CHAPTER 2

Evolution of life and the fossil record

The fossil record provides information about the subsequent evolution of living things

Evolution of living things

2.1

- ***identify the major stages in the evolution of living things, including the formation of:***
  —organic molecules
  —membranes
  —procaryotic heterotrophic cells
  —procaryotic autotrophic cells
  —eucaryotic cells
  —colonial organisms
  —multicellular organisms

It is believed that the environment on early Earth provided conditions for inorganic molecules to form organic molecules, and then for organic molecules to react with each other to form more complex organic compounds. To metabolise effectively, complex organic compounds needed to separate from their surroundings and form membranes, which would result in the first primitive living cells. To advance, cells over time needed to develop specialised compartments to carry out different chemical reactions. These would have become the first **eucaryotic cells**. Co-operation between these cells would have resulted in **colonial organisms**, which in turn with higher organisation develop into **multicellular** organisms. Of course, these changes would have extended over very long periods of time and involved far more complex changes than those summarised above. The changes that were believed to occur from one organism type to another did not mean that all organisms of that group changed, in fact some members of these groups are known to have continued in the original forms to present-day (e.g. cyanobacteria—**procaryotic autotrophic organisms**).

The major stages in the evolution of living things can be best described and illustrated in Table 2.1.

Table 2.1 The major stages in the evolution of living things

Stage of evolution	Number of million years ago	Oxic or anoxic environment	Outline changes that occurred	Examples of life and evidence
Organic molecules	4500	Anoxic	■ Formation of organic molecules (e.g. amino acids) from inorganic molecules, as suggested by the chemosynthetic theory (Haldane, Oparin, and Urey and Miller) ■ Atmosphere consists of N_2, NH_3, H_2O, CO_2, CO and CH_4; water vapour condenses to form seas; there are high levels of ultraviolet radiation, lightning and volcanic activity	N/A
Membranes	4000–3500	Anoxic	■ Membranes may have enclosed chemicals within a microstructure to control metabolic reactions ■ Proteins or nucleic acids may have been able to replicate	N/A
Procaryotic heterotrophic cells	3500–2500	Anoxic	■ Cells may have obtained their energy from the organic molecules in their environment ■ Cells may not have had membrane bound organelles	■ Evidence of microfossils ■ Bacteria
Procaryotic autotrophic cells	2500–2000	Anoxic and oxic	■ Ozone layer forms ■ Cells may have developed the pathway to make their own food (photosynthesise)	■ Evidence of stromatolites (cyanobacteria)
Eucaryotic cells	2000–1500	Oxic	■ Single cells may have developed from procaryotes to increase metabolic efficiency ■ First eucaryotic cells may have appeared with a nucleus, using cyanobacteria as chloroplasts and bacteria as mitochondria ■ Some of the simple procaryotic cells may have engulfed other cells which became internal structures or organelles and evolved into first eucaryotic cells ■ Eucaryotic cells may have advanced to form membrane bound organelles such as mitochondria	■ Protozoans and algae ■ Evidence in deposited banded iron formations (oxic environment) ■ Evidence to support this comes from mitochondria having their own nucleic acids
Colonial organisms	1500–1000	Oxic	■ Many cells may have worked in a cooperative group	■ *Volvox* ■ Slime moulds (can exist at times in colonies of up to 50 000 cells and search for their food supply) ■ Sponges and corals
Multicellular organisms	1000–500	Oxic	■ Cells may have been more organised to become specialised and work together as a multicellular organism (forming into tissues, then from tissues into organs)	■ Evidence of multicellular animals in Ediacaran fauna around 640–680 million years ago ■ Simple organisms such as sponges, jellyfish and coral ■ More complex organisms such as worms, echinoderms (starfish) and algae

Evolution of life timeline

SECONDARY SOURCE INVESTIGATION

BIOLOGY SKILLS

P12
P13
P14

■ ***process and analyse information to construct a timeline of the main events that occurred during the evolution of life on Earth***

Aim

1. To process and analyse information.
2. To construct a timeline of the main events that occurred during the evolution of life on Earth.

