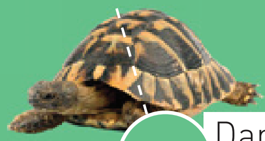
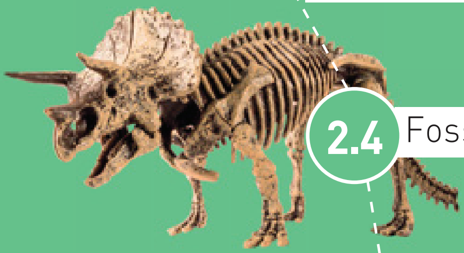
EVOLUTION 2



2.1 Darwin and Wallace were co-conspirators

2.2 Natural selection is the mechanism of evolution

2.3 Different selection pressures cause divergence. Similar selection pressures cause convergence

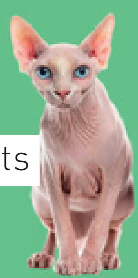


2.4 Fossils provide evidence of evolution

2.5 Multiple forms of evidence support evolution

2.6 DNA and proteins provide chemical evidence for evolution

2.7 Humans artificially select traits



2.8 Natural selection affects the frequency of alleles

What if?

What you need:

range of eating utensils (e.g. spoons, forks, chopsticks or straws), lollies

Make sure you check for food allergies and avoid using lollies that present a risk of anaphylaxis.

What to do:

1 This is a whole-class activity.

2 Each group of students has a different type of eating utensil, such as spoons, forks, straws and chopsticks. Each group has the same mix of lollies. Using only the tool provided, try and collect as many of the lollies as possible into a bowl.

What if?

» What if there were more spoons? (Would some lollies disappear quicker/slower?)

» What if only hard-boiled lollies were available? (Which utensil would collect the most lollies?)

» What if straws were the only utensil available? (What type of lolly could they be used for?)

//SCIENCE AS A HUMAN ENDEAVOUR//

2.1 Darwin and Wallace were co-conspirators

Scientific theories are explanations of the natural world that are based on well-substantiated evidence. These theories are contested and refined over time through a process of review by the scientific community. The statement 'organisms change in response to environmental pressures' is an observation. Natural selection as the mechanism of evolution, as proposed by Charles Darwin and Alfred Wallace, is a scientific theory that has 200 years of reproducible experimental evidence supporting it.

Figure 2.1 These layers of rock are an indication of different time periods. Pale layers can sometime represent volcanic ash released during an eruption.

Before evolutionary theory

The generally accepted belief for many thousands of years was that life was 'created' by a creator god or gods. Even events such as volcanoes and earthquakes were considered to be the consequences of the emotions of the gods. Societies could have one or more gods, which could be human or animal-like in appearance.

There was little thought given to whether organisms changed over time. The idea of extinction was not proposed until the 1790s, when William Smith uncovered fossils while analysing the geology of a mine in England. Fossils were already known to be the remains of living organisms, but Smith identified organisms that had never been seen before and was able to 'date' them by the layer of rock in which they were found. This later became known as relative dating.

Georges Cuvier, a French zoologist, collected and examined many fossils. He concluded that many of the animals represented were remains of species now extinct.

Early evolutionary theory

Evolutionary theories were all proposed without any knowledge or understanding of DNA and genetic inheritance – making the following stories even more remarkable.

Lamarckian theory

One of the first documented theories of evolution was by Jean-Baptiste de Lamarck, a French naturalist. Lamarck believed in evolutionary change – that organisms change over time due to changing environmental conditions. He is best known for his hypothesis of inheritance of acquired characteristics, which was first presented in 1801. In this hypothesis, Lamarck proposed that if an organism changes during its lifetime in order to adapt to its environment, those changes are passed on to its offspring. This is how he explained the long necks of giraffes (Figure 2.2).

There are many problems with Lamarck's hypothesis. For example, Lamarck's hypothesis implied that the children of a man who had lost his arm would also have weak or deformed arms as a result. This was obviously not the case. August Wiesmann finally provided scientific evidence when he cut the tails off 22 generations of mice, continually allowing them to breed with each other. Unsurprisingly, all their offspring were born with tails.

Figure 2.2 Lamarck believed that giraffes stretched their necks to reach food and that their offspring, and later generations, inherited the resulting stretched long necks.

Charles Darwin

Charles Darwin (Figure 2.3) was well educated and had been exposed to the sciences from an early age through his father and grandfather, who were both physicians. Darwin had also read the works of Lamarck. In 1832, the young 23-year-old set sail on a 5 year world cruise as the unpaid naturalist on the HMS *Beagle*.

During the final stages of the voyage, the ship visited the Galapagos Islands, about 1000 km off the coast of South America. Here, Darwin made his most significant observations.

Darwin and his helpers collected specimens, seeking to obtain at least one of each species. Among the specimens collected were 13 finches, all of which resembled one another in terms of the structure of their beaks, the form of their bodies and their plumage. Yet each specimen represented a new species and most had been found on different islands.

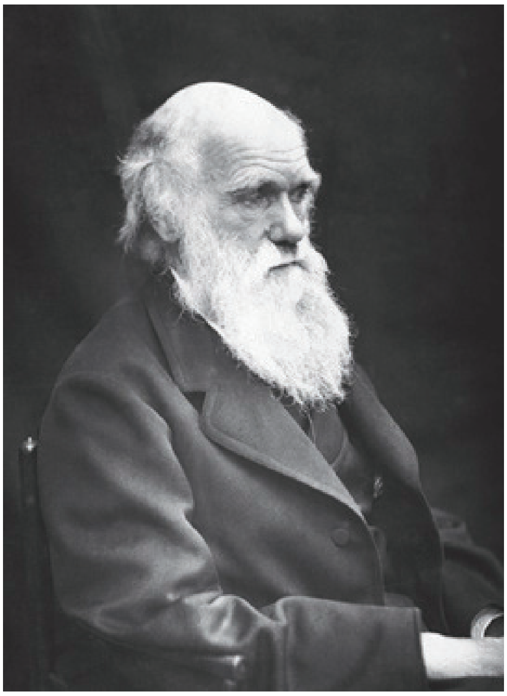


Figure 2.3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism. Darwin was brought up in the Church of England, and at one point was studying to be an Anglican Priest. When he died in 1882, his ideas had increasingly become accepted, at least by the scientific and non-religious society. He was given a state burial at Westminster Abbey.

Figure 2.4 On the Galapagos Islands, tortoises' shells vary in shape according to habitat.

In his journal, Darwin noted that these birds were strikingly similar to those found on the mainland of South America. He wondered why the different populations looked so similar, if new and different beings had been placed on the islands at the time of Creation.

The dry, volcanic Galapagos archipelago is also home to different species of tortoise. Darwin noted that the different types of tortoise had different-shaped shells (Figure 2.4). Tortoises that live on dry islands, such as Hood Island, have shells that are raised at the front so they can reach up for vegetation. In contrast, tortoises that live on islands with dense vegetation have domed shells to help them push through the shrubbery.

Darwin was also aware that humans have selectively bred pigeons and racehorses for more than 10 000 years by choosing breeding partners for animals and other organisms in an effort to 'select' for certain traits in their offspring. Over many generations, the 'wild' traits are often lost and the species is considered 'domesticated'.

Figure 2.5 Was the plague simply nature's way of keeping the human population in check?

Darwin then wondered how 'selection' occurred in nature. Thomas Malthus's paper *An Essay on the Principle of Population* gave Darwin the insight he needed. Malthus argued in his paper that the human race would completely overrun the Earth if it were not held in check by war, famine and disease such as the plague, or 'Black Death', in the 14th century (Figure 2.5). Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last Darwin had a hypothesis to test. But it would take another 20 years of painstaking hard work before he was convinced that his hypothesis had enough support to be developed into a theory.

