Chapter 4

Earth and Space

The Big Bang theory and components of the universe

The early astronomers developed models to explain the motions of the stars and planets in the sky. Over time these models became refined until Newton developed a gravitational model that explained the motion of the heavenly bodies. It wasn't until the twentieth century, however, that answers to the problem of the origin of the elements of matter and the universe itself were developed. One theory, known as the Big Bang theory, eventually emerged as the most likely explanation of the origins of the universe. Like all theories, the Big Bang theory continues to be challenged as new evidence emerges from astronomical and theoretical studies.

Glossary

Astronomical unit—the distance between Earth and the Sun (1 AU)

Big Bang theory—a theory of the origin of the universe; it states that the universe came into existence about 13 billion years ago due to the creation of space-time and the partial conversion of energy into matter

Cosmic background radiation—the electromagnetic radiation in space that remains following the Big Bang; this radiation cooled as the universe expanded and is now at an average temperature of 3 degrees above absolute zero (–270°C)

Galaxy—vast collections of stars that are held together by gravitational forces

Light year—the distance light travels in one Earth year

Nuclear fusion—the process in which nuclei of light elements join together, with the release of large amounts of energy

Red shift—the shift in frequencies of visible spectral lines towards the red end (low frequency) of the electromagnetic spectrum; used as evidence of an expanding universe

Origin of the universe

The following information summarises the important ideas about the origin of the universe.

The equivalence of mass and energy

In 1915 Albert Einstein developed the Special Theory of Relativity. One important aspect of this theory was the famous equation:

$$E = mc^2$$

(E = energy; m = mass; c = velocity of light = 300 000 km/s)

This equation summarises the following major idea:

- **Mass and energy are equivalent.**
- Mass can be converted to energy.
- Energy can be converted to mass (matter).

The energy released by the Sun is an example of this process. Some of the matter of the Sun is being converted continually to energy in a process called **nuclear fusion**.

An expanding universe

In the first 30 years of the twentieth century various scientists (including Einstein, Lemaître and Friedmann) developed theories that suggested that the universe was expanding. No experimental evidence had been collected at the time to show this expansion. The concept of an expanding universe implied that the universe must have been originally much smaller than its current size. From this idea and Einstein's theory concerning the equivalence of mass and energy, the Big Bang theory developed.

Before we examine the Big Bang theory, we look at some of the evidence for an expanding universe.

- **Red shift of stars and galaxies**. Astronomers analysed the light from distant stars and galaxies with a spectroscope. When they looked at various elements in these sources, they found the characteristic frequencies of key lines was shifted towards the red end of the visible spectrum. This observation was made by **Edwin Hubble** in the late 1920s. This observation indicated that these stars and galaxies were moving away from us (and from each other). They are moving away because **space itself is expanding**.
- **Cosmic background radiation.** In 1965 two astronomers (Penzis and Wilson) detected uniform microwave radiation emanating from intergalactic space. This radiation was equivalent to a background temperature of –270°C (3 kelvin or 3 degrees above absolute zero). In 1989 the Cosmic Background Explorer satellite (COBE) studied this background radiation and found small amounts of matter irregularly scattered in the intergalactic spaces. These observations were consistent with the expansion and cooling of space following a very hot 'explosion' billions of years ago.

The steady state theory

Before the development of the Big Bang theory, another theory called the steady state theory (Gold, Hoyle, Bondi, 1948) proposed that the universe always existed and that it will forever continue to look the same as it did in the past. The universe expands because new matter and stars continue to form from a reservoir of energy. There is therefore a balance between expansion and star/galaxy formation. Opponents of the steady state theory have made the following criticisms of the theory:

- The discovery of the variable distribution of galactic radio sources and very distant and very bright quasars implies that the early universe looked different to the current universe. This is inconsistent with the steady state theory.
- The discovery of cosmic background radiation cannot be explained by the steady state theory.

However, the Hubble Space telescope (since 1996) has taken photographs of the most distant regions of space, showing mature galaxies similar to our local ones. This is consistent with the steady state theory.

The Big Bang theory

The Big Bang theory (Gamov, 1948) proposes that about **12–13 billion years ago** space and time came into existence in an 'explosion'. In terms of Einstein's equation, the energy that came into existence was partly converted to matter. Space became filled with hot matter that inflated and expanded rapidly and cooled as it expanded. The sequence of events that followed the 'explosion' can be summarised as follows (see Figure 4.1 on page 113):

- The early universe (<1 second old) was filled with radiation and subatomic particles but no atoms. It was very hot (100 billion degrees). It began to cool.
- One second after the Big Bang the primitive universe had a temperature of 10 billion degrees.
- By 3 minutes, the universe had cooled to 1 billion degrees and atomic nuclei formed from protons and neutrons.
- Over the next 300 000–700 000 years the temperature of the expanding

universe dropped to 3000 K and atoms formed as nuclei and electrons combined to form hydrogen and helium. Light was able to escape from the hot matter.

- Gravitational forces led to the formation of stars, galaxies and planets. This process continues today. The universe continues to expand and cool. Today (~10^{10} years after the Big Bang) the intergalactic temperature is only 3 K.

The radiation from the cooling of the primitive expanding universe following the Big Bang still exists and has been detected by the COBE satellite.

Calculations of the relative proportions of hydrogen and helium in the universe based on the Big Bang theory have been confirmed by astronomical measurements. This is further evidence for the Big Bang theory.

The future of the universe

Various theories have been proposed concerning the fate of the universe.

- **The open universe theory**. This suggests that the universe will continue to expand and cool forever. (There is evidence that the distant regions of the universe are expanding at an ever-increasing rate.) Ultimately the stars will redden and die (~100 trillion years) as they exhaust their nuclear fuel and the universe will become very dark and very cold (>10^{100} years).
- **The closed (pulsating) universe theory**. The universe will expand for a time but will eventually stop expanding and contract as **gravity** draws matter back together. This scenario ends in a big 'crunch' followed by a new Big Bang. This process repeats itself forever.

Electromagnetic spectrum and astronomy

Electromagnetic waves and the electromagnetic spectrum were discussed on page 4 in Chapter 1. **Re-read that section now.**

Astronomers use various bands of the electromagnetic spectrum to investigate the universe. Table 4.1 shows some of the applications.

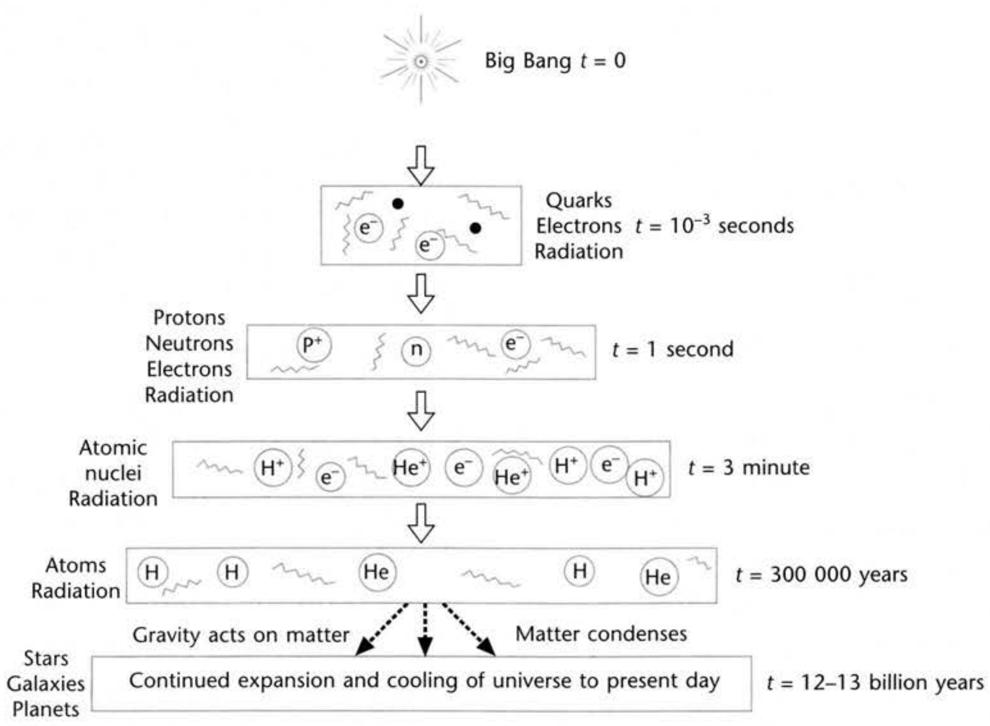


Figure 4.1 Events of the Big Bang

Table 4.1 Uses of the electromagnetic spectrum in astronomy

Electromagnetic band	Uses in astronomy
Radio	Radio telescopes are large dishes (eg. Parkes in NSW) that collect radio waves from space. The weak radio signals are amplified and analysed. Radio astronomy is used to: • observe objects that emit mainly radio waves rather than visible light (eg. dark nebulae; quasars; pulsars) • observe clouds of hydrogen in deep space
Infrared	Infrared telescopes and their spectrometers are used to: • detect objects that are too cool to emit visible light • measure the temperature of the atmosphere of solar system planets • determine the temperature of the background radiation in deep space
Visible	Ground-based optical telescopes and spectrometers as well as space telescopes such as the Hubble are used to: • observe and measure various optical sources such as planets, comets, stars and galaxies • measure the red shift of space objects such as galaxies to determine the extent of expansion of the universe • measure the colour and temperature of stars

Problems in obtaining information in astronomy

Ground-based telescopes

Ground-based astronomy is faced with many difficulties. These include:

- **Earth's atmosphere.** The atmosphere absorbs various components of the electromagnetic spectrum to different extents. Infrared, UV and X-rays are significantly absorbed by the atmosphere. Visible light is scattered and refracted by the atmosphere and clear images are hard to obtain. Locating telescopes on high mountains and using modern adaptive optics improves the quality of the signals detected. The Keck telescopes (in a dormant volcano in Hawaii) have the largest computer-controlled mirrors in the world. At this site the air is very still. The Keck telescopes can see fainter sources than the Hubble space telescope.
- **Light pollution.** Cities emit so much visible light at night that telescopes have to be built (where possible) in sparsely populated areas where there is little visible light pollution.
- **Radio wave pollution.** Mobile phones, microwave sources and pay-TV transmissions make it more difficult for radio astronomers to detect weak radio signals from space.
- **Solar storms.** Solar flares release bursts of electromagnetic radiation that interfere with other electromagnetic sources from space.
- **Optical systems in telescopes.** Lenses and mirrors in telescopes produce some degree of distortion of images. Telescopes are limited by their resolution. Resolution is the ability of an optical system to distinguish between two close objects.

To overcome these problems, space satellites and space probes have been launched. They are not subject to the problems of Earth's atmosphere and pollution from various ground-based electromagnetic sources.

Space telescopes

Because space telescopes are located above Earth's atmosphere, they do not suffer the atmospheric problems of ground-based telescopes. They can also use other bands of the electromagnetic spectrum that cannot be used on the ground. Some of these new generation telescopes include:

- **The Hubble space telescope**. This telescope (launched in 1990) can detect fine detail of visible and ultraviolet urces in nearby stars and distant alaxies.

- e **Chandra X-ray observatory**. This acility was placed in orbit in 1999 and it an examine X-ray sources, such as black oles, in deep space.

ajor features of the universe

om our perspective on Earth the servable universe has a radius of about 13 illion light years.

istances in space

e normal units of distance measurement Earth are replaced by larger units when escribing distances in space outside our lar system.

e **astronomical unit** (AU) is defined as e distance between the Sun and Earth.

One astronomical unit

= 150 million kilometres

his unit is useful for measuring distances in e solar system.

ample: Sun–Mars distance = 1.5 AU

Sun–Jupiter distance = 5.2 AU

Sun–Neptune distance = 30 AU

e **light year** is a common unit used for easurements outside the solar system.

One light year is the distance travelled by light in one Earth year.

One light year = 9 461 000 000 000 km.

ur Sun is 8.5 light minutes from Earth. The oon is about 1 light second from Earth. ars that are part of the Southern Cross d pointers, together with their distances om our solar system, are shown in Figure 2.

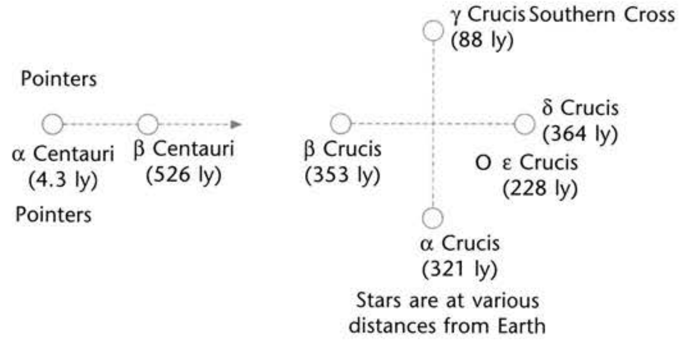


Figure 4.2 Southern Cross stars and the pointers

e solar system

rth is one of nine planets that orbit the n in elliptical orbits. The Sun is a yellow-hite star. The planetary orbits are elliptical, hough most are almost circular, except for Pluto's orbit which is much more elliptical and inclined in a different plane. Other bodies such as asteroids and comets also orbit the Sun. Comets have highly elliptical orbits.

Figure 4.3 shows the location of these major features of the solar system.

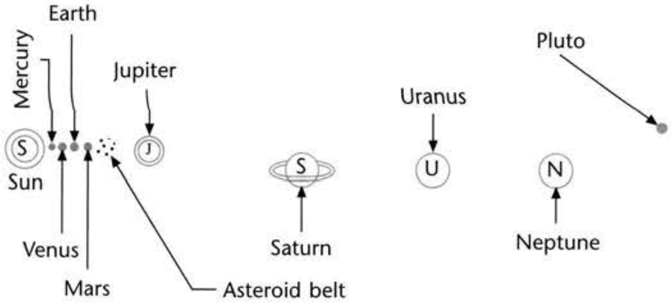


Figure 4.3 Structure of the solar system

Galaxies

The solar system is a small part of the **Milky Way** galaxy. The Milky Way is a **spiral galaxy** with a diameter of 100 000 light years. The solar system is located on one of its spiral arms as shown in Figure 4.4.

