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BIOLOGY

FOR VCE

UNITS 3&4

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SAMPLE CHAPTER

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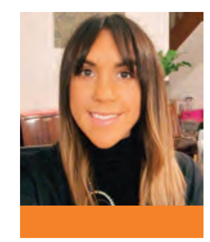
Dr Ngaree Blow



Dr Ngaree Blow is a Noonuccal, Goreng-Goreng, Yorta-Yorta woman living on Wurundjeri country. She is currently working as the Director of First Nations Health for medical education at the University of Melbourne, as well as completing research in the Intergenerational Health team at the Murdoch Children's Research Institute (MCRI). Ngaree completed both her Doctor of Medicine and Masters of Public Health (MD/MPH) degrees concurrently and has a keen interest in public health and paediatric medicine. Ngaree is also a board member of the Australian Indigenous Doctors Association (AIDA) and has been involved in many First Nations health, research and education roles.

Using Biology for VCE Units 3 & 4

Biology for VCE Units 3 & 4 has been purpose-written to meet the requirements of the VCAA Biology Study Design 2022–2026. *Biology for VCE Units 3 & 4* offers teachers and students complete Study Design coverage, unparalleled assessments and practical support, and engaging and scaffolded learning.

Chapter opener

Each chapter begins with a chapter opener that includes:

- Key Knowledge from the Study Design
- Groundwork questions for support, testing student's pre-knowledge
- a list of no-tech, standard and high-tech practicals to support key concepts
- links to digital resources such as revisions notes, chapter tests, Area of Study tests and Unit tests

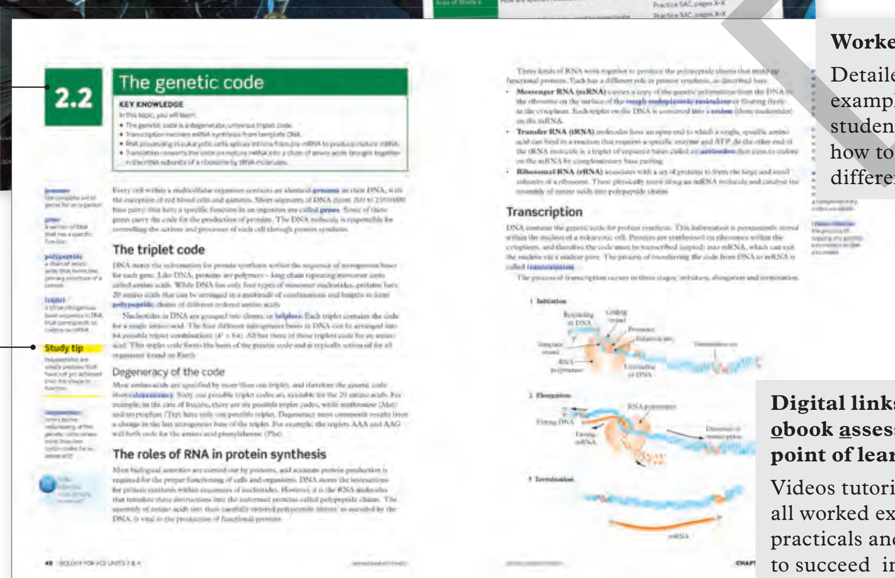
Unit opener

Each Unit begins with a unit opener that includes:

- the outcomes assigned to that unit
- a summary of each Area of Study and their corresponding chapters.

Worked examples

Detailed worked examples take students through how to solve different problems.



Section-based approach

Content is presented in clearly structured sections. Each section is labelled and numbered to help navigation.

Study tips

Practical tips to ensure students do well in their summative assessments.

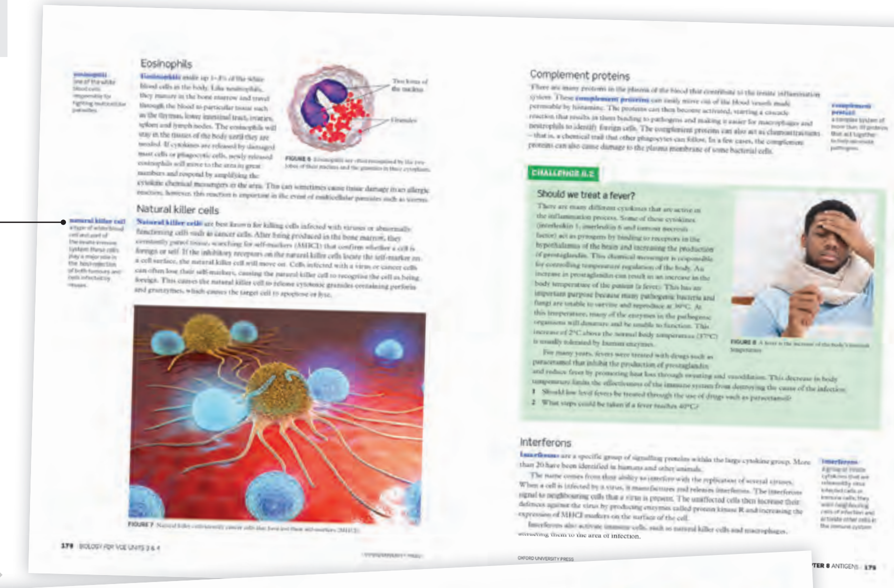
Worked examples

Detailed worked examples take students through how to solve different problems.

Digital links to your obook assess at the point of learning

Videos tutorials for all worked examples, practicals and how to succeed in your assessments

Embedded links to digital resources at the point of learning.



Challenge questions

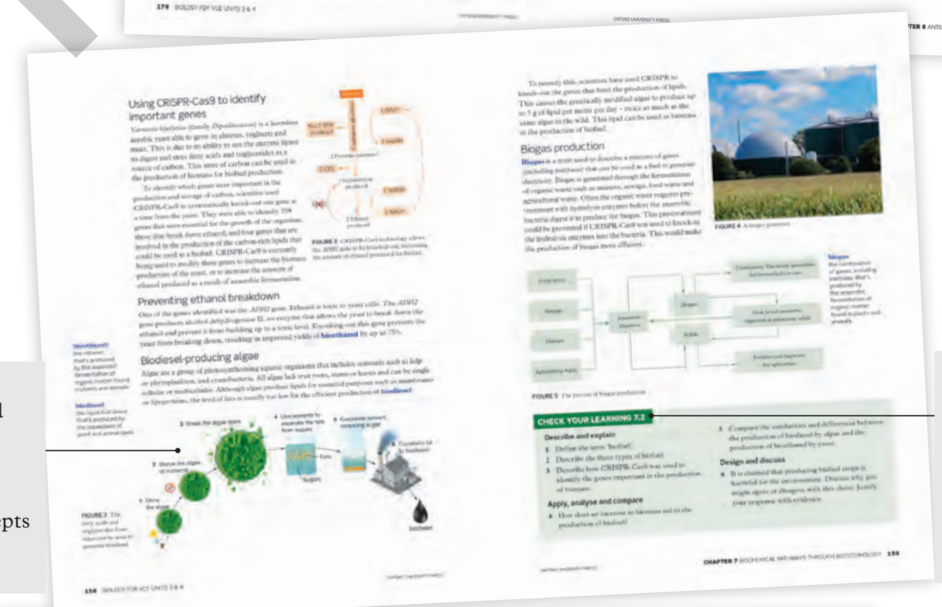
Extension questions and scenarios encourage critical thinking of the chapter content.

Margin glossary

Literacy support is provided for key terms in the chapter with clear and concise definitions.

Case studies

Real-life examples illustrate theoretical points being explained in the text.

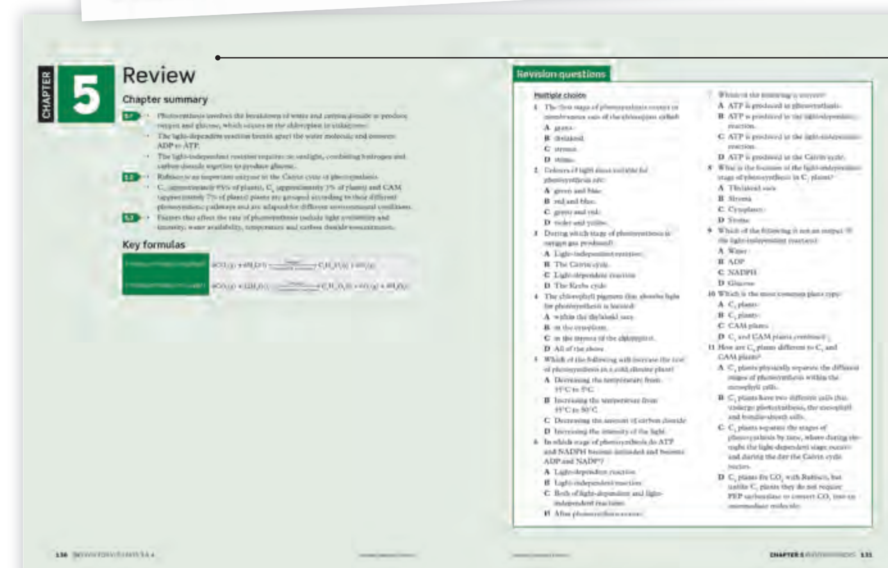


Full colour diagrams and photos

Rich visual materials illustrate concepts and engage students.

Check your learning questions

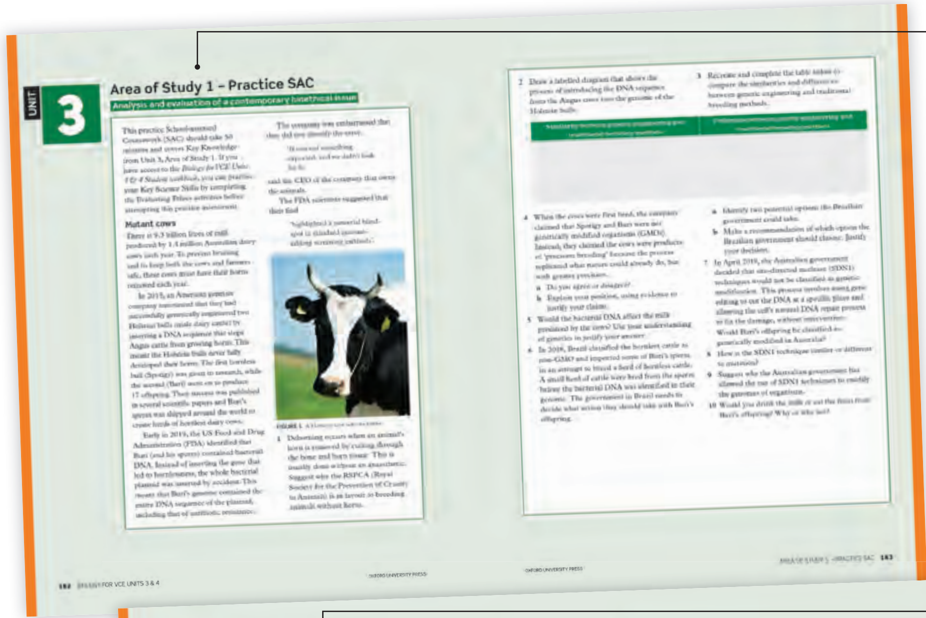
Each section ends with Check your learning questions that revise the content covered in the section set out in the Blooms Taxonomy hierarchal models.