Background information

Scientists have gathered information about life in the past through varying types of fossil evidence and placed it into a **geological timescale** (see Table 2.2). The subdivision of the Earth into eons, eras and periods is related to the fossil assemblages found in each time zone. Unique fossil groups are found in each period of time.

Method

Process and analyse information

Use a variety of different secondary sources in your search such as scientific journals, Internet sites, textbooks, library reference books, CD-ROMs, newspaper articles and experts in the field. Using a variety of sources increases the reliability of your information. Using recent sources, such as scientific journals, improves the accuracy and validity of your information. Start your search with the use of keywords. These are used when looking up the index of a textbook or using a search engine to find relevant Internet sites. After you have sourced the information, you next need to analyse and select the information relevant to this task.

Construct a timeline illustrating the evolution of life

Once you have processed and analysed the information in order to obtain the dates for the evolution of different life forms over time, draw a timeline to scale (e.g. 1 million years = 10 cm) that covers all eras and periods of time up to the present day. You will need to use a large A3 or a number of A4 sheets of blank or graph paper joined together so that your scale can fit each organism type. Once you have plotted the timeline, including the period, era and eon names, start adding in the names of each organism type at each time interval. You may wish to draw diagrams of selected organisms to help assist in presenting your evolution of life timeline, illustrating key moments in time.

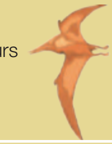
Results

After you have completed your timeline, swap with another member of the class to ensure that you have not forgotten any important points along the timeline.

Discussion/conclusion

1. Describe the distribution or spread of organisms through time.
2. List five of the most significant changes in organisms over time.
3. Discuss why there may be slight differences in your timeline compared to other members of the class.
4. When gathering your information for this task, how did you ensure that the information you collected was reliable and valid?

Table 2.2 The geological timescale *Note*: Diagram is not to scale.

Eon	Eras of time	Periods of time	Age	Millions of years	Major biological events
Phanerozoic	Cenozoic	Quaternary	Age of mammals	2	Humans expand in range Major ice ages and extinction of large animals in northern hemisphere 
		(Tertiary)		12	Extensive radiation of flowering plants and mammals Dominance of gastropods  
	Mesozoic	Cretaceous	Age of reptiles	135	First flowering plants Extinction of ammonites, marine and aerial reptiles 
		Jurassic		181	Cycads, conifers, ginkgoes, dinosaurs dominant. First birds, flying reptiles, marine reptiles   
		Triassic		230	Dominance of mammal-like reptiles Dominance of ammonites 
	Palaeozoic	Permian		250	Extinction of trilobites and many invertebrates Reptiles more abundant as amphibians decline 
		Carboniferous	Age of amphibians	345	Coal swamp forests Amphibians on land First reptiles Algal-sponge reefs Echinoderms and bryozoans dominant 
		Devonian	Age of fishes	405	Oldest land vertebrates Radiation of land plants and fishes Corals, brachiopods and echinoderms 
		Silurian		425	Oldest life on land: plants, scorpions First jawed fishes 
		Ordovician	Age of invertebrates	560	Diverse marine communities: brachiopods, bryozoans, corals, graptolites, nautiloids First jawless fishes 
		Cambrian		600	Evolution of invertebrates with hard skeletons Dominance of trilobites 
Proterozoic	Precambrian		Simple organisms diversify in the sea	2500	Eucaryotes evolve 
Archaen			Origin of primitive life	3800	Origin of procaryotes
Hadeon				4500	

Evidence suggesting when life on Earth originated

2.2

- ***describe some of the palaeontological and geological evidence that suggests when life originated on Earth***

Palaeontology is the scientific study of **fossils** and all aspects of extinct life. **Geology** is the scientific study of the origin, history and structure of the Earth as recorded in rocks. These two studies are valuable in combination to produce evidence from the past.