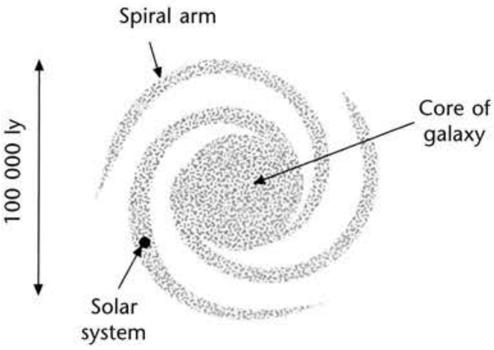


Figure 4.4 The Milky Way galaxy

- **Galaxies** are vast collections of stars, gas and stellar dust.

Some galaxies may have black holes at their centres. Some galaxies are elliptical and some have irregular shapes. Galaxies are organised into local clusters and superclusters that are hundreds of millions of light years across.

Deep space objects

Beyond the galaxy, superclusters are deep space objects. Some common objects found in deep space are:

- **Nebulae**. These are clouds of gas and stellar dust. Some glow brightly and others are dark.
- **Novae and supernovae**. Novae are formed by explosions that shear off the outer layers of stars. This causes the star to shine more brightly than normal. In supernovae the explosions tear the whole star apart and there is a short period where the exploding star shines billions of times more brightly. Eventually a **nebula** is left behind with a rapidly spinning **pulsar** or **neutron star** at its centre.
- **Pulsars** are very small (~20 km) and very dense objects that are about as heavy as the Sun. They emit pulses of radio waves as well as short bursts of X-rays and gamma rays along the direction of their magnetic axes. We detect the pulsar if its pulses are directed towards us.
- **Quasars and black holes**. Quasars are at vast distances in deep space. They are the centres of violent galaxies. They emit huge amounts of energy in jet streams at right angles to a spinning hydrogen gas disc. It is these bright jet streams of radio waves that we detect if they point in our direction. The spiralling gas is subjected to the intense gravity of a **black hole** at the centre. Black holes are extremely massive objects equivalent to billions of suns. Black holes are so massive that nothing, even light, can escape. This is why they look black.

Dark matter

Not all the matter in the universe emits light. It is called **dark matter.** Much of this dark matter is believed to be composed of cool non-radiating matter and subatomic particles such as neutrinos that are emitted in vast quantities by stars. Recent experiments have shown that each neutrino has a very small mass.

Relating features of the universe to the Big Bang theory

Following the Big Bang, the matter that formed spread out as space expanded. This matter was not uniformly spread but irregularly scattered. By 1 billion years after the Big Bang, **gravity** began to pull matter together to form various astronomical structures.

Gaseous clouds of hydrogen and dust collapsed under gravity to form **galaxies**. Inside these galaxies, **stars** began to form and illuminate space with their light. The Sun began to form from a planetary nebula about 5 billion years ago. The nuclear fusion reactions in its core were initiated when the gravitational heating reached 10 million degrees. Circling this young star were protoplanets which formed from the spinning disk of condensed matter. These protoplanets became the **planets** of our solar system about 4.6 billion years ago.

Star formation continues today in distant parts of the universe.

The life of stars

Stars have varying sizes. Some are smaller than the Sun and some are very much larger. They have different life cycles.

a. Stars like our sun

Star birth

The following account refers to stars that are similar in size to the Sun. It takes about

40 million years for a star like the Sun to form.

Vast clouds of hydrogen gas and interstellar dust are the birthplace of stars. This matter gravitationally condenses to form a dull red protostar. As it continues to condense, the material of the protostar heats up. At this stage the remaining matter of the star is still spread over a considerable amount of space. When the centre becomes hot enough due to gravitational heating, nuclear fusion reactions begin and helium is produced. This process generates considerable heat and yellow light. Some of the gaseous matter is ejected to form a rotating disc and over several million years it may lead to the formation of planets around the new star. The new star will shine for about 10 billion years.

Mature and ageing stars

The newly formed star continues to produce energy by the nuclear fusion of hydrogen into helium. The heavier helium sinks into the core of the star. This process generates heat and eventually causes the outer hydrogen shell to begin to fuse. This process is accompanied by a swelling of the star and an increase in its brightness.

The star continues to expand and its surface cools. It will form a **red giant star** which is about 100 times bigger than the original yellow star. At this stage helium fusion begins with the release of more energy. New elements such as carbon, nitrogen and oxygen start to form in the star's core. Eventually the star runs out of nuclear fuel and the core begins to shrink. Material is ejected to form a bright **planetary nebula** that drifts away. The remaining core finally turns into a small (yet heavy) **white dwarf star**. These white dwarfs are very hot. Over the next few billion years it will cool and eventually form a black crystalline object called a **black dwarf**.

The Sun is about half-way through its life cycle.

b. Larger stars

Stars that are five to ten times heavier than the Sun have a different evolutionary path. Their large mass creates rapid nuclear fusion and very high temperatures. These stars glow **blue-white** or **blue**. They have much shorter lifetimes than stars that are similar to the Sun.

These stars swell to form **red supergiants**, and in their cores heavier elements such as magnesium, sulfur and iron form. As nuclear fuel runs out, the star starts to collapse and the heating that is produced causes the outer layers of the star to explode, producing an incredibly bright **supernova**. The remaining core collapses to form a **neutron star** or **pulsar**.

Some stars are 30 to 50 times heavier than the Sun. They swell to form very large red supergiants. Following the explosion and supernova formation the core contracts to form a **black hole**.

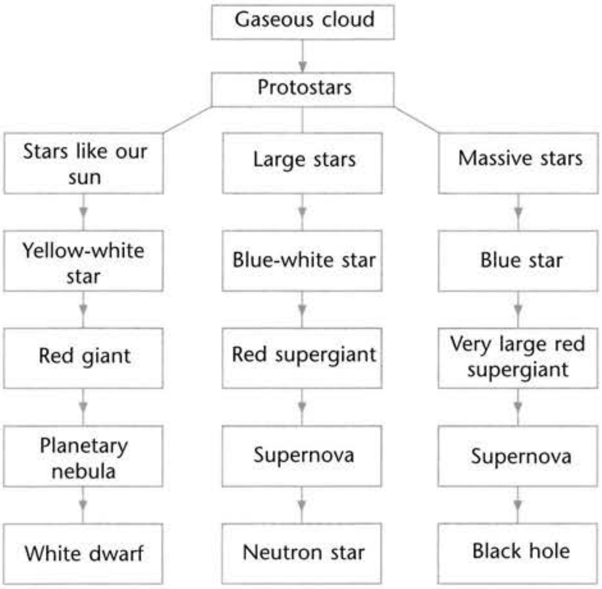


Figure 4.5 Star evolution

c. Very small stars

Stars that are less than half the size of the Sun are called **red dwarfs**. They have very long lives, and never evolve into red giants. Many of these common stars are almost as old as the universe. They fuse hydrogen into helium, but their small size prevents any further nuclear events. After they have exhausted their hydrogen, they cool and darken to form black dwarfs. Their lifetimes are estimated to be 100 billion years. **Proxima Centauri** (the closest star to the solar system) is a very small star with a mass about 15% of the Sun's mass.

Test yourself (answers on pages 221–2)

Part A. Knowledge (answers on page 221)

1 The scientist(s) who proposed the connection between mass and energy was:

- a Newton.
- b Friedmann.
- c Einstein.
- d Penzis and Wilson. (1 mark)

2 The observed red shift of stars and galaxies is evidence for:

- a the steady state theory of the universe.
- b an expanding universe.
- c star evolution.
- d red giant stars about to become supernovae. (1 mark)

3 Infrared astronomy is used to:

- a observe deep space objects that emit radio waves.
- b determine the temperature of the background radiation in space.
- c study the structure of distant galaxies.
- d observe hydrogen clouds in deep space. (1 mark)

4 Ground-based astronomy is faced with many difficulties. Select the statement that correctly identifies a problem and its cause.

- a Earth's atmosphere strongly absorbs IR and UV light and consequently these emissions from space are difficult to study.
- b Cities emit too much light but astronomers must operate from cities where computing systems are available to analyse results.
- c Mobile phones emit so much infrared radiation that astronomers are experiencing interference with the infrared signals from space.
- d Clear images can only be obtained if the telescopes are mounted on very high mountains where the air is very still for most of the year. (1 mark)

5 Select the statement that is true of the Milky Way.

- a The Milky Way is an elliptical galaxy with the Sun close to its centre.
- b The Milky Way is a supernova that exploded about 12 billion years ago.
- c The Milky Way galaxy has a diameter of about 100 000 light years.
- d Pulsars and black holes are common in the Milky Way galaxy. (1 mark)

6 Complete the following restricted-response questions using the appropriate word. (1 mark each part)

- a Pulsars emit regular pulses of _____ waves.
- b The Sun was formed from vast clouds of _____ gas and interstellar dust.
- c When red supergiant stars use up their fuel, they collapse and explode, producing a bright _____ .
- d A light year is the _____ light travels in one Earth year.
- e The open universe theory predicts that the universe will continue to _____ and cool forever.

7 Use the code letters to match the terms or phrases in each column. (1 mark each part)

Column 1	Column 2
a Big Bang theory	f X-ray sources
b Edwin Hubble	g ground-based astronomy
c light pollution	h red dwarf star
d Chandra observatory	i red shift of stars/galaxies
e Proxima Centauri	j expanding universe

8 Briefly outline how stars generate energy. (2 marks)

9 Briefly explain two pieces of evidence that support the view that the universe is expanding. (2 marks)

10 Outline the future stages in the evolution of a star such as the Sun. (3 marks)

Part B. Skills (answers on page 222)

1 a One astronomical unit is equal to 150 million kilometres. Calculate the distance of the following planets from the Sun in kilometres. (2 marks)

   i Venus ($d = 0.7$ AU)

   ii Saturn ($d = 9.5$ AU)

  b The average distance of Pluto from the Sun is 5590 million kilometres. Calculate this distance in astronomical units. (2 marks)

2 One light year is equal to 9461 billion kilometres. Calculate the distance of the following stars from the Sun. (2 marks)

  a Wolf-359 ($d = 7.7$ ly (light years))

  b Beta Crucis ($d = 353$ ly)

3 The stars of the Southern Cross form a constellation. In the sky they appear to be close together. Their recently measured distances from the Sun are tabulated below.

Star	Distance (ly)
Alpha Crucis	321
Beta Crucis	353
Gamma Crucis	88
Delta Crucis	364
Epsilon Crucis	228

  a Do these stars form a cluster in space? Explain. (2 marks)

  b The stars are listed in order of decreasing brightness as seen from Earth.

   i Which star is the brightest as seen from Earth? (1 mark)

   ii Beta Crucis has a higher surface temperature than Alpha Crucis. Why does it appear less bright than Alpha Crucis? (1 mark)

4 Figure 4.6 is a scale diagram of the Milky Way galaxy shown in side view. The position of the Sun is also shown. Use the information to determine:

  a the distance of the Sun from the galactic core (1 mark)

  b the diameter of the Milky Way galaxy. (1 mark)

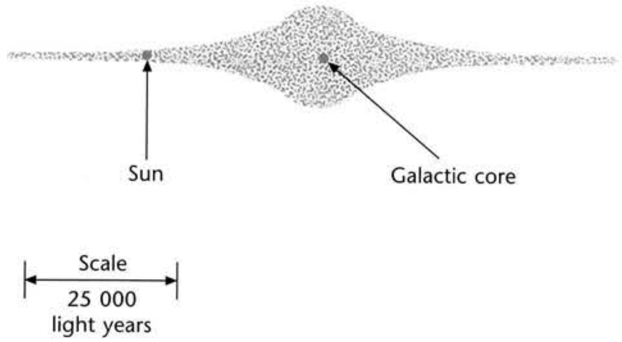


Figure 4.6 Scale diagram of the Milky Way

5 Figure 4.7 is a set of jumbled diagrams that show the evolution of a star such as the Sun. Use the code letters to place these diagrams in their correct sequence. (2 marks)

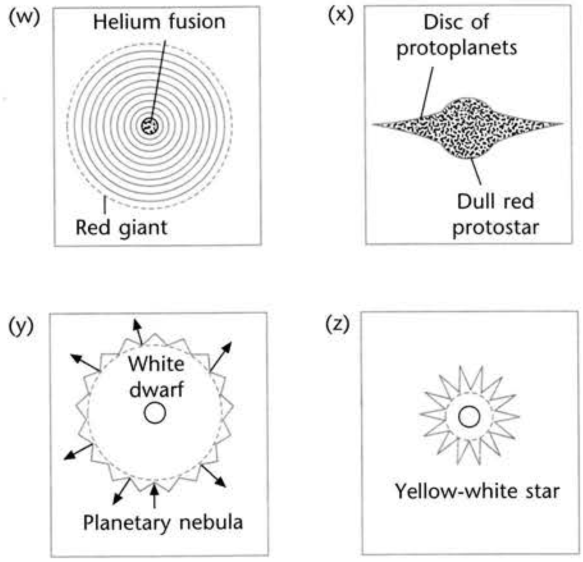


Figure 4.7 Jumbled diagrams of star evolution

6 Figure 4.8 shows simplified diagrams of the rotation of the Milky Way galaxy at various times. The position of the Sun is marked. Use this information to calculate the time for one complete revolution of the galaxy. (2 marks)

7 The surface temperature (T) of a star can be estimated from the wavelength (λ) using the following mathematical formula:

$$\boldsymbol{T.\lambda = 3\ 000\ 000}$$

Temperature is measured in absolute

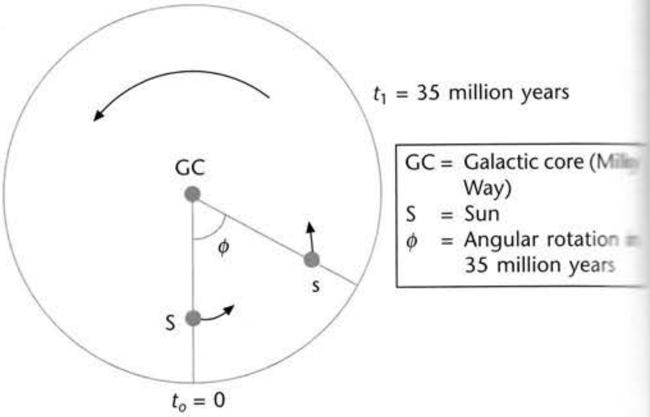


Figure 4.8 Time sequence for the rotation of the Milky

units (kelvin, K) and wavelength is measured in nanometres (nm).