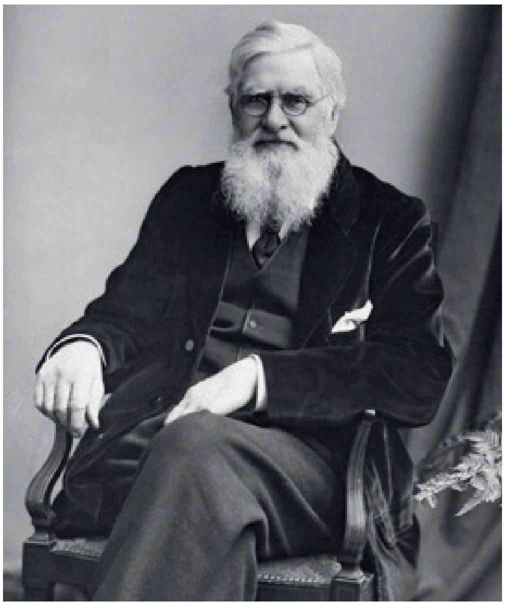


Figure 2.6 Alfred Russel Wallace formed the same theory as Darwin and at the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in Africa. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) (Figure 2.6) was a naturalist working at the same time as Darwin. Wallace collected specimens from tropical regions, particularly the Malay Archipelago, which is now Malaysia and Indonesia. Wallace collected thousands of insects, shells and bird skins, as well as mammal and reptile specimens, many of which were new species to science at the time. One of his best-known discoveries was Wallace's golden birdwing butterfly.

During his time in the Malay Archipelago, Wallace proposed the theory of natural selection as the mechanism of evolution. In 1858, he wrote a series of letters to Darwin outlining his idea. Darwin and his friends were worried about who should get the credit for the two theories that were essentially identical. They decided to read Wallace's letter and Darwin's paper one after the other at the Royal Linnaean Society of London. We now associate Darwin with the theory of evolution because, in 1859, Darwin published his book *On the Origin of Species by Means of Natural Selection*.

Extend your understanding 2.1

1 One of the biggest questions asked by humans is 'Where did we come from?' How have different people answered that question?
2 Charles Darwin wasn't the first person to propose the idea of evolution. What was Lamarck's hypothesis about the way evolution worked?
3 What was it about the tortoises of the Galapagos Islands that helped Darwin develop his ideas about evolution and natural selection?
4 What features of the finches showed similarity in form?
5 Why do you think Darwin waited so long between arriving at his hypothesis and publishing his theory on evolution?
6 Draw a timeline of ideas before and after evolution.
7 Do you think it is fair that Darwin receives all of the credit for the theory of evolution? Justify your answer.
8 Discuss why for various reasons the theory of evolution has been controversial for some people.

2.2 Natural selection is the mechanism of evolution

Evolution is the permanent change in the frequency of alleles in a population due to natural selection. **Mutations** introduce new alleles into the gene pool increasing the diversity of a new population. **Selection pressures** cause some of these new variations to survive and others to die. If an organism is suited to its environment, then it is able to mate and produce offspring. The offspring will have the same survival characteristics (and the alleles) as their parent. This gradually changes the frequency of alleles in the gene pool.

Observations and inferences

Although scientists knew that living organisms change over time, how the change occurred was first described by Charles Darwin and Alfred Wallace. They did this through a series of observations.

1. Members of a species are often different from each other.
2. There are always more children than parents.
3. The size of a population does not change.
4. Some offspring do not survive (survival of the fittest).
5. Offspring look like their parents.

These five observations led Darwin to make two key inferences.

1. In the struggle to survive, those individuals that are most suited to their environment survive.
2. Those individuals that survive pass their traits on to their children.

Variations in populations

Natural selection depends on the variation of traits within a population, but where does this variation come from?

Much of the variation between individuals is due to genetic differences that can be inherited – something that Darwin and his contemporaries observed but did not understand.

Individuals of the same population generally have the same number and types of genes, but different alleles (variations of the genes). For example, all humans will have the gene for eye colour, but the alleles they have for this gene may be blue, brown or even hazel. New alleles

Figure 2.7 These Siberian huskies have different versions, or alleles, of the gene for eye colour.

EXPERIMENT 2.2: WHAT IF THE HABITAT OF BEAN PREY WAS CHANGED?
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arise because of small changes in the DNA sequence. Some mutations are not evident in the appearance of an organism. Other mutations cause variations in the physical appearance (phenotype) of the individual. For example, it was a single mutation about 6000–10 000 years ago that resulted in one of our ancestors having blue eyes.

All the different types of genes in the entire population can be thought of as a **gene pool** – a pool of genetic information. The gene pool includes all the alleles for all the genes in the population. New alleles arise through changes (or mutations) in the DNA that makes up the genes.

A mutation may give an individual an advantage, making them better able to survive than others of their population. This means they have a greater chance of mating and passing their genetic advantage on to their offspring.

Allele frequencies

Populations are always evolving. The frequency of an allele is how common that allele is within a population. The allele frequency is affected by environmental conditions. If the environmental conditions are favourable, then more of that allele is passed on to the next generation.

Mutating moths

In the 1950s, scientists in England documented changes in the colour of the moth species *Biston betularia*. These moths range in colour from light grey to nearly black (Figure 2.9). During the day the moths rest motionless on tree trunks. In unpolluted areas, tree trunks are covered with light-grey lichens, against which the light-grey moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so the tree trunks are lichen-free and dark, exposing lighter moths to predation from birds.

It seemed to researchers that, as areas became more polluted, dark moths increased in frequency. This is often described as selection pressure. The darker coloured bark allowed the dark moths to survive (be selected for), and the lighter moths to be eaten (be selected against). Natural selection seemed to be increasing the frequency of the allele for dark colour in the population. This was selection pressure in favour of the 'dark' allele.

In 1952, strict pollution controls were introduced in England, the lichens returned and the tree trunks became mostly free of soot. As may have been predicted, selection pressures started to operate in the reverse direction. In areas where pollution levels declined, light moths were selected for, and dark moths selected against. The frequency of dark moths declined.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of chemicals (i.e. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

Figure 2.8 Syndactyly is webbing between the fingers and toes. It is quite common because a foetus actually has webbing that undergoes 'programmed cell death', or apoptosis, to remove it prior to the baby being born. Syndactyly is biologically neutral, because the webbing is usually neither an advantage or a disadvantage. However, there are certainly situations in which it may be beneficial. Imagine a career as an Olympic swimmer!

Figure 2.9 Dark-coloured moths of the species *Biston betularia* increased in numbers when air pollution killed lichen on trees. Lighter coloured moths were then more visible to predators and were selected against.

Check your learning 2.2

Remember and understand

1. Variation in individuals can occur in different ways, but there is only one way in which new alleles can arise. What is this process called?
2. Darwin made a series of inferences based on observations he made over 20 years. Link each of Darwin's observations with the appropriate inference he made.
3. Describe the selection pressures that caused the allelic frequency of light-grey moths to decrease in England in the 1950s.
4. In your own words, describe the mechanism by which natural selection can influence the frequency of alleles in a population.

Apply and analyse

5. Natural selection cannot increase or decrease the frequency of some mutations in a population. Why is this?

2.3 Different selection pressures cause divergence. Similar selection pressures cause convergence

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When two populations become separated, the gene flow between the species is stopped. If the two species experience different selection pressures, then they gradually become more different from each other. Eventually they may become reproductively isolated and are said to have **diverged**. The two new species may retain homologous structures in common. If two very different species are exposed to the same selection pressures, they may develop analogous structures. Their structures will appear to converge.

