SCIENCE

Unit 4

Origins and Change over Time

Acknowledgements:

Editors: Marissa Rolnick, Tony Lelliott
Writers: Allistair Clacherty
Erna McCarthy
Helen de Wet
Jenny Woolway
Sharika Banwa
Artwork: Nelrie Pieterse
Layout: Lidia Kruger

Contents

Specific aims	Lesson 1 Objects in the night sky, how we learn about them and the solar system
Knowing science: Content	Learning about the stars, constellations and our solar system
Investigating science	Investigating the Universe and Solar System using specific instruments and machines (Activity 2)
Science in society	Looking at careers in astronomy and astronomical projects in South Africa; determining the difference between astrology and astronomy; exploring other planets; understanding the dangers of meteorite impact past and present
Science process skills	Observing objects in the night sky (Activity 1); conducting research and application (Activities 4, 5)
Language skills	Placing sentences in the correct order; comprehension (Activity 3)

Specific aims	Lesson 2 Beyond the Solar System: the origin of the universe and elements
Knowing science: Content	Learning about galaxies and black holes; the life cycle of stars; the birth of elements; formation of the Universe and Solar System
Investigating science	Classifying information (Activity 1); applying theory (Activities 1, 2, 3)
Science in society	Understanding the religious implications of the Big Bang Theory (Activity 3)
Science process skills	Classifying galaxies according to shape (Activity 1); Predicting the fate of the Universe (Activity 3)
Language skills	Comprehension, terminology

Specific aims	Lesson 3 The Geological Time Scale, Origin of the Earth, The Early Earth and Life
Knowing science: Content	Learning about the geological time scale; origin of the Earth; important events of Earth history in the Hadean, Achaean, and Proterozoic; origin of life; oxygen rich atmosphere; ozone layer
Investigating science	Plotting Earth History to scale (Activity 1); responding to data (Activity 2)
Science in society	Learning about the implication of important events in the Hadean, Achaean and Proterozoic for human society today; the religious implications of scientific hypotheses about the Origins of Life for religion
Science process skills	Identifying and extracting information (Activity 1)
Language skills	Writing summaries, comprehension and terminology

Specific aims	Lesson 4 Evolution of life during the Paleozoic, Mesozoic, and Cenozoic Eras
Knowing science: Content	Learning about important events of Earth History in the Paleozoic, Mesozoic, and Cenozoic
Investigating science	
Science in society	Understanding the implications of important events in the Paleozoic, Mesozoic and Cenozoic for human society today; relating knowledge of past climate change to our fears of climate change today
Science process skills	Identifying and extracting information
Language skills	Sequencing sentences and witting summaries, comprehension and terminology

Specific aims	Lesson 5 Human evolution, the formation and dating of fossils
Knowing science: Content	Learning about fossil evidence for human evolution from the Cradle of Humankind; relative and absolute dating of fossils and rocks; formation of fossils through the process of metrification
Investigating science	Visualizing geological time and large numbers; analysing decay curves; responding to data (Activities 1, 2)
Science in society	Learning about the importance of South Africa in the story of human evolution (Activity 1)
Science process skills	Interpreting simple geological sections; describing the process of fossilization; interpreting graphs and diagrams (Activity 2)
Language skills	Explaining processes; comprehension and terminology (Activity 3)

Specific aims	Lesson 6 Life of Darwin
Knowing science: Content	Reading about Darwin's life story and influences which led him to formulate his Theory of Evolution by Natural Selection
Investigating science	Determining evidence for Evolution from biogeography, fossils and rocks
Science in society	Reading about scientists and how society influenced their work; looking at different responses of religious people to the Theory of Evolution
Science process skills	
Language skills	Comprehension

Specific aims	Lesson 7 Natural Selection, Speciation, Evidence for evolution from a common ancestry, the movement of continents and the distribution of organisms
Knowing science: Content	Learning about artificial & natural selection; the pepper moth and resistance to pesticides and antibiotics as examples of natural selection; speciation in isolation, embryology, homologies and analogies; common genetic code; transitional fossils and vestigial organs as evidence for evolution; how the movement of continents has effected the distribution of organisms
Investigating science	Interpreting diagrams and maps (Activities 4, 5)
Science in society	Learning about natural selection and antibiotic and insecticide resistance (Activity 2)
Science process skills	Analysing distribution patterns and structures (Activities 4, 5)
Language skills	Comprehension, interpretation (Activities 2, 4, 5)

UNIT 4

Origins and Change over Time

Figure 1: The South African Large Telescope (SALT)

About this unit

At one time or the other we have all asked questions like:

- Where do humans come from?
- How did life begin?
- Where does the Earth come from?
- Where did the Universe come from?

These are questions which all the great religions have attempted to answer. In this unit you are going to learn about scientific explanations for the origins of the universe, of the Earth, and of life on Earth. Some of the topics that you will cover include the:

- origin of the Universe
- formation of our solar system and the early Earth
- early diversification of life
- invasion of land and beyond
- fossils and South Africa
- formation and dating of fossils
- origins of life
- theory of evolution by natural selection
- effect of Plate Tectonics on the distribution of organisms

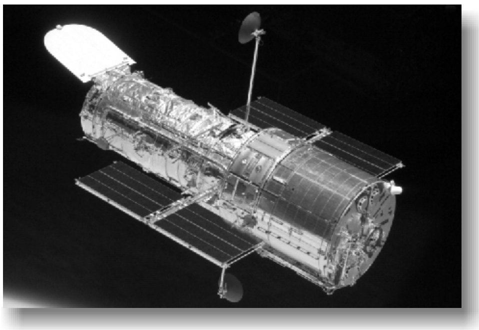


Figure 2: The Hubble Space Telescope

The Hubble Space Telescope is in orbit around the Earth where it can take the most detailed pictures of the universe without interference from the atmosphere, light pollution or dust.

LESSON 1

Objects in the night sky, how we learn about them and our solar system

About this lesson

In this lesson you will be introduced to the common objects that you can see in our night sky with the naked eye as well as some of the technology that scientists use to observe these and other objects in more detail.

For thousands of years people have identified shapes in patterns in the fixed stars. These are the constellations. Astrologers believe that there is great significance in what constellation was in the sky at the time you were born. Today scientists know that astrology should not be taken seriously and that the distant stars are balls of burning plasma where the elements form as the stars are born and die.

You will learn that while the eight planets follow their predictable orbits around the sun, there are less predictable objects in our solar system which could cause damage to our Earth. We need to manage them if we want to survive for any length of time.

In this lesson you will:

- identify and explain common objects in the night sky
- explore methods that scientists use to learn about the universe
- learn about astronomical projects set up in South Africa
- identify some of the constellations recognized by the ancients
- learn the difference between astrology and astronomy
- discover the properties and life cycle of stars
- learn more about our solar system
- learn about the characteristics of asteroids, meteorites and comets

Common objects in the night sky

Look up into the night sky, preferably somewhere far away from city lights, and you will see amazing and beautiful objects or heavenly bodies. The brightest of these is the **moon** (Figure 3) and in the background many thousands of **stars**. Some of the stars appear to be in the same position with regard to one another each night. These are called the **fixed stars** and they may form interesting patterns called **constellations** (Figure 4). Other stars appear to move about and are actually not stars at all. Instead, they are **planets** – named after the ancient Greek word for wanderer, because they appear to wander across the sky over a period of weeks and months. Usually the easiest planet to see is Venus which appears as a bright star in the sky in the evening or morning. You will also see a bright band across the sky called the **Milky Way** which looks like milk splashed over the heavens (Figure 7).

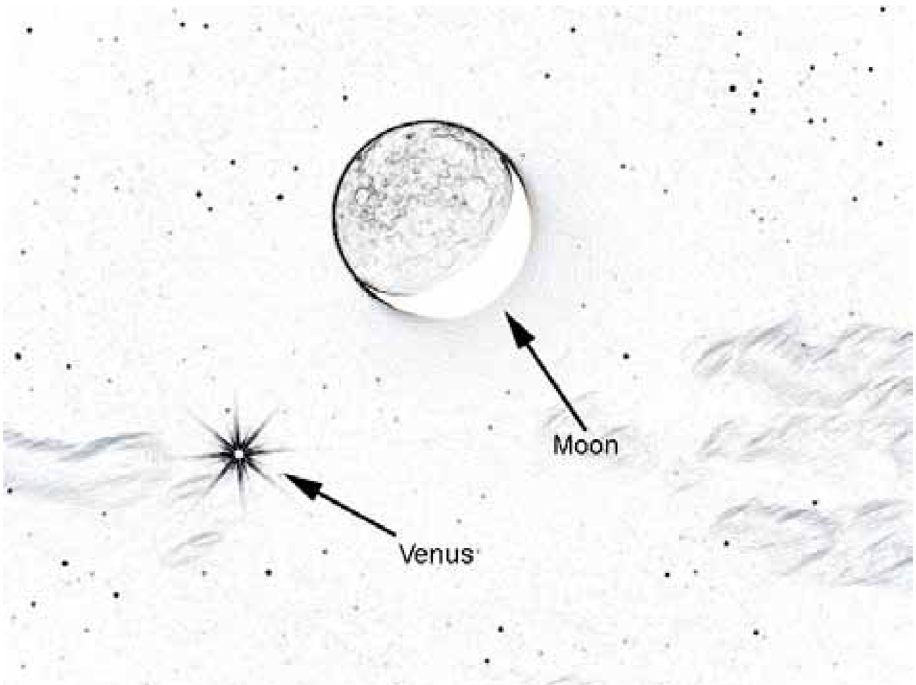


Figure 3: The Moon with a bright star which is really the planet Venus

Every now and again you will see a shooting star or **meteor** flash rapidly across the sky, and more rarely you will see a **comet** (Figure 5) which looks like a slow moving star with a tail.

astronaut:
a person who can pilot or serve as a crew member in a space craft
constellation:
a group of stars which form a pattern when seen from the Earth
fixed star:
a star that maintains the same position relative to other stars in the sky
galaxy:
many stars and their remains held together by gravity often in the shape of a spiral
milky Way:
the galaxy containing our Solar System and Earth
moon:
a natural satellite that orbits around a planet
planet:
a mass of solid, liquid and gas rotating around a star Earth is a good example
satellite:
an object, natural or artificial in orbit around a planet.
solar system:
the name given to a star (or sun) together with heavenly bodies that orbit around it. These include the planets and their moons, together with smaller bodies such as asteroids, meteoroids, and comets.
star:
a cloud of burning plasma like our sun

meteor:
a fragment (usually of rock) from outer space falling towards Earth and burning in our atmosphere
comet:
a ball of rock and ice in outer space that forms a tail when it comes close to the sun

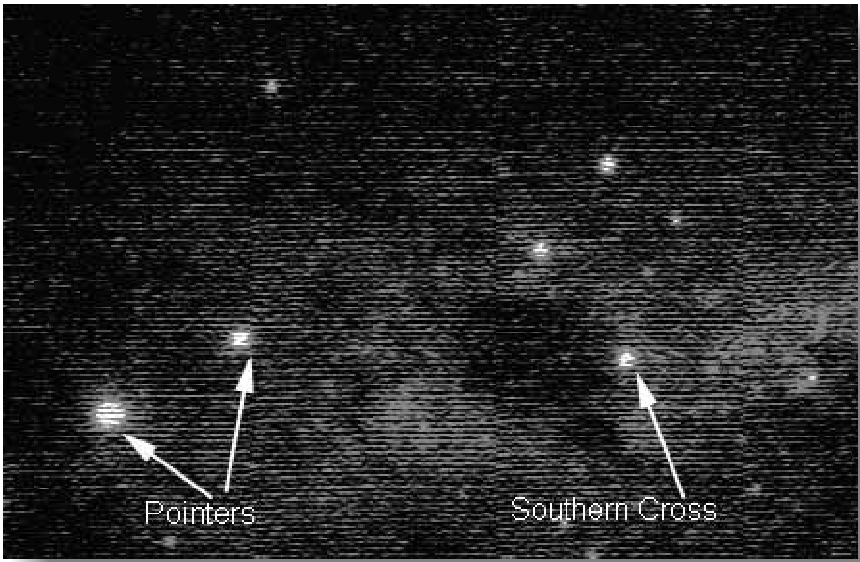


Figure 4: The Southern Cross Constellation with its pointers

Figure 5: Comet

Not all heavenly objects are natural. If you see a 'blinking star' moving rapidly across the sky you are probably seeing an **artificial satellite** (Figure 6), a machine that has been put into orbit around the Earth, which may transmit TV signals or radio signals used by GPS (Global Positioning Systems). If you are very lucky you might even see the **International Space Station** - a laboratory in orbit above the Earth with astronauts performing different types of research.

Figure 6: Communication satellite in orbit around the Earth

Figure 7: A view of the Milky Way in the night sky

ACTIVITY 1

1. Observe the night sky. What do you see?

   Look for the following:
   - the moon (what phase is it in?)
   - venus
   - constellations of fixed stars like the Southern Cross
   - meteor
   - comet
   - satellite
   - space station

   Copy and complete the table below in your notebook.

Name of object	Try to describe what you observe with the naked eye	Definition (in your own words)
moon		
planet		
fixed star		
constellation		
milky way		
meteor		
comet		
artificial satellite		
space st ation		

2. Which of these heavenly bodies could represent a threat to life on Earth? Give reasons for your answer.

ANSWERS ON PAGE 103

COMMENT

The night sky is full of beautiful heavenly bodies which can be seen with the naked eye and explained using scientific methods.

Scientific methods for observing space

In ancient times people were fascinated by the night skies and spent hours mapping the position of the moon and the stars using the naked eye. The ancients had many myths and legends about the heavenly bodies which they mostly thought were gods, giants, or other types of mythical creatures.

Today, scientists understand that the heavenly bodies we observe are clouds of glowing dust and gas, distant suns and worlds. This understanding comes from observations made with many different types of scientific instruments.

Simple **optical telescopes** (Figure 8) were invented 400 years ago and have today become very sophisticated. The **Hubble telescope** (Figure 2) is in **orbit** around the Earth in outer space where it has taken the most astonishing photographs of the heavens without city lights, clouds, or the atmosphere to interfere. The **SALT telescope** (Southern African Large Telescope) is the largest telescope in the Southern Hemisphere (Figure 1). This telescope is located in the Karoo town of Sutherland in the Northern Cape. The SALT telescope has an 11 metre diameter mirror and is so sensitive that it could detect a candle flame on the moon.

Figure 8: Optical Telescope

Ordinary **optical telescopes** use lenses and mirrors to focus and trap light. They are most sensitive to visible light, but some modern telescopes like SALT can also detect near infra-red and near ultra-violet radiation and even X-rays and Gamma rays. Radio telescopes are giant **parabolic** antennae which are able to detect radio waves. In 2012 South Africa was awarded a bid to host the major part of the **Square Kilometer Array** (SKA) (Figure 9). The SKA will be the most sensitive radio telescope in the world: 50 – 100 times more sensitive than any other. The SKA will be a vast network of radio-antennae sited in Australia, New Zealand, South Africa and other African countries, including Madagascar. The network will detect radio waves to give us more information about heavenly bodies.

parabolic:
dish-shaped

Figure 9: Radio telescopes like those used in the SKA

Perhaps even more impressive than these sensitive instruments are the manned and unmanned missions to the moon, Mars, and other parts of our solar system. The Russians sent the first **artificial satellite** called **Sputnik** (Figure 10) into orbit around the Earth in 1957. In the 1960s and 1970s the Americans landed astronauts on the moon where they collected rock samples (Figure 11), made many interesting observations, and returned to Earth.

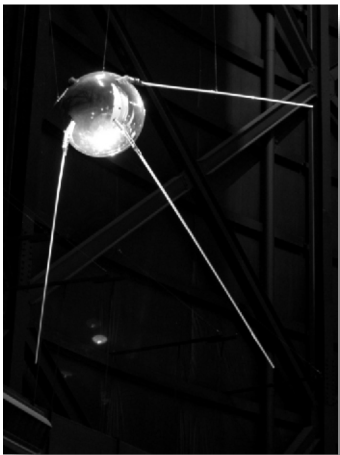


Figure 10: Sputnik

Figure 11: Astronauts can collect and bring back samples from space

More recently, we have explored our solar system with robotic space probes which are types of unmanned space craft that fly past, photograph and observe other planets then transmit the information by radio to Earth. There have been many robotic missions that have actually landed on other planets. **Mars rovers**, for example the Curiosity Rover, have landed on Mars (Figure 12) where they analyse soil and rock, then send the results to Earth. One space probe called the **Voyager Spacecraft** (Figure 13) is travelling beyond our solar system. Astronauts on the **International Space Station** also collect valuable information about the heavens.

Figure 12: A Mars Rover

Figure 13: Voyager Space Craft

Using sensitive instruments and observations from manned and unmanned space missions, Astronomers and Astrophysicists have been able to create accurate theories about the objects in our universe and the way it works. Some of these discoveries are described in the following pages.

ACTIVITY 2

1. Study the table below. Match Column A with the actions shown in Column B

Column A	Column B
a. Astronauts on the moon	i. take a soil sample on a distant planet
b. Space probe	ii. detect an alien radio station on a distant planet
c. Optical telescope	iii. take high resolution pictures of a far galaxy with minimum interference.
d. Robotic Rover	iv. observe planets orbiting a distant star using visible light and other light frequencies.
e. Radio telescope	v. investigate the composition of space beyond our solar system
f. SALT telescope	vi. collect rock samples and return them to Earth
g. Hubble space telescope	vii. study heavenly objects only using visible light

2. Which of the methods from question 1 do you think would be best (in terms of cost and effectiveness) to search for liquid water on a distant planet? Give a reason for your answer.

ANSWERS ON PAGE 103

COMMENT

Astronomers and astrophysicists collect information about the universe using machines such as space probes, instruments such as telescopes, and even specially trained personnel called astronauts.

Fixed stars and constellations

The ancients imagined **patterns**, called constellations, in the arrangement of stars. Each culture has identified different patterns of stars in the sky and created their own constellations. The main **constellations** that we use today were identified by the Greeks and Romans. You will almost certainly have heard of the 12 major constellations of Capricorn, Aquarius, Pisces, Aires, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Sagittarius and Scorpio which are widely used in astrology as the signs of the **zodiac** (Figure 14). It is important to understand the difference between **astronomy** and **astrology**.

Among the patterns the ancients identified were scorpions, lions and archers.

astrology:
The study of the movements and relative positions of heavenly bodies and their influence on human affairs. Do you think that this is a science?

Figure 14: The signs of the zodiac

Figure 15: Orion the Huntsman

Astrologers use the position of the heavenly bodies at the time of birth to make predictions about their effects on the affairs of humans. Astronomers are scientists who study heavenly bodies (planets, moons, stars, galaxies etc.) in a scientific manner to discover as much as they can about them.

Astrology is not considered a science because the predictions made by astrologers are usually vague, and there seems to be no logical reason why the position of the heavenly bodies should have any influence on the affairs of humans at all.

Figure 16: Scorpio the scorpion. Can you see the tail and the sting?

Astronomers, on the other hand, need to work scientifically making observations, hypotheses with predictions, and then testing those predictions and communicating their results to other scientists to replicate and test.

Different constellations may be seen in the southern and northern hemisphere. Here in the southern hemisphere the Southern Cross (Figure 17) with its two pointers is one of our most spectacular constellations. According to the Sotho and Venda people, the pointers and the bright stars of the Southern Cross are giraffes. According to the /Xam bushmen the pointers and bright stars are lions. Two other obvious and beautiful constellations that you might see in our night sky are **Orion the Huntsman** (Figure 15) and **Scorpio the Scorpion** (Figure 16).

Stars as balls of burning plasma

In modern times scientists have analysed star-light and realised that the fixed stars are, like our sun, balls of burning **plasma**. The closest two stars to our sun are **Proxima Centauri** and **Alpha Centauri** (Figure 17). Alpha Centauri is the brightest pointer of the Southern Cross and Proxima Centauri is a nearby star which is invisible to the naked eye. Proxima Centauri is 4.22 **light years** away from the sun while Alpha Centauri is 4.37 light years away.

Light Year:
The distance that light travels in a year, and light travels at a speed of 300 000 km per second.
That is
300 000 x 60 x 60 x 365.25 =
394470000000 km
or 3.945 x 1011 km
in a year

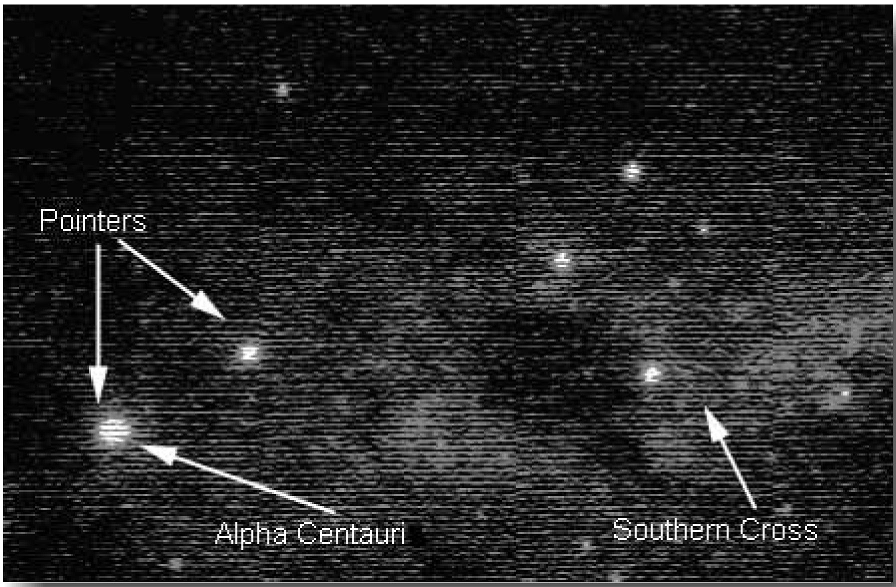


Figure 17: The Southern Cross and Alpha Centauri

How do scientists know what stars are made of?

The stars are made up of elements which are heated up to temperatures of many million degrees Celsius. When elements are heated they emit light. Different elements will give off more light in different wave lengths. Elements in cold gases will also absorb light of different wavelengths as it passes through the gas. (You have learnt about this in *Matter & Materials*.)

Scientists look at star light through an instrument called a **spectroscope** (Figure 18).

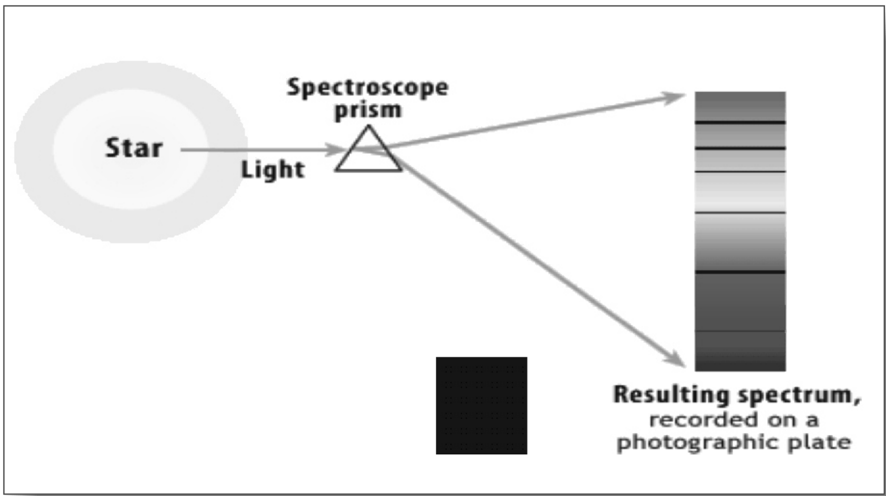


Figure 18: How a spectroscope works

A spectroscope contains a prism which divides up light into bands forming spectra. The spectra are recorded on a photographic plate or by electronic sensors.

By looking at the patterns of dark or light lines on the spectra astronomers can tell what elements are found in a star or cloud of gas trillions of kilometers away.

Using spectroscopes, astronomers are able to tell that our sun is a ball of glowing gas that is made mainly of the elements Hydrogen and Helium and that the distant stars are also balls of burning plasma, some similar to our sun, but very far away.

ACTIVITY 3

1. Explain the difference between astrology and astronomy.

2. Which of the words below would you apply to astrology, and which would you apply to astronomy?
   a. observation
   b. testable prediction
   c. difficult to test prediction
   d. experimentation
   e. fortune telling
   f. faith

3. Apply your knowledge of science to explain why you think that 'scientifically speaking' it is not wise to take astrology seriously.

4. Proxima Centauri is 4.22 light years away from our sun. Use this information and the definition of a light year given on page 10 to work out how many kilometers Proxima Centauri is from our sun.

5. Put the sentences below in the correct order to explain how a spectroscope works. Use Figure 18 to help you.
   a. Elements in a star are heated and give off light energy.
   b. The spectrum is recorded on a photographic plate or electronic sensor.
   c. A prism (or similar device) in a spectroscope splits or disperses the incoming light into its different wave lengths to produce a spectrum.
   d. Light leaves a distant star as a mixture of wave lengths.
   e. The light energy enters a spectroscope.
   f. Scientists examine the spectrum for tell-tale bright bands of light to find out what heated element produced the light they are observing.
   g. When elements are heated they give off more light energy in certain wave lengths than others.

ANSWERS ON PAGE 104

COMMENT

The fixed stars, like our sun, are distant balls of burning plasma which may be arranged in patterns or constellations. We can tell what elements make up a star by using a spectroscope.

The solar system part 1: planets

The solar system is the name given to a star (or sun) and the heavenly bodies which are bound to it by the force of gravity and orbit around it in an **elliptical** (Figure 19) shape. The sun makes up 99.85% of the mass of our solar system while the rest of its mass is made up of the planets, their moons, asteroids and comets.

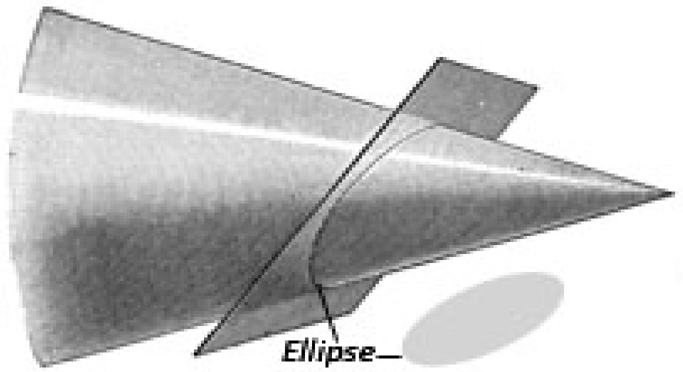


Figure 19: An Ellipse is an oval shape created by cutting a cross-section through a cone

Each of the trillions of stars in our universe may be similar to our sun. They might be the centre of their own solar system with planets rotating around them. By 2012, astronomers, using powerful telescopes, had found more than 800 planets orbiting distant stars.

The Planets

For the ancient Greeks the planets were heavenly bodies which wandered around the night sky in an unpredictable way. Today, scientists can predict the movement of the planets very accurately. Earth is actually one of 8 planets that orbit the sun in an elliptical shape (Figure 20). An **ellipse** (Figure 19) is the oval shape which you get by cutting a section through a cone.