a Light from the Sun has a waveleng of 510 nm. Calculate the surface temperature of the Sun in absolute units. (2 marks)

b Given that 0°C = 273 K and 100°C = 373 K, determine the temperature of the surface of the Su in degrees Celsius. (1 mark)

c Betelgeuse is a red supergiant star. surface temperature is about 4300 Calculate the wavelength of the lig emitted from its surface. (1 mark

8 Figure 4.9 is a graph of the relative brightness of many stars compared

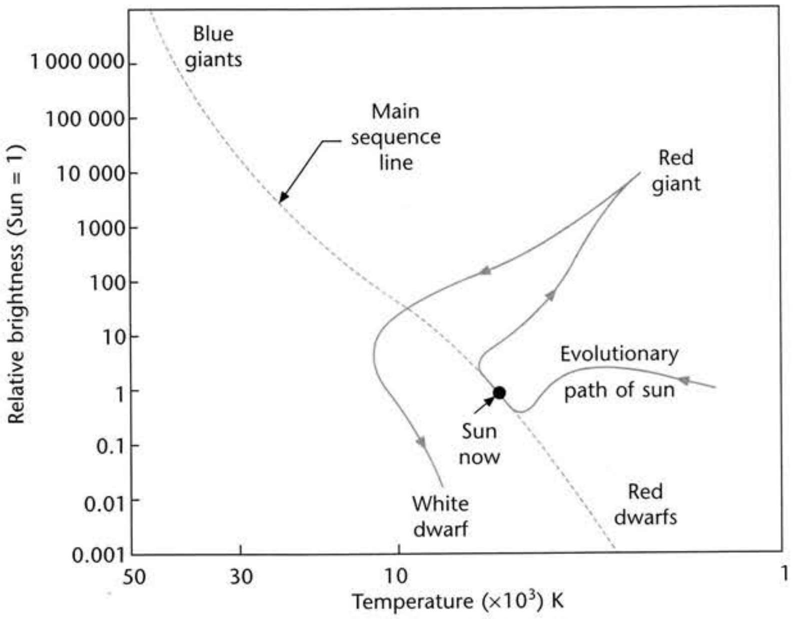


Figure 4.9 Brightness–temperature graph of stars and evolutionary path of the Sun

their surface temperatures. The dotted line is called the Main Sequence and links red dwarfs to blue giants. The graph also shows the evolutionary path of our Sun.

a Are red dwarfs brighter or dimmer than the Sun? (1 mark)

b Compare the brightness and surface temperature of a blue giant and the Sun. (2 marks)

c The Sun will evolve into a red giant. Will the red giant be:

  i brighter or dimmer than the present-day Sun? (1 mark)

  ii hotter or colder on its surface than the present-day Sun? (1 mark)

d Following the red giant stage, the Sun will evolve and cross the Main Sequence line. How will its brightness and surface temperature change? (2 marks)

e What is the ultimate fate of the Sun? (1 mark)

Mid-chapter test (answers on pages 222–3)

1 Explain the evolution of very small stars such as Proxima Centauri that have a mass of 15% of the Sun. (2 marks)

2 Figure 4.10 is a graph of the penetration of various electromagnetic waves through the atmosphere.

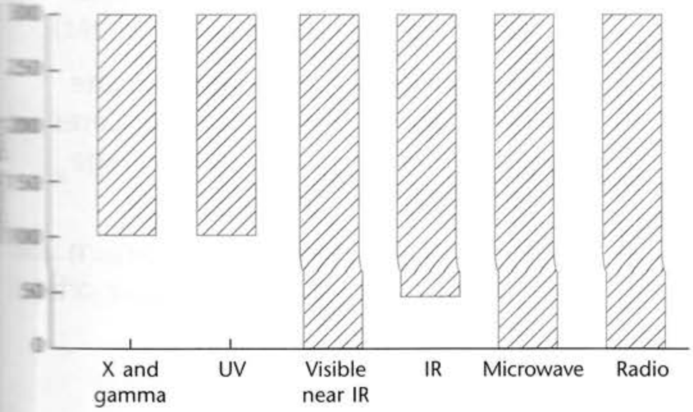


Figure 4.10 Penetration of electromagnetic waves through the atmosphere

a Which rays are quickly filtered out by the upper atmosphere? (1 mark)

b Which rays are able to penetrate below 20 km altitude? (1 mark)

c Use the graph to name the two common types of ground-based astronomy. (2 marks)

3 Figure 4.11A shows three lines in the visible spectrum produced by light emitted from a star that is rotating around another star. These three lines (X, Y and Z) correspond to different directions of motion of the star relative to an observer on Earth. Figure 4.11B shows the direction of motion of the star relative to Earth at different times in its cycle.

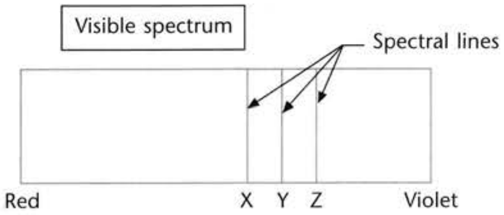


Figure 4.11A Spectrum with three lines

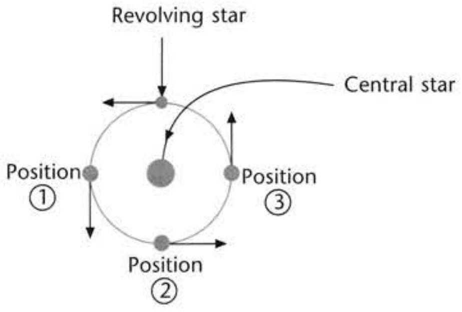


Figure 4.11B Motion of star relative to Earth

a In which position in the star's orbit is the light from the star red-shifted? (1 mark)

b Match the three spectral lines to the rotational direction of the star in Figure 4.11B. (3 marks)

c Stars that are moving towards Earth emit light frequencies that are blue-shifted. In which position of the star's orbit is the light from this star blue-shifted? (1 mark)

d If light from distant galaxies is red-shifted, what can one conclude about the motion of these galaxies relative to our own galaxy? (1 mark)

4 Figure 4.12 shows a model of the steps in the formation of one helium-4 nucleus from hydrogen (H-1) nuclei in a star such as the Sun.

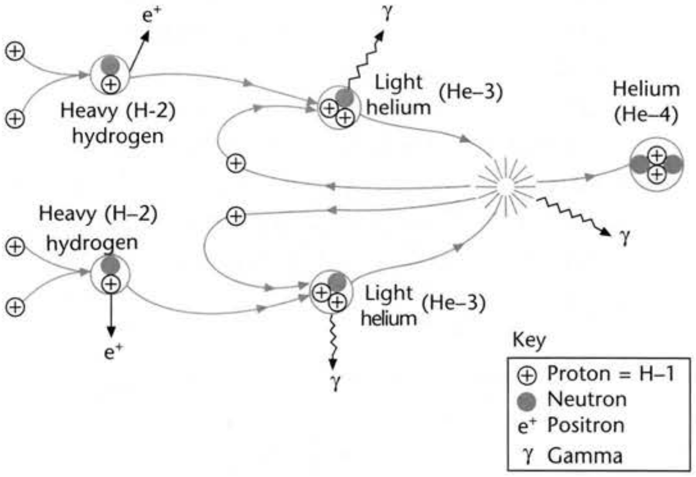


Figure 4.12 Steps of the fusion of hydrogen into helium in the Sun

a How many hydrogen nuclei fuse to form one nucleus of 'heavy hydrogen' in the first step? (1 mark)

b How is 'heavy hydrogen' different from normal hydrogen? (1 mark)

c What is the mass number (A) of the helium atom formed when hydrogen and heavy hydrogen fuse together? (1 mark)

d Write a word equation for the final step that produces helium-4. (2 marks)

e What type of highly penetrating radiation is released during these fusion reactions? (1 mark)

5 Figure 4.13 shows the evolutionary sequence of a star that has a mass ten times greater than the Sun. Use this diagram to explain how the brightness and surface temperature change as the star evolves. (2 marks)

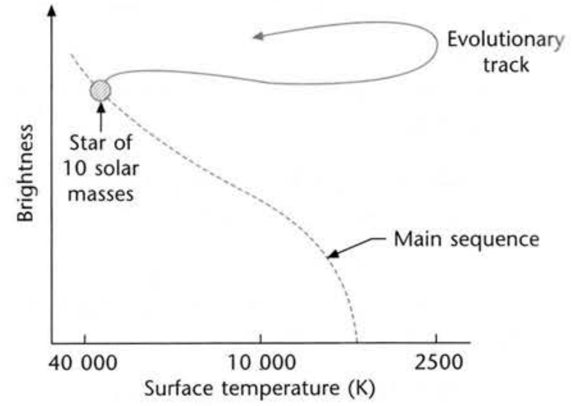


Figure 4.13 Evolutionary track of a large star

6 The planets vary in their orbital speed around the Sun. The following table shows this variation. One value (X) is missing.

Planet	Average distance from Sun (AU)	Average orbital speed (km/s)
Mercury	0.4	48
Venus	0.7	X
Earth	1.0	30
Mars	1.5	24
Jupiter	5.2	13

a Describe the trend in the data. (2 marks)

b Plot a line graph of the data and determine a value for X. (3 marks)

c Use your graph to determine the orbital speed of the asteroid Ceres that orbits the Sun at an average distance of 2.8 AU. (2 marks)

d Which of the two planets (Saturn and Neptune) will have the greater orbital speed? (1 mark)

7 Use the code letters to place the following jumbled statements in the correct sequence. (2 marks)

The Big Bang

a Gravitational forces cause matter to condense to form stars and galaxies.

b Some energy is converted to sub-atomic matter.

c The very hot primitive universe cools as it expands.

d Atomic nuclei start to form.

e The expansion and cooling of the universe continues to the present day.

f Space and time come into existence.

g Atoms of hydrogen and helium form as nuclei and electrons combine.

h Space inflates and expands.

True or false? (10 marks)

a Ground-based telescopes should be located in regions away from cities.

b Infrared astronomy can be used to measure the temperature of the atmospheres of the planets of the solar system.

c The open universe theory predicts that gravity will eventually draw matter back together.

d By three minutes after the Big Bang, atoms of hydrogen and helium had formed.

e Mass and energy are equivalent.

f The Sun generates energy by nuclear fusion.

g The Milky Way galaxy is a spiral galaxy that is about 10 light years in diameter.

h Pulsars are very dense objects formed at the end of the evolution of stars that have masses five to ten times the mass of the Sun.

i Black holes are holes in the fabric of space–time.

j Red dwarfs are very small stars that have very long lifetimes.

Natural events

Earth is a dynamic planet. Although the landscape may appear constant over a person's life, Earth is in a state of constant change. Many natural events shape the planet on which we live.

Glossary

Eons—the largest divisions of the geological time scale

Fossil—remains or impressions of past life forms

Igneous rocks—rocks that have formed from magma or lava

Lithosphere—the outer rigid layer of Earth that includes the crust and upper mantle

Plate tectonics—a study of the forces that cause the movement of the crustal plates

Pyroclastic—describes hot rock and ash fragments released in a volcanic explosion

Unconformity—a break in geological time between younger and older strata

Radiometric dating—determining the age of rocks or fossils using the known half-lives of radioisotopes

Seismology—the study of earthquakes

Strata—layers of rock (singular = stratum)

Geological history

The geological history of an area can often be determined by the sequence of rocks exposed in road cuttings, or through the analysis of cores obtained by drilling into the ground.

Sedimentary strata

Sedimentary rocks are formed from **sediments** that have been **compacted** and **cemented together**. This process takes millions of years. These sediments may have been deposited in a variety of environments, including oceans, lakes, rivers, dams, swamps and deserts. Table 4.2 lists some common sedimentary rocks, the sediments

Table 4.2 Sediments and sedimentary rocks

Sedimentary rock	Sediment	Environment of formation
Mudstone	clay/mud	sediments carried by quiet, slow-moving water and deposited in lakes, lagoons and on the ocean floor
Shale	silt/mud	sediments carried by quiet, slow-moving water and deposited in lakes, lagoons and on the ocean floor
Sandstone	sand	sediments carried by faster moving streams and rivers or ocean waves and deposited on the ocean floor
Conglomerate	gravel/pebbles	heavy sediments carried by fast-moving streams/rivers and deposited in these environments
Limestone	crushed shells/corals	marine invertebrates with shells, and corals, grow in shallow, warm seas; after death their exoskeletons are crushed and cemented together
Coal	plants	swamp plants die and are buried in mud on the floor of the swamps

that they are made from and the environments in which they form.

Sedimentary rocks are deposited in horizontal layers or **strata**. The more recent sediments are deposited on top of older sediments. When these sediments turn into sedimentary rocks they form a sequence in which **the oldest strata are on the bottom** and **the youngest are on the top**. This is known as the **law of superposition.** Figure 4.14 illustrates the law of superposition.

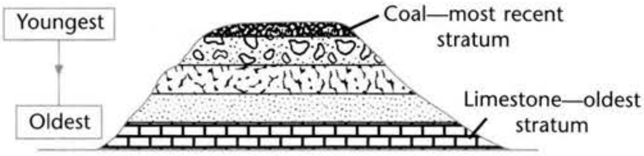


Figure 4.14 Law of superposition

The effect of igneous and metamorphic activity

Igneous rocks are formed from molten rock inside Earth (**magma**). Igneous rocks can be classified into groups based on their crystal size and rate of cooling. When the magma cools slowly deep inside Earth, the rock that forms has large crystals. Such rocks are called **plutonic igneous rocks**. Magma that flows out onto Earth's surface to form **lava** cools rapidly and forms rocks with very small crystals. Such rocks are called **volcanic igneous rocks**. Intermediate size crystals can form in rocks such as dolerite that solidify more rapidly than plutonic rocks.

