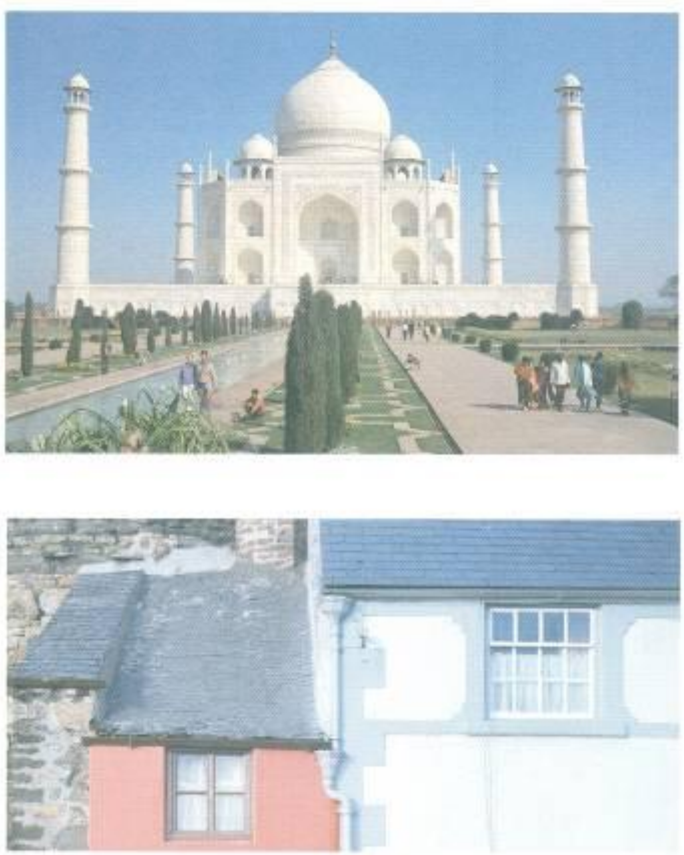


Figure 17.7 The Taj Mahal in India and roofing material are made from the metamorphic rocks marble and slate.

Questions

1. Describe the structure of the Earth.

2. What is:

a. igneous rock?
b. sedimentary rock?
c. metamorphic rock?

Give an example of each type of rock.

Fossils

Fossils are the remains or impressions, in rocks, made by animals or plants when they die. When these organisms decay, they leave their impressions in the surrounding sediment. When the sediment becomes rock, impressions are left in the rock (Figure 17.6b). In some cases the organism decays and dissolves leaving a space in the rock. When this happens, certain minerals may seep into the space and take up the shape remaining, producing a cast of the original organism.

As stated earlier in this chapter, fossils are found in sedimentary rocks such as limestone. Sedimentary rocks are layered with the oldest layers (strata) found deeper underground than the younger rock. Geologists have been able to divide time into three **eras**, based on the type of fossil found in the different rock strata.

- Cenozoic era — this is the most recent era and covers the present to 65 million years ago.

- Mesozoic era — this era covers the time from 65 million years ago to 225 million years ago.

- Palaeozoic era — this era covers the time from 225 million years ago to 570 million years ago.

Figure 17.8 shows the way in which the eras have been divided into **periods** and the periods divided further into **epochs**.

Questions

1. What is a fossil?

2. Use a diagram to help you to describe how fossils were formed.

ERAS	PERIODS	EPOCHS	Present
CENOZOIC The Earth's climate became much colder, resulting in several Ice Ages	QUATERNARY	Holocene	0.01
		Pleistocene	2
The age of the mammals as well as insects and flowering plants	TERTIARY	Pliocene	7
		Miocene	26
		Oligocene	38
Opening of the North Sea		Eocene	54
		Paleocene	65
MESOZOIC The age of the dinosaurs	CRETACEOUS		136
The great supercontinent of Pangaea began to break up, forming most of the continents as we know them	JURASSIC		190
	TRIASSIC		225
PALEOZOIC Initially, most life was in the sea. Plants appeared on the land in the Silurian era, followed after a few million years by the first amphibians. Towards the end of this period the first reptiles appeared on land	PERMIAN		280
	CARBONIFEROUS		355
	DEVONIAN		395
	SILURIAN		440
	ORDOVICAN		500
	CAMBRIAN		570