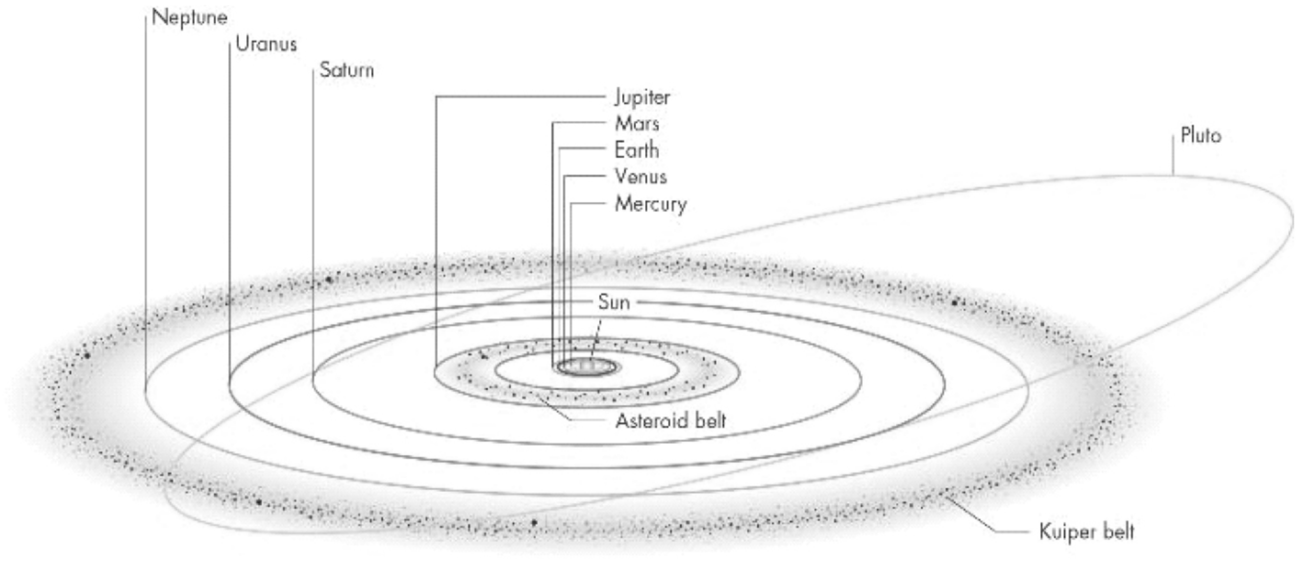


Figure 20 Diagram of the solar system showing the elliptical orbit of the planets

> ***dwarf planet:***
> *a small planet with enough mass to crush itself into a circular shape with its gravitational pull. Dwarf planets do not have enough gravitational pull to clear their path through space of other objects.*

The planets from closest to furthest away from the sun are **Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus,** and **Neptune**. There used to be a 9th planet called Pluto beyond Neptune, but in 2006 it was reclassified as a **dwarf planet** because, among other reasons, it is much smaller than the other planets. The four planets closest to the sun (Mercury, Venus, Earth and Mars) are called the **terrestrial planets** and are made of rock and metal like the Earth. The outer planets (**Jupiter, Saturn, Uranus** and **Neptune**) are enormous in size and are called the **gas giants** or **Jovian planets**. They are composed of substances such as Hydrogen, Helium, Methane, Ammonia and water. Jupiter is the largest planet. It is 312 times the size of Earth with a huge red 'eye' that is actually an ancient storm system three times the diameter of Earth (Figure 21).

Figure 21 Jupiter with its eye – actually a gigantic 300 year old storm

The planets and their moons

Many of the planets have large natural satellites or **moons** in orbit around them. The Earth's moon is our most familiar example. It goes through a cycle of changes in shape (phases) every 29.5 days (Figure 22) and causes our tides.

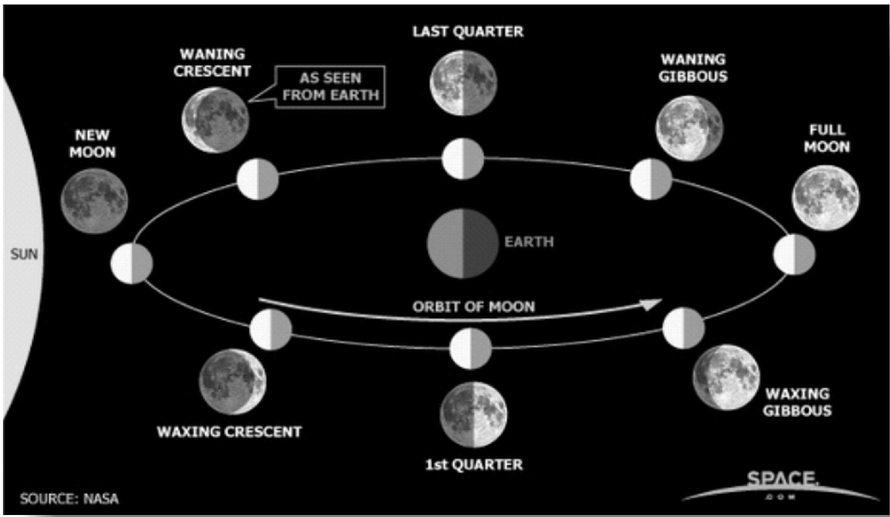


Figure 22: The phases of the moon as seen from the Northern Hemisphere

Phases of the moon

new moon:
the moon is dark as no light is reflected from it onto earth

crescent:
*a crescent of sun light is reflected off the moon onto the earth. We say it is **waxing** when the moon is getting bigger, and **waning** when it is getting smaller in size*

last quarter** and **first quarter:
the moon is half lit

gibbous moon:
the moon when it is more than half but less than fully lit

full moon:
a moon that is fully lit

Actually, the gravitational pull of both the sun and moon on the oceans causes our tides (Figure 23).

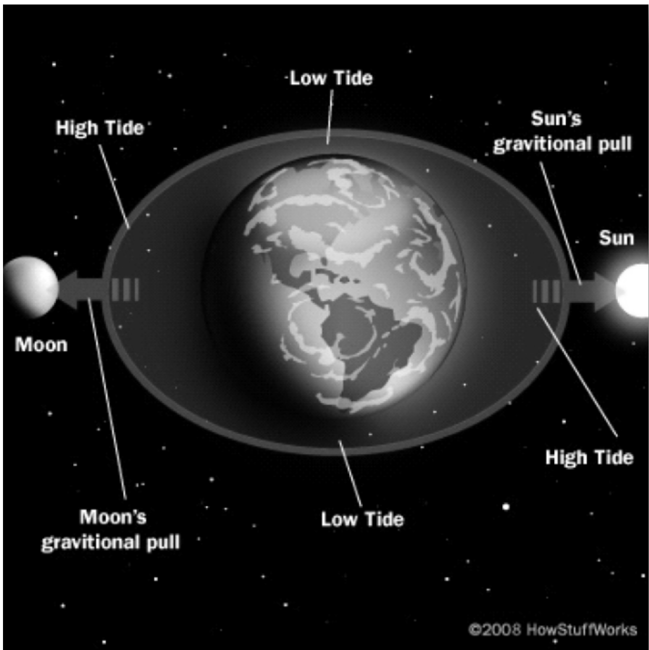


Figure 23 The pull of the moon and sun on the oceans cause the tides

Earth has one moon, Mercury and Venus have none, but Mars has two moons, while Jupiter has over 63, Saturn 62, Uranus 27, and Neptune 13. Some of these moons are very large, for example Ganymede, Jupiter's largest moon, which is slightly bigger than the planet Mercury.

Is there life on other planets in our solar system?

At the moment the only confirmed life in our entire universe is here on Earth. Conditions on the other planets are too hostile for life as we know it to exist. Venus, for example, has a surface temperature of 460°C and experiences sulphuric acid rain storms. Mercury has day temperatures of around 300°C and night temperatures of -160°C. The gas giants are equally impossible places for Earth-style life. Visiting Jupiter would be very uncomfortable. You would need to carry your own oxygen, food and water as well as a special space suit to withstand deadly radiation and an atmospheric pressure ten times that of Earth. The space suit would also help you move about in a place with a gravitational force 2.5 times that of Earth and no solid surface

Water (H_2O) has been found on Mars, Europa (Jupiter's fourth largest moon) and Enceladus, the sixth largest of Saturn's moons. The water on Mars is mostly frozen, but the planet has other possible tell-tale traces of life such as the gas methane which may be produced by bacteria. There is good evidence that **Mars** (Figure 24) was covered by a large ocean billions of years ago. Europa has a thin oxygen-rich atmosphere and may have a liquid ocean below a surface layer of ice. Enceladus may also have a liquid ocean of water beneath a layer of ice. In August 2012 the Curiosity Space Rover landed on Mars with the purpose of using sophisticated instruments to search for life on this mysterious planet.

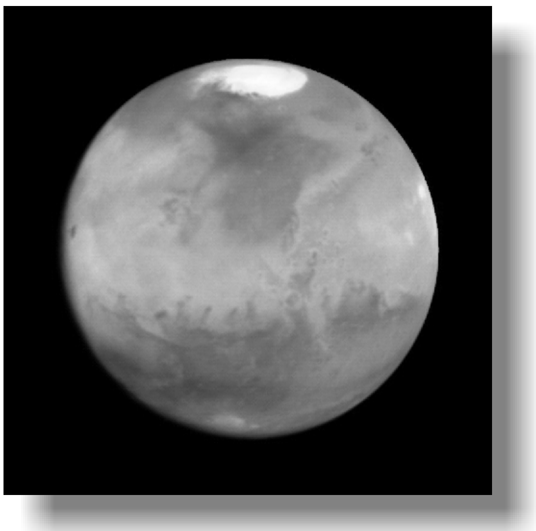


Figure 24: Mars with its ice caps that are mainly made of frozen water

ACTIVITY 4

1. What is a solar system?

2. If you watch fixed stars at night (for example, the Southern Cross) you will notice that they move throughout the night. In the early evening they may be just above the horizon, and later they might be higher up. What causes this movement, and why do we call them fixed stars if they are moving all the time?

3. Imagine that in the future humans decide to send astronauts to visit a distant planet. However, their space ship can go no further than 5 light years and still return to Earth. Where would you suggest they go? (Read the section on fixed stars and constellations again.)

4. Imagine you want to start the 'Extra Earth' gold mining company which explores for precious minerals on other planets in our solar system. Which planets would not be worth exploring? Give reasons for your answers.

5. What is the difference between a dwarf planet and an ordinary planet? Give an example.

6. What are the eight phases of the moon? Name them in order, starting from the new moon.

7. Explain very briefly how the sun and moon cause our tides.

8. Comment on the statement that the Earth is a very special planet because it has a moon.

9. Which three celestial bodies other than Earth in our solar system may also have life and what evidence is there that this might be so?

10. Why do you think that scientists believe that a planet with water may have life?

11. You have been banned from planet Earth for some horrible crime you committed, but the judge allows you to choose another planet for you to live on. Analyse the different planets (do a little research if necessary) and then explain which planet you would choose and what you would require to survive there for many years.

ANSWERS ON PAGE 104

COMMENT

Our sun together with the eight planets orbiting around it is called the solar system. The rocky terrestrial planets are found closest to the sun while the huge and majestic gas giants are found further away. Certain planets or the moons of planets may also have simple forms of life, but as yet no evidence of life has been found.

The solar system 2: asteroids, meteorites and comets

Asteroids and Meteorites

Between Mars and Jupiter is a band of irregular shaped rocks that orbit around the sun. These are called the **asteroids** and they range in size from dust-sized particles to dwarf planets with a diameter of up to 900 km. This band of asteroids is called the **asteroid belt** (Figure 25).

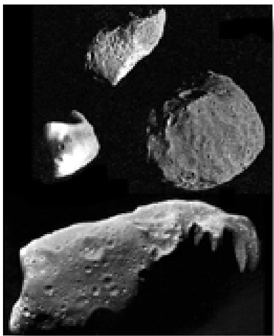


Figure 25: Some asteroids in the asteroid belt

Figure 26: As they enter the atmosphere dust from asteroids and comets burns up forming a meteor

Not all asteroids are trapped in the asteroid belt. Some, called **Near Earth Objects**, have orbits which bring them near to the Earth where gravity may pull them towards it at speeds of over 6000 km per hour.

As the objects fall towards the Earth they collide with the molecules of the atmosphere. The collisions cause the falling dust particles to heat up, glow and shine brightly, and become a 'shooting star' or **meteor** (Figure 26). Sometimes, though, the falling meteors are so large that they do not burn up but strike the Earth. If it strikes land the falling meteor may disintegrate, break into countless fragments, and disappear. Occasionally a rock called a **meteorite** (Figure 27) is left behind.

The largest meteorite ever recovered comes from Hoba in Namibia. This meteorite fell about 80 000 years ago and weighs 55 000 tons (Figure 28).

Figure 27: *A meteorite is a fragment of rock left behind if a meteor does not burn up completely*

Figure 28: The Hoba meteorite

A very large meteorite may leave a hole in the ground called a meteorite impact crater.

Even further back in time the Earth has been struck by truly enormous meteorites. One such meteorite struck the Earth in Chicxulub Mexico 65 million years ago (Figure 29). This meteorite was about 10 km across and formed a crater about 200 km in diameter. This enormous impact threw a huge cloud into the atmosphere, blocking out the sun, killing plants, and probably causing the extinction of large animals like the dinosaurs and many other species of life. An extinction of so many species at one time is called a **mass extinction** (see Lesson 4 of this unit).

Figure 29: Artist's impression of the meteorite that caused the extinction of the dinosaurs

Comets
Comets are chunks of ice (frozen water, methane and carbon dioxide) mixed with rock and dust. Comets have an orbit that takes them from the outer parts of the solar system to near the sun then back to the outer parts of the solar system again. As the ice approaches the sun it heats up, creating a layer of vapour around the icy core which may get drawn out into a long tail.

One famous comet is called Halley's Comet (named after the British astronomer who predicted its return) which comes close to the sun and is visible from Earth every 75 years. The earliest sighting of Halley's Comet was 240 years before the birth of Christ. The last sighting was in 1986, and the next sighting is predicted to be in 2061.

Comets, like asteroids, can also enter the Earth's atmosphere, forming meteors, meteorites and meteorite impact craters.

ACTIVITY 5

1. What is the difference between an asteroid, a meteor, a meteorite, and a comet?

2. Where are most of the asteroids found in our solar system?

3. Where do comets originate in our solar system?

4. How did the Chicxulub meteorite drive the dinosaurs to extinction?

5. In 1954 a lady in Alabama was lying on a couch listening to the radio. Unexpectedly, a large (8.8 kg) rock came crashing through the roof of her house, bounced off a table, and bruised her leg. Apply your knowledge of asteroids, comets and meteorites to explain what happened.

6. Meteorites are still a hazard to life on Earth and it is possible that a meteorite like the one that drove the dinosaurs to extinction could strike again. Apply your knowledge about the solar system to explain what precautions humans could take to avoid suffering a similar fate to the dinosaurs.

ANSWERS ON PAGE 106

COMMENT

The solar system, in addition to the sun and planets, contains smaller objects with more irregular orbits such as asteroids and meteorites. These objects may come too close to the Earth's gravitational field and fall towards it, striking its surface. When they strike they may form a rock called a meteorite in a hole called a meteorite crater. Meteorites have had catastrophic effects on life in the past, causing mass extinctions. Humans will need to learn to manage meteorites to avoid a similar fate in the future.

CHECKLIST

Are you able to:

- ❐ identify common objects in the night sky
- ❐ give scientific explanations for the objects
- ❐ describe some of the methods that astronomers and astrophysicists use to learn about the universe
- ❐ name and describe some world-class scientific projects set up in South Africa to observe the heavens
- ❐ identify some of the constellations recognized by the ancients
- ❐ explain the difference between astrology and astronomy
- ❐ name the closest star to the Earth other than the sun
- ❐ describe our solar system with its planets and its moons
- ❐ explain the properties and characteristics of asteroids, meteorites and comets
- ❐ explain what probably caused the extinction of the dinosaurs.

NOTES

LESSON 2

Beyond the solar system: the origin of the universe and elements

About this lesson

You will be introduced to some of the objects beyond our solar system, such as galaxies and black holes. You will discover how elements are formed during the birth and death of stars. Finally, you will discover where it all began as you learn about the birth of our solar system and the origin of the universe according to the Big Bang theory.

In this lesson you will:

- find out how elements are formed inside stars
- find out about black holes and galaxies
- learn about the birth of our solar system
- explore the Big Bang theory of the Origin of the Universe.

Beyond the Solar System: Galaxies and Black Holes

Galaxies

Stars are not spread randomly through the universe. They are held together by gravity to form clumps called galaxies. Galaxies contain millions, even billions (a thousand million) or trillions (a thousand billion) of stars. These are unimaginably large numbers. Even one million is a huge number. Lesson 5 activity 19 contains some exercises that will help you to visualize exactly how big a million is.

Our universe contains about 170 billion galaxies. Galaxies have different shapes. Some are elliptical (oval shaped), others are spiral, and some are irregular. Many galaxies have a bright central area where stars are especially densely concentrated (Figures 1 and 2).

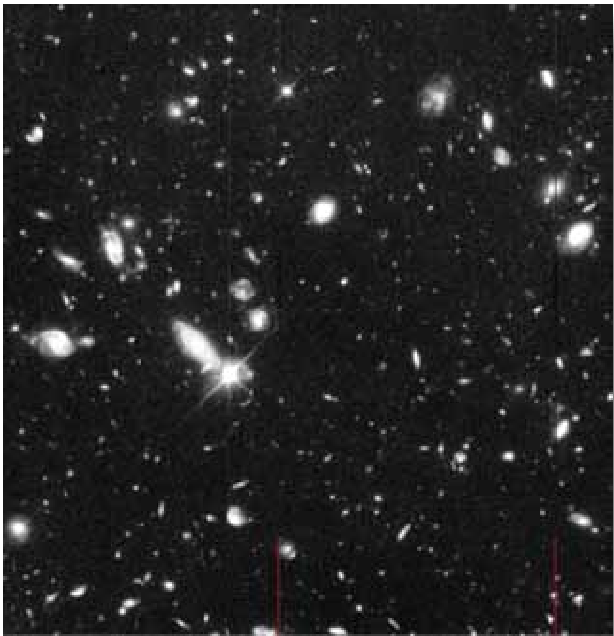


Figure 1: Some of the many galaxies in our universe. Every smudge and dot you see is a galaxy

The Hubble classification system rates galaxies on the basis of how elliptical they are, ranging from E0, being nearly spherical, up to E7, which is very long.

Spiral galaxies consist of a rotating disk with a central bulge of generally older stars. Extending outward from the bulge are fairly bright arms. In the Hubble classification scheme, spiral galaxies are listed as type S, followed by a letter (a, b, or c) that indicates the degree of tightness of the spiral arms and the size of the central bulge.

Most spiral galaxies have a bar-shaped band of stars that extends outward to either side of the core, and then merges into the spiral arm structure. In the Hubble classification scheme, these are shown by an SB, followed by a lower-case letter (a, b or c) that indicates the shape of the spiral arms.

Our solar system is one of 200 billion stars in our galaxy, the Milky Way. The Milky Way is a spiral galaxy. (Figure 2): a flat disc of stars spiraling out from a bright galactic centre. Our sun is thought to be situated on an outer arm of the Milky Way.

Figure 2: What our Milky Way Galaxy may look like

To observe the Milky Way you need to find a dark place away from city lights. The Milky Way (Figure 7, Lesson 1) will appear as a bright band across the night sky. Look towards the brightest part of the Milky Way and you will be looking towards the centre of our galaxy. It would take light travelling at 300 000 km per second just over 27000 years to travel from the Earth to the centre of the galaxy.

Black Holes

Massive stars (huge stars many time the size of our sun) may collapse inwards, crushing the matter in them together and increasing their density. As the density of the collapsing star increases, so its gravitational attraction increases. Eventually the force of gravity will increase to the point that even light is unable to escape. The collapsed star will appear completely black (i.e. not visible to us) and a **black hole** has been formed. The huge force of gravity exerted by the black hole will not only trap light but consume all nearby objects such as stars, and black holes will slowly grow bigger and bigger. Light near a black hole is 'stretched out' – its wave length increases and it turns red and fades. The Milky Way galaxy, along with many other galaxies, is thought to contain a super massive black hole at its centre with a mass of 4 million of our suns.

massive:
very large amount of matter (mass)

Although black holes are invisible to telescopes they can be detected because of the effect their gravity has on the stars around them. Black holes exert such huge gravitational forces that they bend the light of nearby stars towards them.

ACTIVITY 1

1. What is a group of stars called?

2. What is the name of the galaxy that our solar system is found in, and what is the shape of our galaxy?

3.

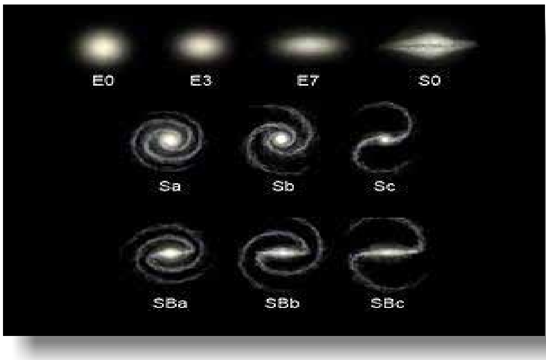


Figure 3 Shapes of galaxies

Figure 3 shows the shapes of different galaxies. Tabulate the different galaxies according to these shapes: elliptical, spiral and barred (irregular). In column A write down the number of the galaxy and in column B its shape.

4. How are black holes formed and why are they called black holes?

5. Imagine you are travelling through space in a space ship. Accompanying you in another ship is your friend Captain Buck Rogers. Buck moves away from you to investigate a strange object which he has seen. Suddenly, to your horror, his ship starts to stretch, getting longer and longer. As it stretches it turns red and slowly fades. Eventually his ship fades away completely and is never seen again. What has happened to Buck Rogers? Explain your answer.

ANSWERS ON PAGE 106

COMMENT

Stars are clumped together forming galaxies. Galaxies have different shapes. Huge stars can collapse, forming gravitational traps called black holes.

The Birth and Death of Stars and the formation of elements

Stars start off as huge clouds of 'molecular dust' composed of Hydrogen, some Helium and other elements. The 'dust particles' are attracted by the force of gravity and as they move together they heat up because of the release of gravitational potential energy (see Unit 3: Movement and Energy). Eventually the 'dust particles' become hot and so compressed by gravity that the Hydrogen atoms start to stick together and **fuse**. Each Hydrogen atom contains one proton and different amounts of neutrons dependent on the isotope (see Unit 2: Matter and Materials to find out more on elements and isotopes). When two Hydrogen atoms fuse they form an atom with two protons. This is an atom of **Helium** (Figure 4). As the atoms combine they release energy. The process by which atoms fuse together, forming new elements and releasing energy, is called **nuclear fusion**.

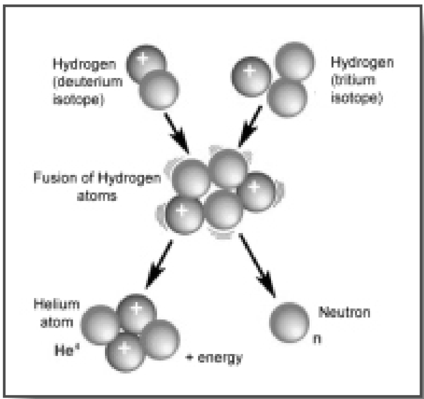


Figure 4: Helium is formed from the fusion of two Hydrogen atoms

The energy released by fusion causes the star to heat up to enormous temperatures and give off electromagnetic radiation (see Unit 3: Movement and Energy) which we see as light. Stars are very hot. The sun has a core temperature of close to 16 000 000 C° and a surface temperature of over 6000 C°.

When all the Hydrogen atoms in the centre of the star have fused to form Helium, the Hydrogen fusion reactions stop. The centre of the star collapses, forcing the Helium atoms closer and closer together. The centre of the star becomes very dense and hydrogen atoms from the outside of the star are sucked in and new fusion reactions can begin. All the extra energy from the fusion reactions can cause the star to expand a million times its normal size where it burns with a red colour and is called a **Red Giant**. In four billion years time our sun may expand to form a Red Giant, even consuming the Earth.

Eventually the Red Giant becomes so hot that the helium atoms at its centre also start to fuse, forming heavier elements such as Carbon. As the star grows older it may expand and contract, throwing off plumes rich in Carbon and Oxygen into outer space. Finally, all that is left of the star is a faintly glowing core of Carbon called a **White Dwarf**.

The life cycle of stars varies with their size. Small stars (less than 8% the size of our sun) do not have enough mass to start nuclear fusion. Very large stars (with a mass of more than nine times that of our sun) are able to fuse elements higher up the periodic table (see Unit 2: Matter and Materials) than Hydrogen and Helium. These are elements such as Carbon (C), Neon (Ne), Oxygen (O), and Silica (Si), up to elements such as Nickel (Ni) and Iron (Fe). When the fusion reactions in very large stars slow down they collapse to form a dense mass of neutrons, called a neutron star. An even larger star may collapse and become so dense that it will become a black hole. These stars may also explode, forming the huge clouds of 'molecular dust' mentioned earlier. These explosions are called supernova explosions. During a supernova explosion heavier elements such as silver and gold are formed when neutrons smash with high energy into iron or even heavier atoms.

ACTIVITY 2

1. Which force brings the 'molecular dust' in a young star so close together that it starts to fuse and give off energy?

2. What happens when two hydrogen atoms fuse?

3. How are heavier elements such as carbon formed?

4. What are the explosions called when very massive stars explode forming a cloud of 'molecular dust'?

5. On Earth, elements such as gold and silver are extremely precious. One of the reasons for this is because they are so rare. Apply your knowledge of the formation of elements in the stars to explain why elements such as Hydrogen, Helium and Carbon are more common and elements such as Gold and Silver are rarer.

ANSWERS ON PAGE 107

COMMENT

Most of the elements of the Periodic Table are formed by nuclear fusion during the life and death of stars.

The Birth of our Solar System and the Universe

Birth of the Solar System

Our solar system formed about 4.6 billion years ago after a giant star exploded in a **supernova** explosion. The dying star left a huge mass of 'molecular dust' called a **nebula cloud** (Figure 5). This nebular cloud collapsed under its own gravity, forming a spinning flat disc with the young sun at its centre. Gravity caused the gas cloud spinning around the sun to form 'clumps' which became planets and moons.

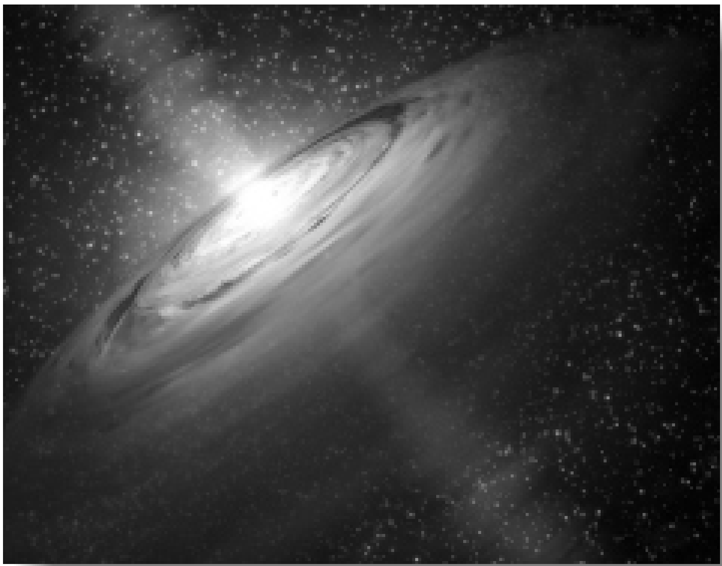


Figure 5: Early in its life our solar system consisted of a young sun in a spinning nebula cloud. Gravity caused the dust of the nebula cloud to clump, forming the planets

The area of the solar system closest to the sun was so hot that water and methane and other elements and molecules with low melting points (volatile substances) did not easily condense, but elements such as Silica and Iron with high melting points could. The result is that the rocky planets – Mercury, Venus, Earth and Mars – formed close to the sun and are made mainly of Silica and Iron with small amounts of water and other volatile substances.

Further away from the sun where it is cooler volatile substances such as water and methane could condense, and because these substances are far more common in our solar system than Iron and Silica, they formed the huge gaseous planets called the gas giants, namely Jupiter, Saturn, Uranus and Neptune.

The Birth of our Universe

We have seen how stars and solar systems are formed but where does the universe itself come from?

The birth of our universe is described by a theory called the Big Bang theory. This theory is well supported by observations and most astrophysicists agree that a version of it is correct.

According to the Big Bang theory, the universe expanded from a tiny point called a singularity about 13.7 billion years ago. At first the young universe was a super hot and super dense ball, but as it expanded it cooled, forming protons, neutrons and electrons. Later, the subatomic particles combined to form the first elements which were mainly hydrogen, with small amounts of helium and lithium. These early elements began to stick together under their own force of gravity, forming the first stars and later galaxies. Heavier elements were formed in the stars and in supernova explosions (as described earlier).