Chapter review

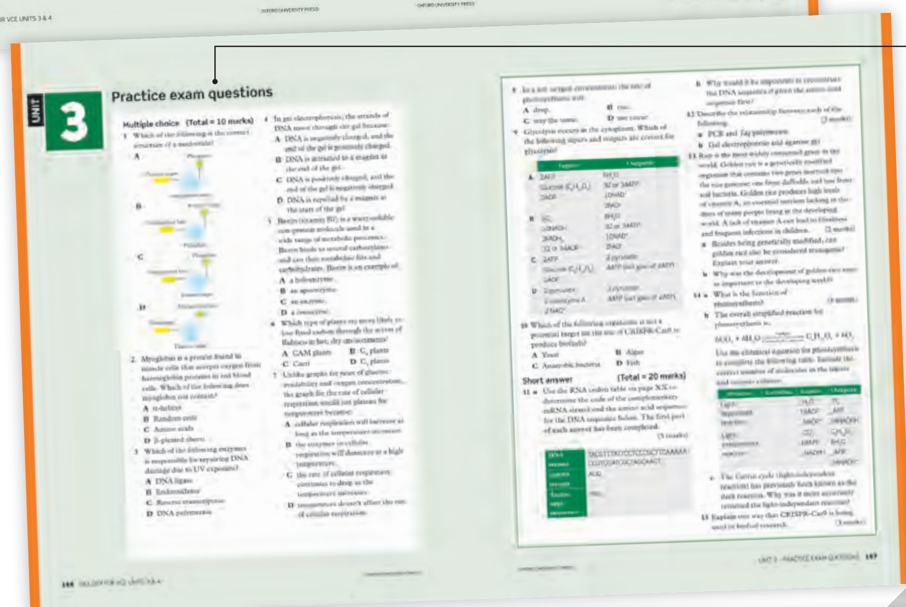
Each chapter review includes:

- summary of Key Knowledge in each chapter section
- key summary diagrams
- key formulas
- multiple-choice review questions
- short-answer review questions
- links to digital resources such as revisions notes, chapter tests, Area of Study tests and Unit tests.



Practice School-assessed Coursework (SACs)

5 practice SACs to familiase students with the internal assessments: (×1) case study analysis, (×1) primary and secondary data analysis, (×1) comparison of 3 practicals, (×1) bioethical evaluation and (×1) student-designed scientific investigation



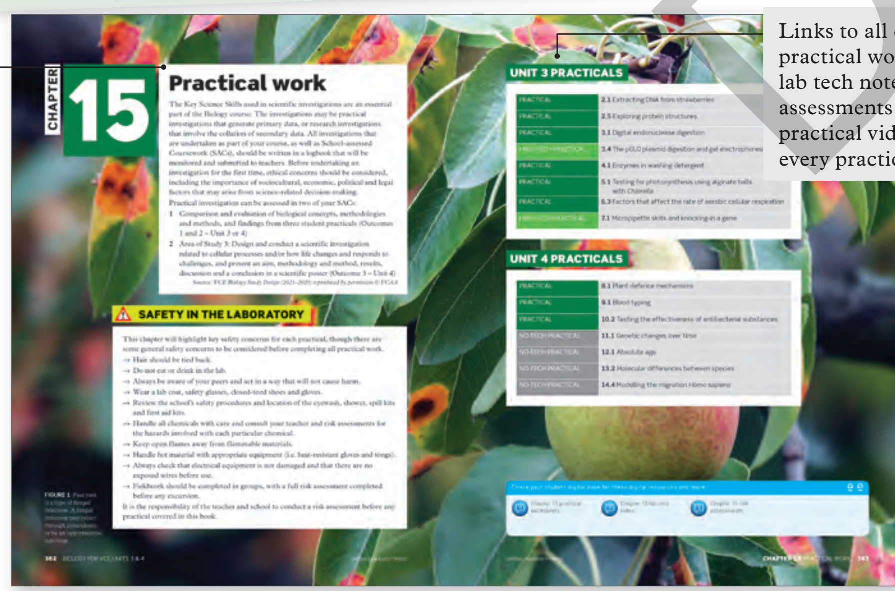
Practice exam questions

- practice exam questions in the style of VCCA's external examination
- Unit 3, Unit 4 and Units 3 & 4 multiple choice and short answer questions to practice student's knowledge

Practial work

The practical work includes:

- at least one practical per chapter
- safety guidelines for working in a lab
- no-tech practicals that can be completed outside of the lab
- standard practicals that can be completed in any school lab
- high-tech practicals that use specialty equipment
- video and mock data links for all practicals.



Links to all online practical worksheets, lab tech notes, risk assessments and practical videos for every practical.

Student Workbooks

Biology for VCE Student Workbooks are designed to help students succeed in VCE, providing activities and questions to support every internal and external assessment. With an engaging design, full-colour photos and relevant scientific diagrams throughout, these write-in workbooks help students to develop examinable Key Science Skills. The workbooks include:

» a stand-alone **biology toolkit** teaching students how to read and use biological data, how to write and present reports, how to use their logbooks, and how to answer exam questions and read an examiners report
» full **chapter summaries** and chapter checklists for students to self-assess their understanding of Key Knowledge
» **support groundwork questions** different to the student book, to gauge the student's pre-knowledge from junior science
» four activities per chapter – Case cracker, Data drill, Experiment explorer and Evaluating ethics to **practice Key Science Skills** and **prepare for SACs**
» Unit 3, Unit 4 and Units 3 & 4 **practice exam questions**
» write-in **practical worksheets** from the student book
» **answers to all questions**.

obook pro

Biology for VCE Units 3 & 4 is supported by a range of engaging and relevant digital resources via obook pro.

Students receive:

» a complete digital version of the Student book with note-taking and bookmarking functionality
» **video tutorials** demonstrating practicals, worked examples, exam success and more!
» **write-in worksheets** to accompany all groundwork questions, challenge questions, practicals and Check your learning questions
» **groundwork support resources** should students need a refresher
» interactive auto-correcting multiple-choice quizzes for each chapter, Area of Study, Unit and course with immediate feedback and **markbook** functionality
» a range of engaging weblinks to support understanding
» revision notes for exam preparation
» access to work assigned by their teacher: reading, homework, tests, assignments.

Teachers receive:

» **answers to all questions** in the student book
» **mock data and answers to all practicals**
» detailed **planning resources**
» **practice exams and guidance for developing SACs**
» the ability to **assess, track** and **report** student's progress in one place.

CHAPTER 12

Evolving species

Evolution is the process of organisms developing new characteristics from their ancestors over time. Evidence of evolution is observed through fossils – the preserved remains, impression or trace of once living organisms – and through the fossil record, showing the succession of life forms on Earth over millions of years. The fossil record is just one form of evidence that supports the divergence of a single ancestral species into different species. This divergence can result from a population being separated by a permanent barrier, or by the availability of a new niche in the environment. New mutations and selection pressures can contribute to the reproductive isolation of a population so that it becomes separate species.

KEY KNOWLEDGE

- → changes in species over geological time as evidenced from the fossil record: faunal (fossil) succession, index and transition fossils, relative and absolute dating of fossils
- → evidence of speciation as a consequence of isolation and genetic divergence, including Galapagos finches as an example of allopatric speciation and *Howea* palms on Lord Howe Island as an example of sympatric speciation

Source: *VCE Biology Study Design (2021–2025) reproduced by permission © VCAA*

FIGURE 1 Fossils do not need to be the bones and teeth of past species; they can also be impressions of species left behind. This image is of a three-toed dinosaur footprint at Gantheaume Point in Broome.

PRACTICALS

NO-TECH PRACTICAL	**12.1** Absolute age

For full instructions for each practical, go to Chapter 15 Practical work. For additional practical support, including video demonstrations, risk assessments and lab tech notes, go to your obook pro.

GROUNDWORK QUESTIONS

Before you start this chapter, try the following groundwork questions. They will help you to make sure you understand the key concepts that we will build on in this chapter.

12a What geographical barrier could prevent two populations from mating with each other?

12A Groundwork resource
Evidence for evolution

12b Use natural selection to explain how traffic noises may cause changes in the mating call of a bird?

12B Groundwork resource
Natural selection

12c How long ago was Australia joined with any other landmass?

12C Groundwork resource
Continental drift

If you need help with any of the questions, have a go at the corresponding groundwork resource on your obookPro.

12.1 Species change over geological time

KEY IDEAS

In this topic, you will learn that:

- fossils are evidence of species change over geological time.
- the geological timescale provides the sequence of events in Earth's history.
- relative dating and absolute dating are two methods of dating fossils.

The continual change in allele frequencies that occurs as a result of changing selection pressures (as discussed in Chapter 11) can result in phenotypic variations in a population. In time, these phenotypic variations can result in different populations no longer being able to reproduce with each other. This reproductive isolation is the key determining factor in the two populations becoming different species. These sorts of changes have been occurring since the beginning of life on Earth.

There is a large body of evidence that supports changes in species over geological time. This includes studies of living species with similar features, fossil evidence and dating techniques. Although comparisons of the structural and biochemical features of living organisms can only give a glimpse of shared common ancestors, it is supported by the fossil record and dating techniques that are evidence of the **geological timescale**.

geological timescale the sequence of events in Earth's history based on the geological rock record

fossil the preserved remains, impression or trace of a once living organism

Fossils

The term **fossil** is a broad umbrella term that covers the preserved remains of organisms or traces of organisms such as footprints, coprolites (fossilised faeces) or other impressions.

Since few fossils can survive the high temperatures at which igneous and metamorphic rocks form, almost all fossils are found in sedimentary rock. The structures that are most likely to remain as fossils are 'hard' shells, bones, teeth, woody tissues and leaves. Soft tissues decay quickly and rarely fossilise. In all cases, the formation of fossils requires:

- quick burial
- a lack of oxygen
- a lack of disruption to the remains.

This is why fossils are such a rare occurrence.

Fossils originate when organisms become encased in sand or mud sediments, usually at the bottoms of seas, lakes or marshes. New layers of sediment build up to cover the older layers, sealing the traces or remains from rapid decay due to bacteria. Dissolved minerals wash through the fossils and are left behind in the gaps between tissue. The hardened minerals eventually form the rock-like structure of some fossils. At a much later time, the sedimentary rocks covering the fossils may become exposed and be susceptible to erosion, revealing the preserved fossils.

FIGURE 1 A fossil impression of a leaf. The leaf itself is not preserved, just an imprint of the leaf on the rock surface.

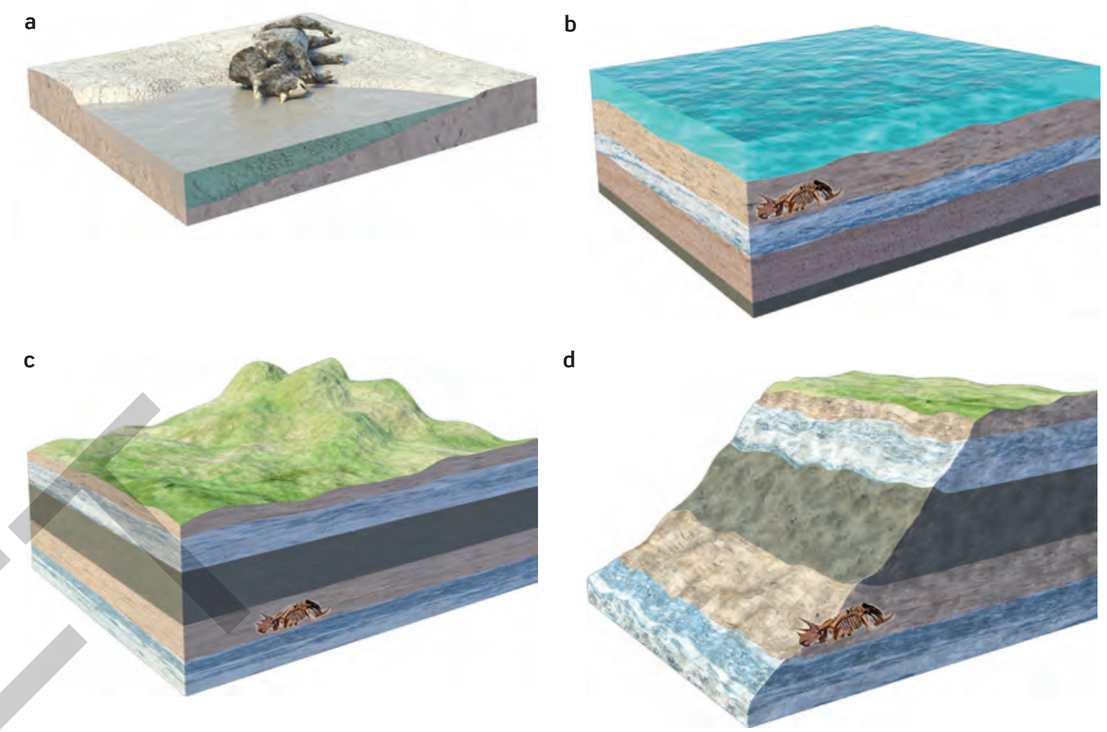


FIGURE 2 The formation of a fossil: **a** an organism dies and is **b** buried under fine-grained sediment and water. **c** Over millions of years more sediment covers the fossil and minerals start to preserve the fossil. **d** The fossil is exposed through erosion and uplift.