Magma can intrude into existing strata to form various structures such as **plutons**, **dykes** and **sills**, as shown in Figure 4.15.

Table 4.3 Classification of some common igneous rocks

Type of igneous rock	Crystal size and rate of cooling	Examples
Plutonic	Large crystals due to very slow cooling of magma	granite (rich in light-coloured minerals such as feldspar and quartz) gabbro (rich in dark minerals such as hornblende and biotite mica)
Volcanic	Fine crystals (or none) due to rapid cooling of lava	rhyolite (rich in light-coloured minerals) basalt (rich in dark minerals) pumice (lava froth filled with gas cavities) volcanic glass (no crystals)

The presence of such **intrusions** can complicate the geological history of an area.

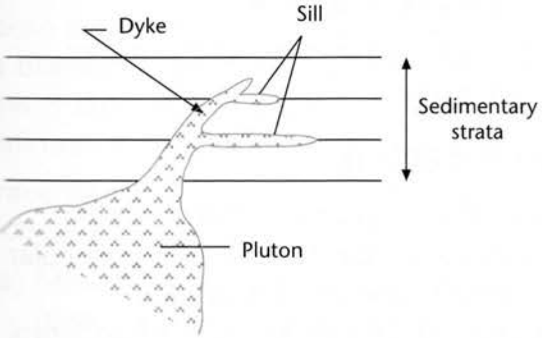


Figure 4.15 Intrusive structures

Changes in rock strata can also occur due to prolonged periods of heating and pressure caused by igneous activity or tectonic activity in the crust. This leads to the formation of **metamorphic rocks**. The presence of metamorphic rocks is therefore evidence of periods of tectonic or igneous activity.

Table 4.4 lists some of the common metamorphic rocks and the parent sedimentary rock from which they are formed. Hornfels is formed when shale is baked by contact with hot magma. Slate, schist and gneiss are formed by the heat and pressure associated with mountain building.

Table 4.4 Metamorphic rocks

Parent sedimentary rock	**Metamorphic rock(s) formed**
Quartz sandstone	Quartzite
Limestone	Marble
Shale	Hornfels, slate, schist, gneiss

The effect of folding and faulting

The geological history of an area may also be complicated by tectonic activity that leads to folding or faulting of strata. Figure 4.16 shows some of the structures that result from folding and faulting.

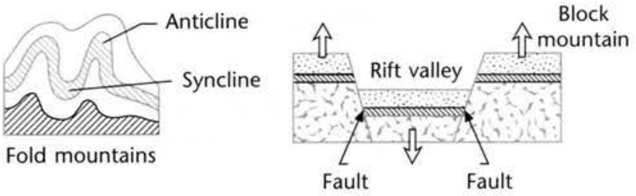


Figure 4.16 Landforms and structures formed from folding and faulting

Interpreting geological histories

The following examples illustrate the steps involved in determining the geological history of an area. In each case the oldest rock needs to be established. This may be the lowest layer but earth movements may have caused some changes. Check that you agree with the sequence of steps in each history.

Example 1

The following history refers to Figure 4.17. The stages in the diagram are listed from **oldest to most recent**. In the case of sedimentary strata the mode of sediment deposition and sedimentary rock formation is not discussed. The deposition events occur under water.

1. The limestone layer at the bottom of the section was deposited first.
2. Deposition of shale layer
3. Deposition of limestone layer
4. Deposition of sandstone layer
5. Faulting of the sedimentary strata occurs.
6. Intrusion of granite occurs and the heat from the cooling magma causes contact metamorphism of the sedimentary

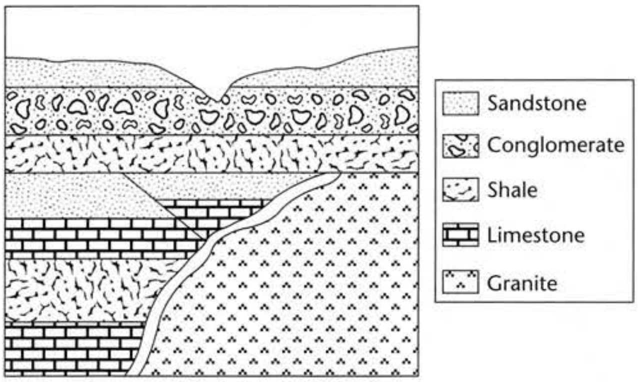


Figure 4.17 Geological cross-section 1

layers to form marble, hornfels and quartzite.

7. The region is uplifted and a period of extensive erosion occurs to produce a plain.
8. Water once again covers the area and shale is deposited.
9. Deposition of conglomerate
10. Deposition of sandstone
11. Erosion to produce the present-day landscape. Note the V-shaped valley cut by a river.

Note. The term **unconformity** is used to describe the break in time between younger rocks and older rocks. This has occurred in the example above as the shale deposited in stage 8 is very much younger than the sandstone layer below it.

Example 2

The following history refers to Figure 4.18.

1. Deposition of sandstone
2. Deposition of limestone
3. Deposition of conglomerate
4. Deposition of shale
5. Folding of strata to form an anticline and syncline
6. Uplift; extensive erosion to form a plain
7. Deposition of mudstone (note the unconformity that is now produced)
8. Deposition of sandstone
9. Deposition of coal
10. Intrusion of igneous rock (dolerite) to form a dyke and sill
11. Erosion to form the present-day landscape

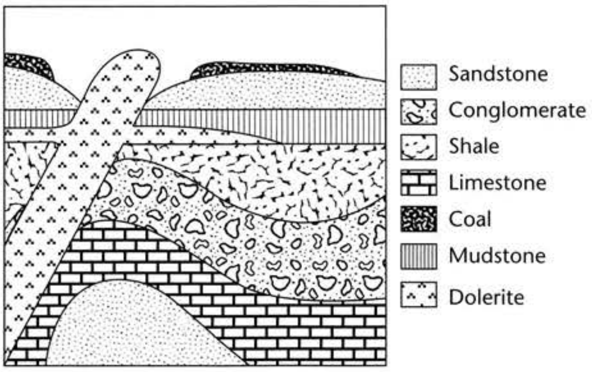


Figure 4.18 Geological cross-section 2

Fossilisation

Fossils provide useful information in reconstructing the history of a particular area. **Fossils are the remains or impressions of a living organism from Earth's past.**

Fossils will form only if the organism is preserved in some way before it decays. There are few fossils of the soft parts of organisms because they decay more readily than hard parts such as bones and shells. Organisms that live in water are more likely to be preserved than terrestrial organisms. Their remains sink to the floor of the body of water and quickly become covered with sediments. This helps to exclude oxygen that promotes decay.

The surrounding sediment gradually turns to sedimentary rock and this entombs the remains as a fossil. Sedimentary rocks are the sources of many fossils. Other types of rocks, such as igneous and metamorphic rocks, do not favour fossilisation as the fossils become destroyed quickly by the heat or pressure.

Examples of fossils

Examples of fossils include:

- **Whole organisms that remain almost unchanged**—Mammoths frozen in ice are examples of this recent group of fossils.
- **Unaltered hard parts**—In more recent fossils, the hard exoskeletons of insects are often preserved in amber, and mollusc shells are preserved in sedimentary rocks.
- **Altered hard parts**—In older fossils, bones and shells of some organisms become altered by minerals replacing existing minerals. Some bones become

opalised in this process. Tree trunks may form fossils called **petrified wood,** due to minerals filling the intercellular spaces. Some fossils (eg. plant leaves) are turned to **black carbon,** leaving only an imprint. This is common in plant fossils and sedimentary rocks including coal.

- **Trace fossils**—These common fossils include:
  - (a) **Moulds and casts**—Sediments can pack hard around the remains of an organism to form a mould. A cast is formed if minerals fill and harden in the space left in the mould when the original remains dissolve away.
  - (b) **Footprints and imprints**—Footprints of ancient animals such as dinosaurs can be preserved if the mud on which they walked hardens before they are washed away. Soft-bodied invertebrates (eg. jellyfish) may also leave imprints in hardening sediments.

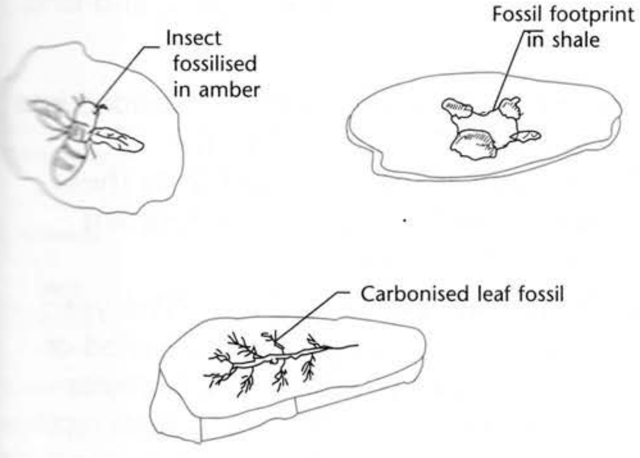


Figure 4.19 Examples of fossil formation

The fossil record and geological time

The presence of fossils in sedimentary rocks helps geologists to date the rock strata.

Relative dating

The law of superposition (see page 124) allows geologists to establish the relative age of strata. In undisturbed strata, the oldest layers are on the bottom. The presence of fossils in some of these layers therefore allows geologists to establish the relative ages of fossils.

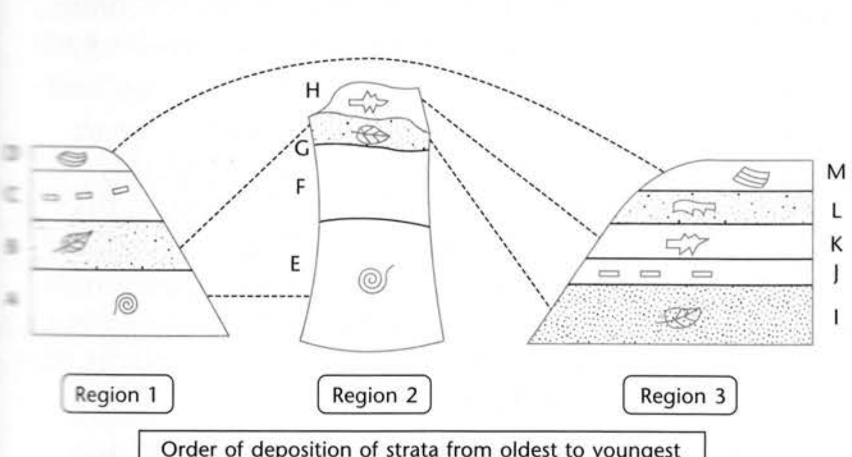
- **The simplest fossils are located in the deepest sedimentary layers.**

By comparing particular fossils in similar sedimentary strata around the world, geologists were able to construct a relative time scale for the evolution of living things.

Figure 4.20 shows an example of the use of fossil correlation to establish the order in which strata were deposited.

Absolute dating of rocks and fossils

The real (or absolute) age of rocks and fossils can be established by techniques such



Order of deposition of strata from oldest to youngest
(A, E) → F → (B, G, I) → (C, J) → (H, K) → L → (D, M)
Rocks in brackets are the same stratum

Figure 4.20 Example of fossil correlation to establish sequence of strata as **radiometric dating**. By measuring the amounts of certain radioactive elements and their decay products in a sample, a scientist can use the known half-life of the radioisotope to calculate the age of the sample.

Some useful radioisotopes are:

- **Carbon-14**—useful for dating carbon-containing fossils up to 60 000 years old. The age of the sedimentary layer is equal to the age of the fossil.
- **Potassium-40**—used to date the minerals in igneous rocks and feldspar minerals.
- **Rubidium-87**—used to date minerals in metamorphic rocks as well as micas and feldspars.

Some very old minerals, such as zircons, have been dated at 4.2 billion years old using K-40 and Rb-87 dating. Earth is believed to be 4.6 billion years old.

If a sedimentary layer is located between crystalline rocks (such as igneous and metamorphic rocks), the age of the sedimentary layer can be deduced by dating the surrounding crystalline rocks. The sedimentary layer cannot be directly dated because the process depends on radioactive minerals being trapped by crystals.

Geological time scale

The geological time scale divides the time between Earth's formation and the present into divisions and smaller sub-divisions according to major events and the types of life forms that appeared or became extinct in Earth's history. As scientists gain more knowledge about these events the placement of the divisions on the time scale is changed. The time scale shown in Figure 4.21 is an average of the current range of published data.

Note: You do not need to remember all the details shown in this time scale but you will be expected to process data based on it.

Some of the major features of the geological time scale include:

- The 4.6 billion years is divided into four **eons** of varying length.
- There is no fossil evidence of life forms in the **Hadean** eon (4.6–3.8 billion years ago).
- Simple life forms (bacteria) appeared in the **Archean** eon (3.8–2.5 billion years ago).
- The fossil record shows increasing complexity of life forms in the **Proterozoic** eon (2.5 billion—545 million years ago). Protozoans, aquatic plants and hard-shelled invertebrates (eg. corals) had appeared by the end of this eon.
- The current eon (**Phanerozoic**—545 million years ago to the present day) shows the continued evolution of animals, including vertebrates, and land plants.