SOME FOSSILS

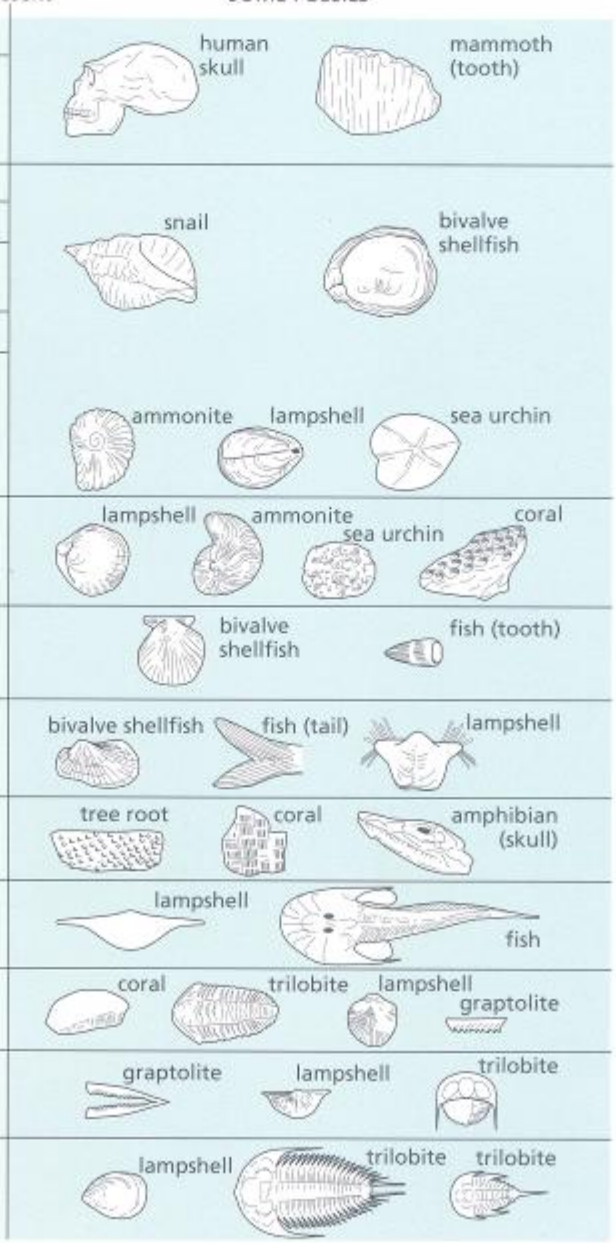


Figure 17.8 Geological time (figures refer to millions of years before present).

Weathering

Weathering is the actual breakdown of exposed rock on the Earth's surface. There are two main ways that rock can be broken down: by chemical means and by physical means.

Chemical means

Rainwater contains dissolved carbon dioxide (Chapter 8) as well as other gases such as sulphur dioxide (Chapter 16) and nitrogen dioxide (Chapter 10). The effect of these substances is to reduce the pH to quite a low value. This means that this now 'acid rain' can dissolve particular rocks, such as lime-stone, quite easily.

calcium carbonate + carbon dioxide + water → calcium hydrogencarbonate

$$CaCO_3(s) + CO_2(aq) + H_2O(l) \rightarrow Ca(HCO_3)_2(aq)$$

Minerals may also be oxidised. Oxygen from the air can combine with iron silicates to form iron (III) oxide. This leads to a brown stain on the surface of rocks containing this mineral.

Some minerals combine with water molecules and take them into the crystal structure. They become hydrated, which causes expansion, leading to stresses within the rock structure. This causes the rocks to break up. An example of this type of weathering takes place with haematite (Fe_2O_3). With water it forms limonite ($Fe_2O_3.H_2O$).

Physical means

These include the actions of water and temperature. Rainwater enters cracks in rocks. When water freezes, its volume expands and it forces the rock apart. Stresses can also be built up in a rock formation by temperature changes. Minerals within the rock will expand and contract with changes in temperature at different rates. In the temperate areas of the world, such as the UK, where alternate freezing and thawing happens a lot, you find that the pieces of rock which break off fall down mountain sides, forming **scree** (Figure 17.9).

Figure 17.9 This scree slope in Gorsdale Scar, Yorkshire, was formed by physical weathering.

Erosion

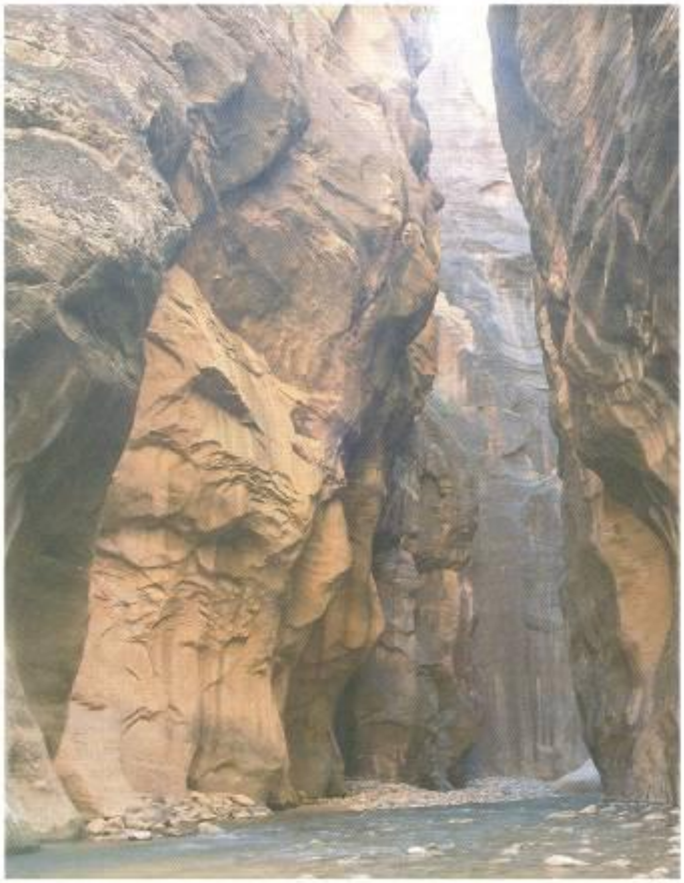
Erosion involves the wearing away of rock and its transportation to another place. The photographs in Figure 17.10 show the four main ways by which erosion takes place.