Speciation

When a variation within a species is favoured by the environmental conditions, it is referred to as an **adaptation**. Variations within a species provide 'options' for the species when environmental conditions change. Although individual organisms may be wiped out, some members of the population with the favourable adaptation survive and continue the species' gene pool.

Along the way, entire species may become extinct and a new species will emerge, increasing the biodiversity of organisms in the environment.

Under normal conditions, genes in a given population are exchanged through breeding. This means the genes will flow from one generation to the next as different families or groups in the population choose partners and mate. This is called **gene flow**. But the gene flow is interrupted if the population becomes divided into two groups – **isolation**. If there is no exchange of genes between the two groups, then they may begin to look and behave differently from each other. Over time, different selection pressures occur in the two groups. Different characteristics are selected for. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding should they ever come together again. They become reproductively isolated and therefore are different species (**speciation**). The two species have diverged.

Allopatric speciation is one of the most common ways species become different or diverge.

Even though populations diverge and become different species, they retain some characteristics in common. These characteristics, such as forelimbs, may be used for different purposes, because the selection pressures have changed. Common structures that are found in different species often have a similar pattern but different function. These structures are known as **homologous structures**. The most commonly discussed homologous structure is the **pentadactyl limb** – the pattern of limb bones in all groups of tetrapods (i.e. four-legged vertebrates) that ends in five digits (Figure 2.10). This structure is found in the fins of certain fossil fishes from which the first amphibians are thought to have evolved. Throughout the tetrapods, the basic structure of the pentadactyl limbs is the same.

EXPERIMENT 2.3: DIVERGENT AND CONVERGENT EVOLUTION OF BIG BEAKS AND SMALL BEAKS
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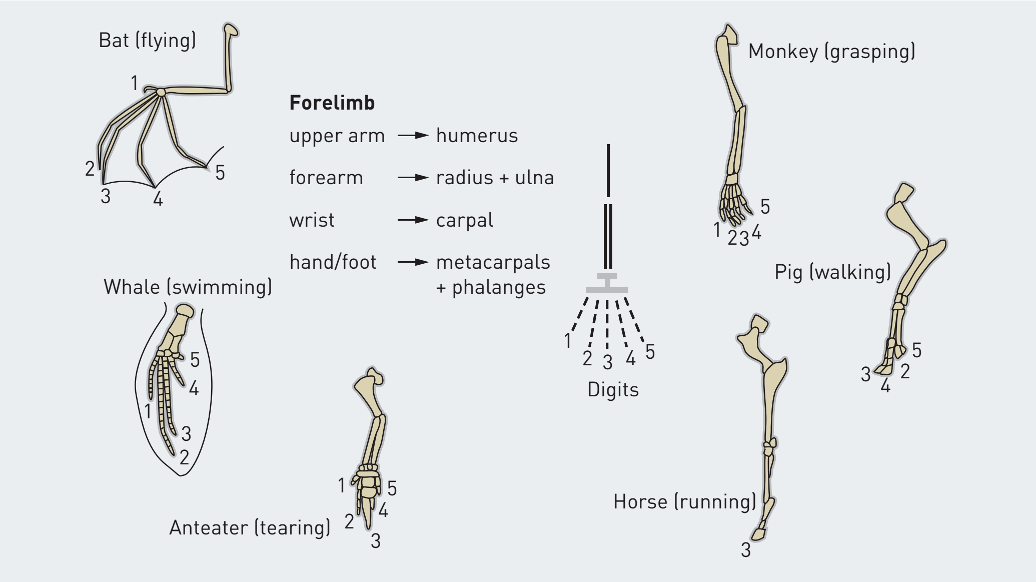

Figure 2.10 The homologous forelimbs of different mammals show the same basic structure, with a single upper bone, two lower limb bones, small wrist or ankle bones and five digits that are adapted to different uses.

This indicates that these organisms originated from a common ancestor. But, during the course of evolution, these structures have become modified and are used for different purposes as a result of different selection pressures.

Analogous structures are structures in organisms that perform the same function but are structurally different (suggesting no recent common ancestor). For example, a dolphin (mammal) and a shark (fish) have the same environmental selection pressures. Although these species do not share a recent common ancestor, they both need to move through water fast enough to catch fish and escape predators. As a result they both have a streamlined body with fins and tails. This is an example of **convergent evolution**. The wings of birds and butterflies are also analogous structures (Figure 2.11).

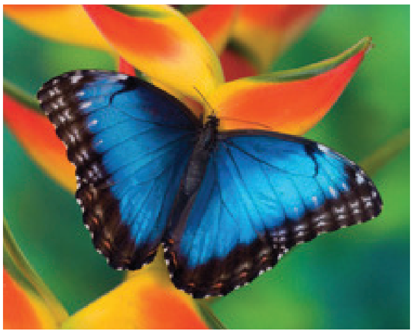

Figure 2.11 The wings of a bird and the wings of a butterfly are analogous structures: they perform the same function, but have significantly different structures.

Check your learning 2.3

Remember and understand

1 Give an example of how physical isolation could create a new species.
2 How does gene flow influence the process of speciation?
3 Define the term 'homologous structures'.
4 Give an example of an analogous structure.

Apply and analyse

5 Describe how the land ancestors of dolphins evolved to become the streamlined mammals we see now.

2.4 Fossils provide evidence of evolution

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The existence of fossils is one form of evidence supporting evolution. Fossils are remains or traces of an organism that once existed. The fossilisation process requires the dead organism to be buried without oxygen. Transitional fossils are intermediary fossils that have traits of both the ancestral organism and the more recent organism. Relative dating determines the relative order the fossilised remains were buried. Older fossils are found in deeper layers than more recent fossils. Absolute dating uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age.

Evolution

Support for any theory, including evolution, requires evidence from a range of sources that all point towards the same explanation. Early evidence for evolution came from the discovery of fossils that identified extinct species. Evidence of large-scale extinctions reinforced the fact that life forms change with changing environmental pressures – even if that simply means that many die and only few survive.

What are fossils?

Fossils are the remains or traces (footprints, imprints or coprolite/fossilised faeces) of organisms from a past geological age embedded in rocks or other substances by natural processes.

Fossilisation requires the organism, or its traces, to be buried quickly so that weathering and total decomposition do not occur. Skeletal structures or other hard parts of the organisms that resist weathering are slower to decompose.

Figure 2.12 This fossil of *Triceratops horridus* is 65 million years old.