Fossil record and dating techniques

The **fossil record** refers to the history of life on Earth documented in fossils. It shows that there has been a succession of different life forms on Earth over millions of years. The law of **faunal (fossil) succession** says that the types of organisms found in the different layers of rocks are in a consistent order. Over time, new fossils form on top of the old fossils. This means that the deeper the fossils are found in the Earth, the older the fossil is thought to be.

The law of faunal succession can be extended to determine the **relative age** of the fossil. If the same fossil is found in rocks from different places, it can be assumed that the organism from which the fossil came from lived at the same time, and therefore that the rock is the same age. This process is called **relative dating**.

Absolute dating is a dating technique that uses the rate of isotope decay to determine the age of the fossil.

Some fossils show characteristics of both an ancestral species and more recent species. These fossils are classified as **transitional fossils**. Transitional fossils can be said to offer a 'missing link', providing evidence of species progression over time.

There are many examples of transitional fossils in the fossil record. One of the most common examples is the fossil of *Archaeopteryx*, which has characteristics of both reptiles and the modern bird. With a blend of both avian features (feathers, wings, wishbone and reduced fingers) and reptile features (a complete set of teeth, flat sternum, long bony tail and three claws on the wing), *Archaeopteryx* has been dated to about 150 million years ago in the late Jurassic period.

fossil record the record of organisms over geological time as inferred from fossil evidence

faunal (fossil) succession the observation that fossils found in sedimentary rock strata succeed each other vertically in an orderly manner

relative age the age of a rock determined by the ages of surrounding rocks, events and organisms; this is an estimation age or age range

relative dating an expression of the geological age of a fossil or rock strata, relative to other organisms, rocks, features or events without expressing absolute age

absolute dating a technique to determine the age of a fossil based on the decay of radioactive isotopes

transitional fossil a fossil that exhibits traits that are common to both an ancestral group and its descendent group

Video
Relative and absolute dating

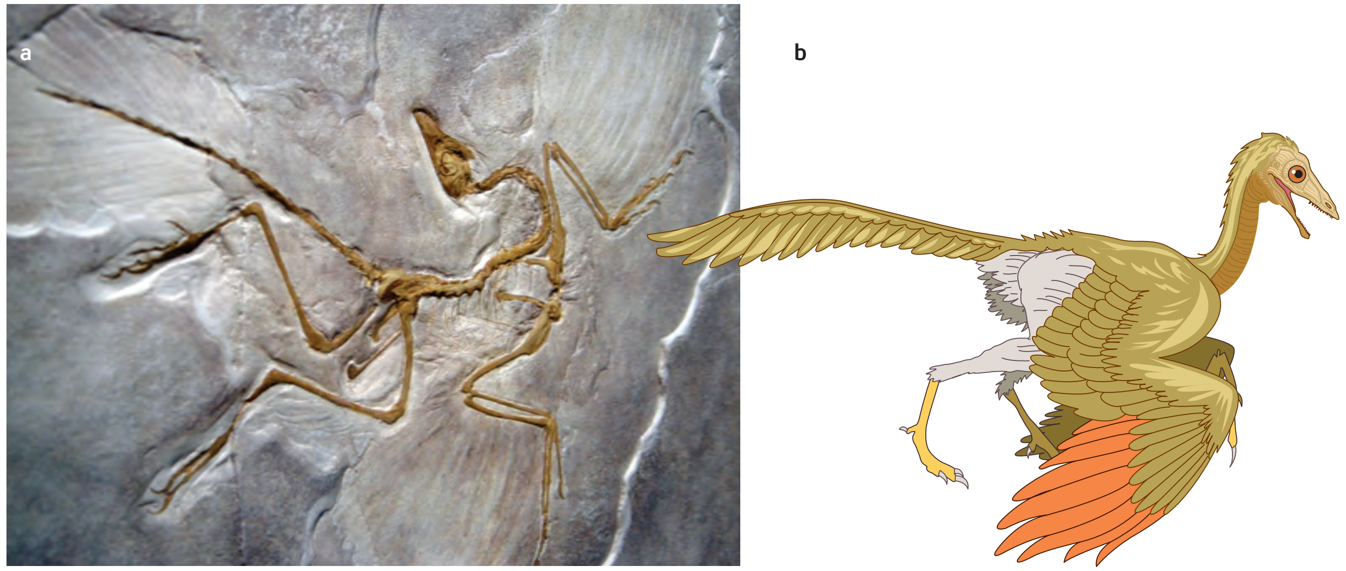


FIGURE 3 **a** A fossil of *Archaeopteryx* and **b** a 3D rendering, showing both avian and reptile characteristics

Relative dating

strata
the layers of sedimentary rock

index fossil
a distinctive, abundant fossil with a wide geographic distribution over a relatively short geological period of time

Fossils that are found in ancient, deeper **strata** tend to have simpler structures than younger, upper strata fossils. Each strata layer of rock has unique fossil groupings. Fossils from deeper, older strata contain similar types of organisms across the world. Relative dating is a dating technique that uses the understanding that fossils found in deep layers of strata are older than those from more recent layers of rock.

Occasionally, some fossilised species completely disappear from the upper levels of rock. As a result, palaeontologists devised methods of identifying different rock layers that contain similar fossil forms; the fossils in these rocks are defined as **index fossils**. Rock sections with index fossils have a lower boundary and an upper boundary, where the index fossil first and last appeared in the rock record. The order of geological events is able to be determined using the lower and upper boundaries of rock strata.

For example, the trilobites were the first hard-shelled invertebrates and were constantly evolving to inhabit new areas for around 270 million years. Some species lived in sediment, while others crawled or swam in open water. The formation of large ice sheets over the ocean caused most trilobite species to die within a relatively short geographical time period. This means trilobite fossils can be found in rock aged between 540 million to 252 million years old.

Study tip

Remember that there are three different types of rock:

- igneous
- sedimentary
- metamorphic.

Igneous rocks are formed through the cooling of magma. Sedimentary rocks are formed from sediment of weathering and erosion, and metamorphic rocks are igneous or sedimentary rocks altered through temperature and pressure.

FIGURE 4 Fossilised remains of the trilobite, the first hard-shelled invertebrate on Earth

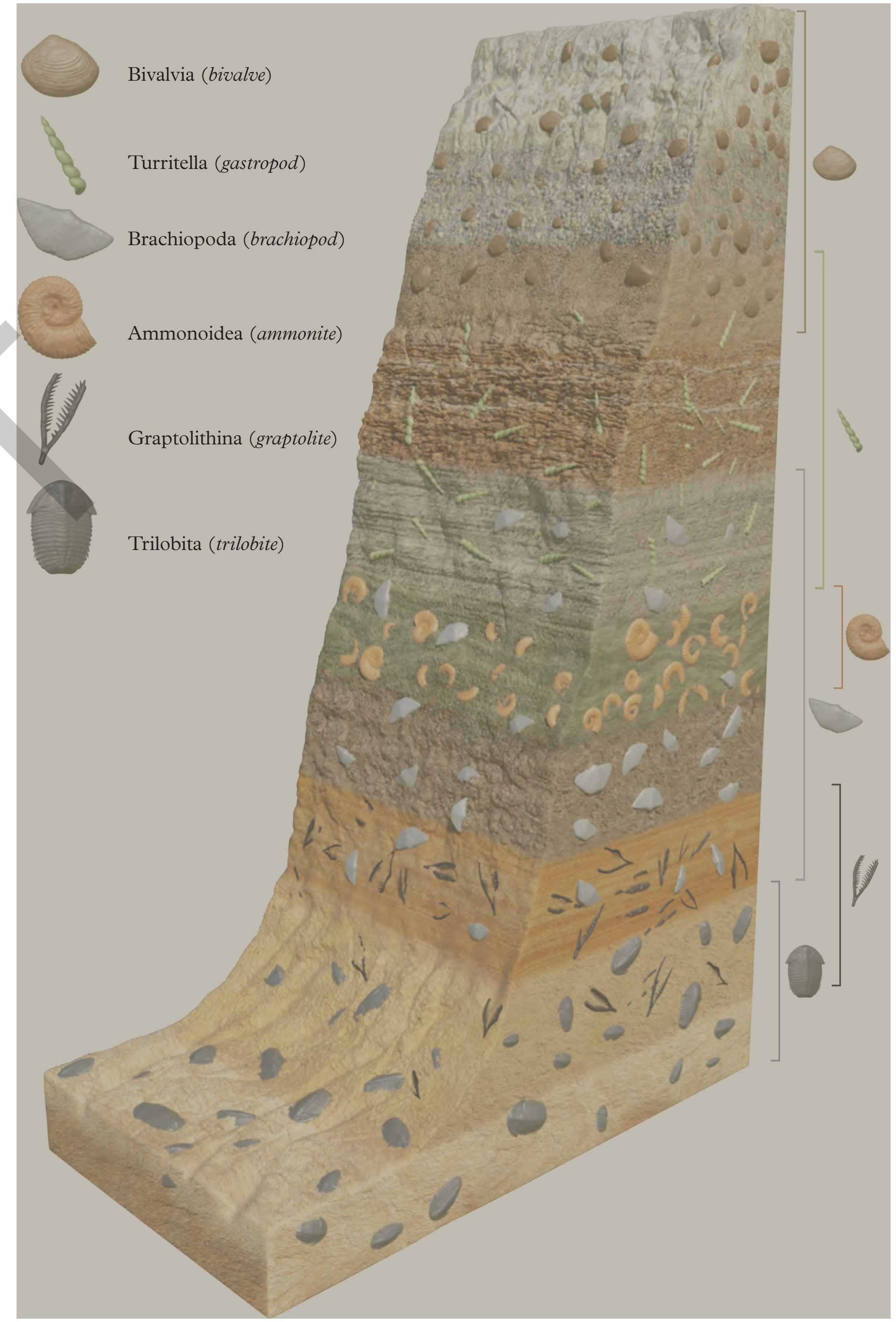


FIGURE 5 The law of fossil succession. Each fossil has a limited range in a succession of strata. Widespread fossils with a short range are index fossils.

Absolute dating

isotope
variations of an element that differ in the number of neutrons within their nuclei; many isotopes are radioactive forms of an element

The atmosphere surrounding Earth is constantly being bombarded by cosmic rays. This causes some atoms to form **isotopes** (i.e. elements that have a different number of neutrons in the nuclei to their standard amount). Although they have the same atomic number (i.e. number of protons), their atomic masses differ (i.e. protons and neutrons). Some isotopes are radioactive and release energy (e.g. carbon-14), whereas others are stable (e.g. carbon-12). Living organisms absorb background levels of radioactive material, such as carbon-14, through uptake of gas and nutrients.

half-life
the time taken for a quantity of a radioactive isotope to decay to half of its initial value

While an organism is alive, the number of radioactive isotopes present in their body remains constant. However, once an organism dies, the isotopes change to a more stable state (i.e. they are said to decay). This change decreases the amount of radioactive isotope. How fast this happens is called the rate of decay. The length of time it takes for half the remaining isotope to become stable is called the **half-life**. For example, 1 kg of carbon-14 will take 5730 years for half (0.5 kg) to become stable. After another 5730 years, half the remaining mass of carbon-14 (0.25 kg) becomes stable. This means after 11 460 years, only a quarter of the original radioactive carbon-14 will remain.