Some interesting aspects of the theory are that:

- We do not know what was before the singularity or where it came from, though a field of physics called quantum theory may have some of the answers.
- The universe was created during the Big Bang: matter, space and time. So before the singularity at the beginning of the universe there was no space or time. The early expansion of the universe is called inflation (Figure 6).
- Take a balloon and draw dots (these represent galaxies) on it with a marker pen. Blow up the balloon and as it grows bigger the dots will become bigger and further apart. In the same way, as the balloon expands, so the universe is expanding and the space between the galaxies is expanding.

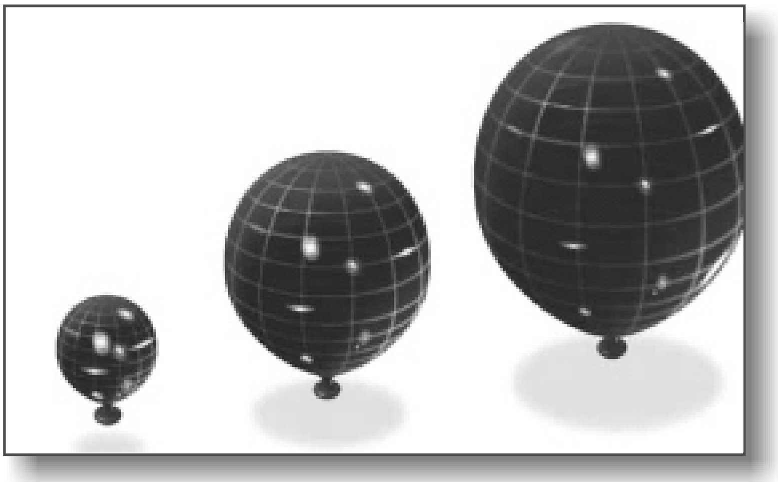


Figure 6: Just as a balloon expands when you inflate it, so space and time expand as the universe expands

Support for the Big Bang theory comes from many observations. Two of the most important are:

- In 1929 the astronomer Edwin Hubble observed that galaxies are accelerating away from one another exactly as if they were once clumped together in a hot, dense, young universe and then moved apart as the universe expanded. Actually, the universe is still expanding, which is why the galaxies are still moving apart.
- In 1964 radio astronomers, using a radio telescope, detected a glow of microwave radiation in deep space between the stars and galaxies. Where does this radiation in deep space come from? It turns out that the radiation is the remains of radiation formed when the universe was still hot and young.

ACTIVITY 3

1. Explain why Iron-rich and Silica-rich planets formed close to the sun, and gas giants made of volatile elements such as water and methane formed further away.

2. What evidence is there in our solar system that we originated from products of a supernova explosion?

3. What is the theory called that describes the birth of our universe?

4. What is the tiny point called which formed a 'seed' for our universe?

5. What else, other than the matter of our universe, was formed during the Big Bang?

6. What two observations provide evidence that the universe was formed small, hot and dense and then expanded to the size that it is today and is still expanding?

7. Imagine that you are a billionaire and that you are visited by a team of scientists and engineers looking for funding. They would like you to fund a project to develop a super space-ship that would travel at the speed of light. They would like to travel beyond our universe and visit other universes using this space ship. Explain why you would or wouldn't support the project.

8. At the moment our Universe seems to be expanding. What do you think might happen in the future? Give three possibilities.

9. An **atheist** tells you that the Big Bang theory excludes the idea of a God creating the Universe? Do you agree or disagree? Give your opinion with reasons.

ANSWERS ON PAGE 107

atheist:
someone who does not believe in God

COMMENT

According to the Big Bang theory, the Universe, including space and time, was formed (it actually expanded) from a tiny point or singularity 13.7 billion years ago. Next you will learn about the history and formation of the most important planet.

CHECKLIST

Are you able to:

- ❐ explain what a galaxy is
- ❐ explain what a black hole is
- ❐ describe the birth and death of stars
- ❐ explain how elements are formed inside stars
- ❐ describe the birth of our solar system
- ❐ explain the Big Bang theory of the Origin of the Universe
- ❐ describe the evidence for the Big Bang theory of the Origin of the Universe.

LESSON 3

The geological time scale, origin of the earth, the early earth and life

About this lesson

In the last lesson you learnt about the origin of the universe and the solar system. This lesson is about the origin of the Earth, the origin of life on Earth, and the history of its evolution from simple bacteria to eukaryotes, and early multicellular organisms. You will also see how the Earth gained an oxygen-rich atmosphere, and how the moon formed in a gigantic interplanetary explosion.

In this lesson you will:

- find out how the geological time scale is used to divide up Earth history
- learn about the origin of the Earth
- learn about the environment on the early Earth during the Hadean Eon
- explore the Archaean Eon
- learn about the earliest life forms, simple bacteria
- learn about the Miller-Urey Experiment and different hypotheses for the origin of life
- explore the Proterozoic Eon
- learn about the appearance of eukaryotic cells and multicellular forms of life
- discover how the Earth gained its oxygen-rich atmosphere.

Geologist:
A scientist who studies the origins, history and structure of the Earth.

Palaeontologist:
A scientist who studies the remains of life preserved in rock called fossils. Palaeontologists are interested in how life has changed over time and what it can tell us about Earth's past environments and climates.

The Geological Time Scale

Palaeontologists and Geologists studying the history of the Earth have divided it up according to the Geological Time Scale. Just as units of length are divided into smaller units such as millimetres, centimetres, metres and kilometres, the Geological Time Scale is divided into time intervals such as Eons, Eras, Periods and Epochs. Each of these intervals has similar types of life, climates and environments which set them apart from other similar intervals.

Figures 1 and 2 show the major divisions of the Geological Time Scale with the different life forms.

Eons	**Eras**	**Periods**	**Epochs**	**Myr**
Phanerozoic	Cenozoic	Quaternary	Holocene	0.012 -0
			Pleistocene	2.6-0.012
		Neogene	Pliocene	5-2.6
			Miocene	23-5
		Palaeogene	Oligocene	34-23
			Eocene	56-34
			Palaeocene	65-56
	Mesozoic	Cretaceous		145-65
		Jurassic		199-145
		Triassic		251-199
	Palaeozoic	Permian		299-251
		Carboniferous		359-299
		Devonian		416-359
		Silurian		443-416
		Ordovician		488-443
		Cambrian		542-488
Proterozoic				2500-542
Archaean				4000-2500
Hadean				4600-4000

Figure 1: The main divisions of the geological time scale in Myr (Millions of Years)

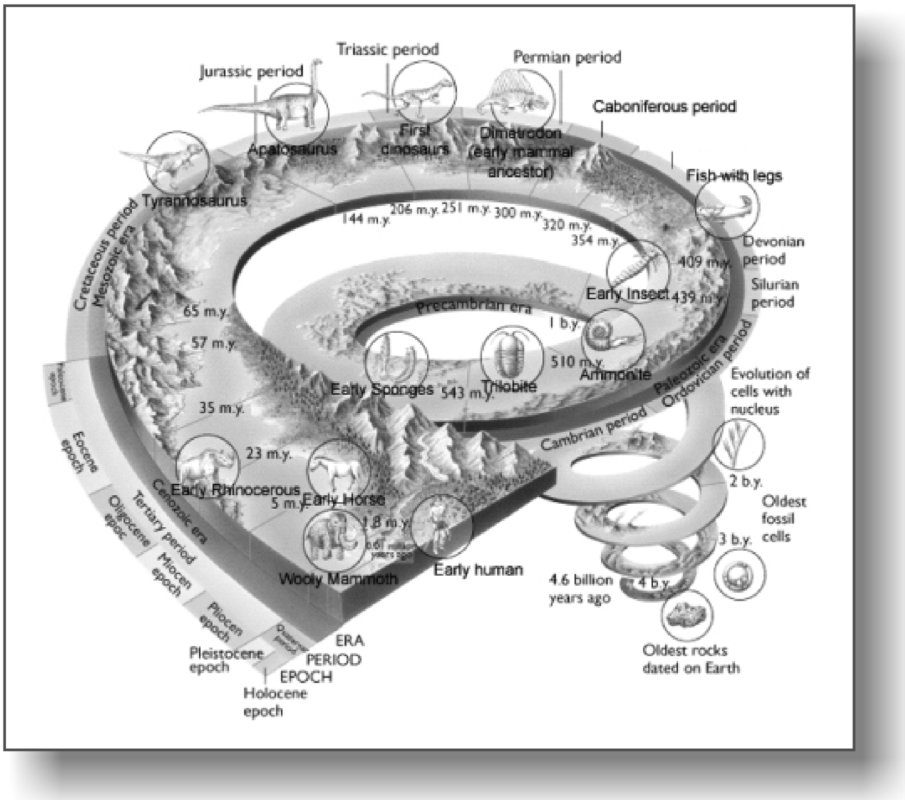


Figure 2: Some of the changes that have occurred in life over time

Since the earliest time in the Geological Time Scale when the Earth first formed, life has evolved from simple bacteria, to first cells with nuclei and multicellular organisms, until only about 200 thousand years ago when modern humans evolved (Figure 2)

ACTIVITY 1

Use Figures 1 and 2 to answer the following questions:

1. What does the abbreviation Myr stand for?

2. According to the figures, how old is the Earth in millions of years and in billions of years?

3. What are the major divisions of the Geological Time Scale?

4. When did the Mesozoic Era begin and end?

5. During which Period did early four-legged animals (fish with legs) invade land?

6. During which Era did early humans arrive on Earth?

7. In the next few lessons you will be introduced to some of the major events in Earth History. The following exercise may help you to remember what they are and when they occurred.
   a. The major divisions of the geological time scale may be remembered using the sentence:
      Hippos **A**t **P**lay **P**refer **M**ilk and **C**ookies
      Hadean, **A**rchaean, **P**roterozoic, **P**alaeozoic, **M**esozoic, and **C**enozoic.
   b. Copy the table below and complete it as you work through the activities and lessons that cover the Earth's geological time scale.

Name	Time period in millions of years	Eon or Era	The most important events that happened during this time in order
Hadean			
Archaean			
Proterozoic			
Palaeozoic			
Mesozoic			
Cenozoic			

   c. Use the information from the diagrams and your summary table to create a scale map of the history of the Earth. You can use a tape measure or a 500 sheet single ply roll of toilet paper. In this way you will create a geological time line with all the major intervals drawn to scale. It is best to do this outside, as you will need a lot of space.

If you decide to use a tape measure you can measure out your geological time line as follows. Let 5 cm = 10 million years. You will be able to compress the Earth's history of 4500 million years into 22.5 meters. Once you have marked out the time periods, write out the major events on pieces of paper and then place them in the correct order in the correct time period.

If you choose the toilet paper let one square of toilet paper = 10 million years. Now roll out the toilet paper in a large space. Using 450 squares of toilet paper you will be able to map out the entire history of the Earth. Use a marker pen to mark the time intervals and fill in the major events in each time period.

ANSWERS ON PAGE 108

COMMENT

Earth Scientists use the Geological Time Scale to communicate changes in life and the environment throughout Earth's history.

Origin of the Earth and the Hadean Eon (4600-4000 Myr)

Earlier you learnt how gravity caused clumping of silica- and iron- rich dust in the nebula cloud close to the early Sun. Slowly, as the dust stuck together, it formed larger and larger clumps the size of small moons. This clumping process is called **accretion**. Collisions between these moon-sized bodies formed Mercury, Venus, Earth and Mars.

Hadean Eon:
The first part of Earth's geological history. The word comes from Hades, the Greek word for Hell, because the Early Earth is thought to have been a hot and unpleasant place to be.

About 4.5 billion years ago a very young Earth collided with another body, perhaps the size of Mars. The collision threw up a huge cloud of dust and rock which clumped together to form the moon. The result of the collision was the moon orbiting around the Earth. This hypothesis to explain the formation of the moon is called the **giant impact hypothesis**.

*Figure 3: The Earth during the Hadean Eon was probably hot and unstable. Eruptions or **Outgassing** from volcanoes formed the early atmosphere and oceans, and there were many meteorite impacts*

As the young Earth formed, energy from the collisions, like the one that formed the Moon, melted it at least partially (see Figure 3). As the Earth cooled, the continents formed. Eruptions or **outgassing** from volcanoes formed the atmosphere, which was rich in gases such as methane, hydrogen, ammonia, carbon monoxide and water vapour. Condensation of the water vapour formed the early oceans.

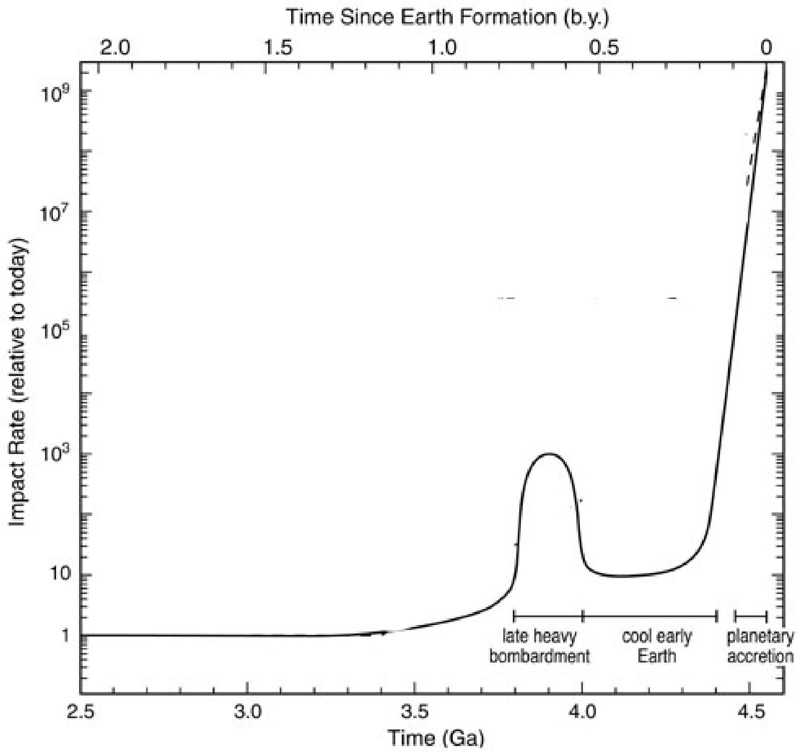


Figure 4: Graph showing the rate of meteorite impacts on Earth during the first two billion years (Ga) of its life

There was no life and no oxygen in the atmosphere. The Earth was still cooling and even growing as it was constantly being bombarded by meteorites. The moon today is covered with craters formed by meteorites bombarding it at that time. Also, there was no ozone layer (see later in this lesson) to protect the Earth from cosmic rays.

ACTIVITY 2

1. What is the process of gravitational clumping in the nebula cloud which formed the planets called?

2. Describe the **giant impact hypothesis** explaining the formation of the moon.

3. How did **outgassing** form the early atmosphere and oceans?

4. Give two reasons why a visitor to early Earth would have had to wear a space suit to survive?

5. Study Figure 4 and answer the following questions.
   a. What is meant by planetary accretion?
   b. Where is the boundary between the Hadean and the Archaean Eons?

c. Why is the rate of meteorite bombardment so high in early Earth history before tailing off at about 4.3 billion years ago?

d. What do you think is the cause of the peak in the rate of meteorite impacts during the late heavy bombardment 3.9 billion years ago?

ANSWERS ON PAGE 109

COMMENT

The Earth formed and cooled during the Hadean Eon, forming the continents, oceans and an early oxygen-free atmosphere.

Origin of Life and the Achaean Eon (4000-2500 Myr)

During the Archaean Eon, the earth had cooled and the early oceans, continents and atmosphere had fully formed. The bombardment of the Earth by meteorites had also slowed.
The very earliest life forms appeared about 3.6 billion years ago (Figure 5). These were the **Prokaryotes**, a group which belongs to the Kingdom called the Monera (See Unit 7, Lesson 3). They include the bacteria and archaea. These were simple organisms which had no proper nucleus. Instead they had a strand of DNA, called a **nucleoid**, hanging as a free loop in the cytoplasm (Figure 6). Some of these early life forms lived in hot springs and have been found fossilized in the rock of Mpumalanga, near Barberton in South Africa.

Archaean Eon:
The second major part of Earth history, from the Greek word 'Archaios' meaning old, ancient or from the beginning.
Prokaryote:
a simple single-celled life form with no true nucleus

Figure 5: A scene from the Archaean with dome-shaped stromatolites in the ocean

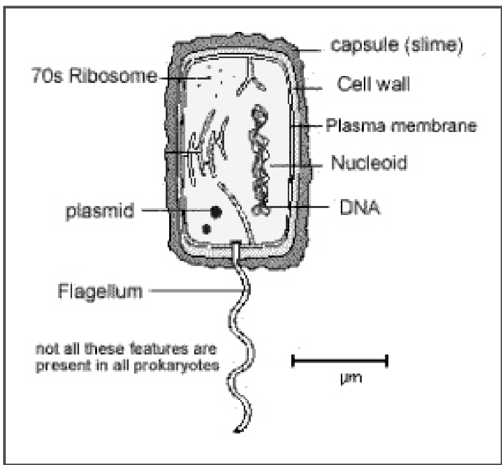


Figure 6: Structure of a prokaryote which has no nucleus

Billions of years later some archaea and bacteria still survive in places where there is no oxygen and at very high (up to 80°C) temperatures, while others can even survive freezing. Another interesting group of early life forms were the oxygen-producing **blue-green bacteria** also called **Cyanobacteria** which live in dome cushion-shaped colonies called **stromatolites** at the bottom of a shallow sea (Figure 5). Today fossils of these stromatolites are also found in Mpumalanga.

Stromatolite:
a colony of blue-green bacteria (cyanobacteria) with the shape of a large cushion that lives on the bottom of the sea.

During the Archaean you would also have needed a space suit and oxygen supply to live on Earth as there was no oxygen in the atmosphere and no ozone layer protecting life from the ultra-violet rays of the sun.

ACTIVITY 3

1. How was the Earth during the Archaean Eon different from the Earth during the Hadean Eon?
2. What were the earliest life forms that appeared on Earth?
3. Name a place where the fossils of these early life forms may be found today?
4. What type of environments did these early life forms live in?
5. What is a stromatolite?
6. What important gas did blue-green bacteria produce?

ANSWERS ON PAGE 110

COMMENT

During the Archaean Eon the first life appears. These are simple prokaryotes which lack a nucleus.

Origin of Life

We have seen how earliest life forms appeared in the Archaean Eon, but how did life on Earth originate?

In 1953 Stanley Miller and Harold Urey conducted an experiment that helped to explain the Origin of Life.

They took a sterile flask (Figure 7) and filled it with water vapour, methane gas (CH_4), ammonia gas (NH_3), hydrogen gas (H_2) and carbon monoxide (CO). These are all gases that are thought to make up the early atmosphere of the Earth during the Hadean and Archaean Eons.

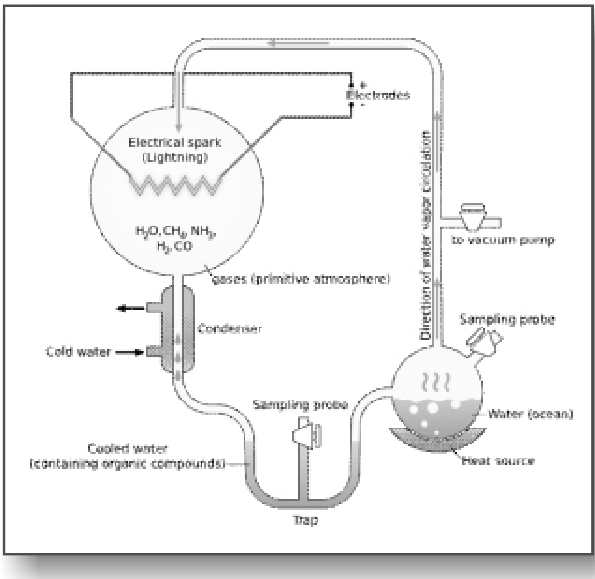


Figure 7: Miller and Urey's experimental apparatus

Miller and Urey passed an electric current through the gases for two weeks. At the end of two weeks they found a dark substance on the inside of the flask. When this was analysed it was found to be very rich in organic molecules, the molecules of life, and included more than 20 types of amino acids.

Miller and Urey had proved that that the chemicals of life could be produced if you have an energy source and the gases that made up the early atmosphere of the Earth. The early oceans may have been full of organic compounds (like a soup) which then somehow gave rise to early forms of life. This is called the **primordial soup** hypothesis.

Some important things to know about the **primordial soup** hypothesis are:

primordial:
first

- Scientists have many **hypotheses** about how the simple chemicals of life could have given rise to the first life forms, but nobody knows for sure.
- Just because there is a scientific explanation for the origin of life it does not mean that scientists are saying that there is no creator or God. Many scientists believe that God created life using natural processes that are being uncovered by scientists.

People who believe that God created the universe and life using natural processes are called **theistic creationists**.

- Organic molecules have also been found in clouds in outer space and in carbon-rich meteorites. So it is possible that the very first chemicals of life (and even life itself) were brought to Earth from outer space. This hypothesis is called **panspermia**.

ACTIVITY 4

1. Which gases did Miller and Urey use in their experiment, and why?

2. Where did the organic molecules come from in the Miller-Urey experiment?

3. What do scientists still need to explain about the origins of life?

4. What is a theistic creationist?

5. Explain the panspermia hypothesis?
   Many people try to explain the origin of life by saying that life was first brought to Earth by aliens from a distant planet. Do you agree with this hypothesis? Give reasons for your answer.

ANSWERS ON PAGE 110

COMMENT

Life on Earth may have originated in primordial soup - a mixture of water, methane, carbon dioxide, ammonia and hydrogen - which was exposed to some energy source.

The appearance of more complex life and an oxygen-rich atmosphere in the Proterozoic Eon (2500-542 Myr)

During the early Proterozoic Eon large portions of the Earth were covered with shallow seas. Growing at the bottom of the sea were the cushions of blue-green algae called stromatolites which we have already mentioned earlier in the lesson. Living stromatolites may still be found in some places such as Shark's Bay in Australia (Figure 8).

These blue-green bacteria produced so much oxygen that eventually, about 2000 Myr ago, an oxygen-rich atmosphere and a protective ozone layer developed. Most living organisms at the time did not need oxygen to breathe and actually found it poisonous.

Figure 8: Modern stromatolites are found growing in the shallow sea in Shark Bay, Australia

The appearance of the first eukaryotes

To survive, several bacteria 'teamed up' to form the (eukaryote) cells which appeared about 1.6 billion years ago. Eukaryotes are cells which have their DNA in a nucleus and have organelles like the mitochondria and chloroplasts. Interestingly, the mitochondrion has its own DNA outside of the nucleus. The mitochondrion is the organelle that helps the cell to respire using oxygen.

Scientists hypothesise that an early bacterium, through the process of phagocytosis, absorbed free-living bacteria − the flagella, chloroplast and mitochondrion − to form a partnership (mutualism and symbiosis), creating the first eukaryotic cell (Figure 9).

We say that the flagellum, mitochondrion and chloroplast are beneficial endosymbionts in the cell. The mitochondrion helped the cell to cope with oxygen, the flagellum enabled the cell to move about, and the chloroplast helped the cell to create sugars out of carbon dioxide and water using the process of photosynthesis.

The appearance of the first multicellular life

Later the eukaryotic cells themselves began to 'team up', forming the first multicellular organisms. One of the advantages of being multicellular is that different cells can specialize to perform different tasks such as digestion, movement or defence. There is little trace of these soft-bodied organisms in the fossil record but paleontologists believe that this happened about a billion years ago.

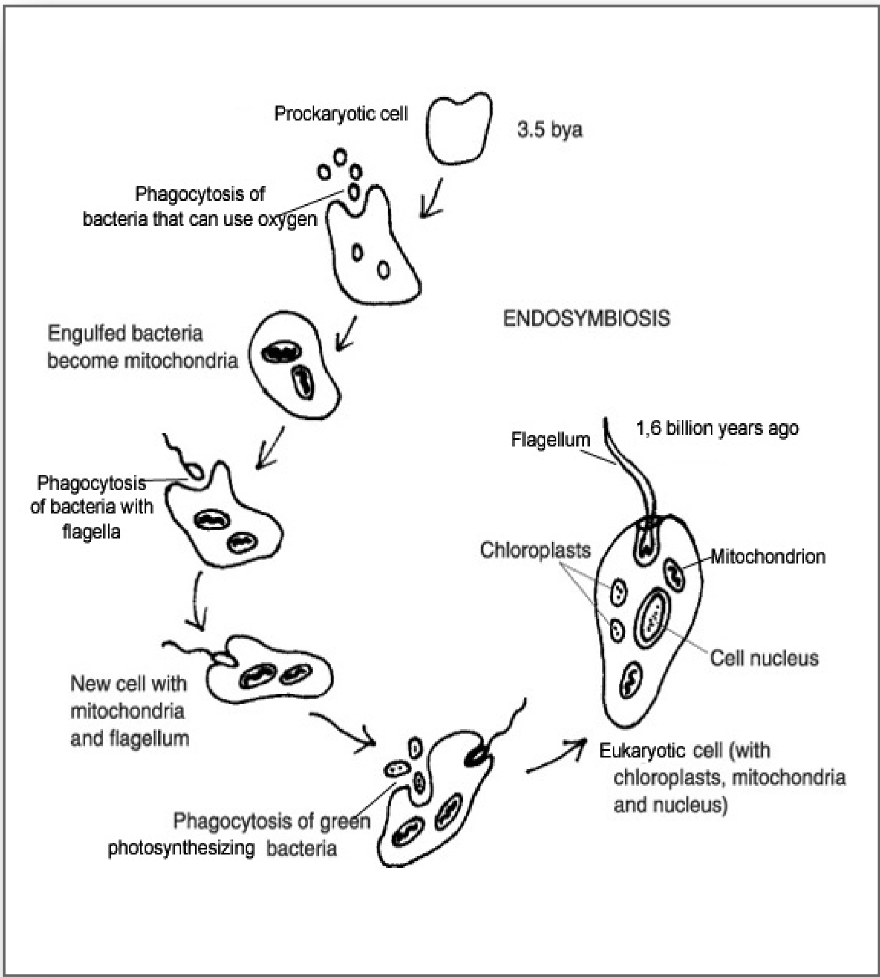


Figure 9: How the first eukaryote was formed by phagocytosis and endosymbiosis

The mysterious Ediacaran fauna

By the end of the Proterozoic some more complex multicellular life forms appeared. These were mostly very different from anything that had gone before and which survives today (Figure 10). These strange life forms are called the Ediacaran fauna after a range of hills in Australia. Like all life up to this time they lived in the sea. The most common forms must have looked a little like large leaves waving in the water. At least two modern Phyla of animals appeared during this time. They were the sponges (Porifera) and jellyfish and corals (Cnidaria). The Ediacaran fauna are also found preserved in the rocks of Namibia hundreds of million years later.

At the beginning of the Proterozoic you would have needed a space suit and oxygen supply to wander the Earth, but by end of it you would probably have been safe if you moved around in normal clothes and breathed the air.

Figure 10: A reconstruction of the Ediacaran Fauna
(Image Credit: National Museum of Natural History, courtesy of the Smithsonian Institution)

ACTIVITY 5

1. Where did the Earth get its oxygen-rich atmosphere from?

2. Explain how the appearance of the first Eukaryotic cell might have been a way for early life forms to cope with the new oxygen-rich atmosphere.

3. What is an endosymbiont?

4. What is one of the main advantages of being multicellular?

5. Which two modern Phyla of animals appear to have survived from Ediacaran times?

6. In your opinion, what were the **three** most important events in the Proterozoic Eon that were crucial to our appearance and survival today? Justify your answers.

ANSWERS ON PAGE 111

COMMENT

During the Proterozoic Eon the Earth's oxygen-rich atmosphere appeared which provided a layer of ozone that protected the evolving complex life forms against cosmic rays. Life really took off and diversified in the next Eon, the Phanerozoic. The first interval of the Phanerozoic is called the Paleozoic Era.