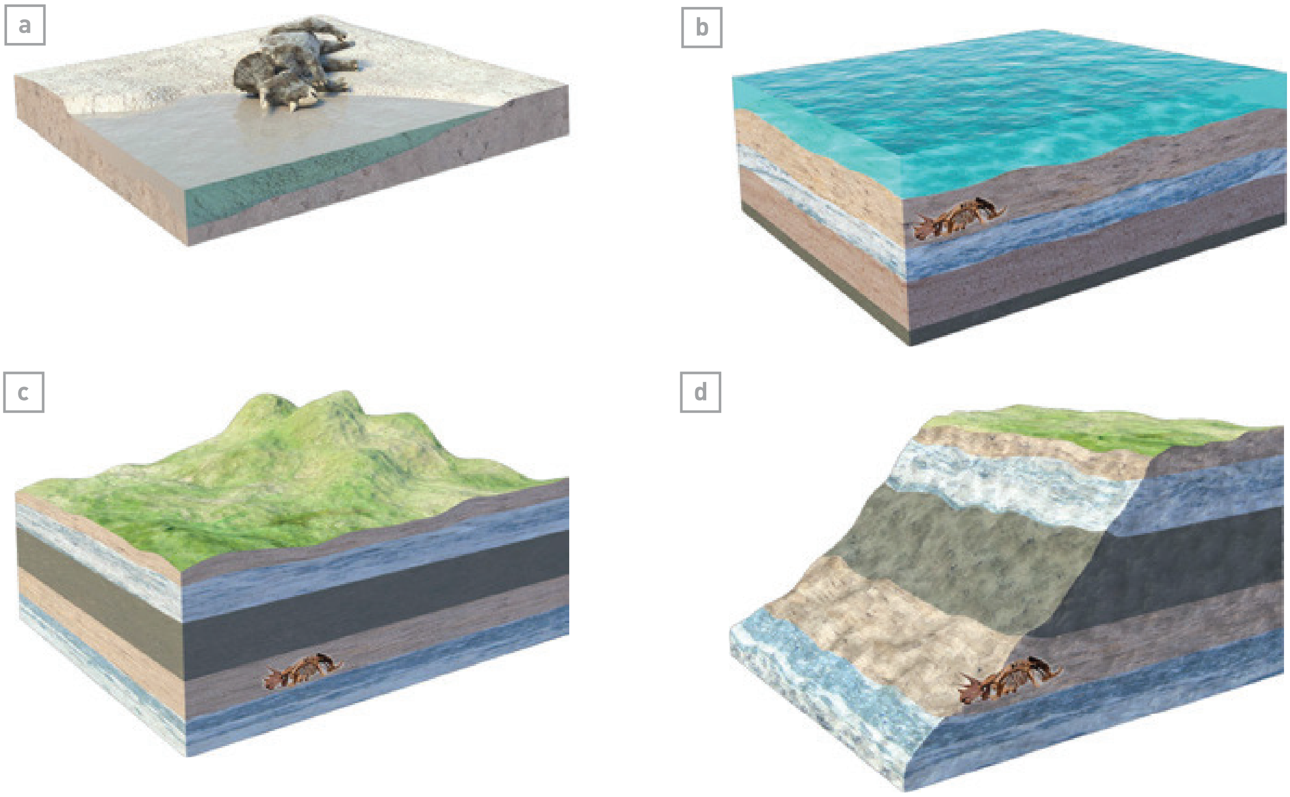

Figure 2.13 Formation of a fossil. (a) and (b) If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. (c) Over millions of years, more sediment is deposited and the remains are transformed gradually into sedimentary rock. (d) Years of geological movement, weathering and erosion may eventually expose the fossil.

These are the most common form of fossilised remains. Figure 2.13 shows how the process of fossilisation occurs.

Transitional fossils

Darwin's theory suggests that life originated in the sea, crawled onto land and then took to the skies or grew fur. The evidence that links these stages is in the form of **transitional fossils**, which are sometimes referred to as 'missing links', although the reality is a 'chain of missing links' is required over many generations.

When Darwin first published his theory, he stressed that the lack of transitional fossils was the largest obstacle to his theory because, at that time, very little was known about the fossil record. Since then, many excellent examples of transitional fossils have been found, such as *Archaeopteryx* (Figure 2.14), which was discovered in the Solnhofen area of Germany just 2 years after Darwin's work was published. *Archaeopteryx* is the earliest and most primitive bird.

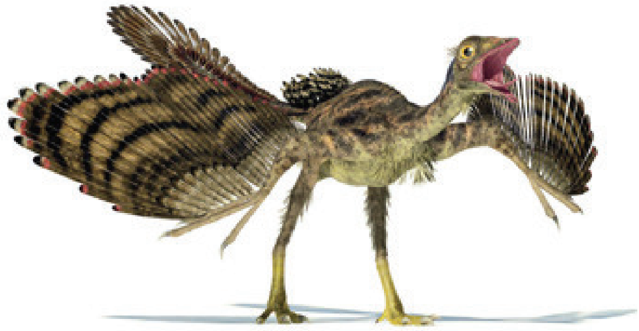

Figure 2.14 *Archaeopteryx* is an important transitional fossil. It displays a number of features common to both birds (hollow wishbone and feathers) and reptiles (teeth, flat sternum/breastbone, three claws on the end of its wings and a long bony tail).

Figure 2.15 Fossil stromatolites in Pilbara, Western Australia

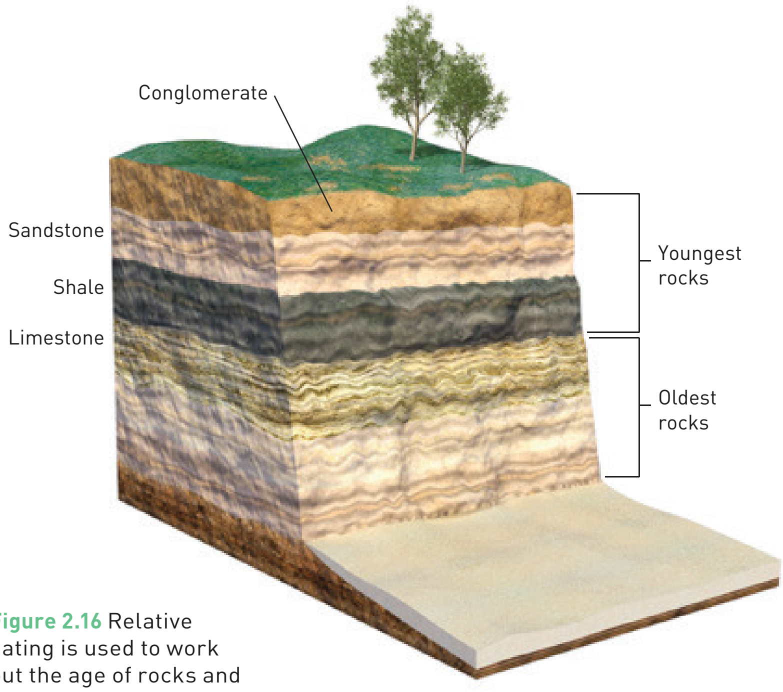

Figure 2.16 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.

Dating fossils

It is possible to find out how a particular group of organisms evolved by arranging its fossil records in a chronological sequence. Relative dating can provide approximate dates for most fossils because fossils are found in sedimentary rock. Sedimentary rock is formed by layers (or strata) of silt or mud on top of each other (Figure 2.16). The deeper the layer, the older the rock. Each layer contains fossils that are typical for that specific time period. Old fossils are buried deeper than younger fossils.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils. **Absolute dating** relies on the level of radioactivity in rocks containing radioisotopes. Every living organism maintains a constant low level of radiation. When an organism dies, the amount of radioactivity starts decreasing. The time it takes for half the radioactivity to decrease