Taking into account the four main methods of erosion, researchers have found that the erosion rate for the land area is between 8 cm and 9 cm of depth per 1000 years.

Questions

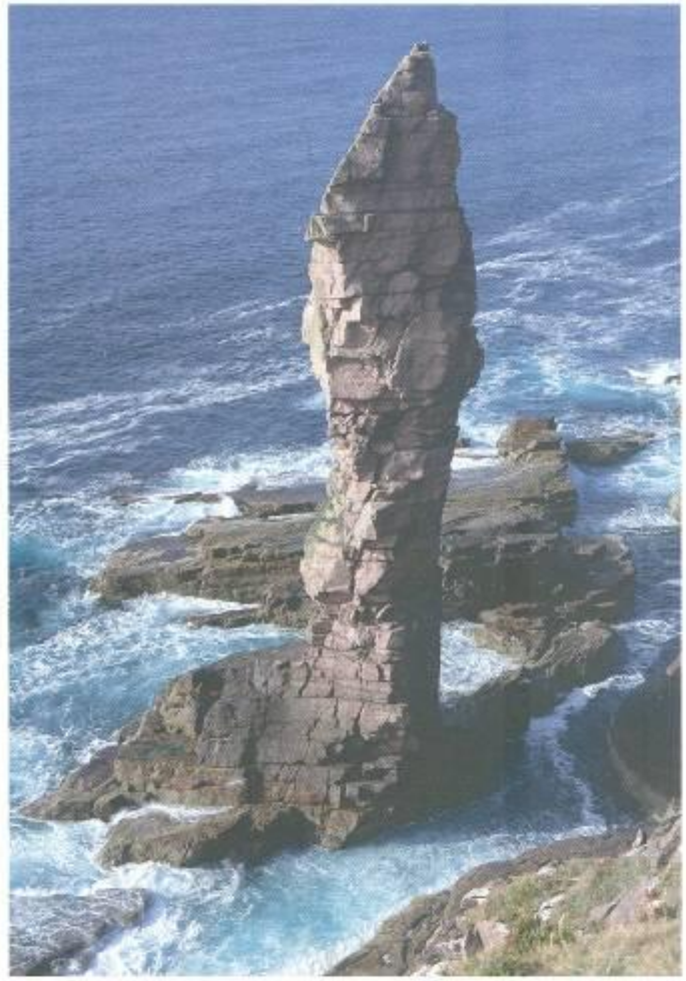
1. What is the difference between weathering and erosion?

2. Describe, using a diagram, how rock from a mountainous region can get into the sea.

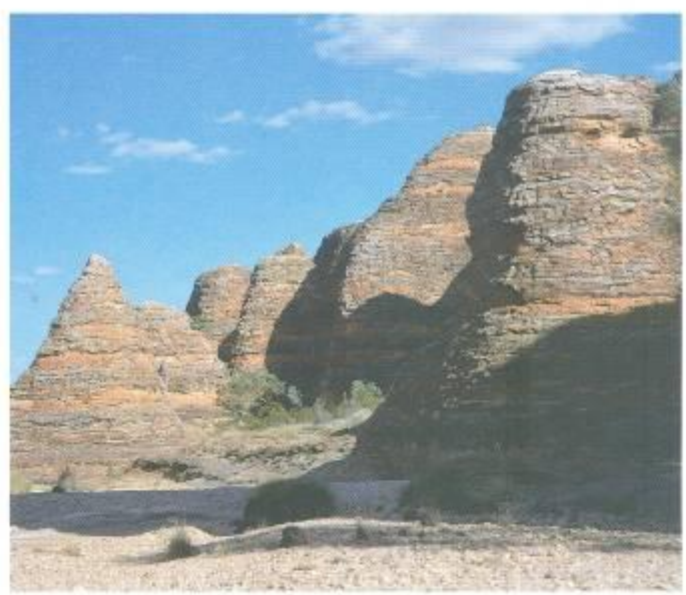


a This gorge was formed by the eroding action of the river.

b Glaciers erode the mountain to which they are attached.



c This stack was formed by wave action.



d Wind erosion caused these formations.

Figure 17.10

Soil

The smaller pieces of rock produced by the different weathering processes are transported by the different methods shown in the photographs in Figure 17.10 and are deposited to cover the surface of the Earth.

Humus, which is decayed (or partly decayed) organic material from plants and animals, mixes with the different types of rock material. This mixture of humus and rock particles is called soil. It takes 400 years for 1 cm of soil to form.

The soil provides nutrients and minerals as well as water for the plants to grow. Plants remove nitrates (Chapter 15) as well as elements such as sodium, potassium, magnesium and copper from the soil.

The pH of a soil depends on the type of rock from which the soil was formed as well as the amount of humus present. For example, soil formed in limestone areas tends to be alkaline, while soil formed in granite areas tends to be acidic. Also, the more humus present, the lower the pH of the soil.

There are different types of soil.

- **Loams**. These are the ideal soils for agriculture. This type of soil has sufficient clay (20%) to retain nutrients and hold moisture, sufficient sand (40%) to ensure the soil is well aerated and to prevent water-logging and silt (40%) which acts like an adhesive, holding the clay and sand together.