CHECKLIST

Are you able to:

- ❒ describe how the divisions of the Geological Time Scale are used to divide up Earth history
- ❒ describe the Hadean, Achaean, and Proterozoic divisions of the Geological Time Scale and the major events that occurred within them
- ❒ explain how the Earth originated by the process of accretion
- ❒ describe:
  - ■ the formation of the Earth's continents, oceans, and atmosphere
  - ■ the earliest life forms
  - ■ how Earth obtained an oxygen-rich atmosphere
  - ■ the symbiotic hypothesis for the formation of Eukaryotes
  - ■ early multicellular organisms
  - ■ the primordial soup hypothesis and panspermia hypothesis
  - ■ how the Miller-Urey experiment provides evidence that life may have originated from simple chemicals
  - ■ why a belief in the origin of life by natural means does not exclude a belief in God.

LESSON 4

The evolution of life during the Palaeozoic, Mesozoic and Cenozoic Eras

About this lesson

In this lesson you will see how more complex life forms evolved in the Paleozoic, Mesozoic, and Cenozoic Eras. These Eras are all part of the Earth's latest Eon, the Phanerozoic. You will explore the Cambrian explosion when most of the major phyla of animals arose on land, the invasion of land by plants and animals, and early plants in the prehistoric coal forests. Next you will learn about the age of reptiles, the magnificent dinosaurs, the arrival of flowering plants and mammals and the catastrophic impact of a huge meteorite at the end of the Cretaceous which eradicated the dinosaurs. After the disappearance of the dinosaurs (except for the birds) the mammals dominated, giving rise to the groups we see today. Grasses became common, the Earth's climate cooled, and ice caps re-formed at the poles.

In this lesson you will:

- learn about the appearance of the major phyla of animals during the Cambrian Explosion
- explore the invasion of land by plants and animals
- discover the huge variety of reptiles and other life on Earth during the Mesozoic Era
- learn about the extinction of the dinosaurs at the end of the Mesozoic
- learn about the diversification of mammals and other animals during the Cenozoic Era
- discover how the climate and environment changed throughout the Cenozoic.

Phanerozoic Eon:
The word Phanerozoic means 'apparent, evident or mainly obvious life', because this was the Eon when the Earth really teemed with life. The Phanerozoic is divided into three Eras
Palaeozoic Era:
The word Palaeozoic means 'time of ancient life'; this Era is divided into six Periods: Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian.
Mesozoic Era:
The word Mesozoic means 'time of middle life' and includes the Triassic, Jurassic, and Cretaceous Periods.
Cenozoic Era:
The word Cenozoic means 'new life' and includes the Palaeogene, Neogene and Quarternary Periods. Each Period is divided into a number of Epochs (see Figure 1 of Lesson 3).
Transitional Fossil:
any fossilized remains of a life form that has traits of its ancestor as well as later groups that arose from it.

Life's explosion and invasion of land during the Palaeozoic Era (452myr to 251myr)

An amazing event occurred at the beginning of the Palaeozoic Era 542 million years ago. In the short period of time of only about 20 million years most of the major groups of animals or Phyla appeared.

The appearance of these different life forms was so rapid and spectacular that paleontologists call it the “Cambrian Explosion” (Figure 1). It is called this because the Cambrian is the name of the first Period of the Paleozoic Eon, and is called an explosion because the appearance of all these different types of life was so sudden.

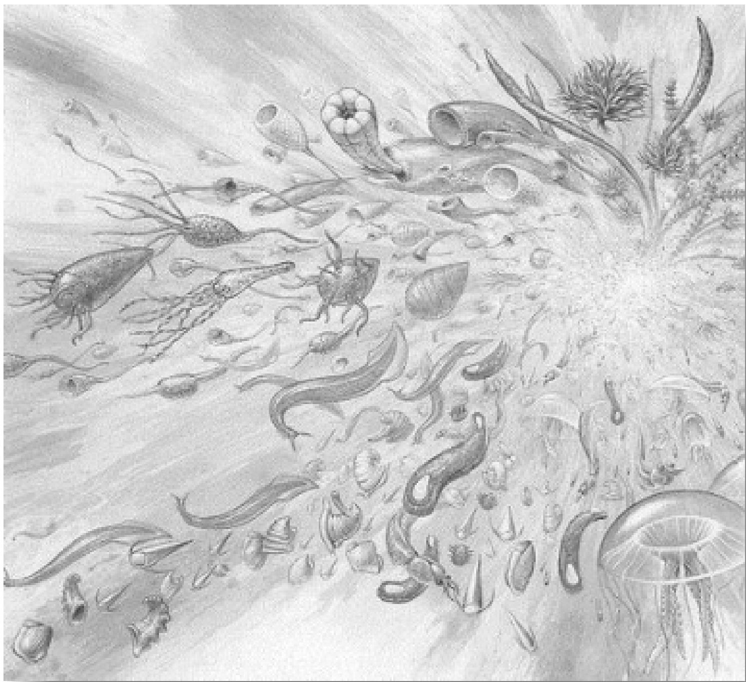


Figure 1: An artist's representation of the Cambrian “Explosion”

Some of these were the ancestors of the insects, crustaceans, spiders (Arthropoda), earthworms (Annelida), snails, oysters, octopi (Mollusca), and vertebrates (Chordata).

Throughout the Palaeozoic, life continued to diversify. At first most of the life was in the oceans. There were corals similar to ones we find today, but there were also bus-sized carnivorous armoured fish called placoderms (Figure 2) and sea scorpions larger than a fully grown man (Figure 3). Fossils of these creatures have been found in the Eastern and Western Cape.

Figure 2: Reconstruction of a Placoderm

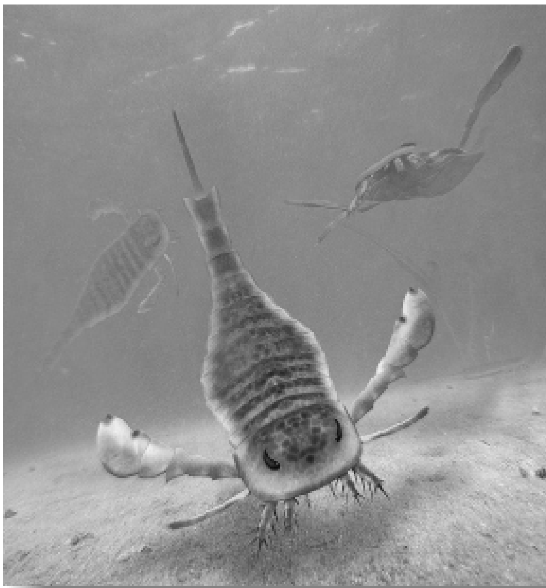


Figure 3: Reconstruction of a Eurypterid

Later, during the Silurian Period (443 Ma), life moved onto land. At first there were only bacteria and algae, and, later, simple plants related to mosses (Bryophytes). Fossils of these very early land plants are found near Grahamstown today.

A little later more complex plants such as ferns (Pteridophytes), tree-sized horse tails Sphenophytes), club-mosses (Lycophytes), seed ferns (Pteridospermophyta [see Figure 5]), and Gymnosperms (cycads, conifers and their kin) emerged. These plants existed in huge swamps in Europe and South Africa (Figure 4).These swamps became buried and fossilized to form coal. In South Africa the remains of our coal forests are found at places such as Emalahleni, Vereeniging, Ermelo, Newcastle and Dundee. These are all towns built near coal mines which supply Eskom to drive its power stations and give us energy.

The early plants reproduced with spores and had to be near water in order to survive and reproduce, but later plants had seeds with water-proof coverings so that they could survive away from water.

The invasion of the land by plants during the Silurian Period was followed by the invasion of land by animals during the Devonian Period. The early land animals were invertebrates like insects and spiders and of course the **tetrapods** (animals with four legs like amphibians, reptiles and mammals). The ancestors of tetrapods were lobe-finned fish: fish with fins on fleshy stalks like the **Coelacanth** (Figure 6). There are two living species of coelacanth.

One lives off the East African Coast (including South Africa) and the other in Indonesia. We also find fossil coelacanths hundreds of millions of years old, and for this reason living coelacanths are called **living fossils**.

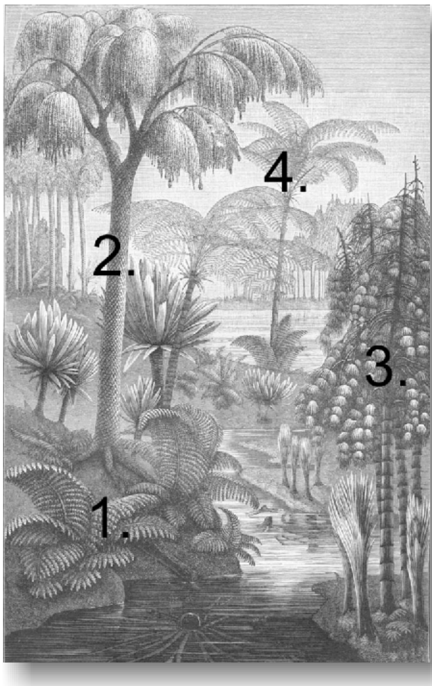


Figure 4: A reconstruction of an ancient Coal Forest 1. Fern, 2. Club Moss 3. Horse Tail, 4. Tree Fern

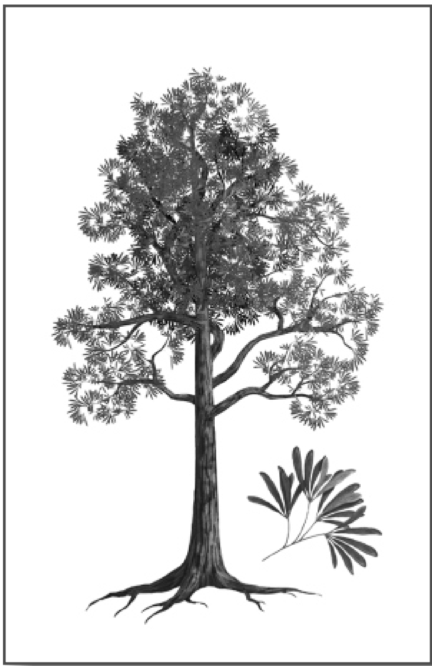


Figure 5: A Glossopteris tree is an example of a seed fern

An early tetrapod and amphibian was called Acanthostega (Figure 7). It was covered with scales and had a fish tail and gills. But it also had ribs and lungs, feet with toes, and could have moved about on land, perhaps to bask in the sun. Acanthostega was part fish and part amphibian. It was transitional between the two groups and is known as a **transitional fossil**. Some call Acanthostega a 'fishapod'. Other early amphibians did not have a fish tail, were rather like large crocodiles, and spent most of their time in the water. All these amphibians laid their eggs in water like modern frogs and toads.

Later in the Palaeozoic, at the same time as the great coal forests of Europe, a small group of lizard-like animals evolved from the amphibians. These animals had eggs which they could lay away from water. These eggs are called **amniotic eggs** and the animals are called amniotes. The amniotes divided into a branch which led to the mammals and a branch that led to the reptiles and birds.

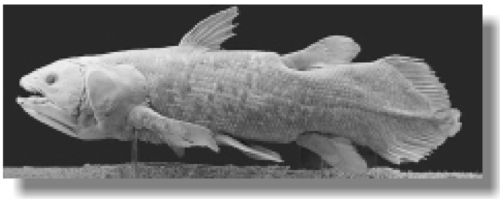


Figure 6: A preserved specimen of a Coelacanth

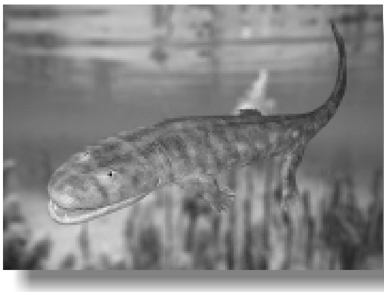


Figure 7: Acanthostega

The last period of the Paleozoic is called the Permian. Many mammal ancestors wandered the Earth and examples are shown in Figure 8. There were plant eaters called **dicynodonts** which had beaks like a tortoise and tusks like a warthog and also ferocious meat eaters called *Gorgonopsians*. There were many different types of reptiles, large tortoise ancestors called *Pareiosaurs*, and also early ancestors of the dinosaurs. At this time the first cycads and gymnosperms appeared and *Glossopteris*, seed ferns, together with ordinary ferns and horse tails (Figure 8), were very common. The Karoo of South Africa is famous because it has so many fossil mammal ancestors.

dicynodonts:
means 'two dog teeth'

The Palaeozoic Era ended dramatically with the extinction of most life on Earth. Something destroyed most of life on Earth, although nobody knows exactly what: 90% of all marine organisms and 70% of all terrestrial life became extinct. When so many species became extinct at one time we say that a **mass extinction** event has taken place. Extinction of current biodiversity is discussed in Unit 7.

ACTIVITY 1

1. Name four Phyla which appeared during the **Cambrian explosion**.
2. Name three groups of plants that lived in the coal forests of Europe and South Africa.
3. What is a **Tetrapod**?
4. Why are living coelacanths called **living fossils**?
5. Why is *Acanthostega* called a **transitional fossil**?
6. What adaptation allows amniotes to live away from water?
7. Which three groups of amniotes are common today?

8. In Permian times *dicynodonts* were common herbivores while *gorgonopsians* were rarer ferocious carnivores. Name 6 animals in the game reserve today that play similar roles to the *dicynodonts* and *gorgonopsians* in the Permian?

9. Place these events from the Palaeozoic in the correct order from oldest to more recent.
   a. The end-Permian Mass extinction ended most of life on Earth
   b. Most of the animal Phyla appear very rapidly in the Cambrian Explosion
   c. Simple plants rather like mosses invade the land
   d. Plants with water-proof seeds appear
   e. Plants appear that require moist conditions to reproduce.
   f. Coal forests rich in ferns, tree ferns, club mosses and horsetails are common.
   g. Lizard-like animals called amniotes appear. They lay water-proof eggs away from water.
   h. First four-legged animals arise. These had gills, fins, and scales like aquatic fish, but also had lungs, and legs like land animals.
   i. The two main branches of amniotes that are alive today split off, giving rise to the reptiles and mammal ancestors (later, the reptiles give rise to birds).

10. Examples of a number of fossils are given below. Study them and decide whether they are transitional fossils, ordinary fossils, or ancestors of living fossils. Justify your answers.
   a. A fossil zebra 15 000 years old, similar to the ones you find in the Kruger Park today
   b. A 68 million-year-old fossil snake with short legs
   c. A winged dinosaur with feathers and teeth
   d. A fossilized mat of blue-green algae that is three
   e. A fossilized ape which walks erect like humans and uses stone tools
   f. A fossilized dinosaur

11. In your opinion, what were the **four** most important events in the Palaeozoic Era that were crucial to our appearance and survival today? Give reasons for your answers.

ANSWERS ON PAGE 112

COMMENT

During the Paleozoic, life diversified and invaded land, setting the stage for the next Era – the Mesozoic or Age of Reptiles.

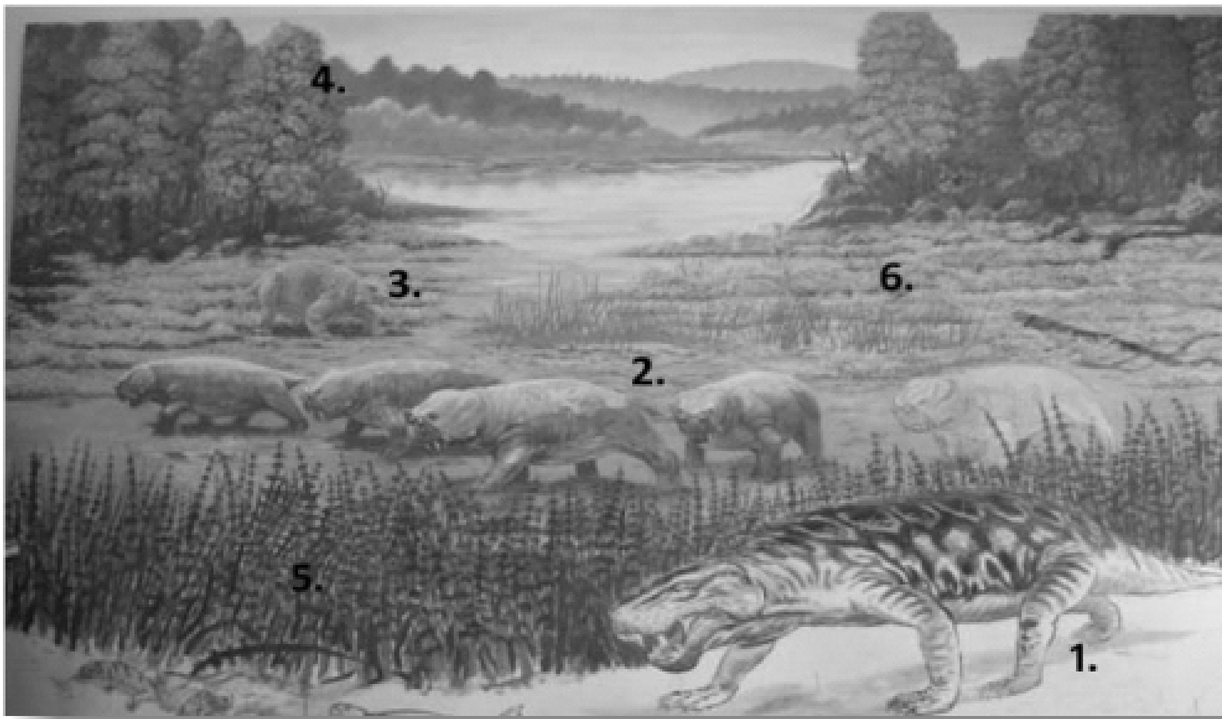


Figure 8: Life in the Permian: reconstruction from fossils found in the Karoo of South Africa 1.Gorgonopisan, 2. Dicynodonts, 3. Pareiosaur, 4. Glossopteris, 5. Horsetails, 6. Ferns

The Mesozoic Era and the age of reptiles (251 - 65 Myr)

During the Mesozoic the reptiles were the most common group of animal. In the oceans the mighty *Icthyosaurs, Plesiosaurs* and other marine reptiles dominated (Figure 9). A *Plesiosaur* was found near Uitenhage in the Eastern Cape.

Mesozoic Era:
The word Mesozoic means 'time of middle life' and includes the Triassic, Jurassic, and Cretaceous Periods.
dinosaur:
A group of extinct reptiles. The word dinosaur means 'terrible lizard'.

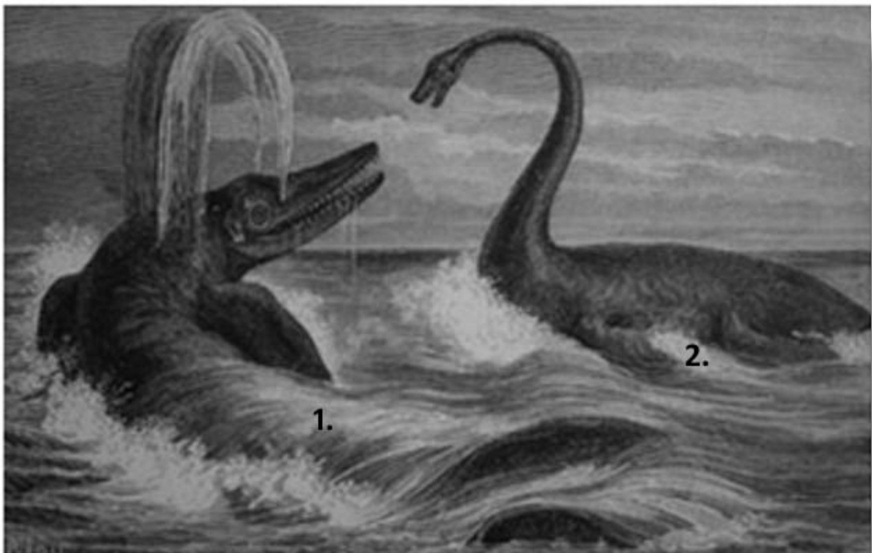


Figure 9: Some marine reptiles
1. Icthyosaur 2. Plesiosaur

On land, 'ruling reptiles' like crocodiles and winged Pterodactyls reigned. The most famous of the ruling reptiles were the dinosaurs (Figure 10). They ranged in size from the mighty *Tyrannosaurus*, one of the largest predators that ever lived (length 13 m), to the long-necked sauropod dinosaur called *Argentinosaurus* (length 35 m, and one the largest animals that ever lived), to the smallest dinosaur, *Compsognathus*, about the size of a chicken. Some dinosaurs were warm blooded and covered with feathers (Figure 11), so it is not surprising that the first birds arose as a specialized group of flying dinosaurs in the middle of the Mesozoic about 150 million years ago.

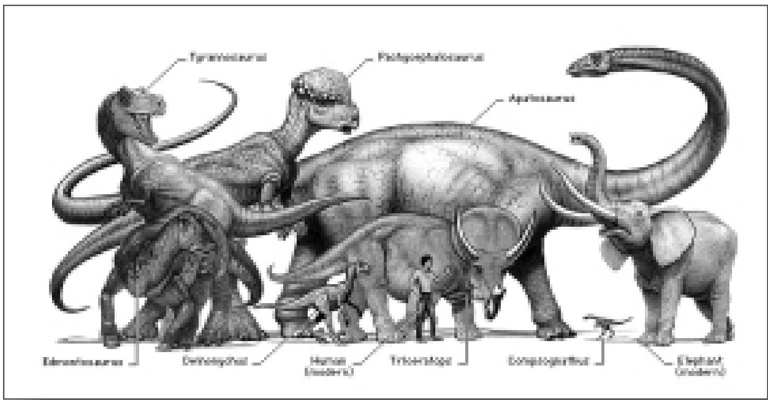


Figure 10: A variety of dinosaurs

Figure 11: A feathered dinosaur

The very first bird was a small dinosaur with teeth (instead of a beak), and wings with claws. This bird's name was *Archaeopteryx* (Figure 12) and it is another example of a transitional fossil. Africa had its own special dinosaurs such as *Massospondylus* (Figure 13), *Antetonitrus* and *Aardonyx*. Fossils of these creatures are found around the borders of Lesotho. During the Mesozoic, snakes, lizards, frogs, and tortoises appeared.

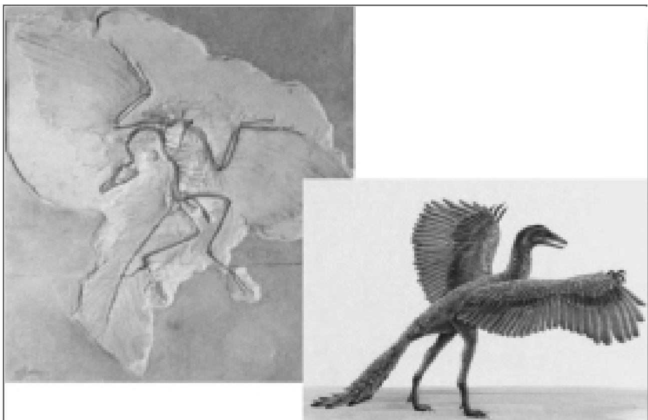


Figure 12: Archaeopteryx, a dinosaur with teeth and wings, is considered the first bird

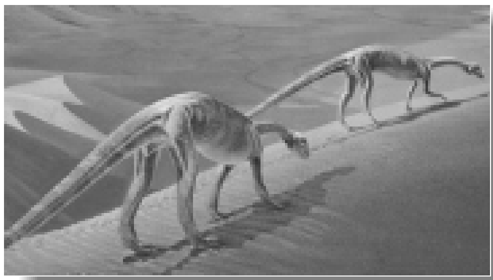


Figure 13: Massospondylus a South African dinosaur

Mammal ancestors such as *Lystrosaurus* and *Thrinaxodon* (Figure 14) were common in the Karoo 235 million years ago and fossils have been found near Harrismith. *Thrinaxodon* may have been warm blooded and had fur (Figure 14). About 190 million years ago, small insectivorous (insect eating) rodent-like true mammals such as *Megazostrodon* (Figure 15) from the Lesotho border appeared. Towards the end of the Mesozoic, there were also larger, badger-sized dinosaur- eating mammals.

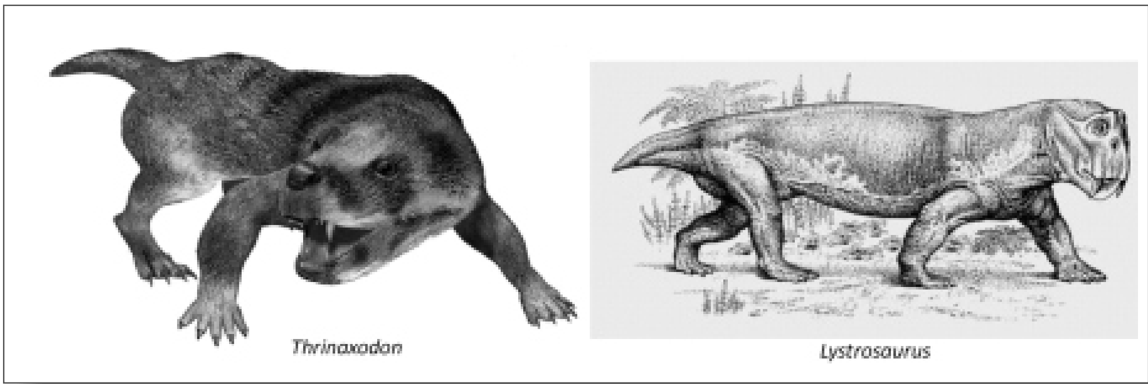


Figure 14: Thrinaxodon and Lystrosaurus

Amongst the plants, the flowering plants made their appearance towards the end of the Mesozoic. Along with flowers came pollinators such as butterflies and bees. Social ants, bees and termites appeared at about the same time. The Mesozoic Oceans had unique molluscs such as spiral shelled ammonites, relatives of the octopi and squids (Figure 16).

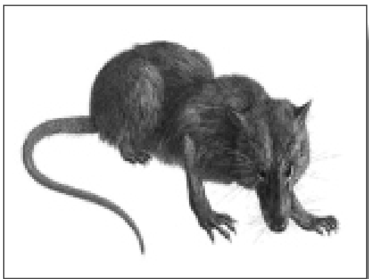


Figure 15: Megazostrodon an early mammal

Figure 16: Ammonites

The Earth during the late Mesozoic was hot and humid with no ice caps. There is evidence of dinosaurs living close to the South Pole. The melting of the ice caps resulted in warm seas and high sea levels. Continents such as North America and Africa were flooded and had shallow seas in their centre. The warm oceans and high sea levels caused enormous storms which drowned thousands of dinosaurs at a time.

The Mesozoic ended with a mass extinction, probably brought about by the impact of a giant meteorite that struck in Mexico 65 million years ago (the Chicxulub meteorite – see Lesson 1). The meteorite threw a huge cloud of dust into the atmosphere and blocked the sun, causing long winters and killing plant life. Many Mesozoic life forms disappeared, including the dinosaurs (with the exception of the birds), the pterodactyls, and the ammonites. Luckily for us, mammals survived, as did crocodiles and many other forms.

ACTIVITY 2

1. Which group of vertebrates was most common in the Mesozoic?
2. What does the word dinosaur mean?
3. What did some dinosaurs have covering their bodies for insulation?
4. What do mammals have covering their bodies for insulation?
5. Which group of dinosaurs survived the mass extinction 65 million years ago?
6. Why did Mammals remain small throughout the Mesozoic?
7. Which group of plants appeared right near the end of the Mesozoic Era?
8. What was the climate like at the end of the Mesozoic Era?
9. We are presently living in a time of global warming when the ice caps appear to be melting. Read the section on the climate during the late Mesozoic carefully. How do you think the conditions on Earth might change if global warming trends continue?
10. In your opinion, what were the **three** most important events in the Mesozoic Era that were crucial to our appearance and survival today? Justify your answers

ANSWERS ON PAGE 113

COMMENT

The Mesozoic Era was the age of reptiles which dominated the land, sea, and air. On land the dinosaurs or terrible lizards – the largest land animals ever – ruled. Only mammals have attained similar size and diversity since, but the mammals only became common in the next Era, the Cenozoic.

The Cenozoic Era and the age of mammals (65 Myr to now)

The Cenozoic was and still is the age of mammals. The mammals of the Early Cenozoic were peculiar. There was *Andrewsarchus* (Figure 17), a large predator with small hooves on its toes, and *Basilosaurus*, an early, predatory whale with a tiny pair of hind legs that were probably used as claspers in mating.