Palaeontological evidence

The discovery of two 3400–3500 million year-old Precambrian fossils from Western Australia provided some of the first evidence towards the origin of life on Earth:

- fossils of single-celled anaerobic procaryotes, or **microfossils**, were found in this discovery. These were very similar to those found living today.
- the fossilised remains of **stromatolites** found provided valuable information about the structure of early organisms. Simple bacteria existed in structures called stromatolites which were very similar to present-day living stromatolites. In water, colonies of the simple bacteria, or cyanobacteria, trap layers of calcium carbonate and 'grow' upwards in columns towards the sun. Deposits of living stromatolites can be found in Western Australia at Shark Bay (see Fig. 2.1), growing at a rate of about 1 mm per year with individual domes reaching a diameter of about 200 cm and a height of 50 cm.

The 1999 discovery of what could be the remains of **nanobacteria**, or **nanobes**, in a meteorite from Mars (found in Antarctica) indicated similarities to nanobes discovered in Queensland in 1996. Nanobes are filament-type structures found in rocks. The nanobes found on Mars were able to withstand radiation, cold and acidic conditions, a time when the environment on Mars may have paralleled that existing on Earth for a few hundred million years. Given the presumed sharing of debris generated from meteorite impacts amongst the early planets, the origins of nanobes on Mars and Earth may be the same. Some scientists hypothesise that nanobes are the smallest form of life (they are ten times smaller than our smallest bacteria). However, some researchers believe nanobes to be merely crystal growths. The debate continues.

In general, palaeontologists using the fossil evidence from different rock layers have found that the more primitive cells and marine organisms are found in the lower layers of rock compared to the more complex and land-dwelling organisms. This trend

Figure 2.1 Living modern stromatolites in Western Australia

suggests that simple organisms evolved into more complex organisms and marine organisms preceded land-dwelling organisms. We can make inferences about extinct organisms by studying their closest modern living relatives.

Geological evidence

2500 million year-old Archaean rocks from north Western Australia were examined by scientists in 1999. They found **biomarkers**, or chemical evidence, for the existence of cyanobacteria. Biomarkers are chemicals that are produced by only one group of organisms providing evidence of their existence in the past.

Oxidised rocks such as banded iron and red bedrock formations provide geological evidence towards the origin of photosynthetic life. Oxygen produced by photosynthetic organisms accumulated in the rocks until fully saturated, before building up as a gas in the atmosphere.

Plant and animal fossils

FIRST-HAND AND SECONDARY SOURCE INVESTIGATION

BIOLOGY SKILLS

P13

- ***gather first-hand or secondary information to make observations of a range of plant and animal fossils***

Aim

1. To gather first-hand or secondary information.
2. To make observations of a range of plant and animal fossils.

Background information

Fossils are any remains, traces or imprints of an organism preserved over a long period of time. It is an extremely rare occurrence as it requires very specific conditions at the time of death of the organism.

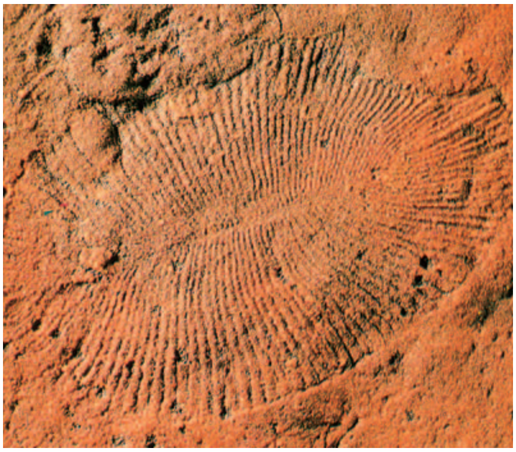
There are four main conditions under which fossils may form:

1. *quick burial*—rapid covering of dead organism or evidence such as footprints (see Fig. 2.2) or coprolites (faecal remains)
2. *prevention of decay*—needs conditions such as lack of oxygen, high acidity, very low temperatures and low moisture to prevent decay by bacteria and fungi
3. *organism lies undisturbed*—completely covered by sediments to prevent scavenger organisms from breaking up and scattering body parts
4. *presence of hard body parts*—for fossilisation to occur organisms need hard parts such as bone, exoskeleton, teeth or shells.

Occasionally the conditions for fossil formation are perfect and impressions for soft-bodied organisms can be preserved, for example, the jellyfish and worms found at Ediacara Hills in South Australia (see Fig. 2.3).