TABLE 1 The half-life of some elements used to date rocks

Radioactive element	Approximate half-life (years)	Product of decay	Appropriate age of fossil for dating (years)
Carbon-14	5730	Nitrogen-14	Less than 50 000
Uranium-235	0.7 billion	Lead-207	More than 50 000
Potassium-40	1.3 billion	Argon-40	More than 50 000
Uranium-238	4.5 billion	Lead-206	More than 50 000
Thorium-232	14 billion	Lead-208	More than 50 000

Video
Worked example 12.1: Absolute dating

WORKED EXAMPLE 12.1

ABSOLUTE DATING

Potassium-40 has a half-life of 1.25 billion years. In igneous rocks closely associated with a fossil layer, potassium-40 has a 1:3 ratio with its radioactive breakdown product, argon-40. What will the age of the fossils in the fossil layer be?

SOLUTION

1 Calculate the percentage of potassium-40 remaining (in this case, use the ratio given):

$$\% \text{ potassium-40} = \frac{1}{4} \times 100 = 25\%$$

2 Calculate the number of half-lives by producing a flowchart, starting from the initial amount (100%) and halving each time until the end amount (25%):

$$100\% \rightarrow 50\% \rightarrow 25\%$$

Therefore, there have been two half-lives (determined by counting the number of arrows in the flowchart).

3 Calculate the age of the fossil by multiplying the half-life by the number of half-lives passed:

$$\text{Age of fossil} = \text{number of half-lives passed} \times \text{half-life}$$
$$\text{Age of fossil} = 2 \text{ half-lives} \times 1.25 \text{ billion years}$$
$$2 \text{ half-lives} \times 1.25 \text{ billion years} = 2.5 \text{ billion years}$$

The fossils in this fossil layer containing 25% potassium-40 will be approximately 2.5 billion years old.

radioactive element
an element that emits radiation as a result of the spontaneous degeneration of its nucleus

Some **radioactive elements** have such a long half-life that they are not useful for dating very young rocks because their products of decay are too small to measure accurately. Similarly, elements like carbon-14 decay so rapidly that their quantities in old rocks and fossils (>50 000 years old) are too small to measure. The age of fossils >50 000 years can be determined by the comparative decay rates of different radioactive elements such as uranium-235 and potassium-40 in the rocks surrounding the fossil. By using the decay of other radioactive elements, geologists have been able to determine the age of Earth at 4.6 billion years old.

History of life on Earth

Video
What is geological timescale?

It has been estimated that the first life forms (i.e. prokaryotes) originated about 4 billion years ago. Each population of prokaryotes would have become specialised to their conditions through natural selection. Evidence of changes in populations over time can be seen in the fossil record. Some of the earliest fossils, stromatolites (e.g. sediment trapping cyanobacteria), can be found across the world, including in Shark Bay in Western Australia (Figure 6). These have been dated back to 3.5 billion years ago.

Figure 7 shows a diagrammatic summary of the history of life on Earth. The timescale is divided into eras, from the Precambrian, which hosted only prokaryotes and some jellyfish, to the Cenozoic that includes all life until the present. Each era is subdivided into periods, and each period is subdivided into epochs. The divisions are all characterised by specific index fossils.

FIGURE 6 The Shark Bay stromatolites in Western Australia are thought to be some of the earliest fossils on Earth.

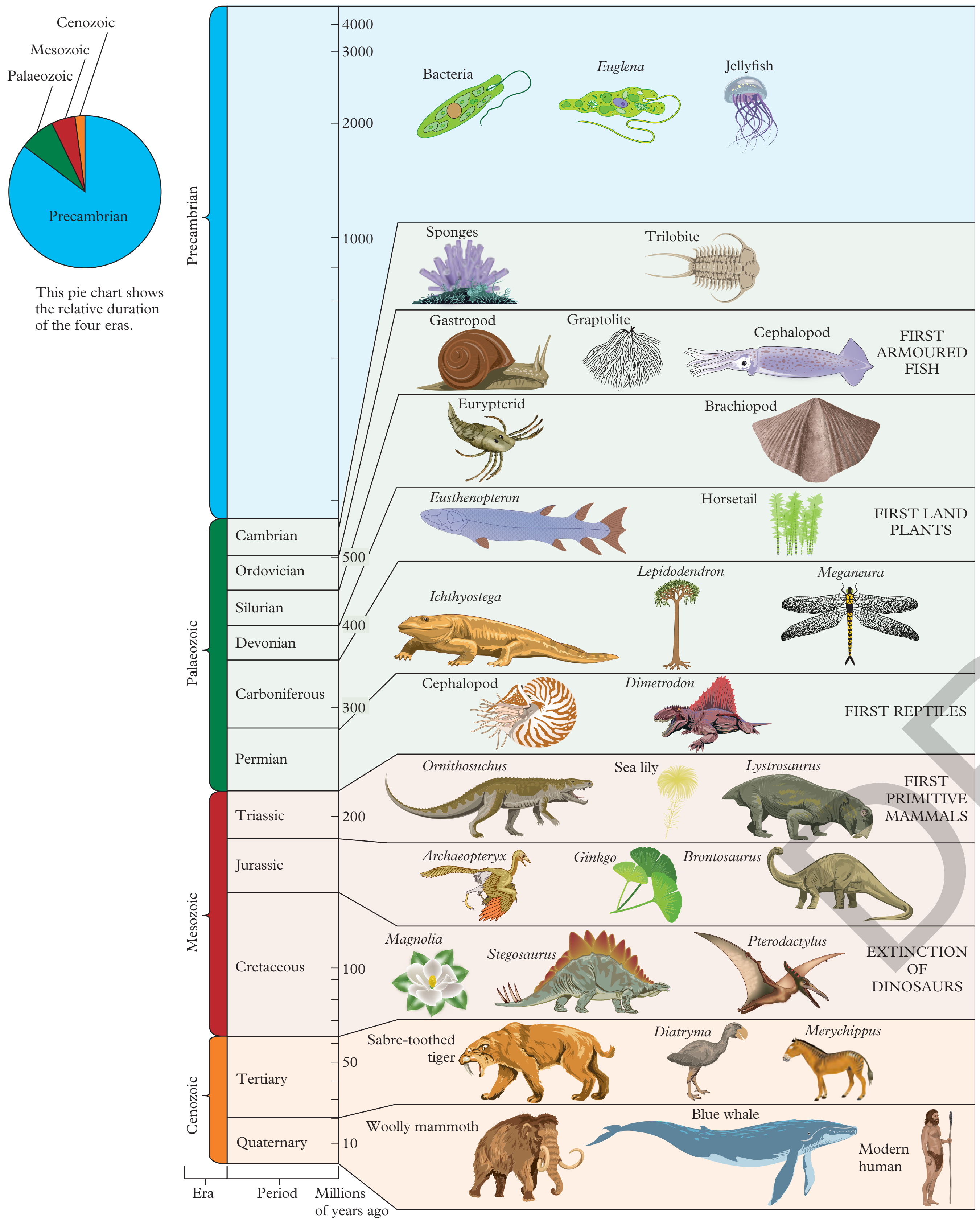


FIGURE 7 Possible history of life on Earth, illustrating the emergence of key species in different periods of geological time.

CHECK YOUR LEARNING 12.1

Describe and explain

1 Explain how fossils provide evidence of evolution.

2 Define the term 'index fossil'.

3 Describe two techniques used to date fossils or rock strata.

4 Identify reasons why scientists may want to date a fossil.

5 Identify the most appropriate absolute dating method for a lizard fossil aged 680 years old.

6 Explain why a fish bone found on the beach is unlikely to be a fossil.

Apply, analyse and compare

7 Why are transitional fossils important in the fossil record?

8 A giant penguin that stood as tall as a person has been identified from fossil leg bones discovered by an amateur palaeontologist on New Zealand's South Island. At 1.6 m and 80 kg, the new fossil species, *Cross waiparensis*, would have been four times as heavy and 40 cm taller than the emperor penguin (*Aptenodytes forsteri*), the largest living penguin today.

  a Describe the appropriate technique to date *Cross waiparensis*, considering the fossil is predicted to be approximately 60 million years old.

  b Which geological period would this species have existed in?

9 When animals die, bacteria decay the remains. This requires warmth, moisture and oxygen. In northern Russia, whole remains of the woolly mammoth (*Mammuthus primigenius*) have been found preserved in frozen soil. Why did they not decay?

10 A mud layer contained a leaf that was 4800 years old. Below that was a fossilised tree trunk in sandstone. Below the fossilised tree was a fish skull dated back to 300 million years old.

  a What age can the fossilised tree be?

  b Is this an example of relative dating or absolute dating?

11 A volcanic eruption destroyed a hillside of vegetation and scientists want to know when the event occurred. There are fossils of burnt trees in the ash layer indicating they died at the time of the eruption. A 1:1 ratio of uranium-235 and lead-207 has been identified in the ash layer. Calculate when the volcanic eruption destroyed the trees.

FIGURE 8 A volcanic eruption

12 A crocodile was struck by a landslide that quickly buried the animal. Apply your knowledge of fossil formation to determine whether the crocodile's skeleton would form a fossil.

Design and discuss

13 Use the timescale of life on Earth (Figure 7) to help you answer the following: Why did land plants appear before land animals? You may need to do further research to answer this question.

12.2 Evidence of speciation

KEY IDEAS

In this topic, you will learn that:

+ genetic divergence describes divergence from a common ancestor due to different selective pressures. Adaptive radiation is a type of genetic divergence.

Genetic divergence

genetic divergence
evolution that leads to descendants becoming different in form from their common ancestor due to different selection pressures

niche
the role of an organism in an environment

Genetic divergence, or divergent evolution, occurs when a population of interbreeding organisms diverges (i.e. separates) into two or more species. This may occur when there is competition for a particular resource, or when a new **niche** becomes available in an environment.

Most populations will have some variation in their physical characteristics, and these occur because of mutations in their DNA. These differences may be large (such as a new colour) or small (such as a slightly louder mating call). These variations allow the organisms to exploit a different resource and therefore have an advantage over other members of the same species. Although these variations may have been present in the population for some time, it is not until environmental pressure acts upon the population that the variations become important for survival. Eventually, two groups of organisms will become so different that they will no longer be able to breed together in natural conditions to produce viable offspring. This means they have become reproductively isolated and are considered a new species.