- **Sandy soils**. These are well drained and aerated. They are, therefore, easy to cultivate as they allow crop roots to penetrate then. However, because they lack humus they are vulnerable to drought. Also, they need large amounts of fertiliser as nutrients drain away quite quickly after rain.

- **Peaty soils**. These grow excellent crops but unfortunately the 'peaty' material can oxidise to carbon dioxide. It also gets blown away quite easily, which means that the level of this type of soil tends to fall by many metres a century.

Questions

1. Explain how soil is produced from rock.

2. Describe experiments you could carry out on a soil sample to determine:

a. the moisture content of the soil
b. the amount of humus it contains.

The rock cycle

The pattern of change we have been discussing, which takes place on the Earth's surface, is known as the **rock cycle**. This concept was first developed by James Hutton. Figure 17.11 shows the full rock cycle. In this cycle the rocks on the upland areas are weathered and the particles are carried away by erosion to form sediments which eventually become sedimentary rocks. These are then brought to the surface by the Earth's movements (uplifting) or they may be heated and compressed to form metamorphic rocks. If these metamorphic rocks are pushed deep below the surface, they will melt to form magma in the mantle. The magma may then rise upwards towards the surface, and igneous rocks are formed. So one type of rock may be recycled to form another type of rock.

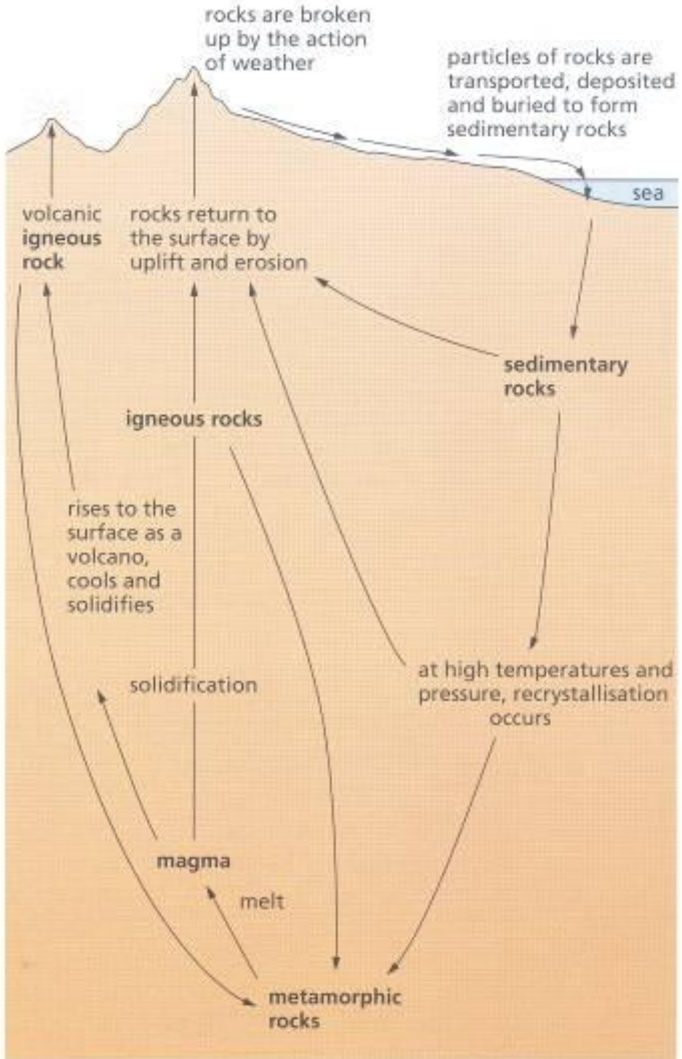


Figure 17.11 The rock cycle.

Question

1. Describe the different processes involved in the rock cycle.

Plate tectonics

Evidence from geologists shows that the Earth's **lithosphere** is not a continuous structure but is divided into sections called **plates** (Figure 17.12). The lithosphere is the near-rigid outer shell of the Earth, made up of the crust and the outermost layer of the mantle. The majority of these plates have continents sitting on top of them. These plates are actually moving very slowly about the Earth's surface. The driving force behind this movement is thought to be convection currents within the mantle.