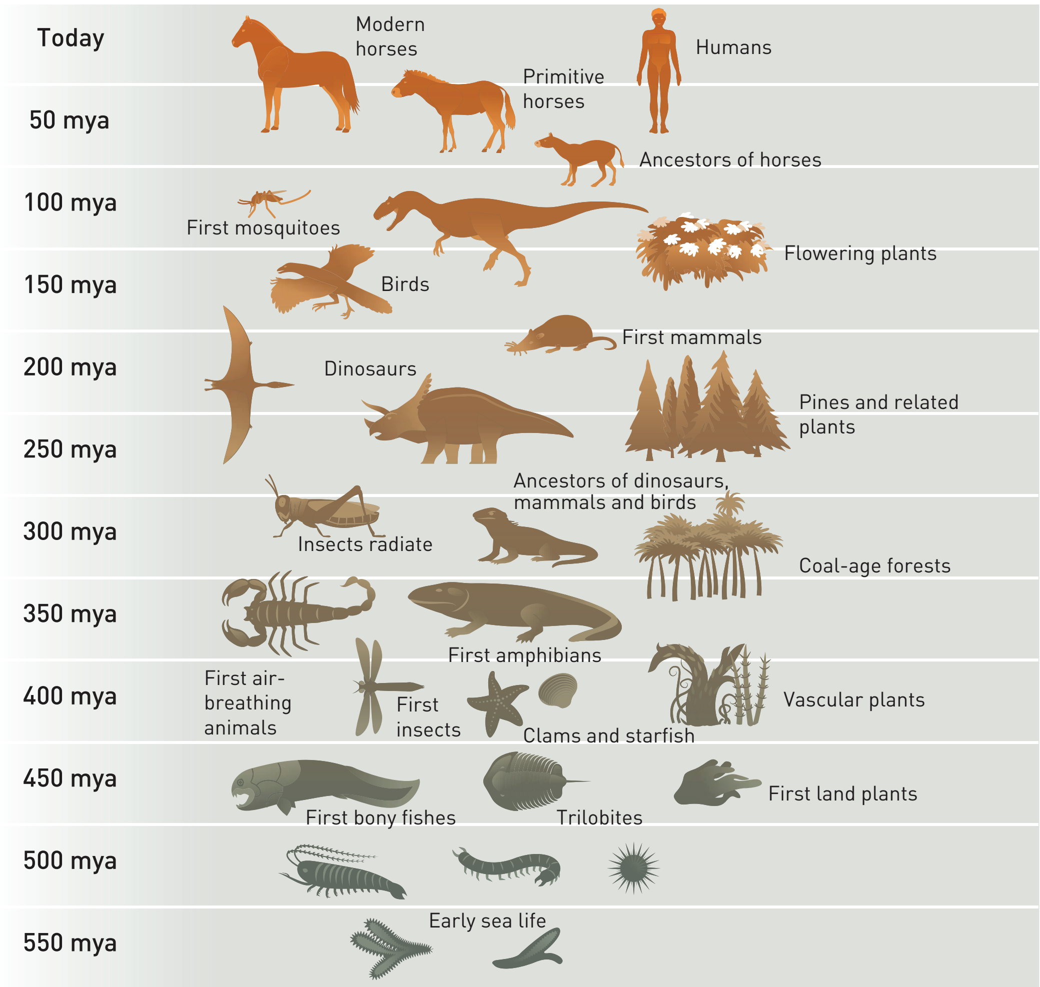

Figure 2.17 The history of living things, as determined by palaeontology (the study of fossils).

EXPERIMENT 2.4: POPCORN DATING
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is called the **half-life**. In one half-life, there is a 50% decrease in the initial radioactivity level. In the second half-life, the remaining radioactivity decreases by half again, leaving only 25% of the starting radioactivity level. This will continue until only very small levels of radioactivity are left. If scientists know the length of an element's half-life, they can determine how many half-lives have passed by measuring the amount of radioactivity. Therefore, they can determine the age of the fossil or rock.

Living fossils

According to fossil records, some modern species of plants and animals are almost identical to species that lived in ancient geological ages (for example, coelacanths, Figure 2.18). **Living fossils** are existing species of ancient lineages that have not changed in form for a very long time. This means the selection pressures for these organisms have not changed and therefore there is no pressure for the organism to change.

Figure 2.18 Unique in the animal kingdom, the coelacanth is a 400 million-year-old species of living fossil fish. Coelacanths pre-date dinosaurs by millions of years and were thought to have become extinct with them. In 1938, coelacanths were discovered living in caves off the continental shelf. This environment has changed little over the past 400 million years and, as a result, neither has the coelacanth.

Check your learning 2.4

Remember and understand

1 What parts of organisms are most likely to be found in fossils? Explain your answer.

2 How does relative dating work? Why is it often used before absolute dating is used?

3 Describe what a transitional fossil is.

4 Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. How has this been possible?

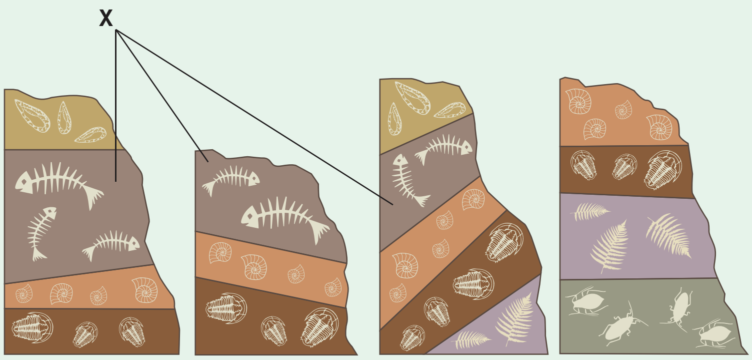

Figure 2.19 Fossils found at four different locations.

Apply and analyse

5 Will the theory of evolution ever become fact? Explain your answer.

6 How might observations of extant (living) organisms contribute to the evidence for evolution?

7 Fossils were found at four locations (Figure 2.19). Use relative dating to determine which fossil is the oldest.

2.5 Multiple forms of evidence support evolution

Biogeography is the study of how the continents move across the Earth, and how this directly affects the location of organisms. The breaking up of the supercontinent Pangaea into Laurasia and Gondwana caused organisms to diverge. When continents collide, species can spread, and when continents separate the new species move with them. The study of how genetic material affects the development of embryos (embryological studies) is a new and growing field of study. The sharing of common genes that control how an embryo develops is further evidence of evolution.

Figure 2.20 The jigsaw fit of Africa and South America supports the theory of continental drift.

Biogeography

At the beginning of the 17th century, the English philosopher Francis Bacon noted that the east coast of South America and the west coast of Africa looked as though they could fit together like pieces of a jigsaw (Figure 2.20). Since then, our knowledge of the structure of the Earth has developed and the theory of continental drift through plate tectonics continues to be supported by observations of various phenomena across the planet. It is now thought that at one time all the continents were connected in a single landmass – **Pangaea** (Figure 2.21). This supercontinent then broke in two to form **Gondwana** in the south and **Laurasia** north of the Equator.

The theory of continental drift has had a major impact on evolutionary theory because living organisms were carried on the landmasses.

The distribution of the fossils of extinct plants and animals, as well as modern-day species, supports the theory of continental drift (Figure 2.22). Some continents have very similar organisms even though they are separated by large stretches of ocean. Animals that can fly or swim could travel from continent to continent, but for the rest, continental drift is the only convincing explanation for their distribution.

Continental drift provides a well-supported explanation for the geographical isolation of species that eventually results in speciation – divergent evolution. Groups of similar species, such as the ratites (flightless birds), and the existence of marsupials on several continents, can be explained by biogeography (Figures 2.22 and 2.23). 'Coincidence' is simply not a scientific explanation.