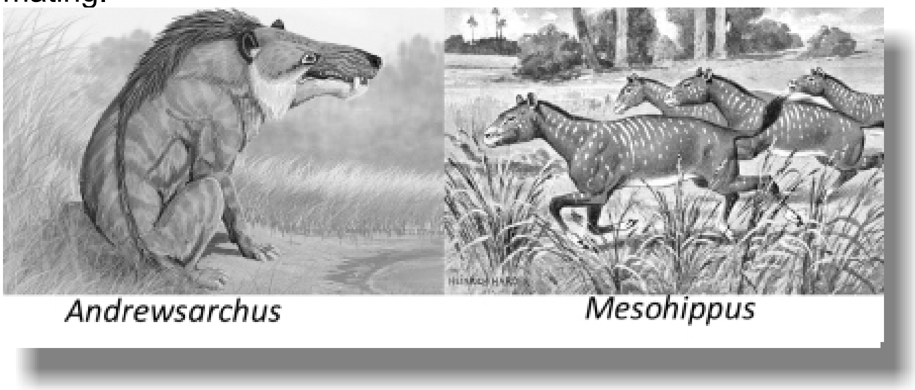


Figure 17: Andrewsarchus and Mesohippus were two peculiar early Cenozoic mammals

Mesohippus, an early relative of horses, stood only 60 cm tall (Figure 17). There were fearsome 'terror birds' – giant flightless birds, one and a half times the size of a man – that actively hunted their prey (Figure 18).

The early Cenozoic Earth was warm and forested. Later the climate cooled, ice caps formed and forests were replaced by grasslands (grasses only appeared in Cenozoic). During the last 20 million years the ice caps expanded. The Earth became covered with ice, almost to the equator, and these cold times became known as the **ice ages.**

Figure 18: A Terror bird

During these times woolly mammoths and sabre tooth cats became common (Figure 19). In South Africa we also had sabre tooth cats together with African Bears and Short Necked Giraffes. Fossils of these may be seen at West Coast Fossil Park in the Cape. Finally, about 7 million years ago the first 'upright walking' great apes or hominins appeared, which were the ancestors of modern humans. Modern humans themselves appeared about 200 000 years ago. South Africa is famous for

Figure 19: Wooly Mammoths and Sabre Tooth Cats during an ice age

ACTIVITY 3

1. Name three predators from the early Cenozoic.

2. Why do you think that mammals were stranger and more peculiar at the beginning of the Cenozoic rather than at the end of the Cenozoic?

3. Approximately when did the first modern humans appear?

4. Which important plant group only appeared in the Cenozoic?

5. How did the climate and environment change during the Cenozoic?

6. In your opinion, what were the **three** most important events in the Cenozoic Era that were crucial to our appearance and survival today? Justify your answers.

ANSWERS ON PAGE 114

COMMENT

The Cenozoic is the Era of mammals and grass. It is also the age when humans and their direct ancestors arose from a common ancestor with chimpanzees. More recently in the Cenozoic there have been ice ages which have threatened human civilization because of the rapid swings in climate.

CHECKLIST

Are you able to:

- ❐ describe the Palaeozoic, Mesozoic and Cenozoic divisions of the Geological Time Scale and the major events that occurred within them
- ❐ describe:
  - the Cambrian explosion
  - the invasion of land by plants and animals
  - plants of the coal forest
  - the importance of water-proof seeds in plant evolution
  - the importance of an amniotic egg in animal evolution
  - life in the age of dinosaurs
  - what occurred to cause the extinction of the dinosaurs
  - the diversification of the mammals, the spread of grass, and the cooling of the climate in the Cenozoic
- ❐ explain:
  - transitional fossils
  - living fossils
  - mass extinctions.

NOTES

LESSON 5

Human evolution: the formation and dating of fossils

About this lesson

In this lesson you will discover more about the origin of humans in Africa and the importance of the Cradle of Humankind in South Africa. You will also discover how fossils are formed through the process of petrification and the absolute and relative dating methods that we use to tell the age of rocks and the fossils within them.

In this lesson you will:

- learn about the history of fossil discoveries in South Africa's Cradle of Humankind
- find out about some of the most famous discoveries of the fossils of human ancestors
- learn how fossils are formed through the process of petrification
- learn how scientists estimate the age of rocks using relative dating and absolute dating.

Human Fossils ancestors and the Cradle of Humankind

Figure 1: Taung Child: the first hominin found in Africa

In 1886 gold was discovered on the Witwatersrand in South Africa. Within months, people from all over the world rushed to the area in search of gold. The process used to extract the gold from gold ore required large amounts of limestone (calcium carbonate), often referred to as 'lime'. Geologists began searching South Africa for lime deposits for use in the gold mining industry. High quality lime deposits were found in the stalagmites and stalactites of ancient caves at places such as Taung, Sterkfontein and Makapansgat. By coincidence, the ancient caves that contained lime deposits also contained many fossil remains of animals. These animals had become trapped in the caves hundreds of thousands and millions of years ago. The lime miners showed the fossils to scientists who found that they belonged to sabre tooth cats, extinct baboons and elephants. Scientists also found that some of the fossils belonged to one very interesting group. This group was not the same as modern humans, but were more human-like than gorillas and chimpanzees.

The first famous discovery of human-like fossils was the fossilised skull of a child found near the town of Taung in the present day North West Province. The skull became known as the Taung Child (Figure 1). Professor Raymond Dart of the University of the Witwatersrand first studied the Taung Child skull in 1925. Professor Dart found that the Taung Child skull had characteristics of both modern humans and chimpanzees. He concluded that it could be an ancestor to modern humans.

At the time, most other scientists disagreed with Professor Dart. Many changed their minds when Robert Broom from the Transvaal Museum discovered more fossils of human ancestors. One of the most famous of these was found at Sterkfontein Caves in the North West Province in 1947. The fossil was named *Plesianthropus transvaalensis*, or Mrs Ples (Figure 2). Mrs Ples had the same mix of chimpanzee and modern human characteristics as the Taung Child. Today the Taung Child and Mrs Ples are placed in the same species known as *Australopithecus africanus* or 'southern ape of Africa'.

Figure 2: Mrs Ples

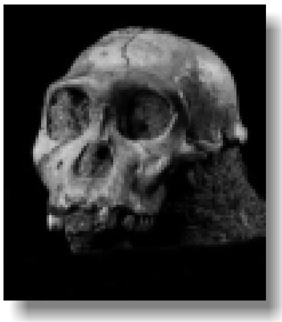


Figure 3: Austalopithecus sediba

Since the discovery of the Taung Child and Mr Ples, fossils of other species of human ancestors and their relatives have been discovered in and around Sterkfontein. For example, *Paranthropus robustus* and *Homo erectus / ergaster* are all human-like species that have been found there. Very recently, a new, almost complete skeleton was found not far from Sterkfontein. This was *Austrolopithecus sediba* (Figure 3), which means 'southern ape from the source or spring'. All the human ancestors, once they had split off from their common ancestor with the chimpanzees, are called the **hominins**. All hominins, like humans, walk upright on two legs instead of on all fours like chimpanzees and gorillas.

Hominini or Hominin: *the name given to humans and their ancestors after they branched from the non-human Great Apes*

Because of the wealth of fossils of human ancestors found in the area, Sterkfontein and its surroundings have been called the Cradle of Humankind. The area was declared a World Heritage Site, and in 2005 two new world-class museums were opened at Maropeng and Sterkfontein in the Cradle of Humankind. The exhibitions in these museums explain how humans evolved and why the Cradle of Humankind is important as a World Heritage Site.

Most of the sites of the Cradle of Humankind are around Maropeng and Sterkfontein Caves North West of Johannesburg. There are also sites in Taung in the North West province (North of Kimberley) and Makapansgat just off the main route to Polokwane in the Limpopo Province.

Most of the human ancestors' skeletal remains found in the Cradle of Humankind belong to the earlier genus *Australopithecus,* although some early *Homo* are also present. In South Africa, the remains of human ancestors belonging to our genus (*Homo*) were found in Florisbad in the Free State near Bloemfontein. Early modern *Homo sapiens* (our species) are also known from Blombos Cave in the Western Cape and the Sibudu and Border Caves in KZN.

These sites are also very exciting because they contain some of the earliest evidence for art (patterned ochre stone), jewellery (shell necklaces), sophisticated stone tools, and the use of plants for bedding between 60 000 and 80 000 years ago at least 20 000 years before humans did similar things in Europe (Figure 4).

Figure 4: A piece of patterned ochre stone, bone tools and stone tools from blombos

Outside South Africa early hominin fossils have been found in East Africa and Chad, which is why all of Africa can be considered the Cradle of Humankind. *Homo erectus* left Africa 1.8 million years ago and *Homo sapiens* left Africa about 100 000 years ago. The fossils of these two species have been found in many parts of the world.

ACTIVITY 1

1. Why were geologists so interested in finding lime after 1886?

2. How did scientists hear about the fossils in the lime mines?

3. Which was the first hominin fossil discovered and why did Professor Dart believe that it might be the ancestor of a human?

4. Early human ancestors have been found outside South Africa, in East Africa and other places in Africa. Do you think it is fair to call South Africa the Cradle of Humankind?

5. What does the name *Australopithicus africanus* mean?

6. What evidence for human culture do we find at caves such as Blombos cave, and how old is this evidence?

7. Study Figure 5, which is a graph that shows how hominin brain capacity increased over time. Answer the questions that follow.

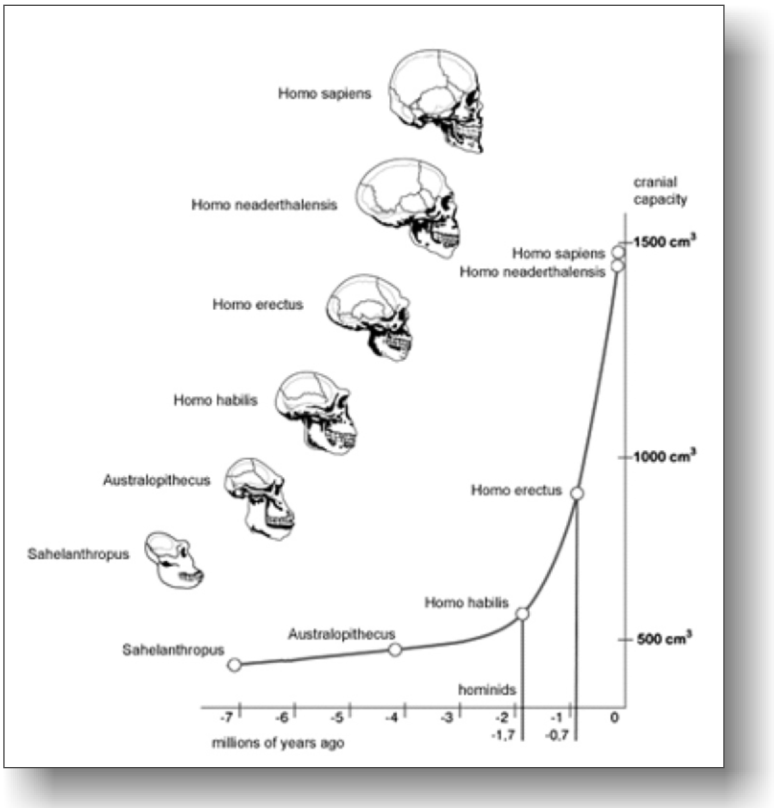


Figure 5 Graph showing how brain size (cranial capacity) of a number of hominin species increased over time

a. Brain size or cranial capacity is measured in cm3. What does cm^3 stand for?
b. What is the approximate average cranial capacity of *Sahelanthropus* and *Homo sapiens*?
c. According to the graph, about how long ago did Australopithecus and *Homo erectus* live?
d. What trend in cranial capacity do you detect between *Sahelanthropus* and *Homo erectus*, and how does this trend differ from the trend in cranial capacity between *Homo habilis* and *Homo sapiens*?
e. Why do you think that brain size is important in human evolution?

ANSWERS ON PAGE 114

COMMENT

The closest living relatives of humans are the chimpanzees. We find the ancestors of humans (upright walking apes, or hominins) in Africa. Many fossils are found in South Africa's Cradle of Humankind. The earliest evidence of art also comes from South Africa. Next you will find out how.

The formation of fossils

extinct organism:
a group of organisms (for example plants or animals) that no longer exists.
petrification:
the process in which living organisms are turned into stone by being soaked in Silica or Calcium Carbonate.
fossil:
remains or trace of an organism that lived a long time ago and has been preserved in rock.
Sedimentary Rock:
rock formed from mud, sand, pebbles, salt or carbonates in a river, lake, sea, desert or icy environment. Examples of sedimentary rocks are sandstones, mudstones, dolomites, and limestone.

How fossils are formed by petrification

People used to believe that strange skeletons preserved in rock belonged to dragons and giants. Today we know that giants and dragons never existed and that the skeletons are fossils which belong to extinct organisms that lived on Earth many thousands and millions of years ago. Actually, fossils are not only the skeletons of animals they can be the remains of any life form preserved in a sedimentary rock. In this section you will learn how fossils are formed.

It has been estimated that only one in a million organisms will become fossilized. Fossils can be formed in different ways. The basic fossilization process, called petrification, is given below. The example shows how a skeleton is fossilized, but it could also work for a piece of wood.

Death and Burial

An animal or plant dies and becomes buried quickly. The quick burial prevents the body from being decayed by bacteria or destroyed by scavengers. Such burial can take place in the sea, a river, a lake or desert (see Figure 6).

Sedimentation

This burial process needs to be repeated year after year. Organisms living in the sea are continually dying, sinking to the bottom and being buried, or a river may flood each year, drowning and burying animals and plants. This carries on for hundreds of thousands of years until eventually the dead animal or plant is buried under many metres of sediments (Figure 7).

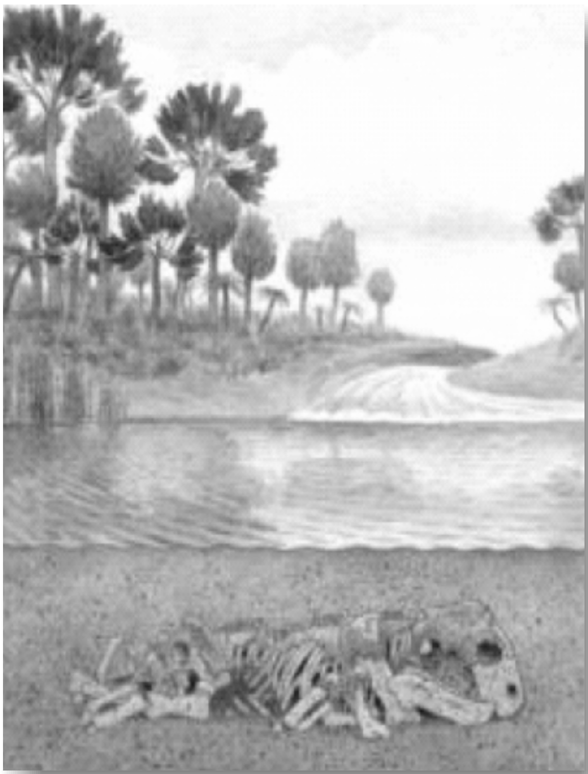


Figure 6: Death and Burial

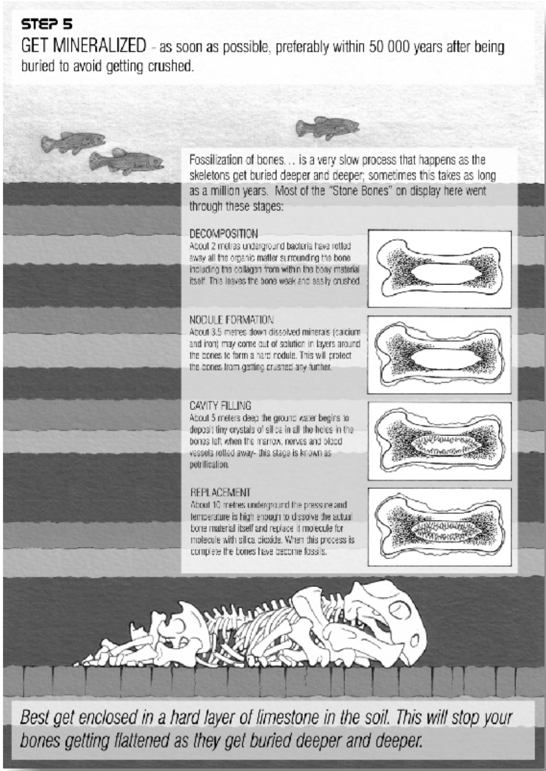


Figure 7: Sedimentation and petrification

Preservation by petrification

Deep underground, pressures and temperatures are high. The particles of sediment become soaked with groundwater that has dissolved Silica.

This Silica-rich ground water glues or cements the sand and mud particles together, forming sedimentary rocks such as sandstone and mudstone. This cement is the mineral Silica.

The Silica-rich groundwater soaks into and replaces the remains of the dead animal and plants (Figure 7). In a well-preserved petrified bone or log you can see cells and matrix perfectly preserved but they are no longer made of Cellulose, Calcium and Phosphorous. Instead, they have been replaced by Silica. Carbonate, instead of Silica, can also petrify an organism.

Uplift and Erosion

Over time, huge forces within the Earth push the newly formed sedimentary rocks and fossils back up to the surface and above sea level.

When the rock and fossils are above sea level, slow erosion by rain, river and wind will carve them up, eventually exposing the fossils to the surface where they can be found by palaeontologists (see Figure 8).

Figure 8: Uplift and Erosion (http://www.iziko.org.za/)

ACTIVITY 2

1. Unscramble the sentences below that describe the process of fossilization.
   a. Forces deep in the Earth lift the fossil skeleton up to the surface where it can be exposed by erosion.
   b. Silica is dissolved in ground water at high temperatures and pressures deep in the Earth.
   c. The skeleton is buried by mud and sand before it can be eaten by scavengers.
   d. Silica, dissolved in water, soaks into the skeleton, replacing the cells and turning the cells into stone.
   e. An animal or plant dies.
   f. The skeleton is buried under a new layer of mud or sand every year for many thousands of years until it is deep in the Earth.

ANSWERS ON PAGE 115

COMMENT

The basic process of fossilization is called petrification. Organisms become preserved and buried deep in the Earth where the basic cellular structure is replaced by silica or calcium carbonate, creating stone. Next you will learn how scientists estimate the age of fossils.

Estimating the age of fossils

The Earth is about four thousand five hundred million years old (4.5 billion years old). Life on Earth has changed dramatically throughout the Earth's history. Palaeontologists use geological time when they study the history of life on Earth. Geological time is measured in millions of years. The unit that palaeontologists use as their unit of time is called million years ago (Myr).

The question that you should ask, then, is how do scientists estimate the age of fossils? How can they say that the Earth is 4.5 billion years old or that one fossil is older than another? Scientists use two methods to estimate the age of fossils rocks.

radioactive element:
an element that has an unstable nucleus and changes to a more stable form by giving off Gamma radiation (high frequency electromagnetic radiation), Beta radiation (electrons), or Alpha radiation (helium nuclei, which consist of two protons and two neutrons).
half-life:
the length of time it takes for half a mass of a radioactive element to change into its daughter product.

Relative dating

Relative dating is a method that allows scientists to say that one fossil is older than another, but does not tell them exactly how old a particular fossil is. Figure 9 shows a mountain in the Karoo which is composed of horizontal layers of sedimentary rocks. For hundreds of years geologists have noticed that sedimentary rocks are laid down in layers like the ones in the Karoo. The oldest layers are at the bottom and the youngest layers are at the top.

Figure 9: Horizontal layers of rocks in the Karoo

Absolute Dating

Absolute dating methods allow scientists to estimate how old a rock actually is. Scientists use **radioactive decay** to work out the absolute age of rocks and fossils. You may remember from Unit 2 that certain elements are not stable. These unstable radioactive elements may change or **decay** naturally into another daughter element or isotope.

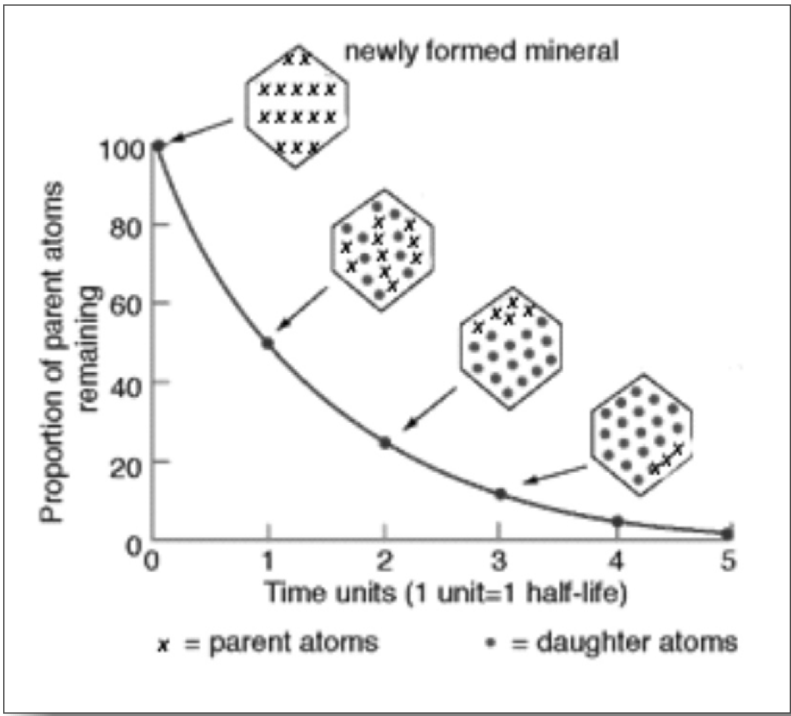


Figure 10: Radioactive decay curve

For example:

- ^{14}C (carbon-14) decays to become ^{14}N (Nitrogen-14)
- ^{238}U (uranium-238) decays to become ^{206}Pb (lead-206)
- ^{40}K (Potassium-40) decays to become ^{40}Ar (argon-40)

The useful thing about these radioactive elements is that we know how long it will take for them to decay. For example it takes:

- 5672 years for half of the 14C atoms in a sample to decay to become 14N atoms
- 4.47 billion years for half of the 238U atoms in a sample to decay to become 206Pb atoms
- 704 million years for half of the 235U atoms in a sample to decay to become 207Pb atoms
- 1248 million years for half of the 40K atoms in a sample to decay to become 40Ar atoms.

The time taken for half of the atoms of a radioactive element in a sample to decay to their daughter product is called their **half-life**. The half-life principle allows us to calculate how old that rock sample is. For example, if we take a lump of rock and count the number of ^{238}U atoms and the number of ^{206}Pb atoms and we find that there is approximately half of each, then we can estimate that the rock is about 4.47 billion years old. If we plot the graph of time versus proportion of daughter product or daughter element we get a curve like the one in Figure 10.

Although scientists can only estimate how old a rock is using absolute dating, the estimates are actually very accurate. For example, Uranium-lead dating is between 1% and 0.1% accurate, meaning that if the dating tells us that a rock is 100 million years old then the rock is probably between 99 million and 101 million years old because 1% of 100 million is 1 million. Scientists use different methods to double-check their dating. For example, they could use ^{235}U/ ^{207}Pb and ^{40}K/ ^{40}Ar methods on same piece of rock to see if they get the same answer.

Scientists use different techniques to estimate the age of rocks or artifacts of different ages. For example, if they think a rock is very old they will use Lead-Uranium dating because Uranium has a half-life of billions or hundreds of millions of years. If they are trying to date a clay pot less than 40 000 years old they will use Carbon dating because ^{14}C has a half-life of only thousands of years.

ACTIVITY 3

1. We are told that rocks and fossils are millions of years old. But how long is a million years? Try the following thought experiments to find out more:
   a. The average generation for humans is 20 years. How many human generations are there in a million years? How could life change in a million years?
   b. If 1 cm represents a year, what distance represents a million years?
   c. Think of a journey. If one step of about one metre represents a year, how far would you have to walk to represent a million years? If you started from your school what city would you eventually reach?
   d. Imagine you were paying a million rand in one rand coins to a teller at a bank. If you paid one rand per second, how long would it take?

2. Imagine that we study three different sections of the cliff in Figure 11 on the next page. The three sections are far apart from each other, but the rock layers were once joined. Figure 11 shows the three sections of the cliff. Use the sections to answer the questions below.
   a. Which are the youngest fossils? What rock type are they in?
   b. Were the youngest fossils mentioned in question a. deposited in the sea or on land? Explain your answer.

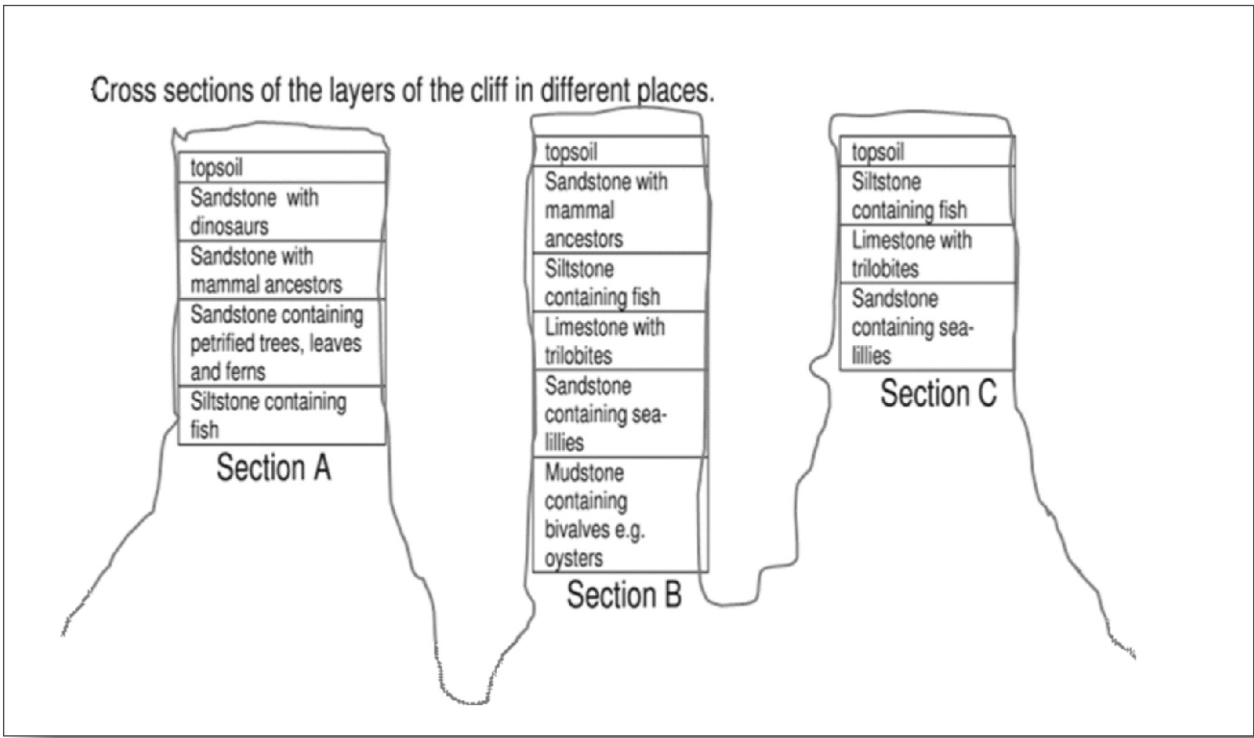


Figure 11: Cross section of a cliff in three places

c. Which are the oldest fossils? What rock type are they in?

d. Were the fossils mentioned in question (c) deposited in the sea or on land? Explain your answer.

e. Sections A, B and C are different. Can you explain why and how the layers have changed from one cliff face to the next?