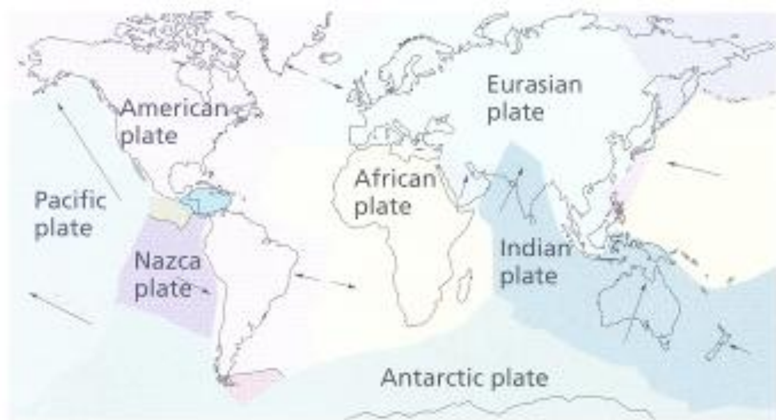
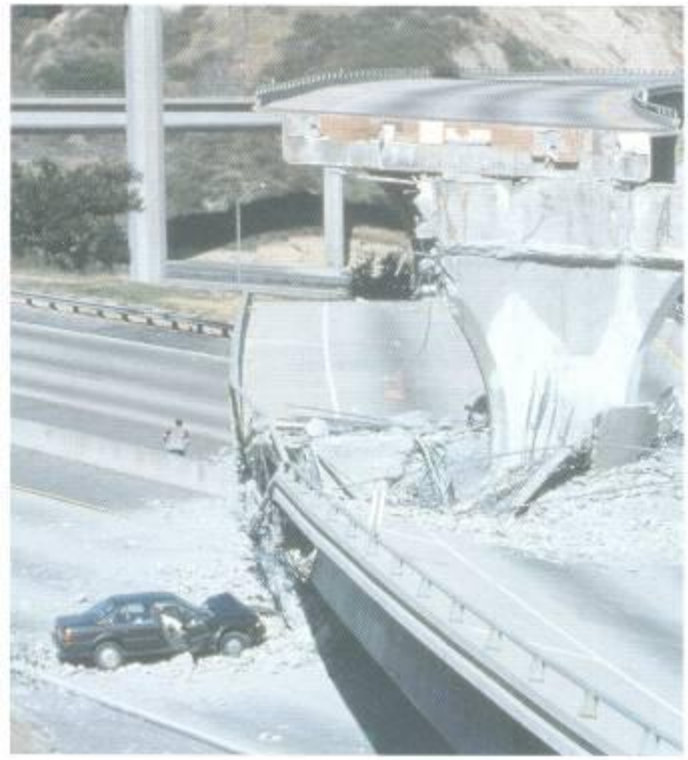


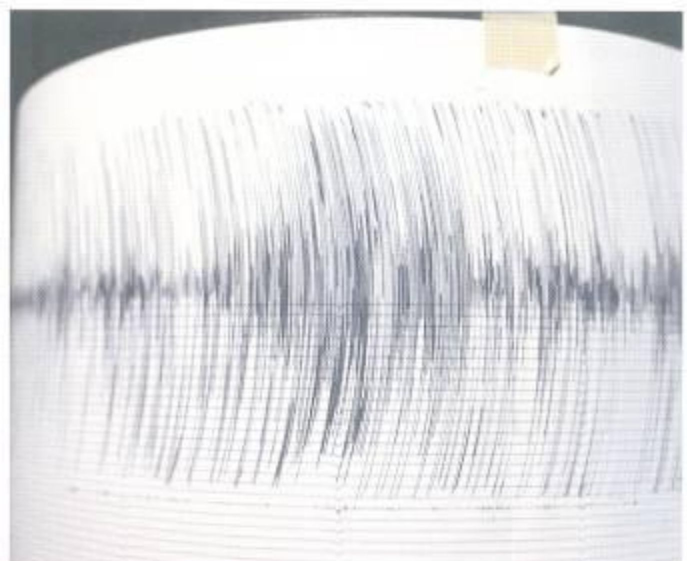
Figure 17.12 The world's plate boundaries. The arrows show the directions in which the plates are moving.

The study of the way these plates behave is called **plate tectonics**. Geologists think that the continents were originally joined together into one giant continent, which they called Pangaea (Figure 17.13). It is thought that it has taken approximately 200 million years for the continents, as we know them today, to drift to the positions they are in now through their plate movement. Evidence for this has been obtained from fossils found in the US. There are great similarities in the fossils found in the US and in Europe, dating from 200 million years ago.

Figure 17.13 The giant continent was called Pangaea. Much of the interior of this huge land mass was hot and dry.



a The 1994 earthquake in Los Angeles caused buildings and bridges to collapse.



b The drum seismogram reading of the Los Angeles earthquake.

Figure 17.14

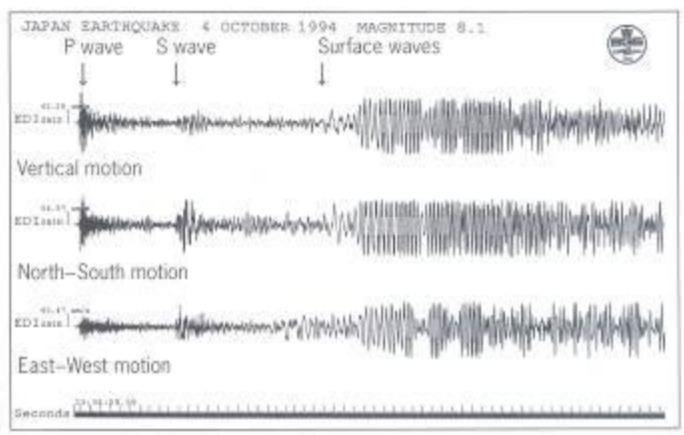
Where plates join, enormous forces are generated. This can, and does, create earthquakes (Figure 17.14) as well as volcanoes and mountains. Earthquakes mainly occur along fault zones:

- where plates are scraping past each other, for example California
- at margins where one plate is descending into the mantle, for example west coast of South America
- at constructive margins, where new rock is being formed from the mantle, for example the Mid-Atlantic Ridge.

a A seismometer site.

b Taking a reading from the seismometer.

c Analysing the data from the seismometer.



d A seismogram showing the three different waves.