The Phanerozoic eon is further divided into three **eras**. (The time before the Phanerozoic is often referred to as the **Precambrian**.) Some of the important events in these eras include:

- **Palaeozoic era** (545–248 million years ago)—This era began with a period of rapid evolution; fish are the dominant vertebrates; amphibians and then reptiles evolve; land plants (mosses, ferns and the earliest conifers) appear; largest mass extinction of marine invertebrates ends the era.
- **Mesozoic era** (248–65 million years ago)—Reptiles continue to evolve; dinosaurs appear and become extinct by the end of the Mesozoic; birds appear and the earliest mammals appear near the end of the era; large land plants such as conifers appear; flowering plants start to appear.
- **Cenozoic (or Cainozoic) era** (65–0 million years ago)—Modern mammals

Eon	Era	Period	Fauna	Flora
Phanerozoic	0 Cenozoic (Cainozoic) 65	0 Time is divided into 7 epochs 65	↑ - Humans appear 2 million years ago - Mammals increase in size - Mammals diversity - Birds diversify	↑ - Modern flora - Forests develop - Grasslands - Flowering plants diversify
	Mesozoic	Cretaceous 146	- Dinosaurs flourish - Major extinctions at end of Cretaceous (including dinosaurs)	- First flowering plants (magnolias/palms)
		Jurassic 208	- Dinosaurs dominate - First birds	- Conifers and ferns dominate
	248	Triassic 248	- Many reptiles - First dinosaurs - First mammals	- Conifers - Cycads
	Palaeozoic	Permian 280	- Amphibians and reptiles are dominant	- Cone trees dominant
		Carboniferous 360	- Giant insects - Amphibians - Early reptiles	- Large tree ferns - Increasing cone plants
		Devonian 408	- Fish flourish - Insects	- First ferns - First seed-bearing plants
		Silurian 438	- Jawed fish - Freshwater fish	- First vascular plants
		Ordovician 500	- Primitive fish - Molluscs - Corals	- Red/green algae - First land plants (mosses)
545	545	Cambrian 545	- Many marine invertebrates - Trilobites and arthropods	Algae No land plants
Proterozoic 2500	Precambrian	—	- Soft-bodied invertebrates (jellyfish, worms) - Algae in the oceans	
Archaean 3800		—	- Life forms appear in the fossil record - Simple cellular organisms including archaea, bacteria, cyanobacteria	
Hadean 4600		—	No life—Earth too hot	

(Dates in MyBP = million years before present day)

Figure 4.21 Geological time scale and major life forms

appear; flowering plants dominate the land; humans appear about 2 million years ago.

These eras are further subdivided into small sub-units called **periods**. The Cenozoic is now divided into **seven epochs** rather than two periods.

Appearance and extinction of life forms

The abundance of life forms has varied throughout geological time. This information can be displayed using a graph. **Abundance** is shown by the **thickness of the band** for each organism. The thicker the band the more abundant is the organism. When the thickness drops to zero the organism has become **extinct**.

Example

Trilobites are invertebrates (crawling and swimming arthropods) that thrived in shallow seas in the Palaeozoic era. They first appeared in the fossil record about 545 million years ago and became extinct about 245 million years ago. Their appearance in the fossil record is often used to signal the start of the Palaeozoic era. Their period of greatest abundance was in the first

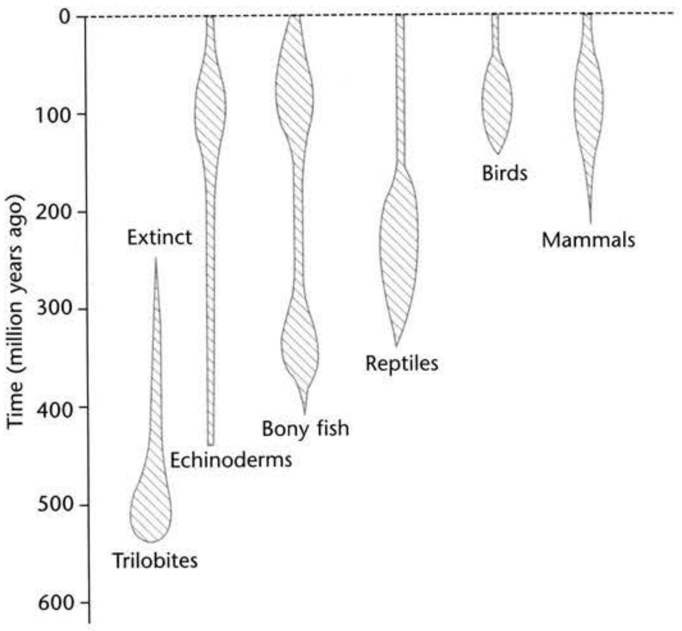


Figure 4.22 Abundance of selected invertebrates and vertebrates over geological time

40 million years of the Palaeozoic era. Their numbers then declined and they became extinct near the close of the Palaeozoic.

Plate tectonics and continental drift

The lithosphere is the outer rigid shell of Earth. It is between 50 and 100 km thick and includes the crust and the rigid upper mantle. The lithosphere is composed of about twelve rigid blocks or **plates**. Geologists suggest that these plates move in response to the combined effects of **convection currents** in the hot, partly molten region of the upper mantle (called the **asthenosphere**) that lies below the plates, and **gravitational forces** that help to pull heavy plate edges downward at subduction zones. **Plate tectonics** is the study of the forces leading to plate movement. Figure 4.23 shows these convection currents in the mantle below a mid-ocean ridge.

Plate interactions

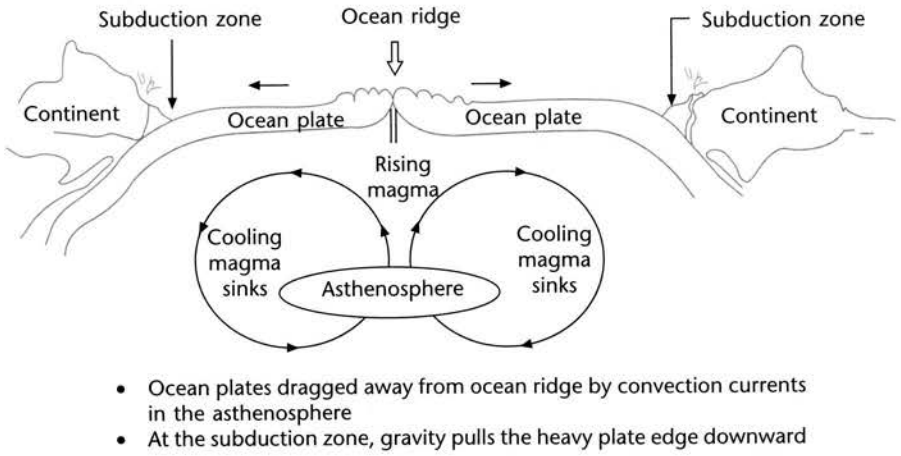
The motion of plates can explain many natural events such as earthquakes and volcanoes. There are four ways in which the edges of plates can interact.

Collision zones

Continental plates can push into each other and this leads to the formation of **mountain ranges**. The Himalayas are formed as the Australian–Indian plate and the Eurasian plate collide. The mountains are rising at 8 cm per year as the land becomes folded upward due to the immense forces of the colliding plates.

Subduction zones

An ocean plate collides and slides underneath a continental plate at the edge of a continent. This is called a subduction zone. This movement is believed to be due to the combined action of convection currents and gravity pulling the plate edges downward into the mantle. Such a zone occurs at the deep ocean trench along the



- Ocean plates dragged away from ocean ridge by convection currents in the asthenosphere
- At the subduction zone, gravity pulls the heavy plate edge downward

Figure 4.23 Convection currents below a mid-ocean ridge west coast of South America. **Mountain building, volcanic activity** and **earthquakes** can result.

Collision zones and subduction zones are examples of **convergent or destructive plate boundaries.** Oceanic crust is dragged down into the mantle at these sites.

Spreading zones

Spreading zones produce **mid-ocean ridges and rift valleys.** This is a site where two plates are moving apart. Such zones are also called **divergent plate boundaries**. Molten rock rises to the surface along these zones and new sea bed and chains of volcanoes form. The mid-Atlantic trench is an example of a spreading zone. Iceland is a volcanic island formed across this zone.

Transform fault zones

Plates can slide past each other along fault lines. The San Andreas fault in California is a transform fault line in which the south-moving Pacific plate slides past the north-moving North American plate. Many **earthquakes** have occurred along this fault line.

Figure 4.24 shows examples of these plate interactions.

Continental drift over geological time

Because of the motion of Earth's plates, the locations of the continents have changed over geological time. This is known as **continental drift.** Figure 4.25 shows the locations of the continents during two key times in the past. The giant continent Pangaea broke up into Laurasia in the north and Gondwanaland in the south. Australia was part of this great southern super-continent. Similar fossils collected at the edges of continents that were once joined

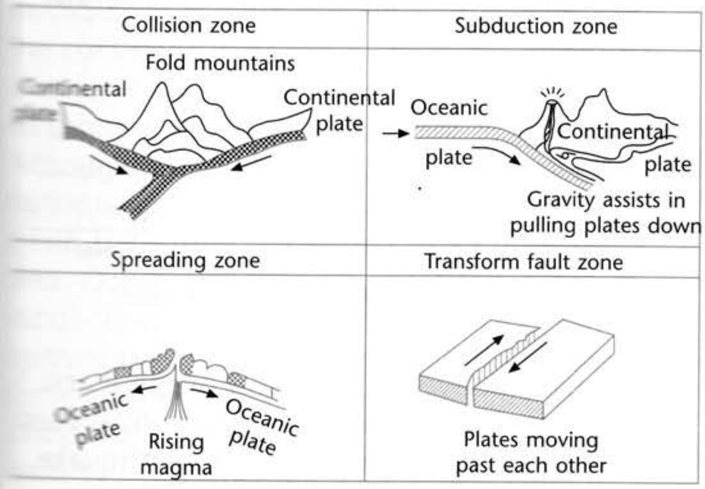


Figure 4.24 Plate interactions

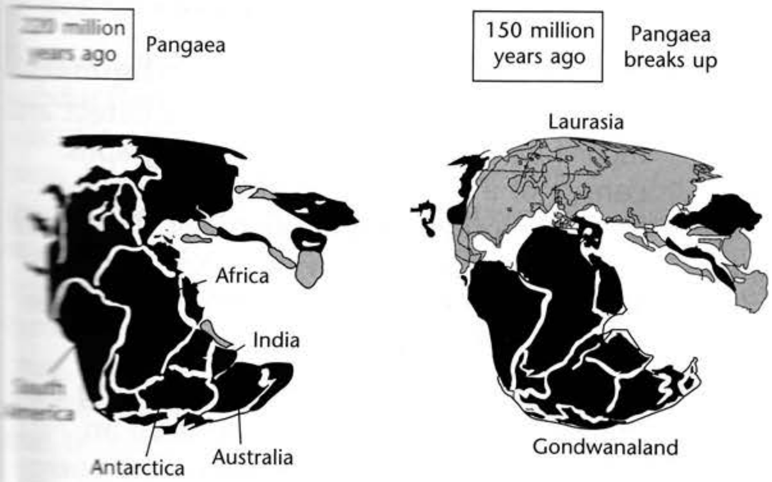


Figure 4.25 Location of the continents as Pangaea breaks up into Laurasia and Gondwanaland

provide further evidence for continental drift. The breaking apart and formation of new landmasses is related to the evolution of new species. When continents are separated, organisms are isolated and natural selection and gene mutation can lead to the emergence of new species.

Earthquakes and vulcanism

Seismology is the study of earthquakes.

Earthquakes occur at the four zones of interaction between tectonic plates.

- **Collision zone earthquakes**—Shallow earthquakes occur due to the intense compression of the colliding continental masses. Some deep-focus earthquakes are also produced in the Himalayas.
- **Subduction zone earthquakes**—These can occur at various depths and lead to various-strength earthquakes, mountain building and volcanic activity.
- **Spreading zone earthquakes**—The activity is low here and occurs at shallow depths as the lithosphere is very thin in these locations. Volcanic activity is found at these locations.
- **Transform fault zone earthquakes**—These occur at shallow depths but no volcanic activity occurs. Huge stresses build up which are released by sudden plate movements, leading to devastating earthquakes such as those in Turkey and California.

Earthquake waves

Earthquakes occur at various depths underground. The site of the earthquake is called the **focus**. The **epicentre** is a point on Earth's surface immediately above the focus.

Seismic (earthquake) waves can be classified into three groups.

- **Primary (P) waves**—These **push** waves are compression waves that can travel through solids, liquids or gases. These waves travel quite fast through Earth. As they pass through different materials the waves bend or refract.
- **Secondary (S) waves**—These transverse **shear** waves travel through the solid Earth but not through liquids or gases. Consequently they do not penetrate the outer molten core of Earth. Shear waves cause rock particles to oscillate at right angles to the direction of movement of the wave. These S waves travel more slowly and arrive at a given seismographic recording station later than P waves.
- **Land surface (L) waves**—These waves (which originate at the **epicentre** of the earthquake on Earth's surface) travel along the surface and cause the **greatest damage**. They are the slowest of all seismic waves.

Figure 4.26 shows **a seismogram**. This recording shows the three types of seismic waves.

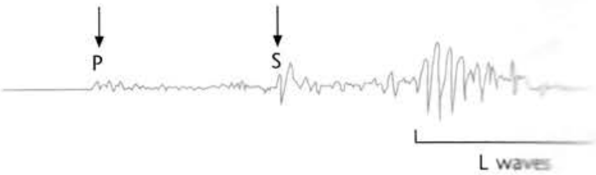


Figure 4.26 Seismogram showing types of waves

The time between the arrival of the P and S waves at different recording stations is used to measure the location of the earthquake. **The longer the time difference the further away is the earthquake**.

Measuring the energy of earthquakes

Seismographs are machines that detect and record earthquake waves. Seismographs consist of a seismometer that detects the ground motion, and an amplifier. The arrival time of the various waves is also recorded. The display of waves on a computer screen or on paper is called a seismogram.

The most common scale for measuring the magnitude or energy released from an earthquake is the **Richter scale.** The energy released is related to the amplitude of the seismic waves. The Richter scale is not a linear scale. A change of one unit on the scale represents about a **thirty-one** times change in energy released by an earthquake. Thus an earthquake of magnitude 7 releases about thirty-one times more energy than one of magnitude 6. The largest known earthquake had a magnitude of 8.9. The Richter scale does not measure damage because large earthquakes that happen in isolated areas cause little damage.

Earthquake	Richter magnitude
minor	0–3.9
light–moderate	4–5.9
strong	6–6.9
major	7–7.9
great	>8

Earthquakes are not common in Australia as the continent does not lie near the edge of a tectonic plate. The 1989 Newcastle earthquake had a magnitude of 5.5. Although it was classified as a moderate earthquake, it caused much damage and death because it happened in a populated area. Ocean trenches associated with subduction zones are common places where earthquakes occur. Earthquakes are much more common in New Zealand since these islands lie over the Pacific plate and the Indian-Australian plate subduction zone.