3. Analyse the decay curves in Figures 12 and 13 and answer the questions that follow.

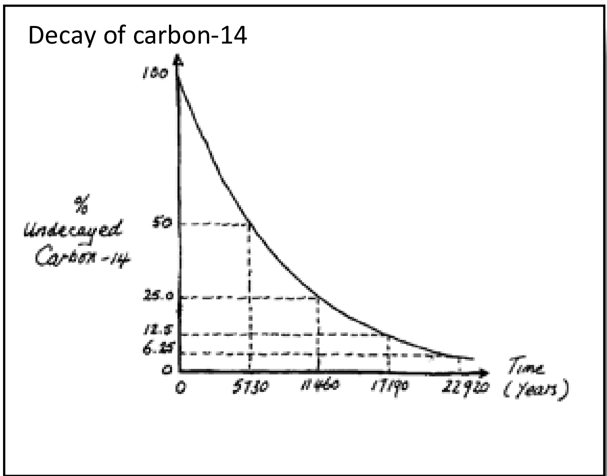


Figure 12: Decay Curve of Carbon-14

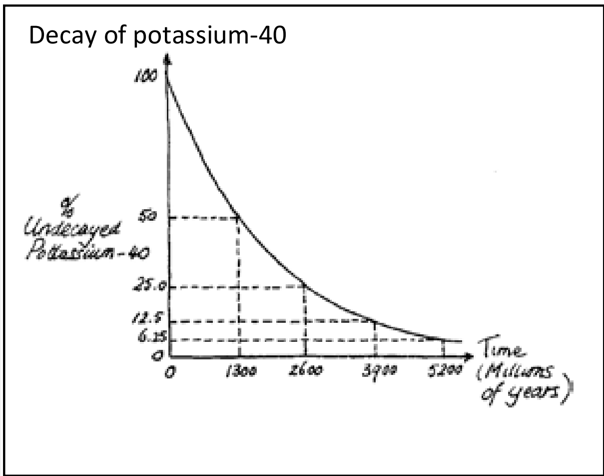


Figure 13: Decay Curve of Postassium-40

a. Suppose scientists took samples from a bone fossil. They found that there was only about 50 per cent of the carbon-14 in the sample compared to the amount that was there when the animal was alive. How old is the fossil?

b. Suppose scientists took samples from a bone fossil, and decided there was only about 25% of the carbon-14 in the sample compared to the amount that was there when the animal was alive. How old is the fossil?

c. Imagine now that the fossil was found in rocks that contained potassium-40. The scientists were able to decide that there was about 25% of potassium-40 in the sample compared to the amount that was there when the rock was formed. How old is the fossil?

d. Absolute dating is accurate, but there is always a small error of about 1 per cent. For example, if rocks were dated as 180 million years old, the age could be out by as much as 1.8 million years. In other words, the rocks could be 1.8 million years older or younger than 180 million years. So the rocks could be between 178,8 and 181,8 million years old.

   Scientists can use different methods to double-check their dating. For example, they could use ^{235}U/ ^{207}Pb and ^{40}K/ ^{40}Ar methods on the same piece of rock to see if they got the same answer. Now imagine if scientists dated a fossil shell and found that it was 10000 years old using ^{14}C /^{14}N dating and there was a 1% error in the method. How old might that fossil really be?

ANSWERS ON PAGE 115

COMMENT

Scientists are confident about the age of rocks because their absolute dating techniques agree with relative dating as well as the type of life forms found in the rocks.

CHECKLIST

Are you able to:

- ❒ describe some of the hominin fossils discovered in South Africa and their characteristics which provide evidence that humans share a common ancestor with chimpanzees
- ❒ explain how fossils are formed by the process of petrification
- ❒ explain how scientists can tell the age of fossils and rocks using relative and absolute dating.

LESSON 6

Life of Darwin

About this lesson

Charles Darwin, the father of evolutionary theory, had a long and fascinating life. In this lesson you will learn how his passion for nature led to an extraordinary trip around the world where his observations, together with his study of domestic varieties of animals and plants, led to the Theory of Evolution by Natural Selection. Darwin might never have published his theory for fear of a negative reaction from conservative Christians. However, when Alfred Russell Wallace came up with a similar hypothesis of evolution he published his theory, and despite a negative reaction from many creationists he received a Christian burial.

In this lesson you will:

Read about Darwin's life story and see how:

- his educated family, hobbies, and life in the countryside developed his passion for nature and science
- extra-curricular activities at university resulted in his training as a naturalist, even though he studied theology
- his observations as a naturalist whilst journeying around the world on the Beagle prompted him to think about evolution
- Alfred Russell Wallace's own discovery forced him to publish his theory of evolution
- his married life provided a stable context for his scientific career
- religious people reacted in different ways to Darwin's theory.

> "There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."
> Charles Darwin - The Origin of Species (final words)

The Life and Times of Charles Darwin

Read about the life of Charles Darwin and answer the questions that follow.

Youth

Charles Darwin (1809 to 1882) spent most of his life at a time when the British Empire and the Industrial Revolution were at their height. Family sizes were large, child mortality was high and diseases such as cholera and scarlet fever killed many people.

The strength of the Empire meant that British explorers were able to travel abroad and collect a whole host of new and exotic living organisms. It was the chief occupation of biologists at the time to classify and make sense of all this diversity. It wasn't long before some free-thinkers were questioning the church's doctrine that all species were independently created.

Charles Darwin was born in 1809 in Shrewsbury, Shropshire, England. As a child he loved playing in the area around his house, which had great natural beauty. He enjoyed exploring the countryside, hiking, horse riding, hunting birds and collecting the creatures he found there. He helped his older brother perform chemical experiments in a laboratory which they had built in a garden shed. These activities gave Darwin a passion for science and nature from an early age.

Darwin was also influenced by his family who were well educated and interested in biology. His grandfather, Erasmus Darwin, had already produced an early theory of evolution but had no facts to prove it. Darwin's father was a medical doctor and his mother bred pigeons. Darwin's mother died when he was aged 8.

Darwin's father, Robert Darwin, was not impressed by his son's passion for nature. He complained that he was only interested in 'shooting, dogs and rat catching'. Robert Darwin was concerned that his son was not doing well at school and that he would end up with no job or suitable employment.

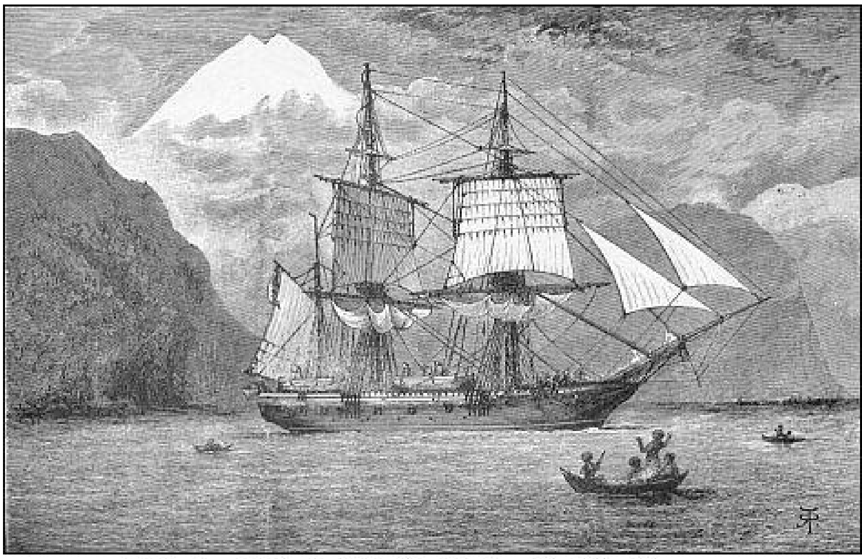
So it was that at the age of 16 Darwin was sent to the University of Edinburgh to study medicine. Darwin hated studying medicine; all the blood and gore repulsed him. Fortunately, he was still able to study nature and even found someone who taught him to 'stuff animals'.

Darwin's passion for nature while he was studying medicine was encouraged by the Professor of Zoology, Robert Grant. Together they went on long walks in the countryside whilst discussing natural history. Darwin joined a natural history society that promoted the idea that nature should be explained without invoking the supernatural. Darwin even presented a paper describing sea urchin eggs that could actually move on their own.

A disappointed Robert Darwin realised that his son was not going to become a successful doctor. His next scheme was that Darwin should join the church. Darwin liked this idea because he thought he might find a post at a country church where he could study natural history. At the age of 18 Darwin went to study theology at the University of Cambridge.

Strangely, instead of becoming a theologian while he studied theology at Cambridge, Darwin became a fully fledged naturalist and started laying the foundations for his theory of evolution by natural selection. He collected beetles, a hobby which cost him at least one girlfriend. Charles became a friend of the Botany and Mineralogy Professor, Reverend John Henslow, and they too wandered around the countryside discussing natural history.

Professor Adam Sedgwick taught Charles field geology, and instead of spending all his time reading about religion he spent hours studying books on natural history, travel and science. By the time he left Cambridge, Darwin had a degree in theology and had also become a competent naturalist.



H.M.S. *Beagle* in Straits of Magellan. Mt. Sarmiento in the distance.

Figure 1: A sketch of the Beagle

The Voyage of the Beagle

After he had finished studying, Darwin took a break and then obtained a job as naturalist and 'gentleman's companion' to Captain Fitzroy of the HMS Beagle (Figure 1). The ship was about to depart on a voyage to chart the coast of South America.

In the end, the voyage of the Beagle took 5 years and Darwin travelled all around the world, visiting South America, the Falkland Islands, Galapagos, Fiji, Australia, and South Africa (Figure 2).

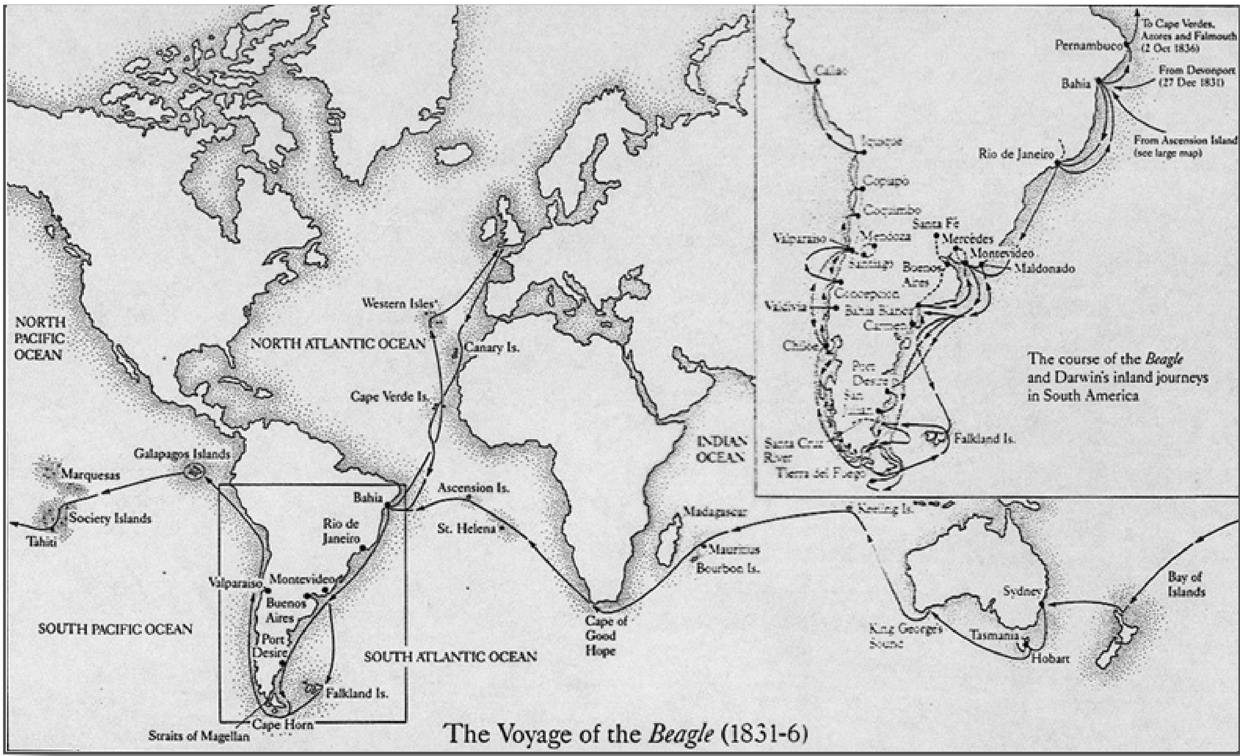


Figure 2 Map showing the voyage of the Beagle

While he was travelling, Darwin collected many plant and animal specimens, including fossils. These were carefully labelled, preserved, and sent back to various naturalists for identification. Darwin kept a diary recording the events of the trip. The voyage also gave Darwin the opportunity to read Charles Lyell's book, the *Principles of Geology*, which suggested that the Earth changed slowly over great periods of time and that the same geological processes that are happening today could be used to explain the past.

On his travels, the young Darwin (he was 22 when the journey started) saw many wondrous sights and experienced many adventures.

Some of his observations included:

- In South America, he discovered fossil giant armadillos called *glyptodonts* (Figure 3) - and, at a separate site, the fossil bones of giant ground sloths. South America was also home to much smaller, living species of armadillos and sloths. Why would fossil remains and modern species found on the same continent resemble each other?

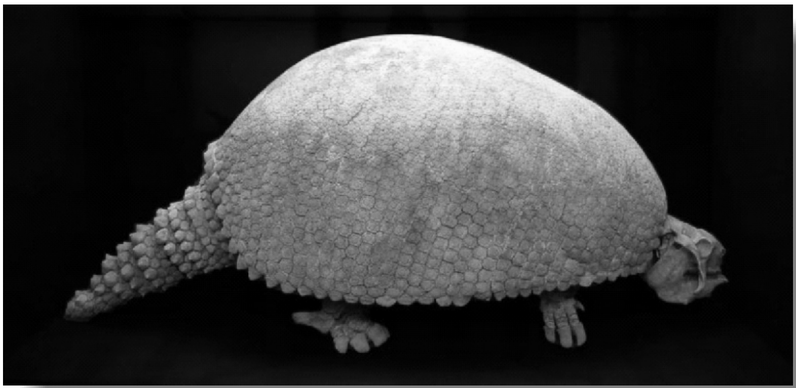


Figure 3: Glyptodonts were enormous armadillos that weighed about 1000 kg

- A horizontal layer of white shells that must have been formed beneath sea level 15 meters above sea level in a cliff face in the Cape Verde islands. How did the sea shells get up there?
- The fossil of a land-dwelling giant sloth in a cliff beneath a layer of marine shells on the coast of Argentina.
- Many fossils of extinct plants and animals which also showed that the climate of long ago was very different from that of today.
- Rocks 1120 kilometres away from the coast line and 2000 m up in the Andes that were formed below sea level. How did sea shells get 2 km above sea level?
- An earthquake in Chile during which rocks were raised several metres in a short space of time.
- Strange animals like the platypus which seemed completely different from all others and which may, he thought, have been independently created.
- Animals in far-away places and climates which were similar anatomically to those back home in England.

Darwin returned home on the 2 October 1836. He was now well known and met with many scientists and naturalists.

Scientists began to send him the results of all the specimens which he had sent them for study. There were some surprises.

The ornithologist John Gould showed that the birds which Darwin had collected on the Galapagos (which he had thought were completely unrelated) were at least 12 different related species of finches.

Darwin starts to explore evolution by natural selection

By 1837 Darwin was beginning to think about evolution. Questions that he was trying to answer included:

- What was the evidence that life had changed over time?
- How did populations adapt to a changing environment?
- How were new species formed?
- How could one explain the similarities between different species?
- How did species manage to reach distant islands?

From this time on Darwin faced a difficult problem: how could he study evolution without getting into trouble? Darwin knew that most people would be extremely offended and threatened by his evolutionary thoughts. Later, after his marriage, he had to consider the affect his evolutionary studies would have on his family as well. Yet he wanted to discuss evolution with other scientists, and needed to learn more about variation in existing species.

Darwin's strategy for developing his evolutionary theory and his own reputation was to publish all his findings from the Voyage of the *Beagle* while starting new studies on selection, variation, and inheritance in various groups of organisms. At the same time, he found other naturalists who were also interested in exploring evolutionary ideas.

By 1838 Darwin had many projects. He was writing a book about his journey on the *Beagle,* a paper on the geology of Scotland, books describing the plants and animals he observed while on the *Beagle,* and was also conducting a survey of domestic animal variation and breeding.

Unfortunately, his health began to fail, possibly from stress and overwork or some disease he picked up during his journey around the world. He suffered from chest pains, nausea and headaches - problems which plagued him for the rest of his life.

Marriage

On 29 January 1839, almost at the age of 30, Darwin married Emma Wedgewood. The marriage lasted 42 years until Darwin's death. Darwin and Emma received enough money as wedding gifts to make it possible for them to live on investments alone.

Charles was free to pursue his life's work, and Charles and Emma had ten children together. The marriage was very a happy one, but Emma, a devout Christian, was afraid that when he died Charles might not go to heaven because of his evolutionary views, and that they would not be able to spend eternity together.

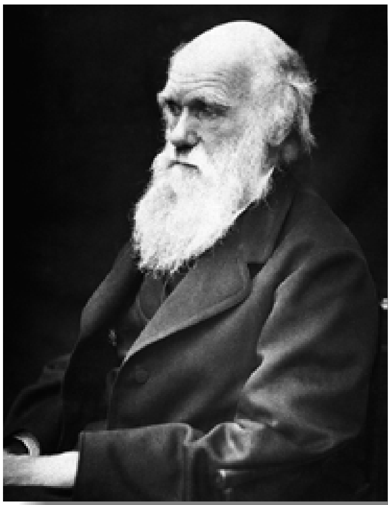


Figure 4: A portrait of Charles Darwin in his later years

Two of Darwin's children died in early childhood, and another, Anne Elizabeth, died at the age of ten from tuberculosis.

The death of Anne was a great blow to Charles's Christian faith and made him question the very concept of God. Charles and Emma lived first in London, but later moved to Kent where Charles was closer to nature and able to breed pigeons and grow orchid flowers.

Publishing the Theory of Evolution

In 1842 Charles wrote his first description of evolution by natural selection in a 35-page summary. He believed that the laws of nature were put into motion by God at the time of creation but that since then there had been no divine intervention. He did not want to be labelled an atheist for his beliefs, so he delayed publishing his theory.

In 1857 Charles Lyell, by now a friend of Darwin, received an essay on evolution from a naturalist, Alfred Russell Wallace, who had independently come up with the idea of evolution by natural selection. Lyell showed the essay to Darwin and said that he should publish his evolutionary ideas if he did not want Wallace to get all the credit them. In response, Darwin started a short essay on natural selection, which turned into a book.
On July 1 1858 the papers of Darwin and Wallace describing evolution by natural selection were jointly presented at a meeting of the Linnaean society. On the 22 of November 1859, Darwin's book *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life*, was published. 1250 copies of the first edition were printed, and most were sold on the first day.

Darwin after he had published his theory

Reaction to Darwin's book was mixed. Darwin's friends, Joseph Hooker and Thomas Huxley, were enthusiastic supporters of evolutionary theory. The church, led by Bishop Samuel Wilberforce, became an equally enthusiastic opponent of evolutionary theory. Those who opposed evolutionary theory felt that the biblical story of Creation should be interpreted literally, and pictures of Darwin as an Ape were published (e.g. Figure 5).

Thomas Huxley started touring the country lecturing on how man evolved from an ape-like ancestor. Darwin continued with his work, publishing books on animal breeding, orchid flowers, the evolution of humans, sexual selection, and the formation of soil by earthworms.

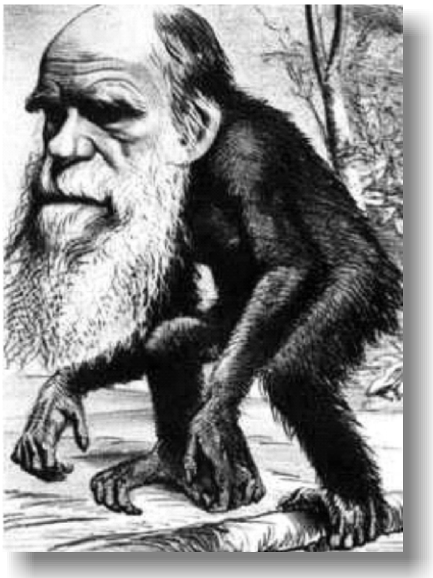


Figure 5: Darwin was characterized as an Ape by some literal-minded creationists

In 1866, Darwin grew a long white beard (Figure 5), perhaps so that people would not identify him in the street. He lived to the age of 73 and died on the afternoon of April 19 1882. He was given a full Christian funeral and was buried in Westminster Abbey not far from the tomb of Isaac Newton. At a memorial service for Darwin, the Bishop of Carlisle said:

> "I think that the interment of the remains of Mr. Darwin in Westminster Abbey is in accordance with the judgment of the wisest of his countrymen…It would have been unfortunate if anything had occurred to give weight and currency to the foolish notion which some have diligently propagated, but for which Mr. Darwin was not responsible, that there is a necessary conflict between a knowledge of Nature and a belief in God…".

ACTIVITY 1

1. What factors in Darwin's youth gave him a passion for nature and science and led him to become a professional naturalist even though he formally studied medicine and theology?

2. How do you think Darwin's observations during the voyage on the *Beagle* channelled him in the direction of a theory of Evolution by Natural Selection?

3. How did Darwin's married life help him to become a professional scientist?

4. Why did Darwin delay publishing his theory of Evolution?

5. Which other scientist also came up with a theory of evolution by natural selection, forcing Darwin to publish his theory?

6. Why do you think that Darwin felt that he had to publish his theory because somebody else had a similar idea?

7. It is said that Darwin grew a white beard because he did not want to be identified on the street. Why do you think he was afraid of publicity?

8. Describe three ways in which some Christians reacted to Darwin's theory of evolution.

ANSWERS ON PAGE 116

Darwin's fascinating life story gives us insight into the human side of science: the influences that made him love nature and science, the observations that led him to his new theory, the importance of his family life, and the reaction of society to his revolutionary ideas.

CHECKLIST

Are you able to:

- ❐ list and explain what influences in Darwin's early life made him so enthusiastic about studying nature
- ❐ describe and explain some of the observations Darwin made during the voyage of the Beagle which led him to the theory of evolution
- ❐ describe the reaction of religious people to Darwin's theory

LESSON 7

Natural selection, speciation, evidence for evolution, the movement of continents and distribution of organisms

About this lesson

Darwin was interested in how living creatures adapt to their environment. People had created a diversity of domestic breeds of cattle, sheep, dogs, cats and pigeons using a process of artificial selection. He called this process natural selection.

You will investigate two cases of natural selection: the case of the peppered moth, and the case of the insecticide-resistant mosquito. You will see how natural selection can cause advantageous traits to spread through a population. This type of evolution is called **microevolution**. Next you will learn how new species are formed using a model called **speciation in isolation** or **allopatric speciation**. One of the predictions of the theory of evolution is that all of life descended from a common ancestor. In this lesson you will study the evidence for this theory. Finally, you will see how the movement of continents over time has affected the distribution of fossils and extant animals such as flightless birds.

In this lesson you will:

- learn about artificial selection and Darwin's theory of natural selection
- learn how air pollution darkened tree bark, causing darker peppered moths to be camouflaged and become more common in Britain
- discover why attempts to control malaria mosquitoes with insecticides failed because of the appearance of insecticide-resistant mosquitoes
- learn how new species are formed using a theory called allopatric speciation or speciation in isolation
- study evidence that all life is related to the development of embryos, homologies, vestigial organs, transitional fossils and common genetic code
- discover how the movement of the continents has affected the distribution of organisms over time.

Natural Selection

Artificial selection

Darwin realized that when human breeders want to produce a breed of long-haired dog they will follow a process of artificial selection by:

population:
a population is a group of animals that could breed, or potentially breed with one another

- choosing dogs with longer hair than average and allowing those dogs to breed.
- studying the puppies produced by the long haired dogs. On average they would expect the puppies to have hair as long as or longer than their parents.
- choosing the puppies with the longest hair and allowing them to breed.
- repeating the process over time until eventually they end up with dogs that have very long hair.

Natural selection

Darwin's big breakthrough was that he realized the process of artificial selection could work in nature.

1. Just as domestic animals vary (for example some dogs have longer hair than others), so organisms in nature vary. Variation may be brought about through the environment (e.g. diet) or shuffling of genes during gamete formation (and genetic mutation). In Darwin's time scientists had not yet discovered DNA or RNA and did not understand genes. For natural selection to work, only gene shuffling and mutation is important as these are passed from generation to generation.

2. Some of the organisms with variations will have an advantage over other variations. We call the variations **traits** or **characteristics**. For example, in a hot climate, wolves with the **trait** of shorter hair will have an advantage over wolves with the **trait** of longer hair (perhaps because they can run further without overheating).

3. Those organisms with a trait that gives them an advantage will be more likely to mate and have offspring than those organisms without the advantageous trait. So the advantageous trait will be passed on from generation to generation and we say that it can be inherited. So, for example, short-haired wolves in a hot climate will be more likely to catch prey, mate and have puppies The short-haired trait (along with the gene for that trait) will be passed on to the puppies which will also have short hair or even shorter hair than their parents.

So the trait of short hair will have been inherited and passed from generation to generation.

4. The advantageous trait will increase in the population and so the population will become adapted to the environment. The short-haired wolves will, over time, become more common than the long-haired wolves, and we would say that the short-haired wolves are better **adapted** to a hot climate than the long-haired wolves, and that the short-haired trait is an example of an **adaptation**.

5. The process by which a new trait (such as long hair or short hair) spreads in a population is called **microevolution**.

ACTIVITY 1

1. An animal breeder wants to produce a larger breed of dog to guard people's houses. How would she go about doing this using artificial selection?

2. What causes some of the variation that we see in natural populations?

3. What do we call a characteristic of an organism which may give an advantage and be passed from generation to generation?

4. What do you call a characteristic of an organism that is passed from generation to generation?

5. What do we call a characteristic that has been shaped by natural selection so that an organism fits its environment?

6. What do you call the type of evolution where an advantageous trait spreads throughout a population?

ANSWERS ON PAGE 117

COMMENT

Darwin's big idea was that artificial selection, a process which humans have used for thousands of years to create varieties of plants and animals for agriculture, can, as natural selection, cause evolutionary change in nature.

Examples of Natural Selection

Read the cases of the peppered moth and insecticide-resistant mosquitoes, then answer the questions that follow.

The case of the peppered moth (*Biston betularia*)

The peppered moth is a rather boring looking night-flying moth found in the Northern Hemisphere. The moth occurs in two colours, a dark form and a light form (Figure 1). This moth drew the attention of biologists when it was noticed that before Britain became industrialised the moths were mostly light- coloured. As Britain become more industrialised the darker form of the moth became more common. At the same time, it was noticed that the bark of trees was becoming darker because soot from all the industries was killing the lichen on the bark. The English naturalist Kettlewell suggested that the reason why the frequency of the two moth forms was changing was because light- coloured moths resting on sooty tree bark were not camouflaged and thus easily spotted and eaten by birds (Figure 1). The darker moths, on the other hand, were camouflaged and could avoid bird predation. After Britain passed strict pollution control laws, the air became less polluted, tree bark became lighter and the light coloured moths again became more common. The change in frequency of the different-coloured moths is a good example of microevolution.

Figure 1: The two forms of the peppered moth on a dark tree

The case of the insecticide-resistant mosquitoes

After the Second World War pesticides were used to control insects and other pests. Initially, pest controllers were very optimistic. They thought that with an arsenal of pesticides such as DDT at their disposal the war against pests would soon be over. Alas, this was not the case.

Let's have a look at an attempt to control malaria. DDT, a **neurotoxin** for insects, was sprayed over large areas of India in the late 1950s and 1960s. At first the number of cases of malaria dropped by as much as 75 million per year. This drop in the number of cases of malaria was caused by a reduction in the mosquito population. This positive effect lasted for 10 to 11 years and then problems emerged as DDT-resistant mosquitoes appeared. When DDT was next applied to the area it had little or no effect on the resistant mosquitoes.

neurotoxin:
a poison that affects the nerves

Thereafter, new insecticides were applied with the same results. Mosquitoes appeared that were resistant to the new insecticide and even combinations of insecticides. Today it is largely agreed that using insecticides to control malaria mosquitoes is a strategy that will not work.