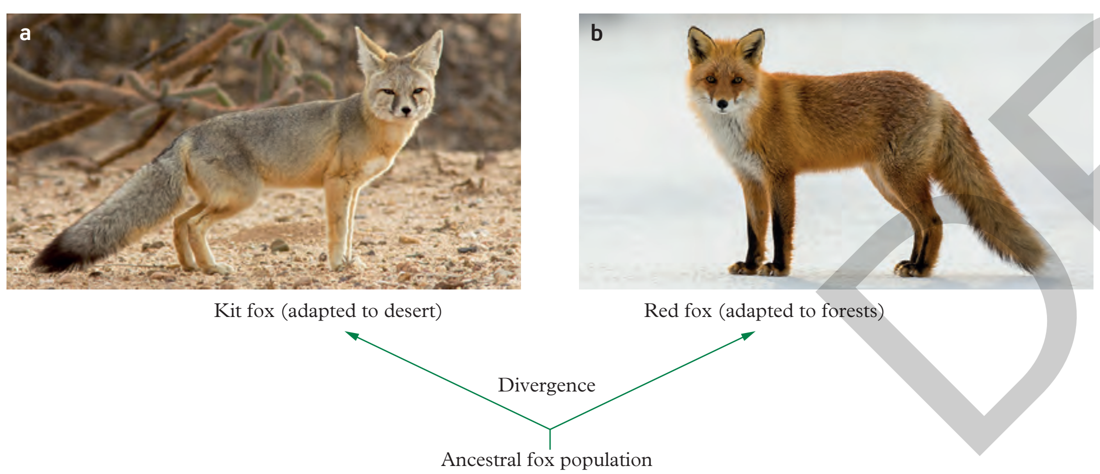


FIGURE 1 Divergence of **a** the kit fox (*Vulpes macrotis*) and **b** the red fox (*Vulpes vulpes*) from a common ancestor due to different selection pressures in their environments

homologous structures
similar structures indicating shared ancestry, but may have different functions

geographic isolation
when a population is separated due to a geographical barrier

adaptive radiation
an evolutionary process in which organisms diversify rapidly from an ancestral species into several divergent forms

Because of their recent common ancestry, different species can have some common structures that have developed slightly different purposes. These are called **homologous structures**. For example, some plants have evolved different functions for their leaves. There are plants that evolved coloured leaves to attract insects, while others (such as pitcher plants) evolved leaves shaped like a container to trap insects.

Two forces can drive divergent speciation: a change in the environment, and **geographic isolation**, which is when a population is separated because of a geographical barrier. **Adaptive radiation** of species is an example of genetic divergence.

FIGURE 2 A common ancestor leaf has diverged as a result of different selection pressures.

Video
Genetic divergence

Adaptive radiation

Adaptive radiation is driven by a single lineage's adaptation to the environment, and can occur rapidly. Groups of organisms descended from a common ancestor that are reproductively isolated from others can accumulate mutations over time and this can result in new species. For this to occur, the common ancestor must have a **key adaptation** or novel phenotypic trait that allows the organism to evolve and take advantage of a new niche or resource. Although the variation(s) may have been present for some time, it is not until a selection pressure acts upon the population that these variations are selected for.

key adaptation
a novel phenotypic trait that allows an organism to evolve and exploit a new niche or resource, resulting in the subsequent radiation and success of a taxonomic group

One of the most spectacular evolutionary radiations in the animal kingdom, in terms of both species richness and diversity of body form, is seen in the Crustacea. Key adaptations in size and shape allowed these species to exploit new regions or niches that had less competition. Continued evolution emphasised the adaptations until they were reproductively isolated. Modern day versions of these animals can include:

- giant crabs
- immobile barnacles
- amorphous forms (i.e. no distinct body shape)
- microscopic plankton.

The plankton of the open ocean are the most abundant multicellular animals (with differentiated tissues) on Earth. Crustacea also occupy most habitats on Earth and are found in such diverse places as deep open trenches, mountain tops and deserts.

A further example of adaptive radiation is that seen in species co-evolving with Australian marsupials. Like many other mammals, Australian marsupials often have parasites such as the platyhelminth parasites. Since marsupials evolved from their original carnivorous diets to omnivorous diets, there were changes in their intestinal tracts that opened up niches for the parasitic worms.

FIGURE 3 Zooplankton seen through a microscope

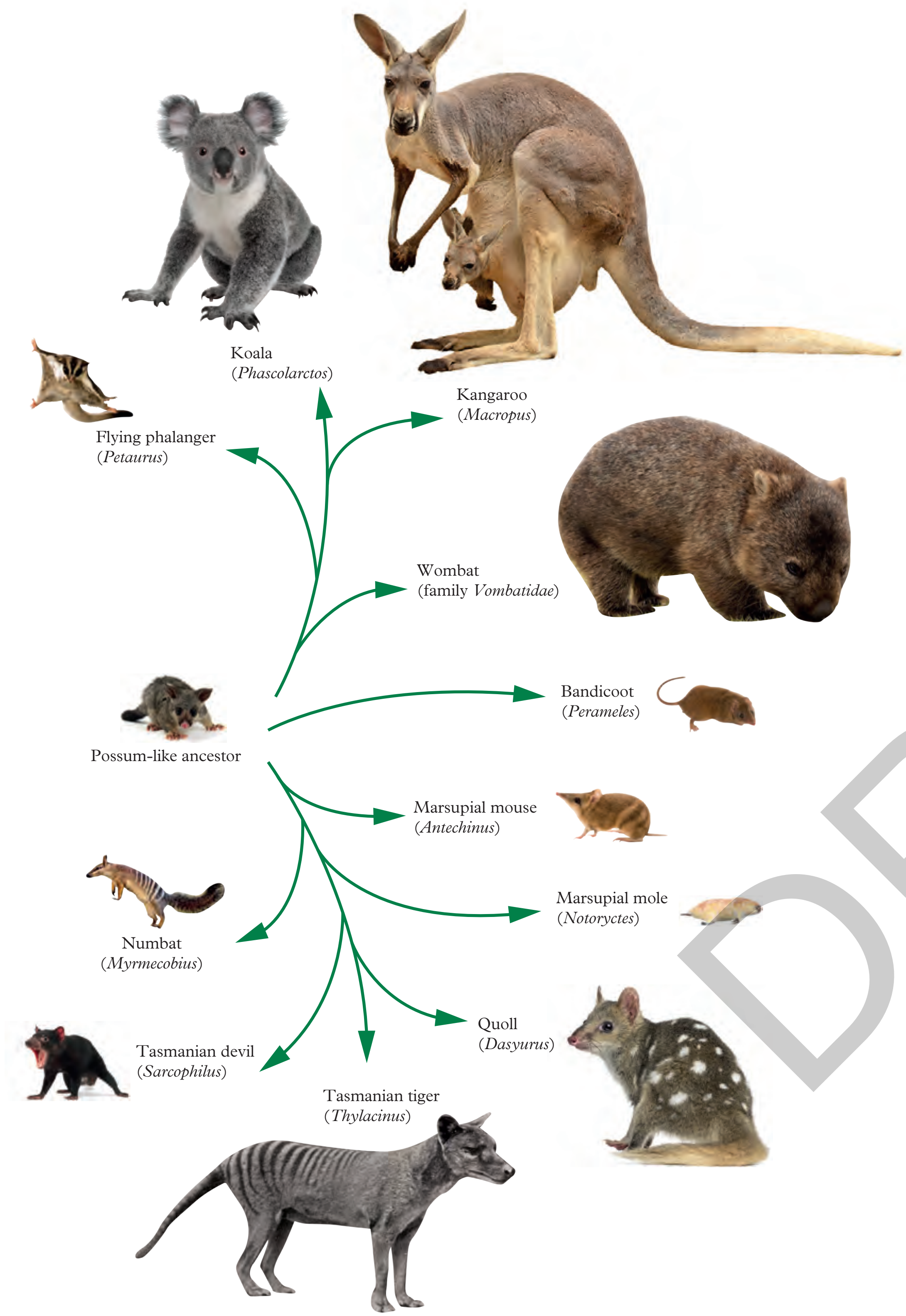


FIGURE 4 Adaptive radiation shown in the Australian marsupials

CASE STUDY 12.2

Cichlid fish in East Africa

Cichlid fish (family *Cichlidae*) are considered one of the most diverse, species-rich families of invertebrates. They serve as an excellent model of evolutionary change over time by observing the morphology of their jaws and teeth. There are approximately 1500 species of cichlid fish found in three East African lakes (Victoria, Malawi and Tanganyika). Lake Victoria is the largest lake in Africa and it is thought that about 12 000 years ago the lake almost completely dried up, leaving only small isolated pools with few fish. The now 500 diverse cichlid species in Lake Victoria are believed to have come from a single common ancestor, radiating explosively during the last 12 000 years.

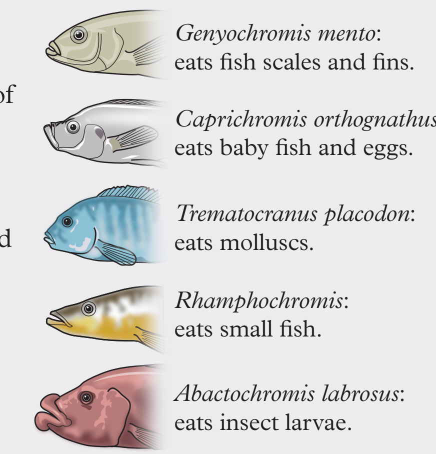


FIGURE 5 The cichlid fish of East African lakes have over 1500 species due to adaptive radiation.

The different species of cichlids are closely related and have developed phenotypic changes to the jaw and teeth to exploit a range of feeding niches. Some cichlids consume algae that grow on rock surfaces; they have flat teeth allowing them to nibble the algae from the rock. Other cichlids are insect eaters and have pointy teeth to allow them access to rock crevices where insects reside. Some cichlids also eat small fish (*Rhamphochromis* in Figure 5), which can hide in tight spots, and these fish have developed large lips to suck the prey from their hiding spots.

For a long time, it was not fully understood how one common ancestor could radiate into so many different cichlid species in a relatively short period of time. Another notable observation was the fact that cichlid species in different lakes developed similar phenotypes even though they were from separate lineages. The answer to these questions was explained when scientists sequenced the genomes of the fish. They found a particular master gene that controlled genes involved in jaw and teeth development in the embryo. This master gene generated physical variations that enabled cichlid fish to exploit a range of feeding niches and radiate into over a thousand different species in a short period of time.

CHECK YOUR LEARNING 12.2

Describe and explain

1 Explain how variation can appear in a species.
2 Use an example to describe how adaptive radiation can occur.
3 Explain why the cichlid fish are an example of geographic isolation.
4 What are the two forces that drive genetic divergence?

Apply, analyse and compare

5 Why are Australian marsupials an example of adaptive radiation? Can you think of another group of organisms, not discussed previously in this chapter, that shows adaptive radiation?

12.3

Types of speciation

KEY IDEAS

In this topic, you will learn that:

+ allopatric speciation occurs when two populations of the same species become geographically isolated and experience new mutations and selection pressures.
+ sympatric speciation is the evolution of a new species from a single population while both inhabit the same geographical region.

speciation
the formation of a new reproductively isolated species as a result of evolution

Speciation is an evolutionary process where a single species evolves over time into two or more species that are unable to produce fertile offspring in natural conditions. Organisms can typically be considered two different species once there is no gene flow between their populations. There are several factors that can act as barriers to isolate a species' gene pool. These factors can act to prevent the species recognising a potential mate, by driving unsuccessful mating, or by blocking fertilisation occurring when mating is possible.

While this definition of speciation is useful, in practice it is limited to particular situations. For example, identifying the exact time an ancestor diverged from a modern living organism enough to be a different species is particularly difficult when using the definition. This means scientists need to modify their definitions to also define different species by body shape or occupation of different niches. In both of these situations, scientists are able to predict that gene flow would be limited or completely prevented between the two different species.

Allopatric speciation

When a single population of organisms is physically separated by a permanent barrier, it can block gene flow between the two groups. The type of barrier that separates the two organisms is dependent on the ability of the organisms to move. Birds, wind-blown pollen, and dingos are able to cross roads or rivers, while small bush mice might have more difficulty. In contrast, floods are not considered permanent, and therefore will not provide a permanent barrier.