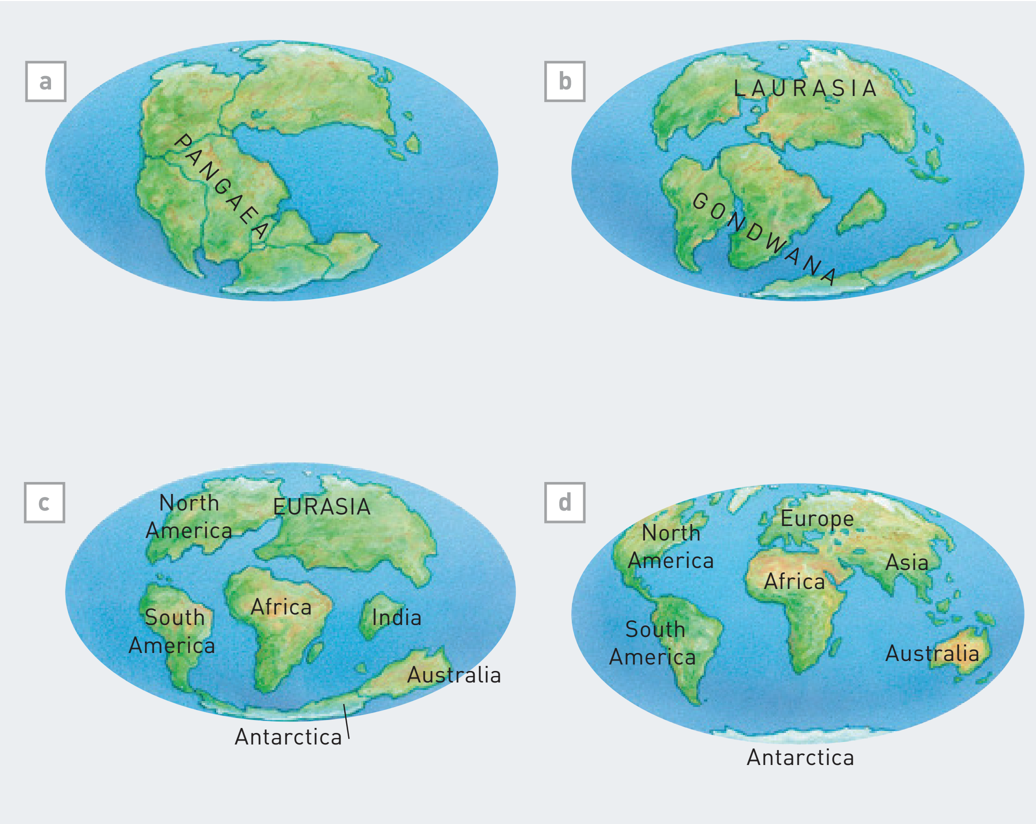

Figure 2.21 How the continents have drifted: (a) 220 million years ago; (b) 135 million years ago; (c) 65 million years ago; and (d) today.

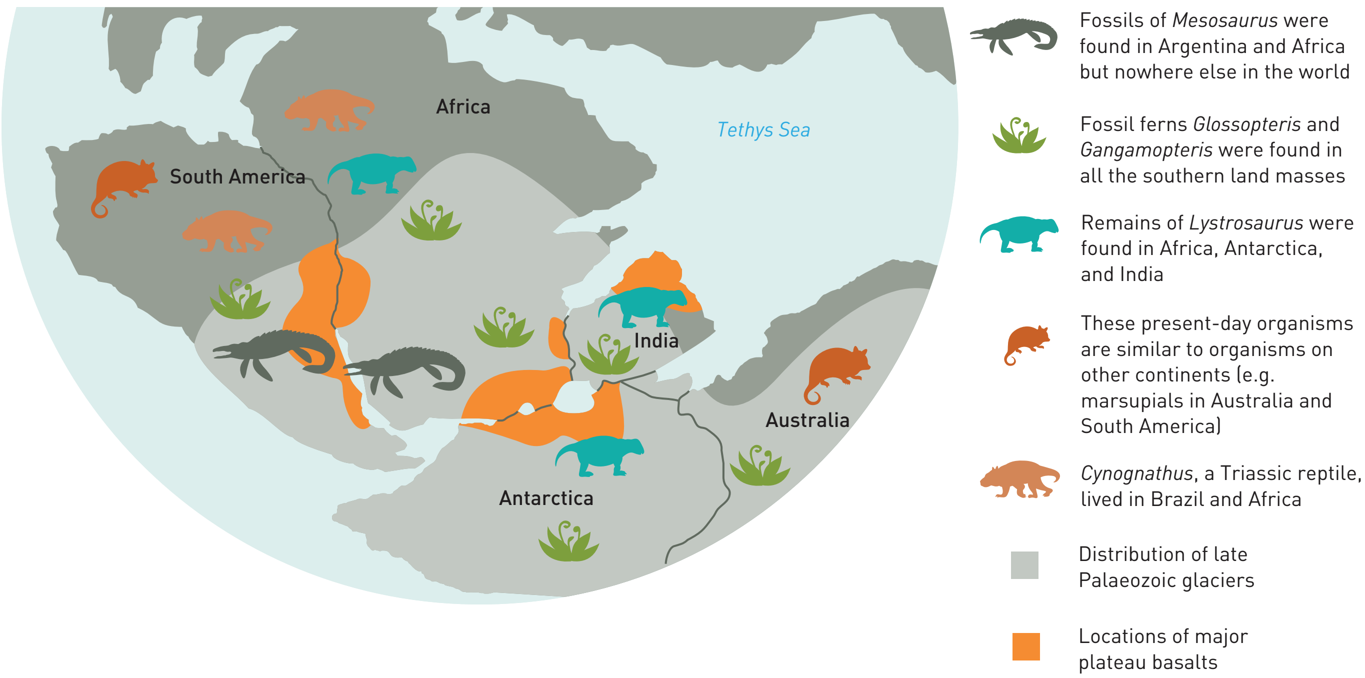

Figure 2.22 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

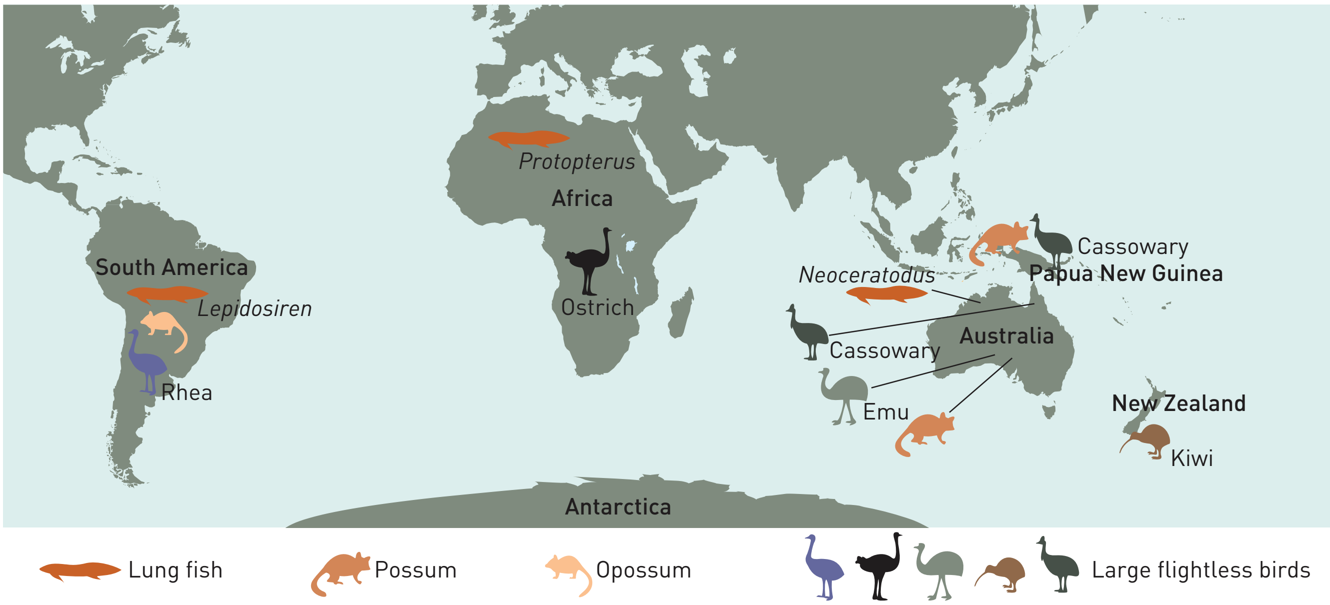

Figure 2.23 Similar lungfish are found in South America, South Africa and Australia. Similar marsupials are found in South America and Australia.