Types of volcanic activity

Tectonic activity at **spreading zones** and **subduction zones** is associated with volcanic activity. Volcanic activity also occurs away from the plate boundaries at **hot spots** or **volcanic plumes**. The Hawaiian Islands have formed from magma released from a hot spot that moved upward through cracks and faults to penetrate the crust. A hot spot under the Newcastle area is believed to have produced the stresses that triggered the 1989 earthquake.

Volcanic activity results when **magma, gases** and/or **ash** are released onto Earth's surface from chambers of magma deep underground. Once the magma is discharged onto the surface it is called **lava.**

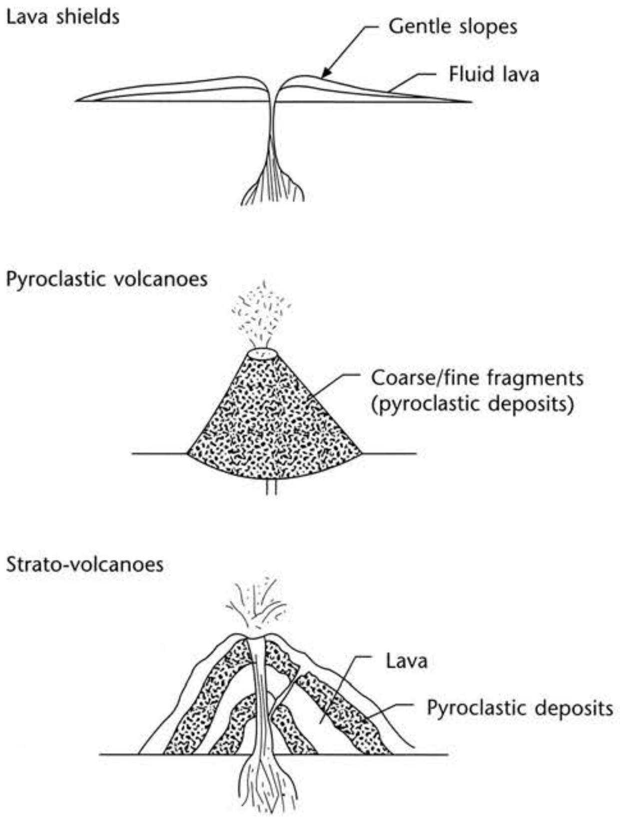
Volcanoes vary in size, shape and composition.

Additional content

The following information is provided as *additional content* for students interested in volcanoes.

- **Lava shields**—These volcanoes are very wide and have very gentle slopes. They are formed by incandescent outpourings of very fluid (basaltic) lava from fissures. The Hawaiian Islands are examples of lava shields. Convex shaped **lava domes** may also occur within the shield.
- **Pyroclastic volcanoes**—These volcanoes explosively produce coarse and fine fragments of lava called scoria or tuff that build up around the vent, forming straight or gently concave slopes.
- **Strato-volcanoes**—These cones are built up by layers of lava flows and pyroclastic deposits. Mt Vesuvius and Mt Fuji are examples of this type. **Composite** volcanoes are like strato-volcanoes except that the lava and the pyroclastic deposits tend to be mixed up.

The most violent volcanic eruptions involve the explosive ejection of viscous lava. The Mt St Helens eruption of 1980 in western USA and the Mt Pinatubo eruption in 1991 in the Philippines are examples of this type. Ash and glowing volcanic gases were released with extreme explosive force from these strato-volcanoes. In the Mt St Helens eruption, a rising magma plug caused the production of superheated steam in overlying groundwater. The hydrothermal blast tore the side of the mountain away. Rising magma then suddenly degassed, producing an ejection of pyroclastic material. Solidifying magma eventually closed the vent.


Lava shields

Pyroclastic volcanoes

Strato-volcanoes

Figure 4.27 Types of volcanic structures

Impact of natural events on the spheres of Earth

Natural events have impacts on the environment in which we live. Our environment includes the atmosphere, hydrosphere, lithosphere and biosphere. Examples of the effects of natural events on these spheres are given below.

Atmosphere (the gaseous sphere around Earth)

The atmosphere is affected by many natural events including:

- release of **poisonous gases** (eg. sulfur dioxide) and **volcanic dust** from **volcanoes**. Dust clouds from volcanoes can block sunlight and cause atmospheric cooling;
- release of **greenhouse gases** (eg. methane) from decaying vegetation;
- release of smoke and gases from **bushfires**. Extensive fires can reduce the air quality for humans;
- **lightning**, which generates nitrogen oxides that produce acidic rain;
- **dust storms** that pollute the air and make it difficult to breathe;
- **cyclones** (atmospheric storms) that damage the natural and built environment.

Hydrosphere (the sphere in which water is located around Earth)

The hydrosphere is affected by many natural events.

- **Lava** released from mid-ocean ridges and fissures increases the concentration of minerals in sea water and thermal lakes.
- **Acid rain** produced from volcanic eruptions can produce acidic lakes and streams.
- Erosion of the land during **floods** causes more minerals and sediments to enter rivers, lakes and seas.
- Earthquakes can produce **tsunamis**.

Lithosphere (the sphere in which rocky material is found around Earth)

The lithosphere is affected by many natural events.

- **Earthquakes** cause sudden earth movements leading to the formation of new landforms.
- **Vulcanism** produces new landforms.
- **Avalanches** lead to new landforms by depositing rocks and scraping out valleys.
- **Erosion of rocks by running water** releases valuable minerals to make the soil fertile.

- **Glaciers** erode rocks to produce new landforms.

Biosphere (the sphere in which life forms are found around Earth)

The biosphere is affected by many natural events.

- **Volcanoes** release poisonous gases and eject pyroclastic materials that kill living things.
- **Earthquakes** can kill living things that live in these zones.
- **Cyclones** can destroy the habitats of living things and cause the deaths of those that live there.
- **Bushfires** destroy living things, their habitats and food supply.

Test yourself (answers on pages 223–4)

Part A. Knowledge (answers on page 223)

1 A limestone layer was discovered during a geological expedition. The layer contained numerous coral fossils. The sediments that formed this layer were originally deposited in a:

- a fast-flowing mountain stream.
- b freshwater lagoon.
- c swamp.
- d warm, shallow sea. (1 mark)

2 A dinosaur footprint in an exposed shale layer is an example of what type of fossil?

- a Trace fossil
- b Petrified fossil
- c Cast
- d Carbonised impression (1 mark)

3 Select the correct response concerning the geological time scale.

- a The divisions of the scale are fixed and will never change.
- b Fossils did not appear in the geological record until the beginning of the Phanerozoic eon.
- c Reptiles appeared in the fossil record during the Palaeozoic era.
- d The first mammals appear in the fossil record late in the Cenozoic era. (1 mark)

4 The volcanic activity and mountain building along the west coast of South America is an example of which type of plate tectonic activity?

- a A subduction zone
- b A spreading zone
- c A collision zone
- d A transform fault zone (1 mark)

5 An earthquake that registers 6.2 on the Richter scale would be described as:

- a major.
- b minor.
- c light.
- d strong. (1 mark)

6 Complete the following restricted-response questions using the appropriate word. (1 mark each part)

- a The law of superposition states that in a sequence of strata, the _____ layers of rock are on top.
- b Granite has very large crystals as the magma from which it formed cooled _____ deep inside Earth.
- c Tree trunks may form petrified fossils if the intercellular spaces become filled with _____.
- d Carbon-14 is a useful _____ that can be used to date carbonaceous fossils up to 60 000 years old.
- e Birds and mammals appeared in the fossil record near the end of the _____ era.

7 Use the code letters to match the terms or phrases in each column. (1 mark each part)

Column 1	Column 2
a asthenosphere	f transform fault line
b spreading zone	g convection currents
c San Andreas fault	h shear wave
d primary waves	i divergent plate boundary
e secondary waves	j push waves

8 Distinguish between the focus and epicentre of an earthquake. (2 marks)

9 Explain why lava shield volcanoes are very wide with gentle slopes, whereas strato-volcanoes are steep-sided cones. (2 marks)

10 Describe three natural events that lead to changes in the atmosphere of Earth. (3 marks)

Part B. Skills (answers on pages 223–4)

1 Figure 4.28 shows a section through sedimentary strata. Use the diagram to list the strata from youngest to oldest. (3 marks)

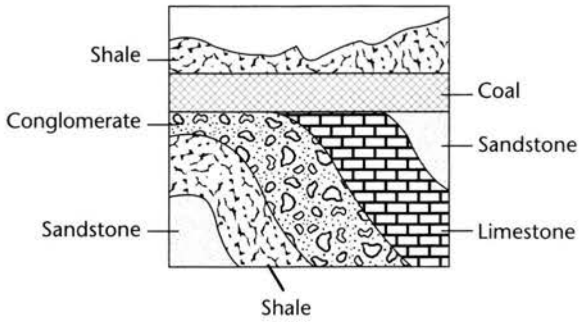


Figure 4.28 Sedimentary strata

2 Figure 4.29 shows a geological cross-section exposed by a road cutting. Write the geological history of this section. (4 marks)

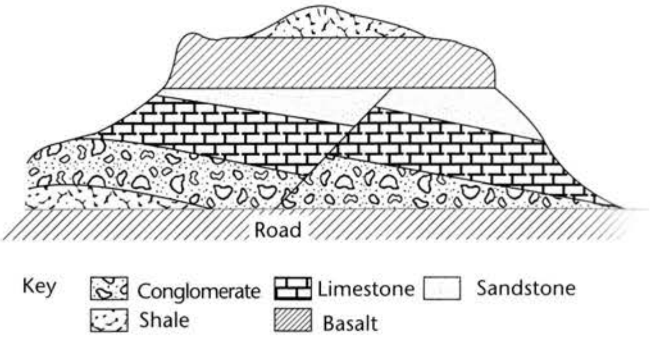
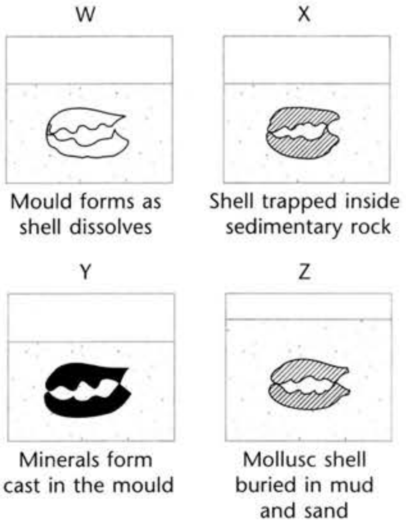


Figure 4.29 Road cutting

3 Figure 4.30 shows the jumbled steps in the formation of a fossil cast of a mollusc shell. Use the code letters to place the steps in their correct order. (2 marks)



W: Mould forms as shell dissolves

X: Shell trapped inside sedimentary rock

Y: Minerals form cast in the mould

Z: Mollusc shell buried in mud and sand

Figure 4.30 Jumbled steps in the formation of a fossil cast

4 Figure 4.31 shows various sedimentary strata containing fossils. Two lava flows are also shown. The age of these flows was determined radiometrically.

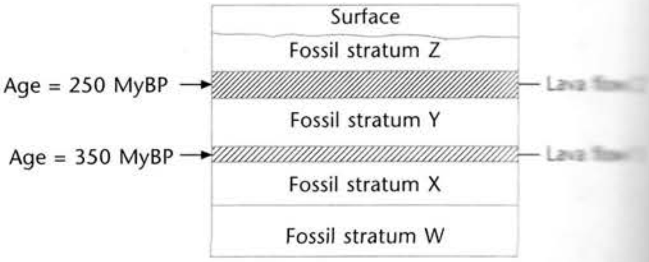


Figure 4.31 Fossilised strata and lava flows

a Name the geological era in which the sedimentary stratum (Y) between the lava flows formed. (1 mark) b Which of the listed fossils would not be found in the sedimentary stratum (Y) between the lava flows formed? (1 mark)

List: coral; fish; algae; bird; trilobite; flowering plant

c Which fossil in the above list could be found in layer W but not in layer Z? (1 mark)

5 Figure 4.32 shows a drawing of a fossilised footprint. The real length of the footprint is 37 cm. What scale has been used in this drawing? (2 marks)

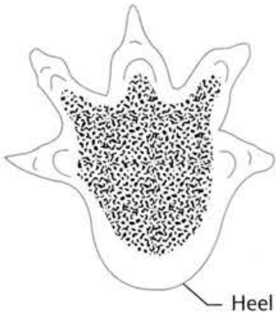


Figure 4.32 Scale diagram of fossilised footprint

6 Figure 4.33 shows plate boundaries between Australia and New Guinea, and Australia and Antarctica. The arrows show the direction of late movement.