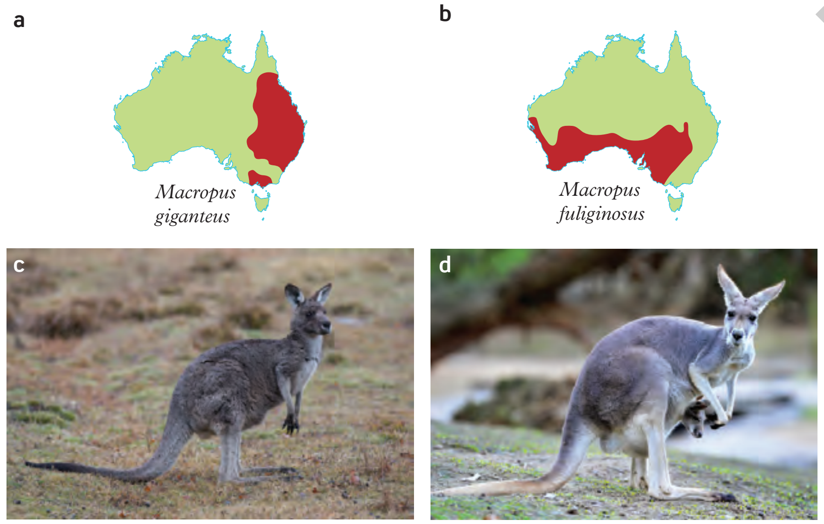


FIGURE 1 The distributions of two kangaroos species: **a** the eastern grey kangaroo (*Macropus giganteus*) and **b** the western grey kangaroo (*Macropus fuliginosus*) due to allopatric speciation

Once two populations are geographically isolated, different genetic mutations will accumulate over time, resulting in new alleles. Each population may experience new selection pressures that will select for or against the new phenotypes (natural selection), causing a change in allelic frequencies. Over time, the differences in the two populations will accumulate until they become reproductively isolated, and become different species. This process of speciation resulting from geographical isolation is called **allopatric speciation**.

allopatric speciation
the process of speciation as a result of a permanent barrier separating the ancestral species

Galapagos finches

One of the best-known examples of allopatric speciation is the evolution of finches on the Galapagos Islands. These finches are known as Darwin's finches, named after Charles Darwin, who first examined the variety of birds. The islands developed as a result of volcanic activity and have never been joined to the South American mainland. Genetic studies have indicated that all the finches shared common ancestors. Over millions of years, the finches radiated out from a single island to other islands (adaptive radiation). Each island presented its own set of selection pressures such as the type of shelter or type of food available (including seeds, fruits, cacti and invertebrates). The finches that survived on each island underwent a process of natural selection. For example, the large ground finch (*Geospiza magnirostris*) has large blunt beaks that can crack the hard shells of nuts and seeds, while the vampire ground finch (*Geospiza septentrionalis*) has smaller sharper beaks that allow them to drink the blood of large sea birds. Because these birds live on different islands, the water offers a natural barrier that restricts gene flow and prevents them from interbreeding.

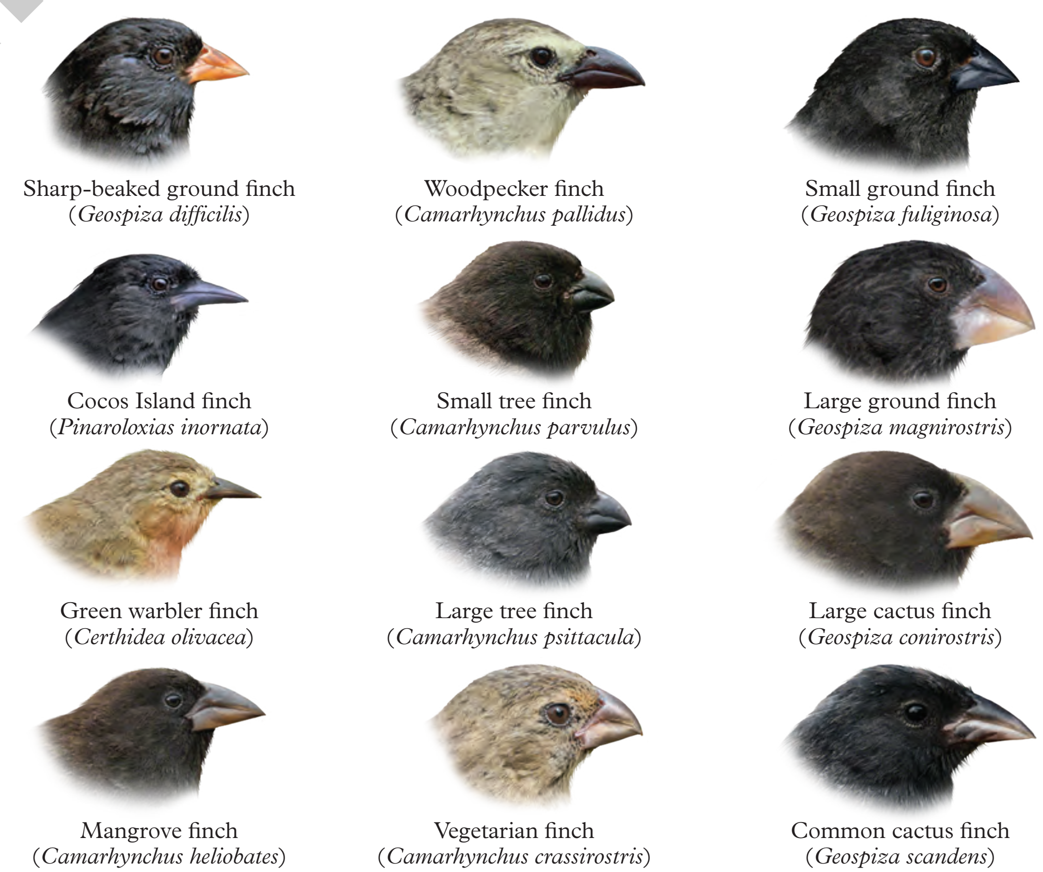


FIGURE 2 The different beak sizes of various Galapagos finches

CASE STUDY 12.3

Speciation in Galapagos finches

Most character changes in a lineage take place over a time period too long to be observed. But sometimes the evolution of a new species can occur in a matter of years. Such an example is a new finch species that arose on the island of Daphne Major in the Galapagos Islands in recent years.

When biologists Peter and Rosemary Grant first arrived on Daphne Major in 1973, there were only two species of finch present: the medium ground finch (*Geospiza fortis*) and the common cactus finch (*Geospiza scandens*). In 1981, a new male finch was blown to the island, and because of the distance was unable to return to its original island. Although similar to the medium ground finch, it had a much larger beak, an unusual hybrid genome and a new kind of song. After locating a mate that had hybrid chromosomes of her own, they produced offspring different from other birds on the island.

The male then mated with two females from one of the local species, the medium ground finch. After four finch generations, a drought killed off many of the birds on Daphne Major. Only a brother and sister pair of the hybrid line remained. The two family members mated with each other, producing offspring that were unique from their parent line. From that point on, as far as we know, this population of finches mated only with each other. They were never seen to breed with the cactus finches or the medium ground finches on the island. A new species, *Geospiza conirostris*, had evolved.

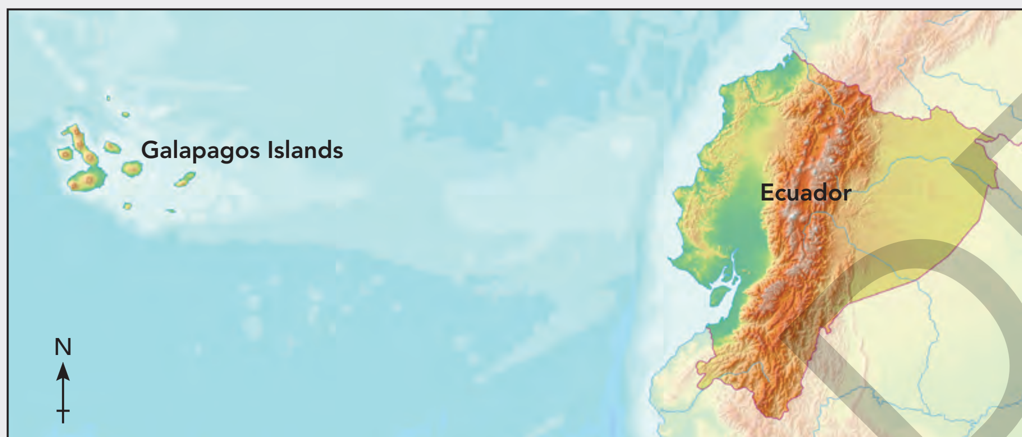


FIGURE 3 The Galapagos Islands are off the north-western coast of Ecuador.

FIGURE 4 An example of rapid evolution on Daphne Major in the Galapagos Islands. **a** The medium ground finch: the new species, *G. conirostris* and **b** the indigenous species, *G. fortis*.

Sympatric speciation

Speciation does not always need a permanent barrier to occur. Sometimes two or more descendent species can evolve from one ancestral species, while occupying a single geographical location – in what is termed **sympatric speciation**. Sympatric speciation can occur when gene flow is restricted by polyploidy (more than two sets of chromosomes), when a species occupies different environmental niches, or when a species' sexual selection preferences change.

sympatric speciation when two or more descendent species evolve from a single ancestral species within a single geographical location

Polyploidy

When an error occurs during cell division, it can result in an extra set of chromosomes. This is most common in plants and can result in a reproductive barrier between the original parent species and the new polyploidy species. This is due to the inability of homologous pairs to form during meiosis. Both sets of plants can survive alongside each other as the reproductive barrier is molecular rather than physical.

Video
Allopatric and sympatric speciation

Environmental niches

When an environment changes it can result in some species being unable to survive. When that occurs, a new environmental niche (e.g. shelter location or resources) becomes available. An example of this is two species of palm trees – *Howea forsteriana* and *Howea belmoreana* – that are found on Lord Howe Island in Western Australia. Genetic studies indicate they shared a common ancestor but had become reproductively isolated from each other despite producing vast amounts of wind-spread pollen in overlapping ranges. *H. forsteriana* prefers to grow in soils containing chalky lime found at low altitudes, while *H. belmoreana* grows in neutral and acidic soils found 90 metres above sea level. Each type of soil affects the timing of the palms flowering, suggesting that this was the mechanism of initial reproductive isolation.

FIGURE 5 The two different Australian palms: **a** *H. forsteriana* and **b** *H. belmoreana*

Study tip

Meiosis is the process by which gametes (egg/ova and sperm/pollen) are formed. An important part of this process is when the matching homologous chromosomes form pairs before the cell can divide. This can be difficult in hybrid organisms.

Sexual selection

Some species are particularly selective when choosing their mate. When mating preferences change, this can result in sympatric speciation. An example of this is the speciation of cichlid fish, *Pundamilia pundamilia* and *Pundamilia nyererei*, found in East Africa's Lake Victoria. Although there are many factors influencing the mechanism of their evolution, including exploiting environmental niches, it is also thought that female mate preference was a factor. When researchers placed males and females of *P. pundamilia* and *P. nyererei* in a tank together, their choice of mate varied according to the kind of lighting present. In natural light, the females only mated with males from the same species; however, in an orange light, the females mated with males from either species. The resulting hybrid offspring were viable and fertile. This suggests that the gene flow barrier is a result of sexual selection due to colouration.