Figure 2.2 Fossilised footprints dated at 3.7 million years old

Figure 2.3 *Dickinsonia costata*—almost a metre long, resembling an annelid worm



Method—gather first-hand or secondary information

If you do not have fossil samples to observe, gather secondary information on a variety of plant and animal fossils. In your search, collect photographs or diagrams of at least four named plant and four named animal fossil specimens. List as many observations as you can for each specimen. Some fossil examples are provided in Figure 2.4. Observations can be listed (as follows for Fig. 2.4c) as comments such as:

- fern-like appearance
- only a sample of one fern frond or branch (not entire plant)
- similar to present-day fern appearance
- leaflets are opposite each other and contain vein-like structures.

Other fossil suggestions to research:

- Wollemi pine
- *Gangamopteris* and *Glossopteris*
- *Archaeopteryx*
- coelacanth
- ammonite.

Results

List your observations next to each fossil photograph or diagram (or description of the real fossil sample you observed).

Discussion/conclusion

1. Identify the four main conditions under which fossils may form.
2. List three examples of the types of things that can be classified as fossils.
3. Describe the types of structures in your observed plants and animals that were able to be preserved.
4. List the plant and animal fossils you observed that are still around today?
5. Of those fossils that are not plants or animals from the present day, try to estimate their age using your previously constructed *evolution of life* timeline (see page 207). Name the plant or animal fossils and your estimate of their age.

SR

Plant and animal fossils—extension

Figure 2.4 Fossils: (a) trilobite—extinct organism found only in rocks dated around 500 million years ago; (b) fossil bones of baby diprotodont (large, herbivorous marsupial) found at Riversleigh, Queensland (one of the richest fossil deposits of the world); (c) fossil impression of an extinct seed fern; (d) *Baragwanathia longifolia*—plant fossil found in Victoria, preserved with planktonic marine organisms (graptolites)

(a)

(b)

(c)

(d)

2.3 Change from an anoxic to an oxic atmosphere

■ ***explain why the change from an anoxic to an oxic atmosphere was significant in the evolution of living things***

An **anoxic** atmosphere is one defined as being deficient, or lacking, in oxygen. An **oxic** atmosphere is one where oxygen is available. A change from an anoxic atmosphere free of oxygen to an oxic atmosphere with plenty of available oxygen had a significant influence on the conditions of early Earth and hence the evolution of living things.

This major change to the atmosphere and increase in oxygen inhibited the growth of **anaerobic** organisms and caused them to decline, while photosynthetic organisms became more abundant. Today, anaerobic organisms only survive in environments with a very low oxygen concentration, such as in swamps, bogs, deep underground or in deep ocean hydrothermal vents.

The next significant change as a result of the increase in oxygen in the atmosphere was that aerobic organisms became more efficient in energy production (respiration), providing a large energy source for increased activity and eventually this led to an increased complexity and size of these organisms.

As the oxygen began to accumulate in the atmosphere, it reacted with the sun's ultraviolet radiation to produce ozone (O_3). As the amount of oxygen increased, so did the amount of ozone produced, until an ozone layer formed. This ozone layer reduced the amount of ultraviolet radiation reaching the Earth's surface. This had a significant influence on future organisms as it protected them from dangerous ultraviolet radiation. Even more so, organisms were able to succeed in inhabiting the land.

Impact of increased understanding of the fossil record

SECONDARY SOURCE INVESTIGATION

BIOLOGY SKILLS

P13
P14

■ ***identify data sources, gather, process, analyse and present information from secondary sources to evaluate the impact of increased understanding of the fossil record on the development of ideas about the history of life on Earth***

Aim

1. Identify data sources, gather, process, analyse and present information from secondary sources.
2. Evaluate the impact of increased understanding of the fossil record on the development of ideas about the history of life on Earth.

Method

Identify data sources, gather and process information from secondary sources relating to the increased understanding of the fossil record and the development of ideas about the history of life on Earth. Once you have refined and summarised your gathered information, analyse the information so that you may evaluate the impact of this increased understanding. Use Table 2.3 to help create your answer.