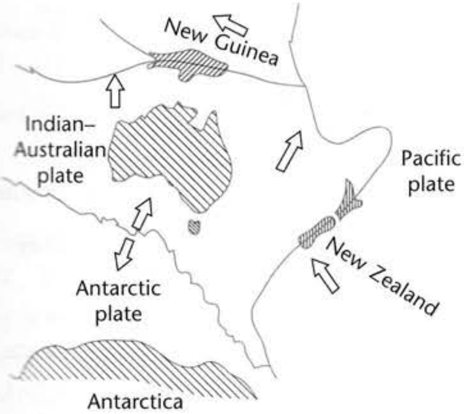


Figure 4.33 Plate boundaries between Australia, New Guinea and Antarctica

a What type of plate interaction between the Indian–Australian and Antarctic plate is shown in this diagram? (1 mark)

b The Australian plate is moving north at an average speed of 6 cm per year. How far will it move in 1 million years? (2 marks)

c Explain why there are high mountain ranges in central New Guinea. (1 mark)

7 Use the theory of plate tectonics to account for the following observations.

a The rim of the Pacific Ocean is called the Ring of Fire, owing to the large number of earthquakes and volcanoes located there. (1 mark)

b Flightless birds such as the ostrich, emu and rhea are found in Africa, Australia and South America respectively. (1 mark)

c The climate of the Sydney region has changed from cold and icy to warm and temperate over the last 135 million years. (1 mark)

d Earthquakes and volcanic activity are common in the Mediterranean area and Middle East. (1 mark)

8 At the time of its death a portion of the leg bone of a bird produced 960 units of radiation per minute due to its carbon-14 content.

a Given that the half-life of carbon-14 is 5730 years, determine the radiation count of the leg bone after it has been fossilised for four half-lives (ie. 22 920 years later). (2 marks)

b Why is the carbon-14 method useful only for determining the age of very recent carbonaceous fossils? (2 marks)

9 Figure 4.34 shows the earthquake waves recorded at Sydney, Brisbane and Perth.

a Which city is

i closest

ii furthest, from the epicentre of the earthquake? (2 marks)

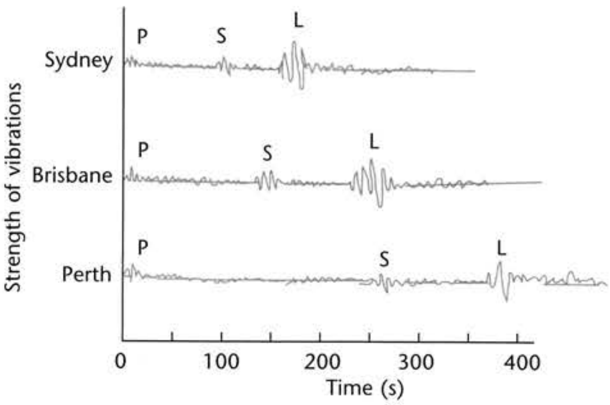


Figure 4.34 Earthquake waves recorded at Sydney, Brisbane and Perth

b The earthquake's epicentre was at one of the following locations. Which one? Justify your answer. (2 marks)

Possible locations: New Guinea (highlands); New Zealand (south island); Japan

End-chapter test (answers on pages 224–5)

1 Read the following information about the formation of the Australian continent from the break-up of Gondwanaland.

a Convert this information into a bar graph by plotting time along the horizontal axis. (3 marks)

(MYBP = million years before the present)

180 MYBP—Gondwanaland (Africa, South America, Australia, India and Antarctica) separates from Laurasia. This break-up is complete by 135 MYBP.

135 MYBP—Gondwanaland begins to break up with Antarctica–Australia–India moving away from the rest of Gondwanaland.

120 MYBP—India separates from Antarctica–Australia.

105 MYBP—South America and Africa separate.

80 MYBP—Australia moves apart from Antarctica.

b In which geological era did the events described above occur? (1 mark)

2 Figure 4.35 shows three geological cores from different areas (X, Y and Z). Some of the sedimentary strata contain fossils. Assuming that the layers with the same fossils are of the same age, determine which core has the most recent fossil. (2 marks)

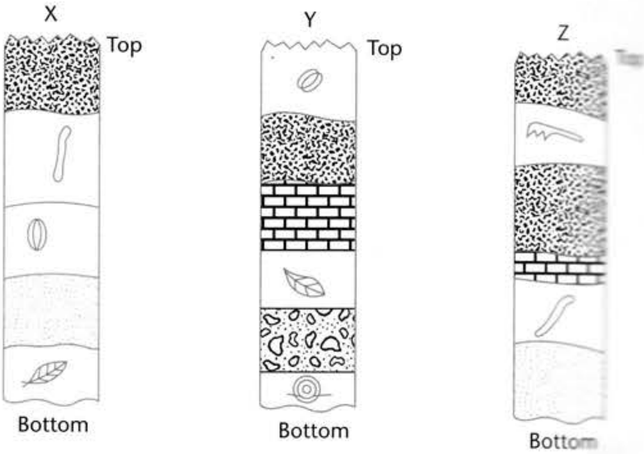


Figure 4.35 Core sections X, Y and Z

3 Figure 4.36 shows a geological cross-section involving dolerite intruding into various sedimentary strata.

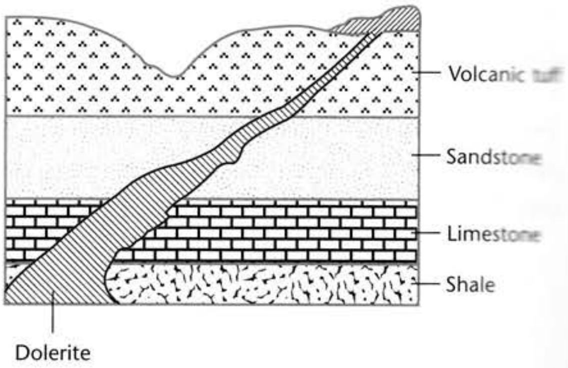


Figure 4.36 Dolerite intrusion in sedimentary strata

a Name the type of igneous structure shown. (1 mark)

b List the rocks in order from oldest to youngest. (2 marks)

c Describe the effect of the intruding magma on the surrounding sedimentary rocks. (1 mark) d Compare the crystal size in the dolerite intrusion to the lava that flowed as an extrusion onto Earth's surface. (1 mark)

4 a Explain how a volcano is formed at a subduction zone. (2 marks)

b Name two locations in the Pacific rim where volcanic activity is due to plate movement at a subduction zone. (2 marks)

5 The potassium–argon method is commonly used to date volcanic rocks and minerals that are millions of years old. Zircons, for example, contain potassium-40.

The potassium-40 decays to argon-40. The half-life of potassium-40 is 1.3 billion years.

a A zircon was formed 3.9 billion years ago. Draw a graph of the amount of K-40 remaining as a function of time. Label the axes. (3 marks)

b Draw a graph of the amount of Ar-40 formed as a function of time. (2 marks)

c In which geological eon was the zircon formed? (1 mark)

d In which geological eon did the amount of K-40 remaining equal 20% of the original amount? (1 mark)

6 Figure 4.37 shows three seismograms (X, Y and Z) of an earthquake with an epicentre in New Zealand. The seismograms were recorded in Melbourne, Adelaide and Perth. Determine which seismogram was recorded in each city. (2 marks)

7 Describe, using examples, the impact of earthquake and volcanic activity on the:

a lithosphere (2 marks)

b hydrosphere (2 marks)

c atmosphere (2 marks)

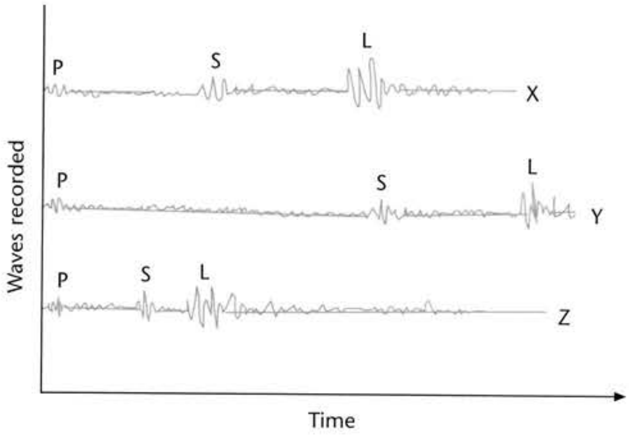


Figure 4.37 Seismograms X, Y and Z

8 Figure 4.38 shows geological activity at a zone between two oceanic plates.

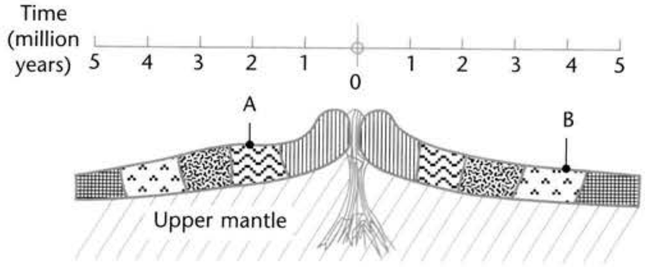


Figure 4.38 Geological activity at a plate boundary

a Name the type of plate tectonic activity shown. (1 mark)

b Use the scale to determine the age of the rocks at points A and B on the diagram. (2 marks)

c Explain why the rocks (A and B) have different ages. (1 mark)

d In which layer of Earth are the convection currents causing crustal movement found? (1 mark)

e If new crust is forming at these zones, why doesn't the crust of Earth expand? (1 mark)

9 Figure 4.39 shows a map of Gondwanaland before it split apart.

Fossils of *Mesosaurus*, a freshwater reptile, were found at the locations marked on the map of Gondwanaland.

Explain why the fossils are not found in

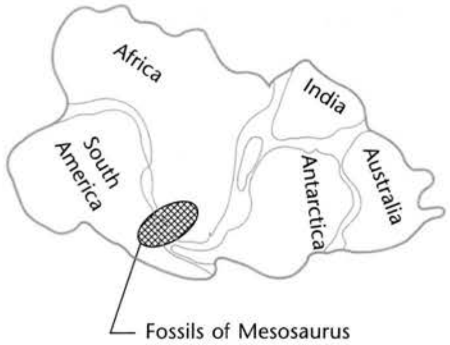


Figure 4.39 Map of Gondwanaland

India, Australia and Antarctica. (2 marks)

10 Match the fossils listed in column 1 to the past environments listed in column 2. (4 marks)

Column 1	Column 2
a coral	e swamp
b fish	f warm, shallow sea
c ferns	g rivers and seas
d coal plant fossils	h warm terrestrial

Summary

The Big Bang theory and components of the universe

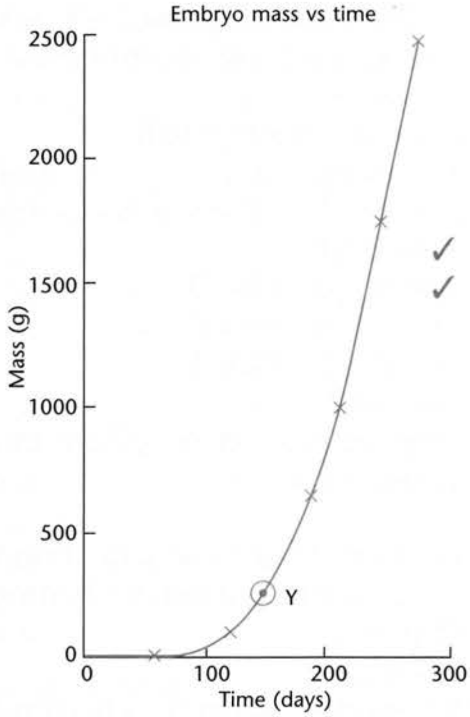
- Astronomical measurements show that the universe is expanding.
- The Big Bang theory is the currently accepted theory for the origin of the universe. According to this theory the universe began in a giant explosion in which space and time came into existence about 12–13 billion years ago.
- Various bands of the electromagnetic spectrum can be used in astronomy to investigate the universe.
- Ground-based telescopes are affected by the atmosphere as well as radio and light pollution from cities.
- Distances in space are so large that they are measured in light years.
- Stars like the Sun form as hydrogen gas and interstellar dust condense and heat up until nuclear fusion begins.
- Stars that have a similar mass to the Sun will evolve into red giants before they eject material to form a planetary nebula. The remaining core is a white hot dwarf star that fades as it cools.
- Large stars evolve into red supergiants before they explode to form a supernova. A neutron star or black hole remains.

Natural events

- The law of superposition states that in a sequence of sedimentary strata the oldest layer is on the bottom and the youngest layer is on the top.
- Igneous activity and metamorphism can influence the geological history of an area.
- Fossils are the remains or impressions of living organisms from the past.
- Fossils include whole organisms that remain almost unchanged; unaltered hard parts; altered hard parts; trace fossils.
- In a sequence of sedimentary strata the simplest fossils are found in the deepest layers.
- Radioactive dating can be used to determine the age of rocks and fossils.
- The geological time scale divides the 4.5 billion years of Earth's history into large and small divisions called eons, eras and periods.
- The lithosphere is broken up into twelve plates that move due to convection currents in the asthenosphere.
- Plates interact in four main ways:

collision zones; subduction zones; spreading zones; transform fault zones.

- Movement of tectonic plates has led to the breaking up and re-forming of Earth's continents.
- Earthquakes and volcanic activity are usually associated with interactions at plate boundaries.
- Earthquake wave analysis can be used to determine the location of earthquakes.
- The Richter scale is used to measure the energy released by an earthquake.
- Natural events such as cyclones, earthquakes and volcanic activity can affect the hydrosphere, atmosphere, lithosphere and biosphere.



✓
✓

X = 37 cm; Y = 250 g

b i about 130 days (from graph); ✓
ii about 230 days (from graph) ✓

c Uterus (womb) ✓ (7 marks)

10 Many keys can be correct.
Example:

1a Microbe is less than 50 micrometres in size and its body is surrounded by a protein coat...D.
1b Microbe is larger than 50 micrometres in size ....go to 2.
2a Microbe is green and produces spores ...B.
2b Microbe is not green and does not produce spores ...go to 3.
3a Microbe has flagella ...A.
3b Microbe does not have flagella ...C.
(7 marks)

Chapter 4

The Big Bang theory and components of the universe pages 118–21

Part A. Knowledge pages 118–19

1 **c** Einstein developed the equation that links mass and energy ($E = mc^2$). ✓

2 **b** Light is red shifted if the source of light is moving away from the observer on Earth. ✓

3 **b** Infrared rays cause a rise in temperature when absorbed by matter. ✓

4 **a** Molecules in the atmosphere absorb UV and IR. Scientists must use telescopes outside the atmosphere to observe these types of rays from distant sources. ✓

5 **c** The Milky Way is a spiral galaxy with a diameter of about 100 000 ly. It is not a supernova. ✓ (5 marks)

6 a radio ✓
b hydrogen ✓
c supernova ✓
d distance ✓
e expand ✓ (5 marks)

7 a/j ✓; b/i ✓; c/g ✓; d/f ✓; e/h ✓ (5 marks)

8 Stars generate energy by nuclear fusion. Hydrogen nuclei fuse together to form helium with the release of considerable amounts of energy. In very large stars, helium can fuse to form heavier elements such as carbon and oxygen with further release of energy. ✓✓ (2 marks)

9 Red shift of stars: The spectrum of light from stars and galaxies shows red-shifting. This is interpreted as evidence for these sources moving away from us and from each other.