What had happened was that even before DDT was applied to the mosquitoes there were a few mosquitoes in the population that, just by chance, possibly because of genetic mutation, were resistant to DDT. The DDT killed all the mosquitoes except for the DDT-resistant 'mutants'. The DDT-resistant mosquitoes mated with other DDT-resistant mosquitoes and produced offspring that were even more DDT-resistant. Over time the trait for DDT-resistance spread through the population of mosquitoes. This is another good example of microevolution.

Insects are not the only organisms resistant to man-made toxins. Other examples are antibiotic- and TB-resistant bacteria. Random mutation causes bacteria that are resistant to antibiotics to appear, with the result that antibiotics stop working when patients take them. To make matters worse, patients may not take all the antibiotic pills that they should. The result is that they may leave a few tough antibiotic-resistant bacteria behind to multiply.

ACTIVITY 2

1. Explain why the trees in Britain became darker as the air became more polluted. Why was it an advantage for peppered moths to have the trait of darker wings as the air became more polluted?

2. Why did attempts to kill malaria mosquitoes with DDT fail in the 1950s?

3. Where did the DDT-resistant mosquitoes come from in the first place?

4. Why is it important to take all the antibiotic tablets given to you by a doctor?

5. A farmer spends R1000 a week on an insecticide to dip his cattle to remove the ticks that cause infected sores and disease. After a year he notices that the insecticide is no longer working and that the cattle have all got ticks on them after a dip. The farmer changes his insecticide and is again successful in controlling the ticks on his cattle. However, after another year has passed he finds that the ticks once again survive the effects of the dip. Explain what is happening. What would you recommend that the farmer should do to solve his tick problem?

ANSWERS ON PAGE 118

COMMENT

The change in colour of the Peppered moth to match the colour of tree bark and the appearance of DDT-resistant mosquitoes are well-known examples of natural selection. The appearance of antibiotic-resistant bacteria is another example. The next question to be answered is how are new species formed?

The formation of species

Biological Species Concept:
organisms are classified as belonging to the same species if they are potentially capable of interbreeding and producing fertile offspring. In other words, if a male and a female from opposite sides of a continent are brought together and they mate and produce fertile offspring, they are said to be in the same species.

One of the most commonly used definitions of a species is the **biological species concept**. According to this concept a species is a group of organisms where all the males and females could mate with one another and produce fertile offspring.

How are new species formed? Evolution which results in new species or even higher-level groups such as new families, or groups such as birds and whales, is called **macroevolution**.

The most commonly used theory of how new species are formed (**speciation**) is called **speciation in allopatry** or **speciation in isolation**. This type of speciation is shown in Figure 2. Look at Figure 2 and follow the steps 1-4 to understand speciation in isolation.

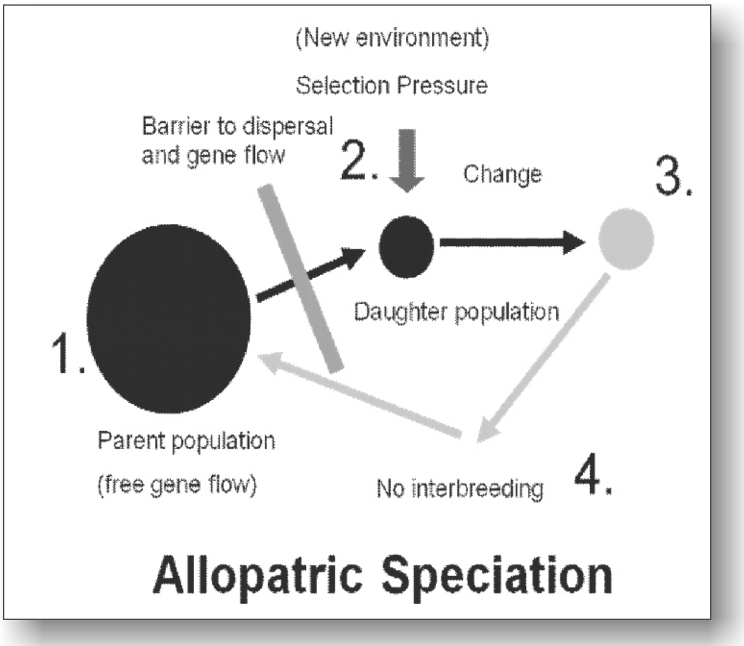


Figure 2: Diagram showing how a new biological species is formed using the model of Allopatric Speciation

1. Imagine a population of organisms belonging to a biological species. This is called the parent population. It could, for example, be a population of flies.

2. A small group belonging to the parent population gets separated and ends up in a new environment far away and isolated from the parent population. This new population is called the daughter population. There is no gene flow between the daughter and parent population which is why it is called speciation in isolation. For example, a small group of flies could get blown away from the parent population during a storm. The flies might even be blown over the ocean to form a small daughter population on an island.

3. The daughter population is in a new environment, and is subject to natural selection. If the daughter population does not adapt to the new environment it will become extinct. On the island, in our example, there are very strong winds. Any fly that tries to use its wings is blown into the ocean and drowns. Flies that have the trait of **non-flight** have an advantage over the flies which fly. Over time the daughter population of flies changes into a population of 'flightless flies'.

non-flight:
unable to fly

4. The daughter population has become adapted to its new environment and has changed so much that if it ever meets up with the parent population it will not mate or produce offspring.

A new biological species has been formed. In the fly example, if the flightless flies ever meet their ancestors who can fly they will not mate. A new species of flightless fly has been formed.

There is a vast amount of evidence that this type of speciation has occurred in real life. Prince Edward Island, a tiny volcanic island 1000 km away from Africa, in the South Atlantic, has species of flightless flies, moths and beetles. All these flightless insects are related to ancestors that can fly on the mainland.

Isolation can occur by movement across the ocean or by the fragmentation of a habitat. For example, a parent population of monkeys in a forest could be separated into many small daughter populations as the forest fragments because the climate becomes drier. Populations can also be broken up by movement of continents, and the formation of new mountain ranges.

ACTIVITY 3

1. Why would a male African elephant in the Kruger National Park and a female African elephant in a zoo in the United States of America be considered as part of the same biological species?

2. Explain the theory of speciation called 'speciation in isolation'.

3. The daughter population can change if it is isolated from the parent population. Explain why.

4. What factors can fragment parent populations, forming a daughter population?

ANSWERS ON PAGE 118

COMMENT

The adaptation of an isolated daughter population to a new environment can result in it changing so much that it cannot mate successfully with its parent population. A new biological species has been formed.

Proof of Evolution

Proof of Evolution

According to the theory of evolution, all life is related. We say that there is evidence for common descent. In other words, all of life comes from a common ancestor (Figure 3).

Embryology

Embryology is the study of the development of animals.
Figure 4 shows the development of **vertebrate** embryos. There is a fish, amphibian, tortoise, bird, lamb and human. It is easy to tell the oldest embryos (the ones at the bottom) apart, but the youngest embryos all look similar. They even appear to have gill slits like fish.

According to the theory of evolution, all **tetrapods** evolved from a fish-like ancestor. Embryology shows that all of the early embryos resemble fish (Figure 4).

vertebrate:
animals with a backbone
tetrapods:
four-legged animals
phalanges:
finger bones
homology:
characteristics that are similar because they have been inherited from a common ancestor
analogy:
characteristics that are similar because they are adaptations to similar environments
vestigial organ:
organs or structures from an ancestor that remain in a degenerate, atrophied, or imperfect condition or form.

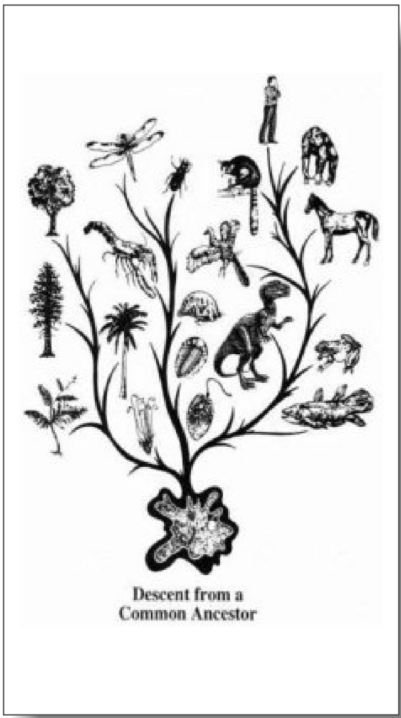


Figure 3: All life descended from a common ancestor

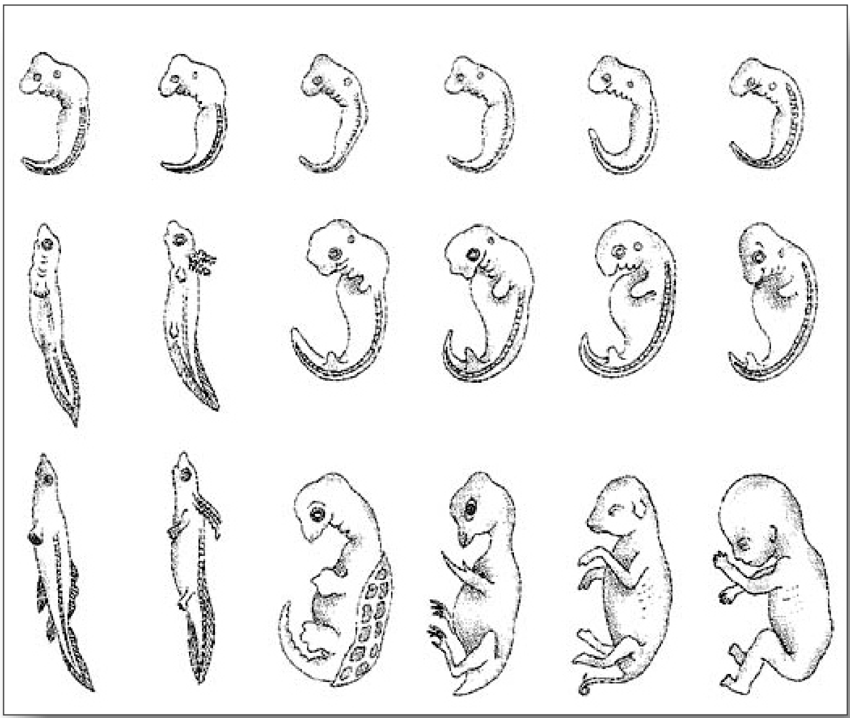


Figure 4: Evidence from embryology: the youngest embryos resemble fish and have gills

Homologies and Analogies

Figure 5 shows the patterns of bones in the front arms of the skeletons of different vertebrates. All the arms have a similar pattern. Do you recognize the humerus, radius, ulna, carpals, wrist bones and **phalanges** in each of the arms? Do you recognize what type of skeleton the arms belong to? There is a human, bird, frog (with four fingers), bat, crocodile, and seal flipper.

All the animals have inherited the same plan in the forearm from a common ancestor. This common plan is called a **homology**. Both the bat and the bird have wings. The wings look similar, but they evolved separately in both these groups. Birds and bats did not inherit wings from a common ancestor. Such structures are called **analogies**. Homologies are proof of evolution because they show that animals evolved from a common ancestor.

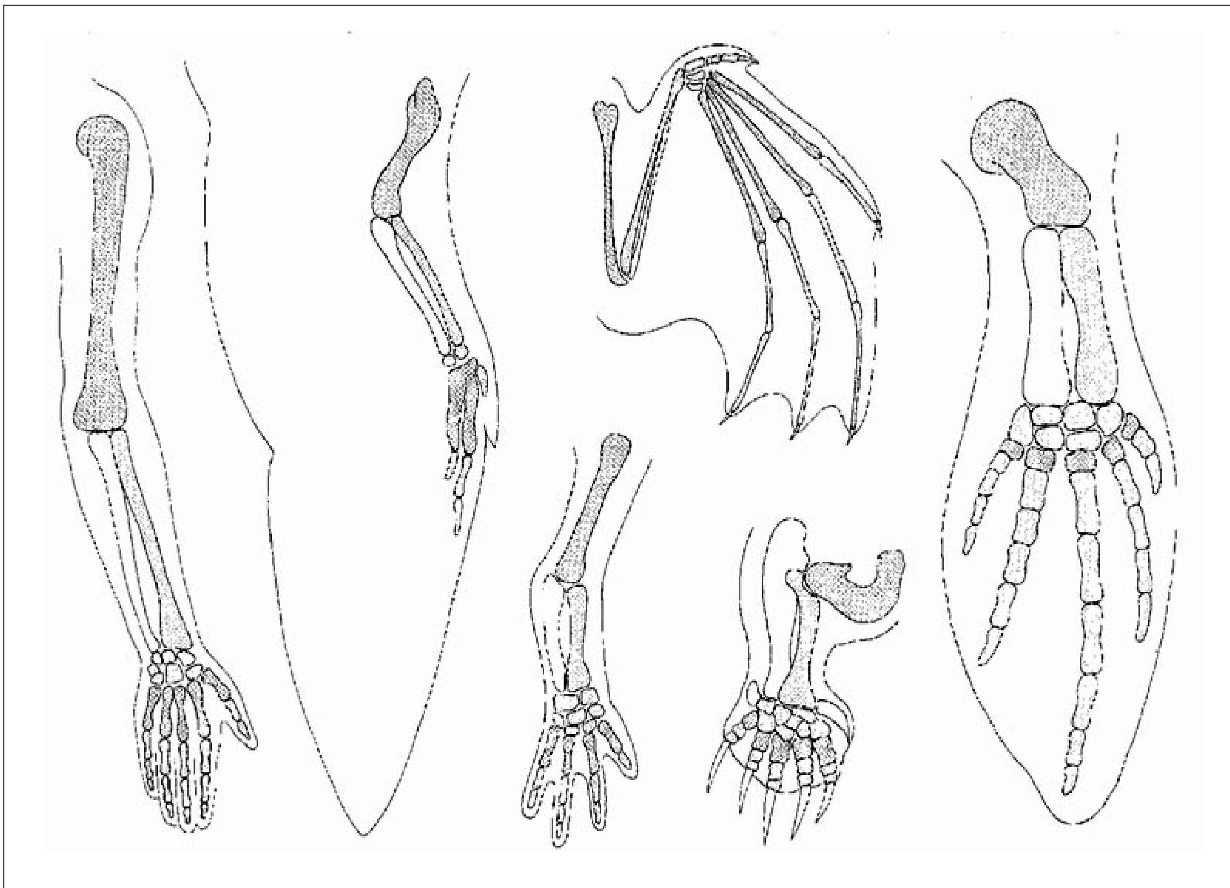


Figure 5: The forelimbs of these animals have a common plan which they inherited from a common ancestor

Vestigial organs

Pythons (Figure 6) have the remains of a pair of pelvic claspers, used in mating, and which were once part of the pelvis. Why do pythons have the remains of a pelvis if snakes have no legs? The answer is that they evolved from an ancestor with legs attached to a pelvis and the claspers are all that remains.

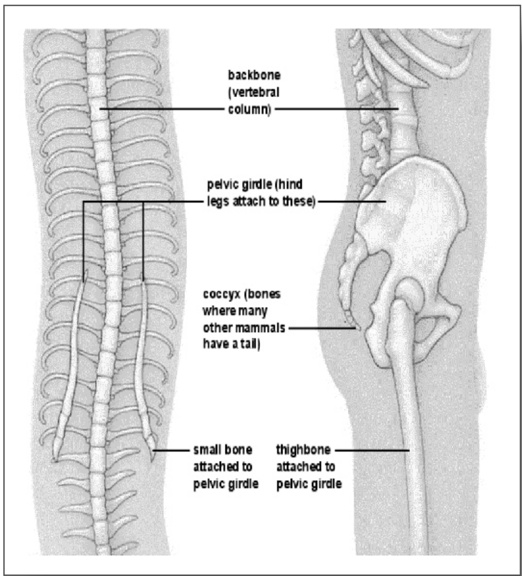


Figure 6: Pelvic claspers in a python

Whales also have the remains of a tiny pelvis which they inherited from an ancestor with legs (Figure 7), perhaps resembling a hippopotamus. Finally, humans and other apes have an appendix, a finger-shaped appendage on the end of the large intestine which was once an extra gut in a monkey-like ancestor for digesting leaves.

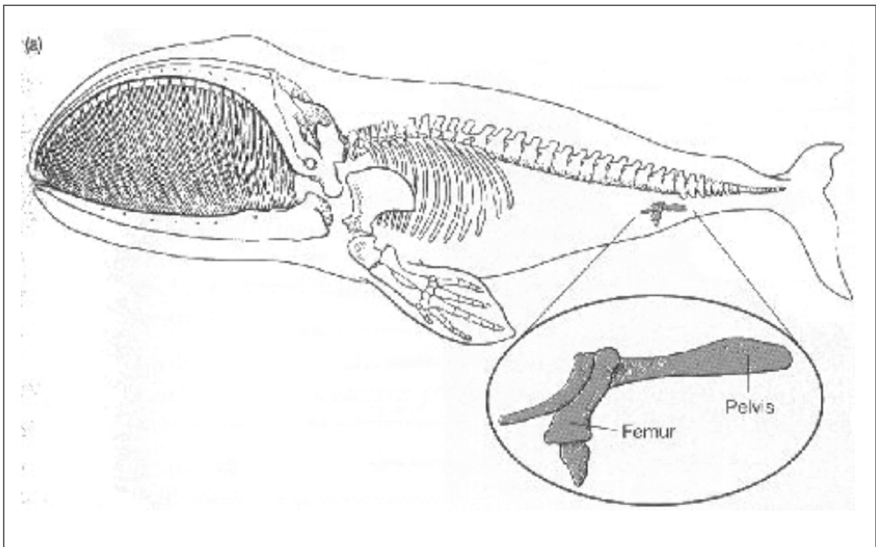


Figure 7: Pelvis and femur in a whale

Transitional Fossils

transitional fossil:
any fossilized remains of a life form that has traits which belong to its ancestors as well organisms that arise from it.

You may remember that in Lesson 4, Figure 7, in the Palaeozoic Era you met a fish with legs called *Acanthostega*, and in the Mesozoic Era, a bird with teeth and claws on its wings called *Archaeopteryx* (Lesson 4, Figure 12).These were both examples of transitional fossils. *Acanthostega* had the gills of its ancestral fish and four limbs like later reptiles and other tetrapods. *Archaeopteryx* had the teeth of its ancestral dinosaurs and the wings of its descendants, the birds. Transitional fossils like these are proof that amphibians arose from fish and birds from dinosaurs.

Common Genetic Code

Do you remember that all of life has DNA built from the same building blocks: a phosphate acid backbone, deoxyribose sugars and the bases adenine, guanine, cytosine, and thymine? During protein synthesis the DNA becomes translated into RNA and then transcribed into amino acids. Different Triplets of RNA code for different amino acids. This is called the genetic code. Except for a few very extreme bacteria, the structure of DNA and the genetic code is shared amongst all life forms, from bacteria through cabbages to humans. This is evidence that all life shares a common ancestor.

ACTIVITY 4

1. What do we mean when we talk about 'evidence for common descent'?

2. Why, according to evolutionary theory, do early stage vertebrate embryos have gill slits?

3. Why is the presence of homologies evidence of evolution?

4. Why do analogies have a similar structure if they were not inherited from a common ancestor?

5. Explain why the remains of a pelvis in a python (vestigial organ) is evidence of evolution.

6. Explain why *Archaeopteryx* is a transitional fossil and proof of evolution.

7. Mushrooms, bacteria and humans share a common genetic code. Is this proof of evolution? Why?

8. The Apes (Chimpanzees, Gorillas, Orangutans, Gibbons) and humans all have an appendix which is a finger-shaped projection on the end of the intestine. Monkeys do not have an appendix but may have an extra gut at the end of the intestine which is used to digest leaves. Explain why the appendix may be a **homology** as well as a **vestigial organ** in the Great Apes.

ANSWERS ON PAGE 119

COMMENT

All of life is descended from a common ancestor. Proof of this comes from a study of embryology, homology, vestigial organs, the genetic code and transitional fossils.

The breakup of the continents and distribution of organisms

According to the theory of plate tectonics, the continents are moving slowly on the back of huge plates of the Earth's crust. The movement of the continents causes changes in climate, the environment, and ecosystems over time.

About 255 million years ago the continents of today were joined together to form the supercontinent Pangea (Figure 8). In the North of Pangea, North America and Eurasia formed Laurasia; in the South of Pangea, Africa, Antarctica, South America, India and Australia formed Gondwanaland. Laurasia and Gondwanaland were separated by the Tethys Sea.

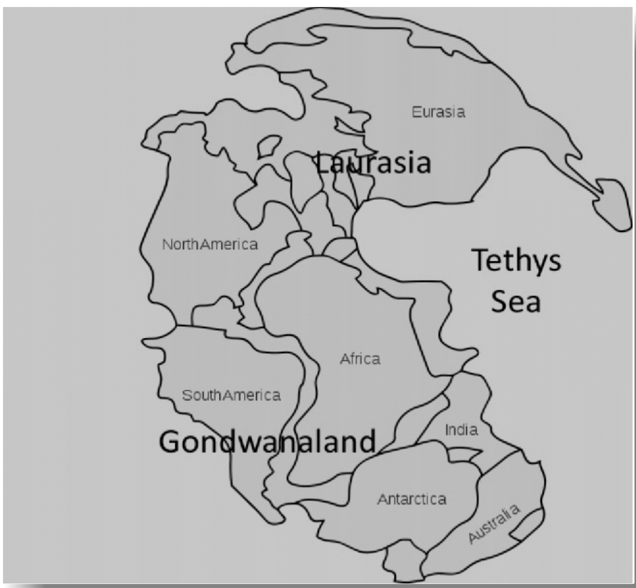


Figure 8: The supercontinent Pangea

Evidence that the continents were joined together comes from the study of fossils. Figure 9 shows that the same fossils of land animals and plants, and also shallow sea animals, have been found in South America, Africa, Antarctica and Australia. This is evidence that these continents must once have been joined to together.

The distribution of life today is partly determined by the movement of continents over time. The study of the movement of organisms through time and space is called biogeography.

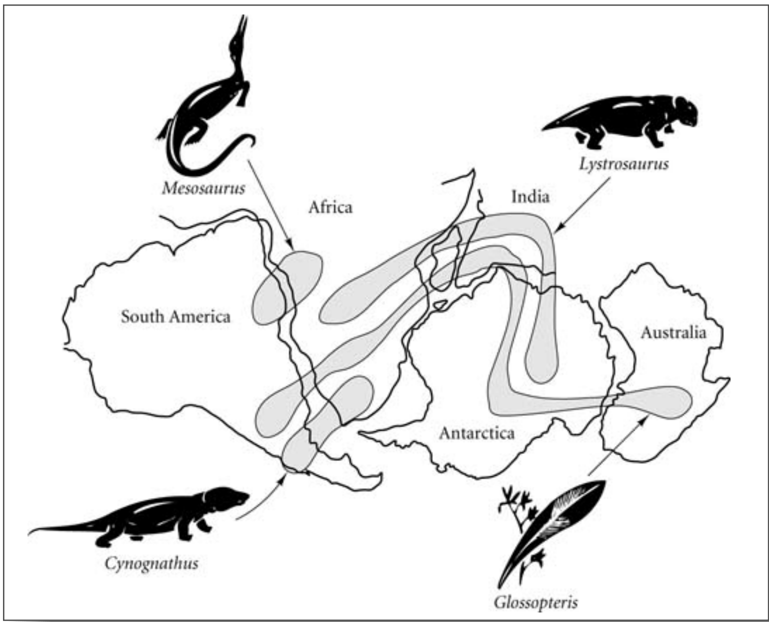


Figure 9: Fossil evidence that the continents of Gondwanaland were once joined

Ratites: *a group of flightless birds, including ostriches, cassowaries, emus, rheas, and emus*

A good example of how plate tectonics affects the distribution of modern animals is the **ratites**. This group of flightless birds includes the ostriches, cassowaries, emus, rheas, and emus (Figure 10).

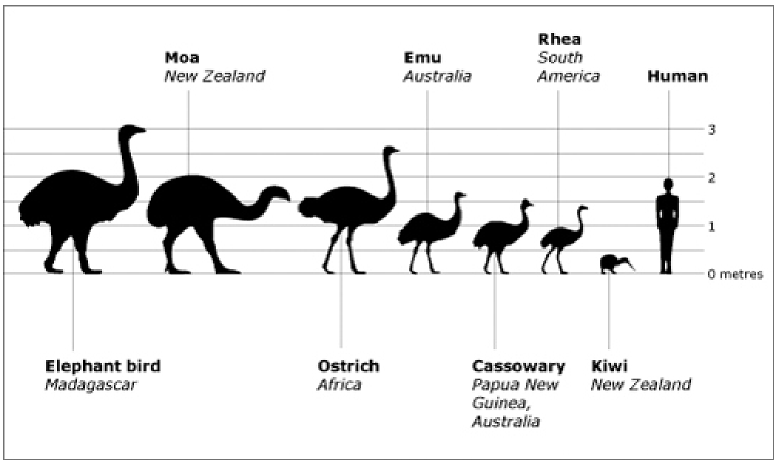


Figure 10: Examples of flightless birds called the ratites

Figure 11 shows how the ratites are distributed on the different continents: the rheas in South America, ostriches in Africa, kiwis in New Zealand, emus in Australia, and the cassowaries in New Guinea. There are also two extinct species, the giant elephant bird in Madagascar (see also Figure 13) and the Moa in New Zealand. All these birds are flightless so the only way that they could have their present distribution would be if they had an ancestor that was present in Gondwanaland and which formed new species as the continents drifted apart

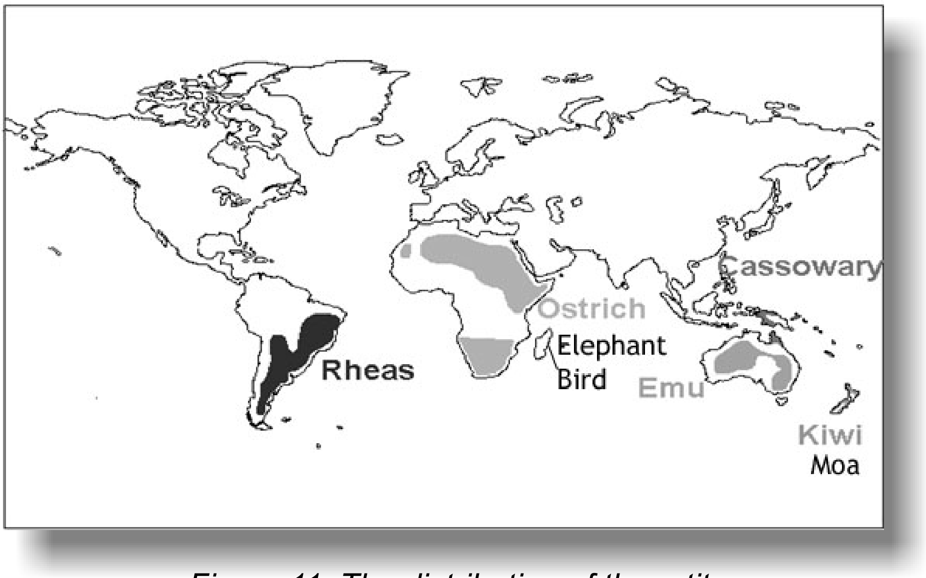


Figure 11: The distribution of the ratites

ACTIVITY 5

1. What is the theory of plate tectonics?

2. *Mesosaurus* is a small aquatic reptile that lived only in shallow water. Fossils of this animal have been found in South America and Africa. Why is this proof of the theory of plate tectonics?

3. On which continents have *Glossopteris* been found?

4. The famous paleontologist James Kitching found *Lystrosaurus*, a small plant- eating mammal ancestor, in Antarctica. Why is this proof of climate change?

5. Baobab trees are spectacular plants which look as if they have been planted upside down (Figure 12). Species of baobab are found in Africa and Madagascar. There is no way the trees could have crossed the ocean. Explain how they manage to be in places separated by thousands of kilometers of ocean.