(Remember to revise your definition of the verbs in this dot point, in particular: analyse—*identify components and the relationship among them; draw out and relate implications,* and evaluate—*make a judgement based on criteria; determine the value of.* Other verbs are defined at the beginning of this textbook on page viii.)

Increased understanding of fossil record	Development of ideas about the history of life on Earth	Impact of increased understanding of fossil record on development of ideas about the history of life on Earth	Evaluation of the impact

Table 2.3 Evaluating the impact of increased understanding of the fossil record on the development of ideas about the history of life on Earth

Results:

Once you have completed your evaluation, present it in one of the following formats:

- a letter
- a scientific journal article
- a flowchart or mind map
- a PowerPoint or overhead presentation to the class.

Discussion/conclusion

Make a conclusive brief statement of your final evaluation of the impact of increased understanding of the fossil record on the development of ideas about the history of life on Earth.

SR

A blank copy of Table 2.3

2.4 The effect of scientific developments on ideas about the origins of life

- ***discuss the ways in which developments in scientific knowledge may conflict with the ideas about the origins of life developed by different cultures***

Developments in scientific knowledge about the origins of life are constantly occurring as discoveries are made and new technologies provide more advanced approaches to unanswered questions. These changes may conflict with the ideas about the origins of life held by different cultures. Some of these different ideas for the origin of life have developed over thousands of years in certain cultures.

The difference between science and religion has been the basis of conflict for a long time between the knowledge of scientists and the beliefs of different cultures. It appears that most of these conflicts have arisen as a result of overlooking the distinguishable differences between science and religion:

- *science* can be defined as the pursuit of knowledge through observations that produce testable hypotheses and models
- *religion* can be defined as involving a god or superior being and is based on a set of beliefs which do not need to be tested. They do not produce testable hypotheses and models.

SR

Extension activity—scientific developments

This means that logically there can be no intellectual conflict. For many people, cultural beliefs about life's origin form part of their religion, where the belief is that God is the creator of the universe. For example, in Australia, Aboriginal beliefs involve an ancestral being that created the Earth a long time ago during a time called alcheringa or Dreamtime. These beliefs have a long tradition in the culture they belong to.

Charles Darwin received much opposition surrounding his 19th century theory of evolution (*On the Origin of Species*, 1859). Heated debate occurred between biologists, religious leaders and people from his culture, particularly in response to his allegations that God was not creator of the universe. Science should not make statements about God and religious beliefs.

Scientific theories and belief systems can co-exist without conflict. Scientific theory is based on rational analysis and is subject to change, particularly with recent technological developments. Belief systems are based on unchanging views. Many scientists with religious beliefs investigate concepts surrounding the origin and evolution of life using scientific experimentation.

Classification systems and modern genetic technologies create issues which also may be potential sources of conflict.

When attempting to resolve or avoid such conflicts, we must consider the beliefs of the individuals, and carefully balance culture, religion and science. This balance may be achieved by recognising the distinctions between each group and understanding what each one means, aiming to be fair to all groups involved.

REVISION QUESTIONS

1. Construct a flowchart summarising the major stages in the evolution of living things (including organic molecules, membranes, procaryotic heterotrophic cells, procaryotic autotrophic cells, eucaryotic cells, colonial cells and multicellular organisms), labelling the time and whether the environment was oxic or anoxic when each stage occurred.
2. Identify three major periods in the geological time scale and *state* the organisms that existed and dominated in each period.
3. Distinguish between the studies of palaeontology and geology.
4. Briefly describe three pieces of palaeontological and geological evidence suggesting when life on Earth originated.
5. Describe the four main conditions under which fossils may form.
6. Identify an example of fossil evidence showing the existence of soft-bodied organisms.
7. *Name* one plant and one animal fossil that you have observed. Give a brief description of each.
8. Distinguish between an oxic and an anoxic atmosphere.
9. Explain why the change from an anoxic to an oxic atmosphere was significant in the evolution of living things.
10. Discuss the ways in which developments in scientific knowledge may conflict with ideas about the origins of life developed by different cultures.

SR TR

Answers to revision questions