Figure 17.15

Geologists monitor the earthquake activity around the Earth through hundreds of **seismic stations**. These stations are able to detect earthquake waves using an apparatus called a **seismometer** (Figure 17.15). Geologists hope to be able to predict earthquake activity through gathering information in this manner.

There are three different types of waves produced by earthquakes.

- **Primary (P) waves**. These are longitudinal waves, produced by pushing and pulling forces which cause the rock to shake backwards and forwards. This type of wave travels at speeds of up to 13 km per second and travels through both solids and liquids.

- **Secondary (S) waves**. These are transverse waves and cause the rock to shake at right angles to the direction of movement of the waves. This type of wave travels at speeds of up to 7 km per second and travels only through solids.

- **Surface (L) waves**. These waves have long wave-lengths and are responsible for the largest land movements and, therefore, cause the most damage. This type of wave travels more slowly than either the P or the S wave.

The energy released by an earthquake is measured and described using the **Richter scale**. Each unit on this scale represents a ten-fold increase on the previous unit. In theory, the scale does not have a limit; however, earthquakes above 8 are rarely encountered (Table 17.1).

Table 17.1 The Richter scale.

Richter scale unit	Destruction level for a nearby earthquake
2-3	Hardly noticed
3-4	Slightly noticed
4-5	Minor
5-6	Damaging
6-7	Destructive
7-8	Major destruction
8+	Enormously destructive

The January 1995 earthquake in Kobe, Japan, measured 7.2 on the Richter scale. Almost 5300 people died and approximately 27000 were injured. In terms of devastation, around 110 000 buildings were damaged or destroyed. The cost of rebuilding has been estimated at £65 billion.

Another area of the world which suffers frequent small tremors and, occasionally, a larger earthquake, as in 1994, is around Los Angeles in the US. This area is prone to earthquakes because it lies on the San Andreas fault — the boundary between the Pacific plate and the American plate. The plates are moving almost parallel to one another, but in opposite directions (Figure 17.16).

Figure 17.16 The displacement of these rows of trees shows how the plates are moving along the San Andreas fault.

The rough edges grind away as the plates slide across one another but occasionally particularly rough sections meet and 'lock' together. The pressure builds up until suddenly they slip across one another, causing the ground on each side to shudder violently and earth-quake damage on the surface.

Along the western edge of South America you can see a boundary region between two plates that are moving in opposite directions. Continental crust will meet oceanic crust at the boundary between the two plates. When this happens, the thinner oceanic plate is pushed down underneath the thicker continental plate and melts.

Sediments scraped from the oceanic plate are pushed up to form fold mountains, such as the Andes. Close to the edge of the continental plate the crust is weakened. Magma forces its way through these areas of weaknesses, forming volcanic regions (Figure 17.17).

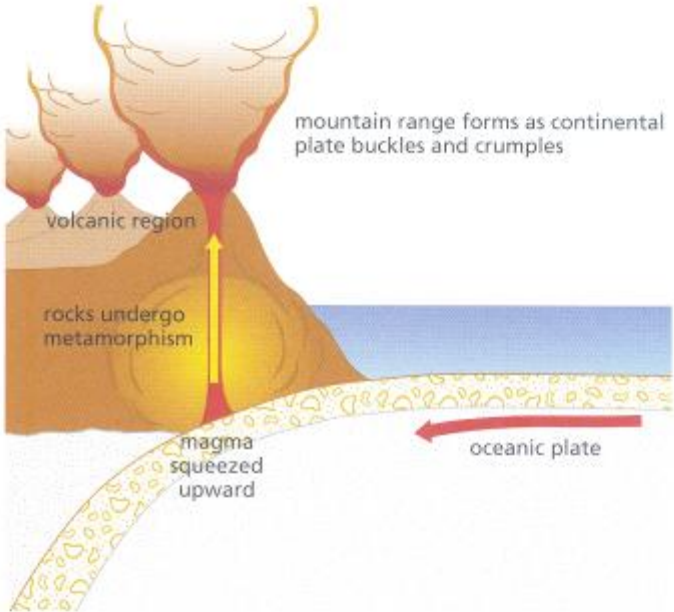


Figure 17.17 Formation of mountain ranges such as the Andes.

Although it may be difficult to believe, there are mountain ranges under the sea that are much higher than those on land. They occur where two plates are moving apart. One such region lies in the middle of the Atlantic Ocean (see Figure 17.12 and Figure 17.18).

Along the line where the plates meet, lava pours through huge fissures or cracks. The magma cools quickly in the colder depths of the ocean, forming 'bubbles'. These are quickly burst by the pressure of the lava below, and fresh lava erupts on top of the previously erupted and now hardened layer. Layer upon layer of basalt is formed, forming a high ridge called the Mid-Atlantic Ridge. As more magma emerges, the older rock layers are pushed further apart — a process known as ocean-floor spreading.

On each side of ocean ridges the rocks show a clear pattern of magnetic stripes. These are caused by iron crystals in the magma which, as the magma hardens, line up in the direction of the magnetic North and South poles. The iron particles themselves are weakly magnetised, with their

North and South poles aligned in the Earth's magnetic field.