ANSWERS ON PAGE 120

Figure 12: Baobab trees are found in Africa and Madagascar

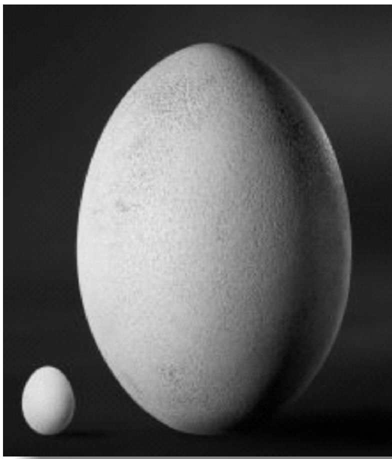


Figure 13: An elephant bird egg was 160 times bigger than a chicken egg

COMMENT

The splitting and movement of the continents has influenced the distribution of living organisms. Certain closely related organisms are found thousands of kilometres apart on different continents which were once joined. This is explained by them having a common ancestor which lived on the 'supercontinent' formed by the joined continents. After the continents split apart, the 'new' daughter species formed by speciation in isolation.

CHECKLIST

Are you able to:

- ❐ explain how artificial selection and Darwin's theory of natural selection are related to one another
- ❐ explain how air pollution darkened tree bark, causing darker peppered moths to be more camouflaged than light ones and become more common in Britain
- ❐ describe why attempts to control malaria mosquitoes with insecticides failed because of the appearance of insecticide-resistant mosquitoes, and how antibiotic-resistant bacteria are formed
- ❐ explain the difference between macro and micro evolution
- ❐ explain what a biological species is

- ❐ describe and give examples of how new species are formed using a theory called Allopatric speciation or speciation in isolation
- ❐ explain the evidence that all life is related, using evidence from the:
  - development of vertebrate embryos
  - homologies
  - vestigial organs
  - transitional fossils
  - common genetic code
- ❐ describe, using evidence from fossils, how the movement of the continents has affected the distribution of organisms over time

NOTES

Answer section

Lesson 1

Activity 1

1. **Moon:** a natural satellite that orbits around a planet
   Planet: large mass of solid liquid or gas rotating around a star
   Fixed Star: a star that maintains the same position relative to other stars in the sky
   Constellation: a group of stars which form a pattern when seen with the naked eye
   Milky Way: the galaxy containing our Earth
   Meteor: A shooting star (asteroid that is falling through the Earth's atmosphere)
   Comet: A frozen mass of ice and dust in orbit around the sun
   Artificial Satellite: A machine in orbit around the Earth which may perform tasks like transmitting TV signals
   Space Station: A laboratory in orbit

2. The space station, artificial satellite, meteor and comet all represent hazards because if they come to close to the Earth and are too large they may strike the Earth, causing a huge amount of damage. The solutions are detecting near large objects approaching Earth and which might strike it and then finding some way of destroying them or turning them off course so they do not strike Earth. Satellites and space stations could be programmed to self-destruct or brought down in a controlled way so they land in the ocean.

Activity 2

1. a. vi; b. v; c. vii; d. i; e. ii; f. iv; g. iii

2. The most cost-effective way to search for liquid water on a distant planet would be to photograph it with a space probe. It would be far too expensive to send an astronaut, and a robotic rover could only cover small areas at time.

Activity 3

1. Astrologers use the position of the heavenly bodies at the time of birth to make predictions about their influence on the affairs of humans. Astronomers are scientists who study heavenly bodies (planets, moons, stars, galaxies etc.) in a scientific manner to discover as much as they can about them.

2. Words that apply to astronomy: observation, testable prediction, experimentation
   Words that apply to astrology are: difficult to test, prediction, fortune telling and faith

3. Science generally involves observation, experimentation, and hypothesis testing to make falsifiable predictions about the world we live in. Astrology uses tradition and faith to make predictions about the influence of heavenly bodies on humans, making it difficult to falsify its claims about events in human society. It is almost a type of fortune telling.

4. Light travels 300 000 km in a second and there are 31 356 000 seconds in a year. So in one year light will travel 9,460,800,000,000.00 Km. In 4.22 years light will travel 39,924,576,000,000 or over 39 trillion kilometers which is the distance to Proxima Centauri.

5. g, a, d, e, c, b, f

Activity 4

1. The solar system is the name given to a star (or sun) and the heavenly bodies which are bound to it by the force of gravity and orbit around it in an elliptical shape.

2. The movement that we see of the fixed stars is brought about by the rotation of the Earth which makes the stars appear to move, in the same way as the sun appears to move in the sky. However, the stars appear to stay fixed in relation to one another giving rise to constant patterns or constellations.

3. Each star may be the centre of its own solar system with its own planets. So if we wanted to visit a planet outside our solar system we should probably visit other stars. Alpha and Proxima Centauri are our nearest stars within a range of 5 light years and so they would be best ones to visit. Of course in real life it would be wise to check the stars with a powerful telescope like SALT to see if there actually were planets orbiting these stars.

4. Your gold mining company would be wise to explore the terrestrial planets which are made mainly of rock and metal. The planets to avoid would be the gas giants which are made of Hydrogen, Helium, Methane, Ammonia and water. You could also search for gold on asteroids and the moons orbiting the gas giants.

5. Dwarf planets are, amongst other things, much smaller than ordinary planets. This means that they lack the gravity to crush themselves into a circular shape and are not able to clear their path through space of other objects. A good example is Pluto.

6. Waxing crescent, first quarter, waxing gibbous, gibbous, full, waning gibbous, last quarter, waning crescent, new moon

7. The gravitational attraction of the sun and moon pull the oceans away from the Earth towards them, raising their level and causing a high tide. At the same time the ocean water left behind is at a lower level, causing low tide.

8. This statement is incorrect as many other planets have moons. Mars has two moons, while Jupiter has over 63 Saturn 62, Uranus 27 and Neptune 13.

9. The celestial bodies which may have life are the planet Mars, Europa, a moon of Jupiter, and Enceladus, a moon of Saturn. All these celestial bodies have water in one form or another. Mars once had a liquid ocean (and methane gas which may have been produced by life) while Europa and Enceladus have liquid water and Europa even has oxygen. The presence of liquid water, the presence of methane, and the presence of oxygen are all clues that these bodies could have life similar to life on Earth.

10. Life on Earth is all water-based. In other words, water is necessary for the existence of life, so the presence of water on another planet or moon suggests that it is possible that life may be there.

11. Choose your own planet here. Think about your basic needs: oxygen, water food, shelter etc. How would you survive on your chosen planet? What equipment would you need? Space suit, a glass or plastic dome filled with air, plants, animals etc.

Activity 5

1.
   - An asteroid is an irregular-shaped rock in orbit around the sun. They range in size from dust-sized particles to dwarf planets with a diameter of up to 900 km.
   - A meteor or shooting star is an asteroid or piece of comet that has entered the Earth's atmosphere and is burning up. It is also called a shooting star.
   - A meteorite is what remains of a meteor that strikes the Earth and is not completely destroyed.
   - A comet is chunk of ice mixed with rocks and dust in orbit around the sun. As it gets near the sun it evaporates a little, forming a tail.

2. In the Asteroid belt between Jupiter and Mars.

3. Possibly in the outer reaches of our solar system.

4. The Chicxulub meteorite threw up a huge cloud of dust which encircled the Earth, blocking out the sun, killing plants and driving the dinosaurs to extinction.

5. The rock could have fallen from an erupting volcano. Otherwise it was probably a fragment of a comet or asteroid whose orbit came too close to the Earth, with the result that it was attracted by the Earth's gravity to come crashing through the roof as a meteorite.

6. Avoiding the impact of a huge meteorite would not be simple. First, we would have to detect the meteorite, which would be difficult to see because it does not produce its own light. Detection would have to be done with an astronomical instrument, possibly an optical telescope, something more powerful like the SALT telescope, or even a space telescope. Once a meteorite near Earth has been detected its orbit would need to be calculated to see whether it was likely to impact Earth. Preventing a meteorite from striking Earth could be done by exploding it into small pieces (as attempted in the film *Armageddon*), or by trying to change its orbit (perhaps by pushing or pulling it away with a rocket).

Lesson 2

Activity 1

1. A galaxy

2. Our solar system is called the Milky Way galaxy and it is a spiral galaxy.

3.

Number of Galaxy	Shape
E3	elliptical
E0	spherical
E7	elliptical
Sa	spiral
Sb	spiral
Sc	spiral
SBa	barred
SBb	barred
SBc	barred

4. Black holes are formed by the collapse of giant star which become so dense that its gravitational attraction even traps light, making it appear black.

5. Poor Buck Rogers has fallen into a black hole. As he gets near it the enormous gravitational forces from the black hole stretch his ship out like a piece of chewing gum. Even the light coming from his ship is stretched, and as the wave length is stretched so it appears red, the energy from light is absorbed, and the ship slowly fades away until it disappears completely, never to be seen again.

Activity 2

1. Nuclear fusion

2. Two hydrogen atoms fuse to form a Helium atom, a neutron, and energy.

3. Carbon is formed by the fusion of Helium atoms.

4. Supernova explosions

5. The more common elements such as Hydrogen, Helium and Carbon are formed by nuclear fusion in the centre of many stars, but rare elements such as Gold and Silver are formed only when a huge star explodes in a supernova explosion, smashing massive elements like Iron together. Such explosions are relatively rare, which is why the massive elements formed in such explosions are also rare.

Activity 3

1. Close to the sun temperatures are too high for the volatile elements (elements with a low melting points such as water and Methane) to condense and become solid and become part of a planet. Substances such as Silica and Iron with high melting points do become solid and become part of the planets closer to the sun.

Further away from the sun where it is cooler, the elements with low melting points become solid and form the gas giants.

2. Our solar system contains Gold and Silver which are elements that could only be formed in a supernova explosion.

3. The Big Bang theory

4. A singularity

5. Time and space

6. a. All the galaxies are accelerating away from one another, suggesting that they were once closer together and have been moving apart ever since.
   b. Deep space is filled with microwave radiation which is the left-over remnant of the radiation that was formed when the universe was still hot and young.

7. This would be a bad project to support because, as far as we know, space and time were created along with all the matter in our universe. This means that we could not travel beyond our universe to other universes because there is no space and time beyond it.

8. The three possibilities are:
   - our universe could carry on expanding for ever
   - our universe could eventually stop expanding and start to contract, getting smaller and smaller
   - our universe could stop expanding and just stay the same size.

9. You are entitled to you own opinion as long as it is supported by logical reasoning. However, it is worthwhile pointing out that it is logically possible that God created the Universe using natural laws and processes including the Big Bang. This is the type of argument that Theistic Creationists use. See also the lessons on the formation of life and evolution.

Lesson 3

Activity 1

1. Millions of Years

2. 4.6 billion years or 4600 million years

3. Eons, Eras, Periods and Epochs

4. It began 251 million years ago and ended 65 million years ago.

5. The Devonian Period

6. The Cenozoic Era

7. b. Make your own summary as you work through the lessons.

Hadean	4,600 million years ago	eon	formation of the earth; planet had just formed; still very hot due to volcanism, a partially molten surface and frequent collisions with other solar system bodies
Archean	2,500 million yrs ago	eon	rocks contain earliest fossils of life on Earth
Proterozoic	2.5 billion to 541 million years ago	eon	transition to an oxygenated atmosphere; glaciations; evolution of soft-bodied multicellular organisms
Palaeozoic	541 to 252 million yrs ago	era	modern phyla appeared; fish and reptiles evolved; forests of primitive plants; reptiles appeared; era ended with the largest mass extinction in Earth's history; took 30 million yrs into the Mesozoic to recover
Mesozoic	252 to 135 million yrs ago	era	age of reptiles; dinosaurs flourished; mammals, birds and flowering plants appeared
Cenozoic	135 to 65 million yrs ago	era	mammals took place of reptiles; shellfish replaced ammonites

c. Work with a friend or partner to create a scale map.

Activity 2

1. Accretion.

2. About 4.5 billion years ago, the young Earth collided with a small planet the size of Mars, forming a huge cloud of rock and dust which clumped together to form the Moon.

3. Outgassing or eruptions of volcanoes poured gases such as Methane, Nitrogen, Carbon dioxide and water vapour out of the Earth, forming the first atmosphere. Condensation of the water vapour would have formed the first oceans.

4. The early atmosphere had no Oxygen and there was no Ozone layer to protect the Earth from cosmic rays.

5. a. Planetary accretion is the formation of planets by the fusing together of many rocks in a nebular cloud.

   b. The boundary between the Hadean and Archaean Eons was 4 billion years ago. At that time, according to the graph, the cool early Earth period was coming to an end and the late heavy bombardment was beginning.

c. Even though the Earth had formed about 4.5 billion years ago accretion still continued as the Earth was bombarded continuously by millions of meteorites. Eventually, though, most of the asteroids in the paths of the young Earth's orbit had been cleared and fallen onto Earth and the rate of meteorite impact slowed.

d. Actually, scientists don't really know. Some say that the gas giant planets formed after the Earth had cooled about 4 billion years ago and their gravitational forces pulled asteroids into the Earth's orbital path which then struck the Earth as meteorites. Others say that meteorite impact craters in very early rocks have been destroyed over time and have not been preserved. We only know about the meteorite impacts during the planetary accretion stage because they are preserved on the moon. The ones on Earth have not been preserved.

Activity 3

1. During the Archaean the Earth was different from the Hadean because:
   a. the Earth had cooled;
   b. the early oceans and continents had formed;
   c. the bombardment of the Earth by meteorites had slowed;
   d. early life forms had appeared.

2. They were prokaryotes, simple organisms that include bacteria, with no proper nucleus.

3. Near Barberton in Mpumalanga.

4. Early prokaryotes were found living in hot springs and at the bottom of shallow seas

5. A stromatolite is a cushion of blue-green bacteria or cyanobacteria found living at the bottom of a shallow sea.

6. Oxygen.

Activity 4

1. The gases water vapour, methane gas (CH_4), ammonia gas (NH_3), hydrogen gas (H_2) and carbon monoxide (CO) were chosen for the experiment because these were thought to have been the gases present in the early atmosphere of the Earth.

2. In the Miller-Urey experiment, the gases of the early atmosphere were reacted with an electrical spark, creating simple organic molecules.

3. How the organic molecules assembled themselves to form the first life.

4. Someone who believes that God created the universe and life using natural processes.

5. The hypothesis that organic molecules or even simple life forms were brought to Earth from outer space, possibly in a meteorite.

6. It is possible that it could have happened that way. Life may have arrived on Earth from another planet or other parts of the solar system. Possibly, life may even have been brought to Earth by aliens. However, all these hypotheses do not explain where life came from in the first place or where the aliens came from. The presence of organic molecules in outer space and comets suggest that very simple life may have been brought to Earth from outer space.

Activity 5

1. Oxygen-producing blue-green bacteria or cyanobacteria grew in large mats called stromatolites, and were very common in the early Proterozoic eon. They produced so much oxygen that they gave the Earth an oxygen-rich atmosphere.

2. The first prokaryotic cells were mainly anaerobic - unable to breathe in an oxygen-rich atmosphere. To cope with this new gas, an early prokaryotic cell engulfed or phagocytosed a type of bacteria that could breathe in an oxygen-rich atmosphere. This new type of bacteria became an endosymbiont within the early prokaryotic cell called the mitochondrion and enabled it to respire using oxygen.

3. Where one organism lives inside the body or cells of another and there is some type of relationship between the two of them.

4. Different cells can specialize to perform different tasks such as movement, digestion, reproduction and defence.

5. The *Porifera* (sponges) and *Cnideria* (jellyfishes and corals).

6. The three most important events from a human perspective may have been:
   a. The development of an oxygen-rich atmosphere which allowed our oxygen-breathing ancestors to evolve and protected life from cosmic rays.
   b. The development of the Eukaryotic cell. Eukaryotic cells are the basic building blocks of the human body.

c. The development of multicellular organisms with a division of labour. These eventually evolved to become bodies like ours with different organs and systems performing tasks such as digestion, respiration and reproduction.

Lesson 4

Activity 1

1. Give any four, for example: *Arthropoda, Annelida, Mollusca* and *Chordata*.

2. Any three of these: ferns, horsetails, tree ferns, seed ferns and club mosses.

3. A vertebrate with four legs such as an amphibian, reptile or mammal.

4. Because they are alive today, but are also known as fossils hundreds of millions of years old.

5. It has characteristics of a fish ancestor (scales, gills and a tail) and a tetrapod (ribs, lungs and four limbs with toes).

6. Amniotes can lay eggs away from water because they lay water-proof eggs with their own water and food supply.

7. The reptiles (tortoises, snakes, lizards and crocodiles), the birds, and the mammals.

8. Today, zebras and impalas are common herbivores just as the *dicynodonts* once were, and lions play the part of the rarer and more ferocious carnivores such as the *gorgonopsians*.

9. b., c., e., h., d., f., g., i., a.

10. a. The fossilized zebra is an ordinary fossil. Zebras are alive today, and we should not be surprised to find a fossil zebra 15 000 years old.
    b. The snake with legs would be a transitional fossil. Snakes had an ancestor with legs, rather like a lizard, and modern snakes lack legs, so a snake with short legs would be transitional between modern snakes and their ancestors.
    c. A winged dinosaur with feathers would be considered a transitional fossil because dinosaurs that evolved earlier had no wings, and probably no feathers. Birds, however, have wings and feathers, so the dinosaur with wings, feathers and teeth would be considered transitional between earlier dinosaurs and birds.

d. The fossilized mat of blue-green algae would be considered a good example of an ancestor of a living fossil. This amazing group or organisms have survived for more than 3 billion year. The fossil ones look very similar to living ones in Australia.

e. The upright-walking ape would be considered a transitional fossil because it is transitional between ancient ape ancestors and humans. It shows the characteristics of both.

f. A fossilized dinosaur would be considered an ordinary fossil.

11. You can give your own answers here. These were my choices:
    a. The Cambrian explosion which led to the appearance of *chordata* (our group)
    b. The invasion of land by plants and animals, allowing our ancestors to adapt to life on land
    c. The evolution of the amniotic egg, allowing animals to reproduce away from water.
    d. The survival of some life at the end-Permian extinction. Otherwise we would not be here.

Activity 2

1. Reptiles

2. Terrible lizard

3. Feathers

4. Hair

5. Birds

6. Possibly because any larger mammals would have ended up as dinosaur food.

7. Flowering plants or angiosperms

8. Hot and wet with no ice caps

9. If trends of global warming continue, the ice caps might melt completely. Then the Earth could become similar to the Earth during the late Mesozoic. The oceans would be warmer, and sea levels would be higher. Low lying areas of the continents might be completely flooded. Huge storms and floods would become more common. We might even find plants and animals reinvading the Antarctica and living close to the South Pole.

10.
- flowering plants appeared, providing us with most of our food;
- social insects appeared including pollinators like the honey bees;
- a mass extinction drove the dinosaurs and many other groups to extinction, giving space for mammals to diversify.

Activity 3

1. *Andrewsarchus, Basilosaurus, Mesohippus* and terror birds.

2. The early mammals at the beginning of the Cenozoic still had to evolve to form the types of mammals we know today, so the early ones were most different from the ones we know. Also, there were many that were completely different from the ones that we know today that have become extinct.

3. About 200 000 years ago

4. Grass

5. In the early Cenozoic the Earth was warm and forested with no ice caps at the poles. Later, the Earth cooled. Ice caps appeared, and the forests were replaced by large areas of grass. At times the ice caps spread from the poles, covering huge areas of the Earth's surface. These time periods when ice covered most of the Earth were called the ice ages.

6. The three most important events of the Cenozoic were:
   a. The mammals diversified into the modern forms we see today
   b. Grasses appeared (think of all the grains that we depend on for sources of food)
   c. Humans appeared

Lesson 5

Activity 1

1. Lime was needed in the gold refining process on the Witwatersrand, so there was a huge demand for this material.

2. While lime miners were mining the lime they found the fossilized remains of pre-historic animals.

3. The first hominin discovered was the Taung Child. Professor Dart saw that it had features of both chimpanzees and modern humans, which is why he suggested it might be a human ancestor.

4. No, it is probably not fair. South Africa could be the Cradle of Humankind, but since many fossils have been found outside South Africa in Africa, humans could have arisen in other places too.

5. Southern Ape of Africa

6. We find art (for example a piece of ochre with patterns on it), jewellery, sophisticated stone tools, and the use of plants for bedding between 60 000 and 80 000 years ago.

7. a. cm^3 stands for cubic centimeters.
   b. *Sahelanthropus* had a cranial capacity of about 400 cm^3 and *Homo sapiens* had a cranial capacity of about 1500 cm^3.
   c. According to the graph, *Australopithecus* lived about 4 million years ago and *Homo erectus* slightly less than a million years ago.
   d. We see a slow increase in cranial capacity between *Sehelanthropus* and *Homo erectus* and a rapid increase in cranial capacity between *Homo habilis* and *Homo sapiens*.
   e. An increase in brain size seems to be important in human evolution because as the size of the brain increased so the amount of nerves that could be packed into the brain increased, and hominins showed signs of more complex behaviour, such as making sophisticated tools, art, the controlled use of fire, clothing, and making their own shelters.

Activity 2

1. Answer: e, c, f, b, d, a

Activity 3

1. a. 50 000 human generations. How do you think life could change in a million years?
   b. 10 kilometers
   c. 1000 kilometers. If you started at Johannesburg you would reach Graaff Reinet.
   d. 11.57 days or 11 days , 13 hours, 40 minutes, 48 seconds

2. a. The youngest fossils are the dinosaurs in siltstone.

b. We know the fossils were in sediments that were deposited on land because we know that dinosaurs are land animals.
c. Bivalves such as oysters contained in mudstones.
d. These fossils were laid in sediments in the sea because oysters are usually found in the seas in a marine environment
e. The layers were once all connected as the ancient environments which are preserved in the cliffs covered a large area. However, section C only preserves three of the environments which are also found as part of section B. So not each cliff contains all the environments. Also, some of the environments may have only covered small areas, which is why the petrified leaves and ferns are only found in Section A, but not in B and C. Possibly, the forest never extended as far as the cliffs labeled B and C.

3. a. 5730 years
b. 11960 years
c. 1% of 10 000 years is 100 years so the fossil could be between 900 years and 1100 years old.
d. 2600 million years

Lesson 6

Activity 1

1. From his earliest childhood Darwin had loved nature and the countryside where he explored, rode horses and hunted. He also did chemical experiments with his brother. He came from an educated family: his father was a doctor, his mother bred pigeons, and his grandfather had already produced a hypothesis about evolution. While at university he joined a scientific society and befriended lecturers who taught him and trained him in subjects such as geology and botany. He also collected beetles, and learnt to stuff animals.

2. Some of Darwin's observations on the voyage of the Beagle included:
   a. Evidence that the Earth had moved in the past. He saw the results of earthquakes, and found layers of sea shells far above sea level.
   b. Evidence that life may have changed over time. For example, he found giant sloths and giant armadillos in the same areas where modern sloths and armadillos are found.
   c. Evidence that environments and sea levels had changed over time. For example, he found a fossil of a giant sloth under a layer of sea shells.

3. Darwin was happily married, which gave him a stable emotional context in which to work and conduct his research. He and his wife also received enough money as wedding gifts to become financially independent so that he did not have to work for a living.

4. Darwin knew that his theory of evolution would annoy conservative Christians and did not want to be labelled an atheist, someone who does not believe in God.

5. Alfred Russell Wallace

6. Darwin had thought of the theory of evolution first, and now, many years later, Wallace had come up with the same idea. Darwin felt that it was right that he should take credit for having come up with the theory of evolution first.

7. Darwin preferred not to be recognized in the street. He wanted to avoid argument or, even worse, physical conflict with people who were offended by his hypothesis.

8. Some, like the Bishop Wilberforce (and even some Christians today), refused to accept the theory of evolution. These hardliners preferred to take their religious texts literally. Others, like the Bishop of Carlisle, could see no conflict between religion and science.

   They felt that scientists were revealing the laws of nature that God had put into place. Darwin's wife loved him dearly, but was afraid that he might go not go to heaven because of his belief in evolution.

Lesson 7

Activity 1

1. First the animal breeder would choose the biggest male and female dog she could find. When they had puppies she would choose the largest male and female, and after they had grown up she would mate them. Again, after they had puppies she would choose the largest and mate them. She would repeat the process until eventually she would have a very large breed of dog.

2. Gene shuffling during gamete formation and genetic mutation

3. A trait

4. An inherited characteristic

5. Adaptation

6. Microevolution

Activity 2

1. As the air became more polluted it became full of soot which killed the lichen covering the bark, staining the trees black.

2. The pepper moths with the trait of darker wings were more camouflaged against the darker bark of trees than the pepper moths with the trait of lighter wings and were less likely to be eaten by birds.

3. The DDT failed to kill mosquitoes with the trait of resistance to DDT, but all the other mosquitoes were killed. The DDT-resistant mosquitoes multiplied, and soon DDT became completely useless as an insecticide to kill mosquitoes. Genetic mutation in some mosquitoes, by chance, caused them to become resistant to the DDT.

4. If you do not take all the tablets you may allow a few antibiotic resistant bacteria to survive and multiply. Next time you take that type of antibiotic it may not work at all.
5. In the population of ticks there are a few individuals that by chance have a genetic mutation which helps them to survive the insecticide. Over time it is these few rare ticks that survive the dip and are able to mate and reproduce, and eventually all the ticks in the population are resistant to the insecticide. The farmer changes the type of insecticide that he uses and the process is repeated until the ticks are also resistant to the new type of insecticide. The farmer can solve the problem by using a combination of different types of insecticide, making it difficult for the population of ticks to adapt to several insecticides at the time (but ticks do anyway) or use cattle from a population that has actually adapted to withstand tick bites and diseases. Indigenous Nguni cattle are one breed of tick-resistant cattle.

Activity 3

1. Although the male and female elephant are many thousands of kilometers apart, if they were ever introduced to one another they could mate and produce fertile offspring. The result is that we say they belong to the same biological species.

2. The daughter population becomes separated or isolated from the parent population so that no gene flow can occur between the daughter and parent populations.

3. The daughter population changes because it adapts to its new environment or when it has changed to such an extent that it will not mate with the parent population, or, if they do mate, their young are infertile.

4. Movement across the ocean, habitat fragmentation, climate change, movement of the continents, and formation of mountain ranges.

Activity 4

1. We are talking about evidence that all of life shares a common ancestor.

2. According to evolutionary theory, early vertebrates like fish had gills. Later forms like amphibians, reptiles, birds and mammals arose from an ancestor with gills, and during their development they repeated their evolutionary development, including an embryo with gills.

3. Homologies are common patterns or structures present in different organisms which they share because they are inherited from a common ancestor.

4. Analogous structures like wings are similar because they are adapted to do similar tasks. For example, wings of bats, birds and insects are adapted to flight and have similar structures to help them perform their tasks.

5. Snakes do not have limbs, but they did evolve from a common ancestor with limbs. Most snakes do not even have any trace of limbs or girdles (like the pelvis), but pythons do still have a pair of claspers, the remains of a pelvis and proof that they evolved from an ancestor with limbs.

6. *Archaeopteryx* is a 150 million-year-old fossil which has a skeleton and teeth very much like its dinosaur ancestors, but it also has wings like the birds which eventually evolved from it. The fossil has characteristics of both its ancestors and descendents, making it a transitional fossil. It is also proof that birds arose from dinosaurs.

7. It is proof of evolution, and suggests that mushrooms, bacteria, and humans have a common ancestor that had the original genetic code which all its descendents inherited.

8. All of the Apes have an appendix, suggesting that they possibly inherited it from a common ancestor which also had an appendix. This means that the appendix is a good example of a homology.

Also, it appears that the appendix in certain monkeys was once expanded to form an intestine for digesting leaves, but has become reduced in the Apes, which are not specialized leaf feeders. In other words, the appendix is a good example of a vestigial organ.

Activity 5

1. Plate tectonics is the theory that the continents are moving slowly on the back of huge plates of crust called tectonic plates.

2. This animal lived only in shallow water, making it impossible for it to cross the ocean between South America and Africa. The only way fossils could be found on both continents would be if they were once joined.

3. Australia, Antarctica, India, Africa and South America

4. *Lystrosaurus* could not possibly have lived in an ice-covered continent, so at the time these animals were alive about 250 million years ago Antarctica must have been a warmer, sunnier place.

5. Madagascar and Africa were once joined. At that time baobabs were spread over both these places. Africa and Madagascar eventually split up and drifted apart, forming isolated populations of baobabs and new species.