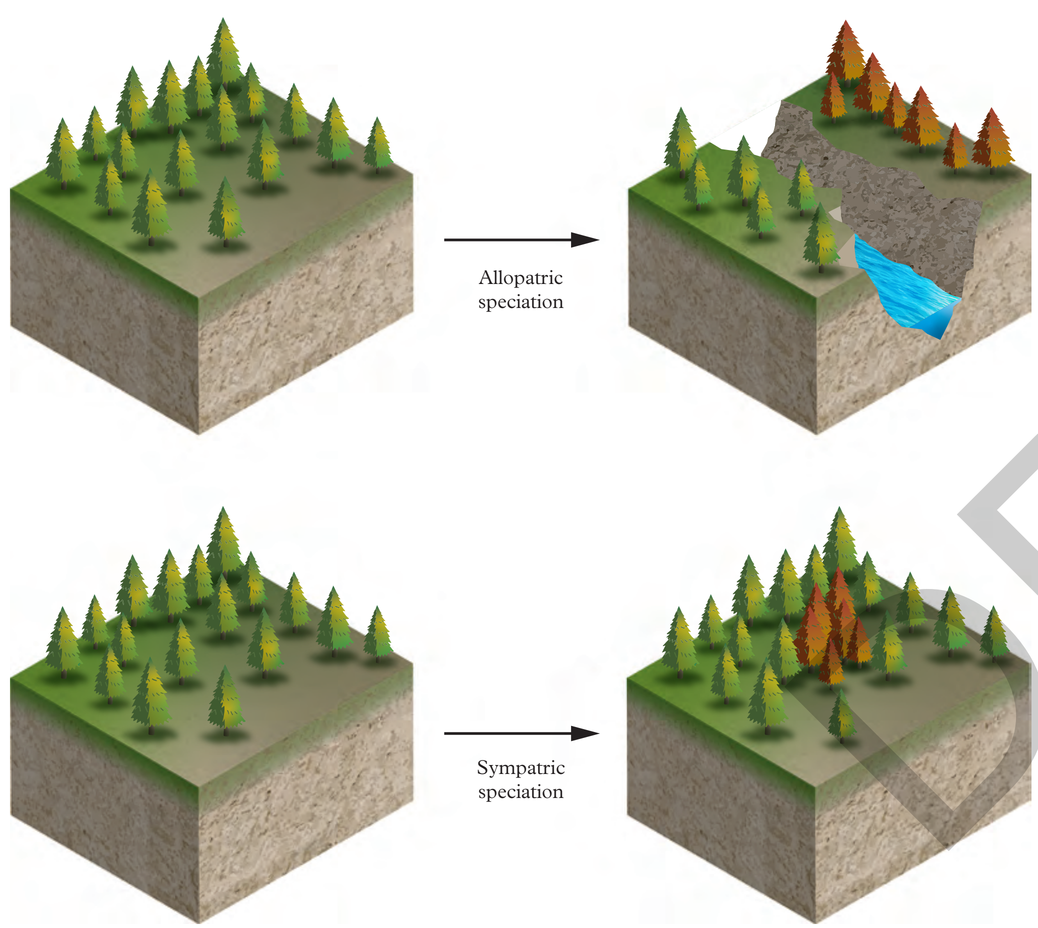


FIGURE 7 A comparison of allopatric speciation and sympatric speciation

CHALLENGE 12.3

African indigobirds

African indigobirds (*Vidua* spp) provide an example of how new species can emerge without first being separated by a geographical barrier. These birds do not directly care for their chicks, instead they lay their eggs in the nest of other birds. When the young chicks hatch, they are exposed to the songs of their adoptive parents. When the indigobird chicks grow up, they are attracted to mates that sing the song of the adoptive parents and seek out nests similar to their adopted home. This means populations of indigobirds will divide into different groups according to their preferred mating song and nest site.

Robert Payne and Michael Sorenson of Boston University undertook genetic analysis that showed that the different groups of indigobirds accumulated genetic differences due to their distinct song preferences. These genetic differences resulted in physical changes in the pattern of mouth spots of the indigobird chicks, making them more likely to be accepted by the adoptive mother. The combination of physical changes, song and nest preferences contribute to the reproductive isolation between the different indigobird groups.

1 What type of speciation is described above? Provide both a definition and evidence to support your answer.
2 Why would learning different songs result in reproductive isolation?
3 Would this type of speciation occur quickly (within two generations) or take many generations to occur?

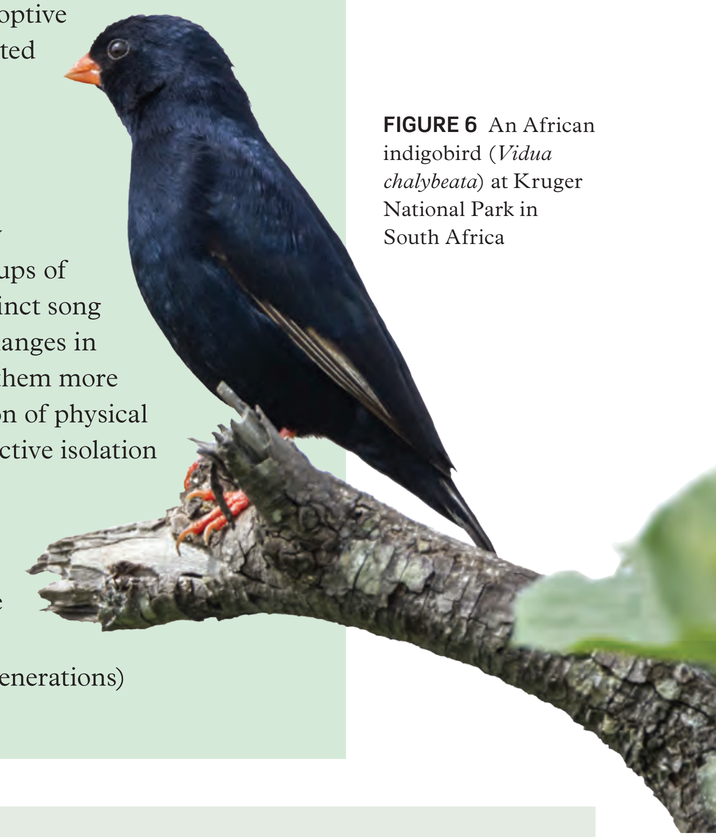


FIGURE 6 An African indigobird (*Vidua chalybeata*) at Kruger National Park in South Africa

CHECK YOUR LEARNING 12.3

Describe and explain

1 What is speciation?
2 What is an environmental niche?
3 Provide two examples of permanent barriers that could lead to allopatric speciation.
4 Identify the different types of sympatric speciation.

Apply, analyse and compare

5 Compare the similarities and differences between allopatric speciation and sympatric speciation.
6 By referring to Case study 12.3, explain how a drought resulted in the new species of finch, *Geospiza conirostris*.
7 What defines the two species of Australian palms on Lord Howe Island, and how did this speciation occur?

Design and discuss

8 On Daphne Major, the *Geospiza conirostris* offspring of the immigrant male finch and female *Geospiza fortis* learnt their mating song from their immigrated parent. Explain how this could have caused reproductive isolation.
9 A scientist found that small populations of birds that lived in urban areas were evolving a higher pitched birdsong than similar populations that lived in suburban areas. Although the birds often learnt the songs of their parents, the ability to hear higher pitch sounds is a genetic trait. Discuss if this is an example of allopatric speciation or sympatric speciation.
10 Research other known examples of allopatric and sympatric speciation and describe your findings.

CHAPTER 12 Review

Chapter summary

12.1
- Fossils are evidence of species change over geological time.
- The geological timescale provides the sequence of events in Earth's history.
- Relative dating and absolute dating are two methods of dating fossils.

12.2
- Genetic divergence describes divergence from a common ancestor due to different selective pressures. Adaptive radiation is a type of genetic divergence.

12.3
- Allopatric speciation occurs when two populations of the same species become geographically isolated and experience new mutations and selection pressures.
- Sympatric speciation is the evolution of a new species from a single population while both inhabit the same geographical region.

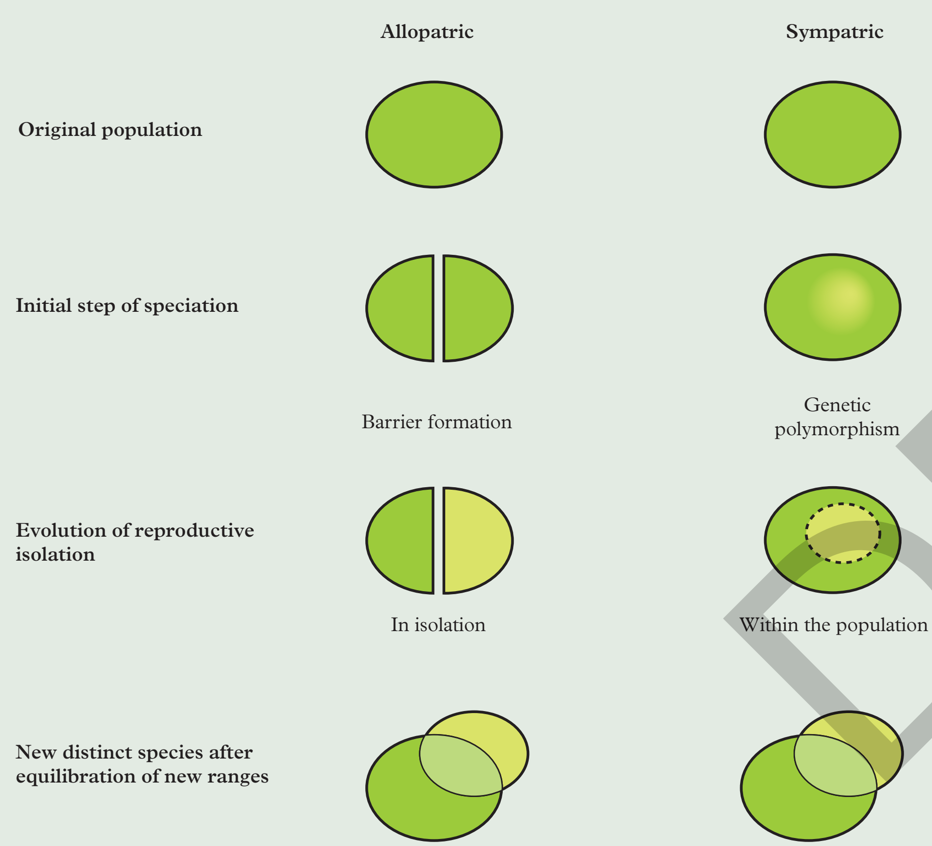


FIGURE 1 A summary of the differences between allopatric speciation and sympatric speciation

Key formulas

Age of fossil	Number of half-lives passed × half-life

Revision questions

Multiple choice

1 Which is important for an index fossil?
   A Short period of time in a wide geographical area
   B Short period of time in a narrow geographical area
   C Long period of time in a wide geographical area
   D Long period of time in a narrow geographical area

2 A fossil is more likely to form if the organism:
   A remains uncovered by sediment on the surface after it dies.
   B does not contain hard body parts.
   C is quickly buried by sediment before it decomposes.
   D dies in a moist, warm environment.

3 Which scenario is an example of where allopatric speciation could occur?
   A Certain members of a population have more offspring than others.
   B Finches with thin, sharp beaks eat fish and small mammals, while finches with larger beaks eat nuts and seeds.
   C A facial tumour disease kills all members of the Tasmanian devil population.
   D A river separates members of a possum population that used to occupy the same geographical area.

4 Scientists observed a rock stratum and hypothesised it was from the Devonian period. Without dating the fossils or the rock in the stratum, how did the scientists make this claim?
   A The absence of insects and presence of fish
   B A range of diverse mammals
   C Large numbers of different aquatic plant species
   D The presence of the transitional fossil *Archaeopteryx*

5 The adaptive radiation seen in the Galapagos finches is the result of:
   A migration from the islands to the mainland.
   B convergent evolution.
   C different food sources on the various islands acting as selective agents.
   D the loss of niches on different islands.