At times during the Earth's history, the magnetic North and South poles have suddenly reversed. The reversal of the magnetically aligned particles in the stripes confirms the changes in the Earth's magnetic field.

The symmetrical nature of the magnetic stripes shows that the basalts on each side of the ridge were intruded into the ridge and became magnetised before the basalt was broken in two and the parts moved apart (Figure 17.19).

The meeting of two continental plates leads to the formation of high mountain ranges, for example the Himalayas. This is where the crust is at its thickest.

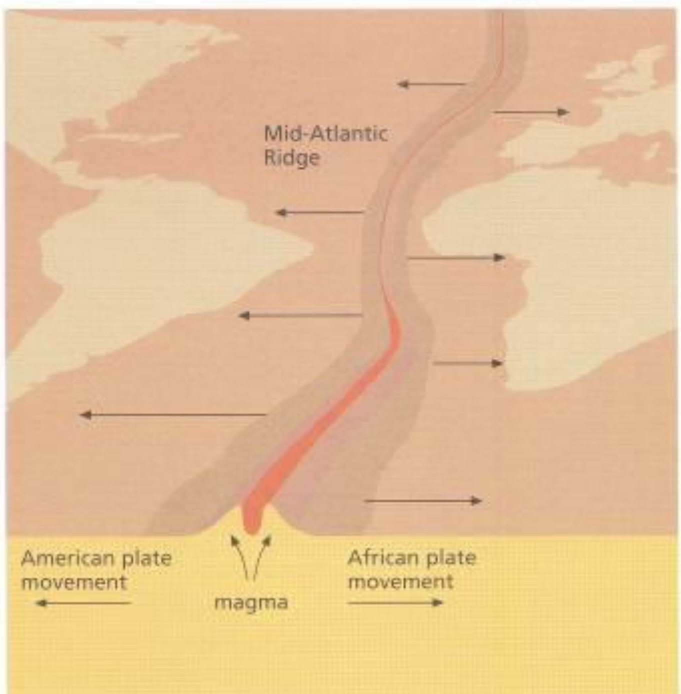


Figure 17.18 The formation of the Mid-Atlantic Ridge.

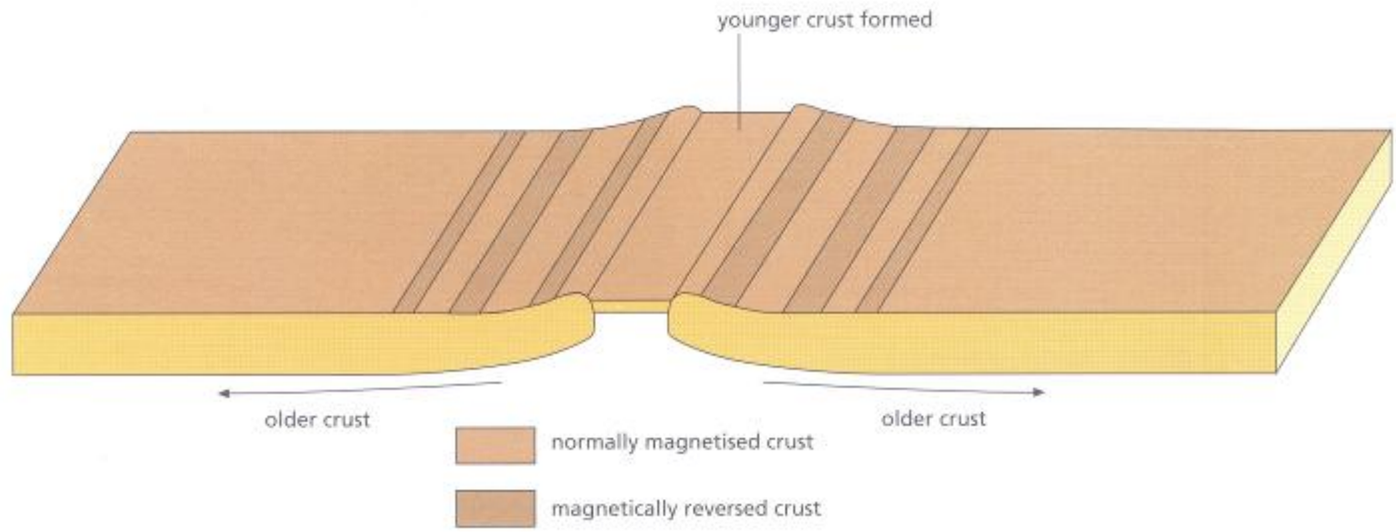


Figure 17.19 Magnetic stripes in the Earth's crust, formed at the Mid-Atlantic Ridge.

Questions

1. Explain why earthquakes usually happen at the boundaries between the world's tectonic plates.

2. Use your research skills to find the earthquake rating, on the Richter scale, of the Los Angeles earthquake of 1994.

Checklist

After studying Chapter 17 you should know and understand the following terms.

Core The central part of the Earth, composed of iron and nickel.

Crust The outermost layer of the Earth, to an average depth of about 40 km.

Earthquake The movement of the Earth's surface caused by plates scraping past each other on a 'fault', or at margins where one plate is descending into the mantle.

Erosion The removal and transportation of material.

Fossils Traces of prehistoric life which have been preserved by natural processes in rocks.