Cosmic background radiation: The microwave background radiation in space shows that space has cooled to 3 degrees above zero. This is interpreted as evidence of the cooling and expanding of an initially very hot universe after the big bang to its current cold state. ✓✓ (2 marks)

10 As more helium is formed by nuclear fusion, it sinks to the core of the sun and the outer hydrogen shell swells and increases in brightness. The star cools and becomes a red giant. Helium fusion begins to produce heavier elements. When the nuclear fuel runs out, the core shrinks and outer layers are ejected as a planetary nebula. A hot white core (white dwarf) remains. Over billions of years it cools to form a black dwarf. ✓✓✓ (3 marks)

Part B. Skills pages 119–21

1 a i Sun–Venus = (0.7)(150) = 105 million kilometres ✓
ii Sun–Saturn = (9.5)(150) = 1425 million kilometres ✓
b Sun–Pluto distance = 5590/150 = 37.3 AU ✓✓ (4 marks)

2 a Distance = (7.7)(9461) = 72 849.7 billion kilometres ✓
b Distance = (353)(9461) = 3 339 733 billion kilometres ✓ (2 marks)

3 a No. Cluster refers to the organisation of local galaxies. These stars are all in one galaxy (the Milky Way). They are a constellation, because they appear to be together in the sky. ✓✓
b i Alpha Crucis ✓
ii Although Beta Crucis is brighter in absolute terms, it appears dimmer, as it is further from Earth. ✓ (4 marks)

4 a ~30 000 light years ✓
b ~100 000 light years ✓ (2 marks)

5 X, Z, W, Y ✓✓ (2 marks)

6 Angle = 60° (= one sixth of one complete revolution).
Time for one complete revolution = 6 × 35 = 210 million years. ✓✓ (2 marks)

7 a $T = 3\,000\,000/510 = 5882$ K ✓✓
b $T = 5882 - 273 = 5609$°C ✓
c Wavelength = $3\,000\,000/T$ = $3\,000\,000/4300 = 697.7$ nm = 698 nm (red end of visible spectrum). ✓ (5 marks)

8 a Dimmer ✓
b Greater brightness and greater surface temperature than the sun ✓✓
c i Brighter; ✓ ii colder ✓
d It will become cooler and dimmer. ✓✓
e It will form a less bright white dwarf. Then it will slowly cool to form a black dwarf (not shown on diagram). ✓ (5 marks)

Mid-chapter test pages 121–3

1 Very small stars have very long lives. After using up all their hydrogen and converting it to helium, they cool and darken to form a black dwarf. ✓✓ (2 marks)

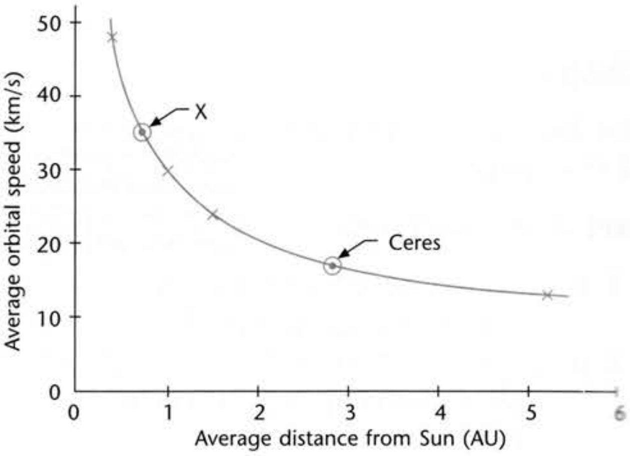
2 a X-rays, gamma rays and UV (some IR) ✓
b visible; near IR; microwaves; radio waves ✓
c visible astronomy; radio astronomy ✓✓ (2 marks)

3 a position 3, as the star is moving away from Earth ✓
b Line X = position 3 ✓
Line Y = position 2 ✓
Line Z = position 1 ✓
c position 1 ✓
d They are moving away from us as the universe expands. ✓ (6 marks)

4 a two ✓
b Heavy hydrogen has a neutron in its nucleus, whereas normal hydrogen does not. ✓
c A = 3 ✓
d helium-3 + helium-3 → helium-4 + hydrogen-1 + hydrogen-1 + γ-rays ✓✓
e gamma rays ✓ (6 marks)

5 Brightness: The brightness remains very high although there are small rises and decreases along the evolutionary path. The star is brightest at the super-red-giant stage.
Surface temperature: The surface temperature decreases as the blue giant evolves to form a red super giant. The temperature increases once more as the star moves back to the left on the evolutionary path. ✓✓ (2 marks)

6 a As the average distance from the Sun increases, the orbital speed decreases. ✓✓
b



X = 35 km/s) ✓ ✓ ✓
c 17.5 km/s (= 18 km/s) ✓ ✓
d Saturn, as it is closer to the Sun ✓ (8 marks)

7 F; B; H; C; D; G; A; E (2 marks)

8 a true ✓
b true ✓
c false ✓
d false ✓
e true ✓
f true ✓
g false ✓
h true ✓
i false ✓
j true ✓ (10 marks)

Natural events pages 135–8

Part A. Knowledge pages 135–6

1 d Corals grow in shallow, warm seawater. ✓

2 a A footprint is only a trace. ✓

3 c Mammals appeared in the Mesozoic era and reptiles first appeared in the Palaeozoic. ✓

4 a The Pacific ocean plate dives down beneath the South American plate along that coast line. ✓

5 d Richter values between 6 and 7 are indicative of strong earthquakes. ✓ (5 marks)

6 a youngest ✓
b slowly ✓
c minerals ✓
d radioisotope ✓
e Palaeozoic ✓ (5 marks)

7 a/g ✓; b/i ✓; c/f ✓; d/j ✓; e/h ✓ (5 marks)

8 The focus of an earthquake is the location in the lithosphere where the earthquake has actually occurred. The epicentre is the point on Earth's surface directly above the focus. (2 marks)

9 Lava shield volcanoes are made from very fluid lava that flows out a great distance from the vent before freezing. Thus their sides are gently sloping. Strato-volcanoes are built from more viscous lava and cinders. They pile up around the vent because the lava freezes quickly. A steep-sided volcano results. (2 marks)

10 Various possible answers.
Decaying vegetation releases greenhouse gases such as methane into the atmosphere; this increases the ability of the atmosphere to retain heat.
Lightning storms generate nitrogen oxides that will form acid rain. ✓
Cyclones are formed in the atmosphere and cause considerable damage.
Volcanoes release gases (including poisonous gases) and ash into the atmosphere. ✓
Bushfires release gases and smoke into the atmosphere. ✓ (3 marks)

Part B. Skills pages 136–8

1 shale; coal; sandstone; limestone; conglomerate; shale; sandstone (3 marks)

2
1. Deposition of shale
2. Deposition of conglomerate
3. Deposition of limestone
4. Deposition of sandstone
5. Layers folded and faulted
6. Erosion to form a plain
7. Basaltic lava flows across a plain and solidifies to form basalt.
8. Deposition of shale
9. Erosion to current landscape

(4 marks)

3 Z; X; W; Y

4 a Palaeozoic ✓ (2 marks)
b bird; flowering plants – these did not appear until the Mesozoic era.
c trilobites—they became extinct in the late Palaeozoic. ✓ (3 marks)

5 Scale = 1 : 10 ✓ ✓ (2 marks)

6 a Spreading zone (divergent boundary) ✓
b 6 × 1 = 6 million centimetres = 60 km ✓ ✓
c There is a collision zone between the two plates. This leads to mountain building. ✓ (4 marks)

7 a The rim of the Pacific contains many plate boundaries (eg. subduction zones; transform fault zones). Earthquakes and volcanoes are produced due to these plate interactions. ✓

b These three continents were once joined as part of Gondwanaland. The ancestors of these birds were isolated when the continents split apart. They then evolved in isolation to their current forms. ✓

c Australia was once joined to Antarctica and the combined land mass occupied cold Antarctic latitudes. The continents then split apart and Australia moved north towards the equator. The climate became warmer and temperate. ✓

d The plate boundary between the African plate, Arabian plate and the Eurasian plate runs through this area. Consequently earthquakes and volcanic activity occur there. ✓ (2 marks)

8 a Count = $6.25/100 \times 960 = 60$ ✓ ✓

b The short half-life means that little radioactivity remains after 60 000 years. Thus, only recent fossils can be dated by this technique. ✓ ✓ (4 marks)

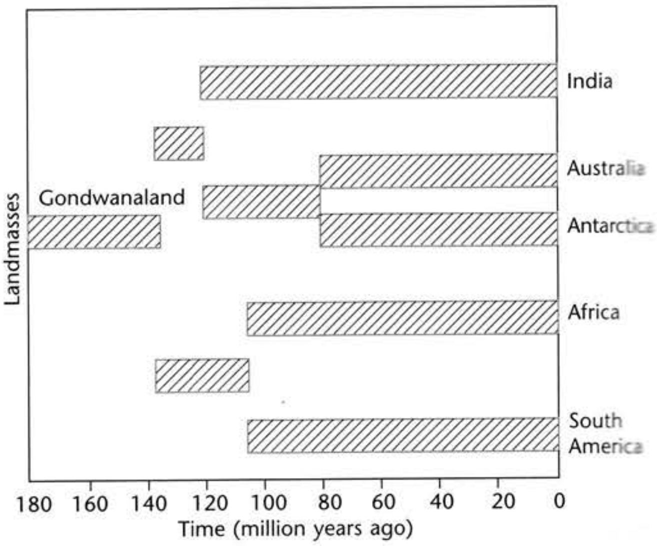
9 a i Sydney; ✓ ii Perth ✓

b New Zealand (south island). This location is closer to Sydney than Brisbane. Perth is much further away and the seismic waves take longer to reach the western side of Australia. If the earthquake had been in Japan, the P and S waves would have arrived at Sydney last. If the quake was in New Guinea then Brisbane would have recorded them first. ✓ ✓ (4 marks)

End-chapter test

pages 138–40

1 a ✓ ✓ ✓



b Mesozoic era ✓

2 Core Z has the most recent fossil. ✓ ✓ (2 marks)

3 a dyke ✓

b shale; limestone; sandstone; volcanic tuff; dolerite ✓ ✓

c Heat from the cooling magma will bake the surrounding rocks, leading to contact metamorphism. The sandstone will turn to quartzite, limestone to marble and shale to hornfels at the contact zone. ✓

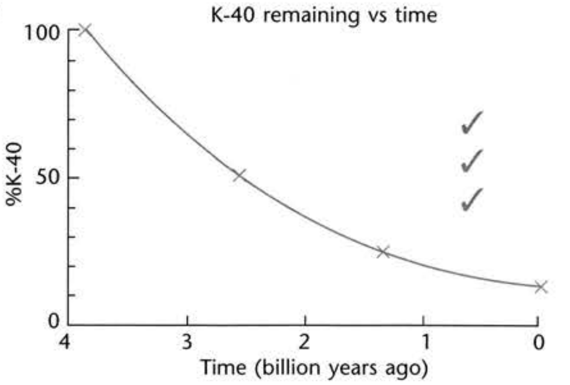
d The crystal size is much larger in the dyke than in the extrusion onto the surface. The slower the cooling of the magma the larger are the crystals that form. ✓ (5 marks)

4 a At a subduction zone an oceanic plate collides with a continental plate. Due to differing densities the oceanic plate moves down beneath the continental plate to form the subduction zone and ocean trench. Frictional heating occurs as the oceanic plate moves down towards the asthenosphere. Earthquakes

result from this frictional contact. Magma is also formed from the heating and it moves upward under pressure through faults. The release of the hot melted rock produces vulcanism. ✓✓

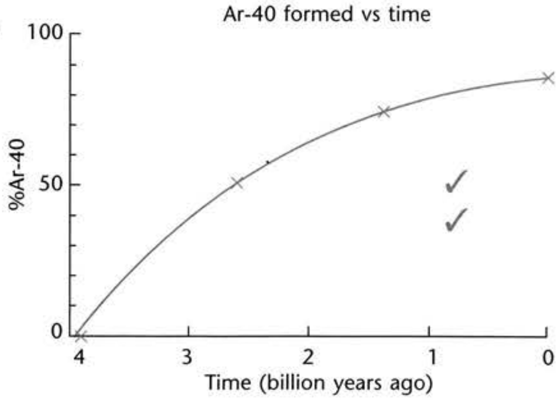
b West coast of South America where the Nazca plate collides with the South American plate; Japan where the Pacific and Philippine plates and the Eurasian plates collide. ✓✓ (4 marks)

5 a



✓
✓
✓

b



✓
✓

c Hadean eon ✓

d Proterozoic eon ✓ (7 marks)

6 X = Adelaide
Y = Perth
Z = Melbourne ✓✓ (2 marks)

7 a Lithosphere: Sudden earth movements can lead to the formation of rift valleys and block mountains. Avalanches may occur in mountainous areas. New volcanic landforms such as cinder cones, lava shields and volcanoes may be formed. ✓✓

b Hydrosphere: Earthquakes can lead to tsunamis; lava emerging from ocean vents can lead to mineralisation of the ocean. Volcanic gases can produce acidic rain. ✓✓

c Atmosphere: Volcanic ash and gases are released into the atmosphere. The ash can block sunlight and cause atmospheric cooling. ✓✓ (6 marks)

8 a Spreading zone (divergent plate boundary) ✓

b A = 2 million years old; B = 4 million years old ✓✓

c New oceanic crust is forming at the mid-ocean ridge. The closer the rock to the mid-ocean ridge the younger is the rock. ✓

d Asthenosphere ✓

e The old oceanic crust is removed and recycled at the subduction zones. This prevents Earth's crust from expanding. ✓ (6 marks)

9 India, Australia and Antarctica had already split away from the rest of Gondwanaland before the reptile colonised these areas. This split occurred 135 million years ago. Africa and South America remained as one land mass until 105 million years ago. ✓✓ (2 marks)

10 a/f; b/g; c/h; d/e

Chapter 5

Ecosystems pages 148–50

Part A. Knowledge pages 148–9

1 **c** Wind speed does not depend on living things. ✓

2 **c** Mangroves are trees that live in saline water along our coast. ✓

3 **a** Crabs scavenge for the remains of animal tissue that is left over after a carnivore has eaten. ✓

4 **b** Nitrogen is an important element in the manufacture of amino acids that are the building blocks of proteins. ✓