Vestigial structures

Vestigial structures are functionless structures found in organisms. They have puzzled naturalists throughout history and were noted long before Darwin first proposed the concept of evolution from a common ancestor (also called common descent). We now understand that individual organisms contain, within their bodies, abundant evidence of their histories. Some of these structures are clearly selected to perform a certain function that is no longer required. However, these features were not selected against and so they remained. Without the theory of evolution, the tiny wings of a cassowary are a puzzling structure. So, too, are the hindlimb buds of many snake species, which still carry vestigial pelvises hidden beneath their skin (Figure 2.24).

Vestigial structures are now interpreted as evidence of an ancestral heritage in which these structures once performed other tasks. The wings of a cassowary are a reminder that a distant relative of this organism once used its wings to fly. Similarly, snakes evolved from a four-legged ancestor. Humans, too, carry the evolutionary baggage of our ancestry. The ancestors of humans are known to have been herbivorous, and molar teeth are required for chewing and grinding plant material. More than 90% of all adult humans develop third molars (otherwise known as 'wisdom teeth'). Usually these teeth never erupt from the gums and in one-third of all individuals they are malformed and impacted. These useless teeth can cause significant pain and an increased risk of injury, and may result in illness and even death.

Analysing embryos

Scientists have noticed that, although adult vertebrates have certain differences, many embryos demonstrate similarities during the early stages of development. For example, a chicken and a human are very different when fully formed, but chicken embryos are very similar to human embryos (Figure 2.26). Even reptile embryos are similar to human embryos. Embryos may also show many interesting features that are not seen in the fully developed animal. As the embryo develops, it goes through a variety of stages. Many of these stages show homologous structures with different species.

If the various life forms developed independently, one would think that their embryonic development would be different and reflect what the organism would look like when it was fully developed. It would make more sense for a horse to develop a hoof directly rather than first develop five finger-like digits that are then modified into a hoof.

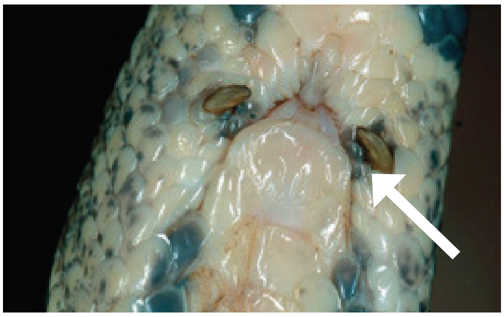

Figure 2.24 The rear legs on a snake (arrows) are an example of a vestigial structure.

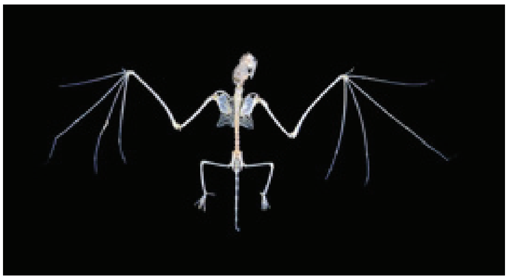

Figure 2.25 As an embryo, the 'finger genes' of the bat become more active. As a result, the bat's fingers grow much faster than the fingers of other embryos.

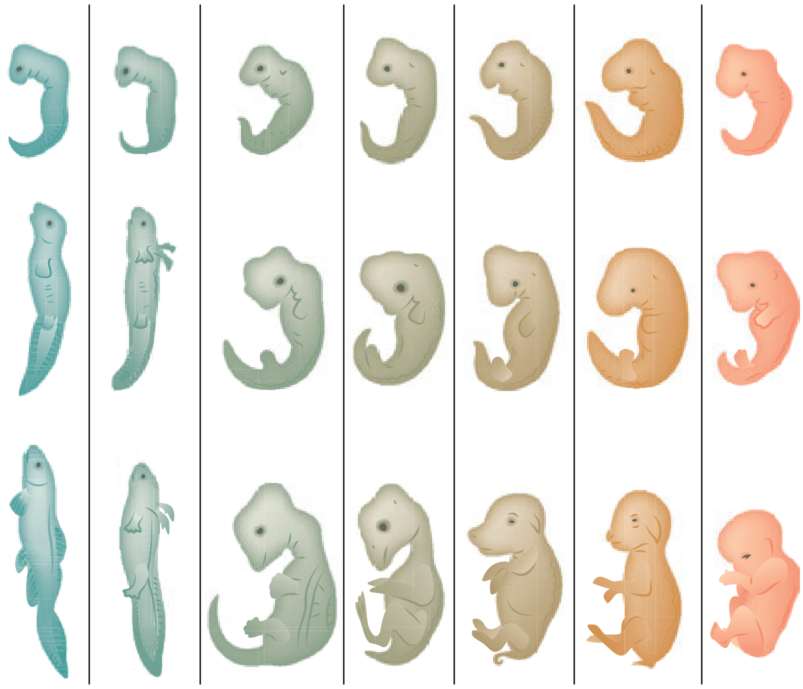

Figure 2.26 Common structures in the embryonic development of vertebrates.

The embryological similarities are explained by inferring that these organisms all had a common ancestry with common genes. Whales start developing teeth embryonically because they evolved from ancestors that had the genes for teeth. Human embryos develop gill-like structures and tails during their early development because they have the genes for these structures. These genes get turned up or down or 'switched off' during later stages of development. For example, the gene for a bat's fingers become 'supercharged' during embryological development so that the fingers start growing faster than the rest of the body (Figure 2.25). This makes the fingers of the bat extra-long compared to the rest of its body. The long fingers then develop into support structures in the bat's wings.

Check your learning 2.5

Remember and understand

1 The frogs in Australia show their closest evolutionary relationships to frogs in Africa and South America. How is this possible? Did humans carry them on boats?

Apply and analyse

2 If native marsupials were found in North America, would this disprove the theory of continental drift? Explain your answer.

3 How does the presence of vestigial structures support the theory of evolution?

4 Why do human embryos temporarily develop gill-like structures?

5 How can the gene that forms fingers be changed to form the wings on a bat?

6 Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years. How could this information be used to support the theory of continental drift? How could it impact the theory of evolution?

2.6 DNA and proteins provide chemical evidence for evolution

The basic structure of DNA and proteins is identical for all species on Earth. **Proteins** are long chains of amino acids arranged in different sequences. Many proteins that are essential for keeping organisms alive are conserved between species. Small differences in the sequences of amino acids can be used to determine the **evolutionary relationship** between species. The sequences in nucleotides in DNA can also be compared between different species. Mutations cause small differences that can accumulate over time. The more differences in the nucleotide sequence between organisms, the more time has passed since they shared a common ancestor, and the greater the evolutionary distance between the species.

Comparing amino acids in proteins

Proteins are like long necklaces made up of a series of beads. The beads are called **amino acids**. Genes in DNA provide the instructions for the order of the amino acid beads. Proteins range in size from approximately 50 amino acids to thousands of amino acids and are among the most important chemicals in life. They can be enzymes that control chemical reactions, or hormones, the chemical messengers in the body. The characteristics of a protein are determined by the order or sequence of amino acids.

All livings things use the same 20 amino acids to make proteins. If life evolved from a common ancestor with only these 20 amino acids, we may expect that these same amino acids are always used.

The same type of proteins in different species can be very much alike. **Cytochrome c** is one such example. Several types of cytochrome c proteins are found among different vertebrates and invertebrates. These cytochrome molecules are all very similar in structure and all serve the function of making energy in the cell (through cellular respiration), yet the order of their amino acid sequences can be slightly different (Table 2.1).