Geological time The geological division of time into three eras: cenozoic, mesozoic and palaeozoic. Each era is subdivided into periods and these are further subdivided into epochs.

Igneous rocks Rocks formed when magma cools and solidifies. Igneous rocks are usually crystalline. There are two main types of igneous rocks: intrusive (for example granite) and extrusive (for example basalt).

Lava Molten rock material that surges from a volcanic vent or fissure.

Lithosphere The near-rigid outer shell of the Earth, made up of the crust and the outermost layer of the mantle.

Magma Molten rock which includes dissolved water and gases.

Mantle The part of the Earth between the core and the crust, 40-2900 km below the Earth's surface.

Metamorphic rocks These are formed when rocks buried deep beneath the Earth's surface are altered by the action of great heat and pressure. For example, marble is a metamorphic rock and is formed by this type of action on limestone.

Plate tectonics The Earth's lithosphere is not a continuous structure but is divided into sections called plates. The majority of these plates have continents sitting on top of them. These plates are actually moving very slowly about the Earth's surface. The driving force behind this movement is thought to be convection currents within the mantle. Plate tectonics is the study of the way these plates behave.

Richter scale The scale used to measure the energy released by an earthquake.

Rock cycle The cycle of natural rock change in which rocks are uplifted, eroded, transported, deposited and possibly changed into another type of rock and then uplifted to start a new cycle.

Sedimentary rocks These rocks cover approximately 75% of the continents. They are formed when solid particles carried in seas or rivers are deposited. Sediment is also carried by wind and moving ice. Dissolved materials may later be extracted from water by plants or animals, or by evaporation to produce sediments. Layers of sediment can pile up for millions of years, and the sediment at the bottom of the pile experiences great pressure, causing compaction. The grains become cemented together by minerals in solution passing through the layers of sediment. Sedimentary rocks, for example limestone, have definite layers or strata associated with them, and you can often see these layers running through the rocks.

Seismometer An instrument used to monitor the magnitude of earthquake waves.

Soil A mixture of mineral particles and organic matter or humus.

Volcano A hole (vent) or crack (fissure) in the Earth's crust through which molten rock (magma) and hot gases escape to the surface during an eruption.

Weathering The action of water and temperature on rock.

The planet Earth

Additional questions

1. If mountains are created where plates are joined, are the plates moving away from each other or towards each other? Explain your answer.

2. Dilute hydrochloric acid can be used to distinguish between pieces of limestone and granite.

a. Which of the two rock samples would give a reaction with the dilute acid?

b. Write a word and balanced chemical equation to represent the reaction taking place in a.

c. Name two other types of rock which would give a similar reaction with dilute hydrochloric acid.

3. The average size of the crystals in a sample of granite is larger than that found in a sample of basalt.

a. What types of rock are granite and basalt?

b. Explain the difference in the average size of the crystals found in the two samples.

c. Granite is an intrusive rock and basalt is an extrusive rock. Explain the meaning of the terms in italics.

4. The core of the Earth is maintained at a temperature of about 4300°C. This temperature drops as you go into the mantle and the temperature just below the crust is only about 1000°C! One of the reasons for these high temperatures is the radioactive decay of the isotopes of elements such as potassium, thorium and uranium.

a. Explain the meaning of the terms in italics.

b. Why does the radioactive decay of the isotopes mentioned help to maintain the high temperatures?

5a. With reference to the rock cycle (Figure 17.11), describe how magma undergoes a change to a metamorphic rock.

b. Describe the differences in the driving forces behind the water cycle and the rock cycle.

6. Plate tectonics is the study of the movement of the Earth's plates.

a. What are tectonic plates?

b. Why are these plates able to move?

c. Explain, as fully as you can, one way the movement of these plates can cause:

(i) earthquakes to happen
(ii) mountains to be formed.

7. A seismometer is an instrument used to monitor the magnitude of earthquake waves.

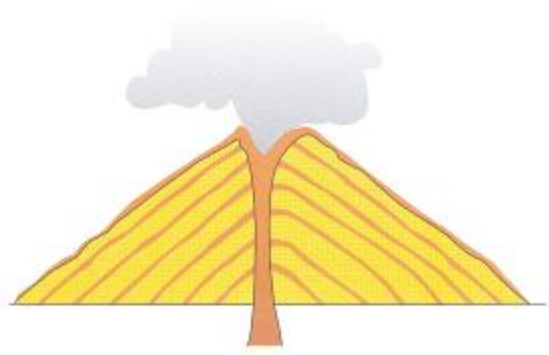
a. Describe how a seismometer works.

b. There are three types of waves produced by earthquakes.

(i) Name the three types of waves.
(ii) Which of these waves would be able to travel through the Earth's mantle? Explain your answer.

c. The waves produced are either longitudinal or transverse. Describe the meaning of these terms as applied to waves.

8. The diagram below shows a volcano.



Copy the diagram into your notes and label the following:

a. (i) a vent
(ii) lava
(iii) volcanic ash.

b Also label the place where:

(i) basalt is likely to be found
(ii) weathering and erosion will take place.

c. Explain how a volcano is formed

9a. Fossils of sea creatures are found high up on Mount Everest.

(i) What does this suggest about how the Himalayan mountain range was formed?

(ii) Explain your answer.

b. What evidence could be gathered to show that the east coast of America and the west coast of Europe were once joined?