6 Samples of sedimentary rock from three different sites is shown below.
   Which is the oldest fossil?

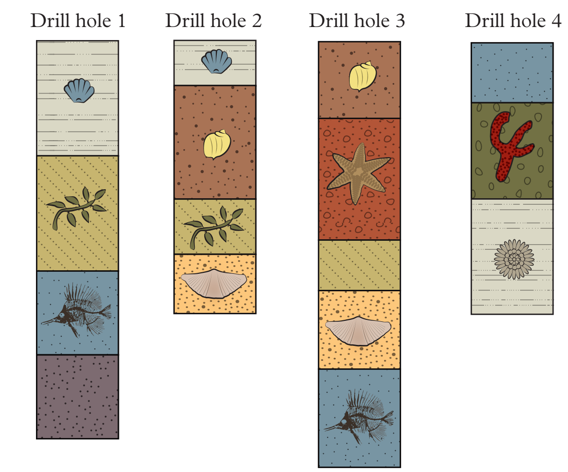


FIGURE 2 Drill cores of sedimentary samples with fossils

   A 
   B 
   C 
   D 

7 Absolute dating is a method of dating fossils that uses the radioactive decay of particular isotopes. Carbon-14 is a commonly used isotope, which decays to nitrogen-14.
   A fossil is found to contain 20% carbon-14. Using Figure 3 on the next page, what is the approximate age of the fossil?

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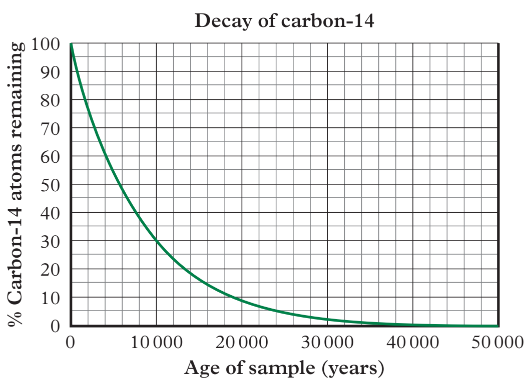

FIGURE 3 Carbon-14 decay with time (years)

A 12 500 years
B 15 000 years
C 17 500 years
D 20 000 years

Short answer

Describe and explain

8 Use examples to explain two different reproductive barriers that could occur in sympatric speciation.

9 What is a transitional fossil?

10 Members of a species living in the same valley begin to diverge from each other over time so that they no longer mate with members of the other group. Use definitions to explain why this is likely to be sympatric speciation rather than allopatric speciation.

11 Explain what is meant by the law of faunal (fossil) succession. How is it used to determine the relative age of a fossil?

12 What is meant by half-life? Explain how it can be used to work out the age of a fossil.

13 What is the difference between genetic divergence and adaptive radiation?

Apply, analyse and compare

14 Why is the fossil record incomplete?

15 Consider why sympatric speciation is more common in plants than animals.

16 Potassium-40 has a half-life of 1.3 billion years. After three half-lives have passed:

a What percentage of the original radioactive element would be present in the fossil?

b If a fossil sample originally included 10 g of potassium-40, how much would be left?

17 If 12.5% carbon-14 was found in a fossil where the remaining 87.5% had decayed into nitrogen-14:

a How many half-lives have passed?

b How old is the fossil if the half-life of carbon-14 is 5730 years?

c How many years would it take for the amount of carbon-14 to be 0.0625 g, if the original amount was 1.0 g?

18 Compare relative dating and absolute dating. Outline the limitations and applications of each type.

19 Why are the speciation of the *Howea forsteriana* and *Howea belmoreana* palm trees on Lord Howe Island a result of sympatric speciation rather than allopatric speciation.

20 Suggest three possible factors that could produce different ecological niches and reduce gene flow.

21 Which parts of an organism are more likely to be preserved as fossils? Explain why.

22 Trilobites were a class of animal that populated Earth's oceans and evolved for almost the entire length of the Palaeozoic era.

a What can you observe in Figure 4 that would suggest trilobites are a good index fossil?

b Explain how palaeontologists would use trilobites to date Palaeozoic rock.

FIGURE 4 A trilobite fossil

23 Uranium-235 has a half-life of 700 million years. Rock surrounding a fossil was found to have ¼ the original amount of uranium-235. Using this information, calculate the approximate age of the fossil.

24 Carbon-14 has a half-life of 5370 years. Calculate how much carbon-14 would be left in a 3.0 g sample after 11 460 years.

25 Around 10 000 years ago, a population of squirrels were separated from each other when the Grand Canyon was formed. Since then, the squirrels have become two separate populations: the Kaibab squirrels and the Abert squirrels.

FIGURE 5 **a** Kaibab squirrel (*Sciurus aberti kaibabensis*) and **b** Abert squirrel (*Sciurus aberti*)

a Describe the process that could have resulted in the ancestor species of squirrel becoming two separate species.

b Examine Figure 5 to identify one physical difference between the two species. Suggest why these physical features have evolved differently.

26 *Howea forsteriana* is a type of palm that grows in soils containing chalky lime and at low altitudes. *Howea balmoreana* grows in neutral or acidic soils 90 metres above sea level. Both types of palm share a genetic ancestor. Discuss how this example demonstrates sympatric speciation.

Design and discuss

27 Discuss how scientists identified that many dinosaurs had feathers and how this evidence came about.

28 Research whether birds and bats are an example of genetic divergence or convergent evolution and describe your findings. Before beginning your research, first write a hypothesis. Use secondary data to support your final conclusion.

29 For each of the following fossils, discuss whether using carbon-14 to date the fossil would be suitable. If carbon-14 is not suitable, explain why and suggest another dating method.

a A footprint of a woolly mammoth

b An insect found in sedimentary rock dating to the Carboniferous period

c A bone of the sabre-toothed tiger (*Smilodon fatalis*) that existed up to 11 000 years ago

30 Discuss why adaptive radiation is an important process in biology, and provide examples.

31 'All living organisms share a common ancestor.' Discuss this statement.

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Chapter quiz
Test yourself on the Key Knowledge covered in this chapter.

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Quizlet Live
Launch a quiz for your students on key concepts in this chapter.

Exam essentials

Responding to questions

In your exam, you may be expected to identify key information about a process and link it to the important information in the stem of the question.

Describe, Explain, Relate to the question (DER)

The DER method is a useful approach for responding to questions that ask you to explain:

- **D**escribe or identify the key information
- **E**xplain why it is important
- **R**elate the information to the stem of the question

Consider how the DER method has been used in the responses to the real exam question below.

QUESTION 8b (2020 Biology Written Examination)

b Fossils of species of fish are more likely to be found than fossils of land-dwelling animals.

Explain why this is the case with reference to two conditions required for the fossilisation of an organism.

2 marks

Source: 2020 Biology Written Examination Question 8b, Short answer, reproduced by permission © VCAA

Response 1

Fossils are more likely to be found in water because water covers them and stops them decomposing.

Relates to the question

Identifies one condition, but does provide an accurate or specific explanation

Response 1 does not provide the two conditions needed for fossilisation or explain why these conditions help fossilisation. The key information that needs to be included for each mark is the condition of fossilisation followed by explaining why this helps fossilisation.

Response 2

Fossilisation in water is more likely because on land it is harder to cover the remains with sediment so scavengers can eat the bones. It is warmer on land and so easier for bacteria to decompose the remains.

Relates to the question

Describes the first condition

Explains how the first condition reduces the likelihood of fossilisation on land

Describes a second condition

Explains how the second condition reduces the likelihood of fossilisation on land

Response 2 would receive full marks as it describes the conditions for fossilisation and explains the reasons why this is less likely on land and therefore more likely in water (relating to the question).

Think like an examiner

To maximise your marks on an exam, it can help to think like an examiner. Consider how many marks each question is worth and what information the examiner is looking for.

Mark the response

A student has given the following response in a practice exam. Imagine you are an examiner and use the marking guidance below to mark the ir response.

QUESTION 7 b–c (2019 Biology Written Examination)

In 2014 palaeontologists discovered a frozen, well-preserved, complete specimen of an extinct species, the steppe bison, in Siberia. The intact specimen was dated at 9300 years old.

b Scientists are debating the cause of the steppe bison's extinction. Give **one** possible cause of its extinction.

1 mark

The steppe bison became extinct due to unprecedented climate change.

Though steppe bison are extinct, palaeontologists know a lot about them as they have found several frozen, intact steppe bison bodies.

c Describe what would have occurred to lead to the preservation of the animal from when the steppe bison died to when the frozen, well-preserved remains were discovered.

4 marks

After death, the steppe bison would have been covered by sediment and water, which became sedimentary rock. In this process, minerals preserve the fossil. The fossil would then have been discovered when erosion of the rock revealed the preserved fossil.

Source: 2029 Biology Written Examination Question 7b-c, Short answer, reproduced by permission © VCAA

Marking guide

7b	- 1 mark for correctly identifying one possible cause of extinction (e.g. hunting by humans, ice age or cold environment, habitat destruction) Note: climate change is not specific enough. Students must specify an increase or decrease in temperature.
7c	- 3 marks for identifying three of the following: organism not eaten by scavengers; body frozen and does not decay; lack of oxygen; uplift, erosion or melting of glacier exposes remans - 1 mark for correctly recognising that the steppe bison was frozen or rapidly buried (not covered by rock) Students need to relate their response specifically to the question. Prepared answers about the fossilisation process are unlikely to earn full marks.

Fix the response

Consider where you did and did not award marks in the above responses. How could the responses be improved?

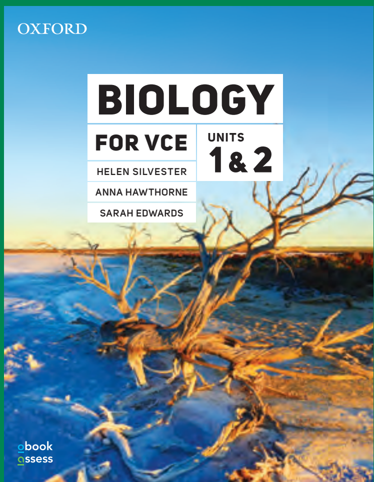
Write your own responses to the same question to receive full marks from an examiner.

Check your student obookPro for the following digital resources and more:

Video
The DER method

Weblink
Past examinations and examiners' reports

UNITS 1 & 2



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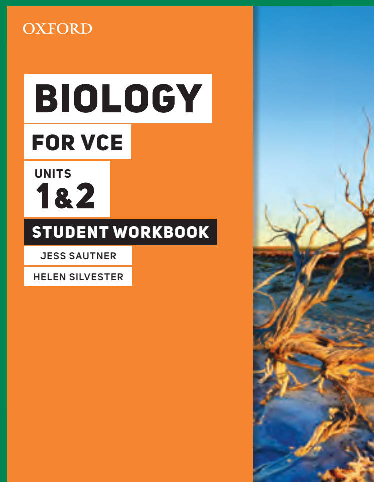

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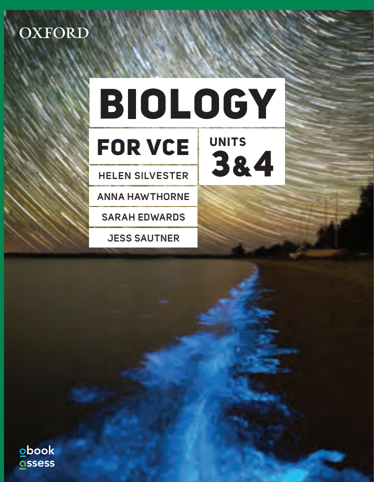

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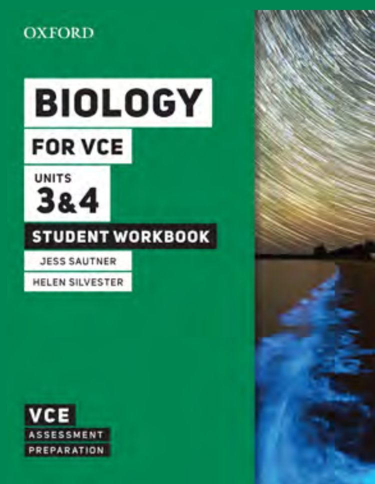

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