Comparing the sequence of amino acids in a protein can show the evolutionary relationship between different species. Before the two species diverge, they will have exactly the same protein with an identical sequence of amino acids. When the two species diverge, the number of mutations gradually accumulates. This may not affect the structure or function of the protein, but it can change a few amino acids in the long chain. The more time that passes, the more the changes to the amino acid

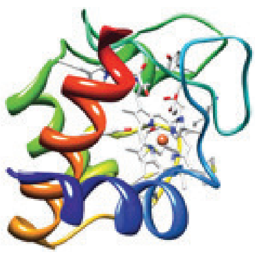

Figure 2.27 There are many different sequences of amino acids that could make a functional cytochrome c molecule.

Table 2.1 The sequence of amino acids that make up cytochrome c in different animals

HUMAN	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile
CHICKEN	Ile	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val
LUNGFISH	Val	Glu	Lys	Gly	Lys	Lys	Val	Phe	Val
FLY	Val	Glu	Lys	Gly	Lys	Lys	Leu	Phe	Val

EXPERIMENT 2.6: WHO IS MY COUSIN?
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sequence can accumulate. Therefore, the more similar the proteins, the more closely related the species. This means organisms with similar proteins share a very recent common ancestor.

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of gene sequences. Comparing DNA sequences examines the relationship between different species. If the theory of evolution is supported, then species that share a common ancestor will have inherited that ancestor's DNA sequence. Any mutations (permanent changes in the order of DNA nucleotides) will cause slight differences between the species. The more alike the two DNA sequences are, the more closely related the two species are. The more differences in the DNA sequence, the more time has passed since they had a common ancestor and the less related the species are now (Figure 2.28).

Phylogenetic trees

Before scientists were able to compare proteins and DNA, they examined the structures of organisms to determine if they were related. The difficulty with this is some organisms, such as dolphins and sharks, look very similar because of convergent evolution. Currently, scientists use the differences in DNA sequences to compare the evolutionary relationship. This relationship is shown in a **phylogenetic tree** (Figure 2.28).

Early DNA sequencing work on the genome of humans and great apes has shown that humans share a common ancestor with gorillas and chimpanzees. In fact, the chimpanzee is our closest living relative, with a 98% similar genome. DNA sequencing of the β-haemoglobin gene has also confirmed this (Figure 2.29).

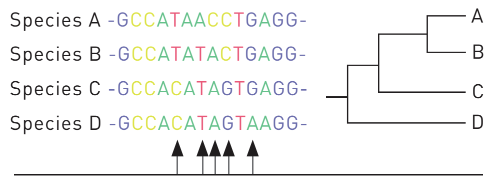


Figure 2.28 Comparing the DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is most closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

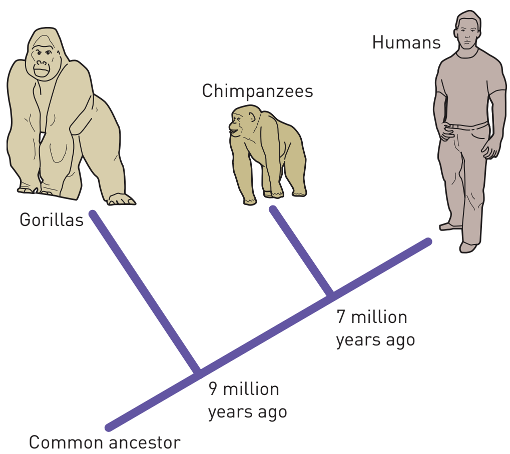


Figure 2.29 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

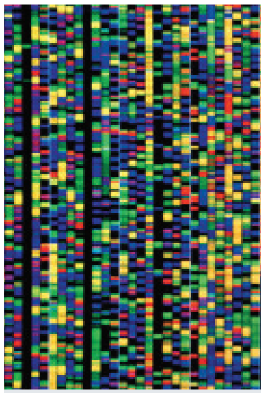


Figure 2.30 Comparative genomics is a relatively new field of biological research in which the genome sequences of different species are compared. This is an effective means of studying evolutionary changes among organisms. In this computer screen display of the human DNA sequence, each colour represents a specific base.

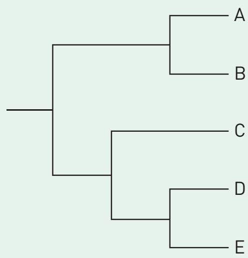
Check your learning 2.6

Remember and understand

1 What smaller (bead-like) structures make up proteins?
2 Cytochrome c is of interest to biologists studying evolution. What is the function of this molecule?
3 Table 2.1 shows a small section of the cytochrome c molecule for humans, chickens, lungfish and flies. Which species shows the greatest similarity to humans? Explain your answer.
4 What causes gradual changes to the sequence of nucleotides in DNA?

Apply and analyse

5 Use the phylogenetic tree on the right to determine which species is most closely related to species A.



6 Explain how DNA sequencing supports the concept of evolution from a common ancestor.

2.7 Humans artificially select traits

Artificial selection occurs when humans breed organisms that have desirable traits. This increases the likelihood of that trait occurring in the next generation. Over time, these organisms become domesticated and dependent on humans for survival. The frequent and incorrect use of antibiotics selects for resistant bacteria. Rapid regrowth through binary fission or horizontal transfer has led to an increase in some bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA).

Selective breeding

Humans have practised selective breeding for more than 10 000 years. When many human populations moved from the hunter–gatherer way of life to more permanent settled communities, they captured and tamed wildlife for their own purposes. Wild sheep grew wool in winter climates to keep warm. During the warmer summer months, they shed their wool in large clumps. Early humans chose the wild sheep that produced the most wool and bred from them. A random mutation caused the wool to grow all year round. These sheep were selected by breeders and the offspring of these wild animals became more reliant on humans to survive. Over many generations, the 'wild' traits were lost and the species was considered 'domesticated'.

Figure 2.31 Some animals have become so dependent on humans that they struggle to survive in natural conditions. This sheep was found with wool 42 cm long. The fleece weighed over 40 kg when it was eventually shorn.

Artificial selection

Artificial selection occurs when humans choose breeding partners for animals and other organisms in an effort to 'select' certain traits for their offspring. This is most evident in our pets. Many breeds (or subspecies) of dogs result from certain traits being selected by breeders (Figure 2.32).

Evolution of super-bacteria

One of the deadliest species of bacteria in hospitals is methicillin-resistant *Staphylococcus aureus* (MRSA or golden staph). This bacteria has arisen as a result of humans overusing antibiotics. *Staphylococcus aureus* is normally found on the skin and in the noses and

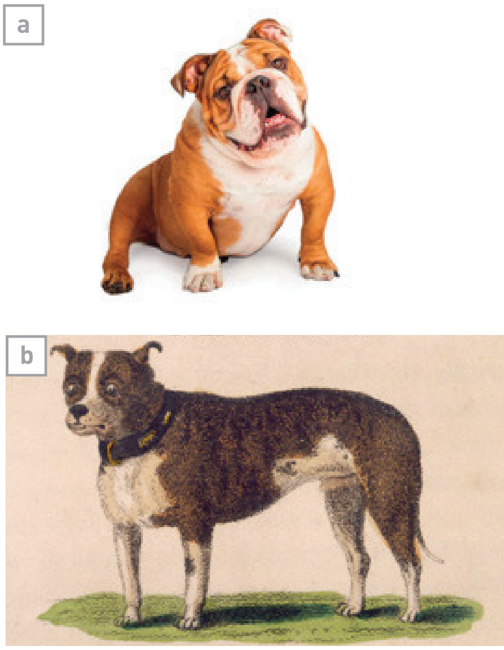


Figure 2.32 (a) Modern bulldog and (b) the bulldog 200 years ago. Over the last 200 years, breeders of British bulldogs have selected dogs with large flat faces. This has resulted in many birthing difficulties for female dogs. Up to 90% of bulldogs are born by caesarean. The flat faces also make the dogs more prone to breathing difficulties.

CHALLENGE 2.7: SELECTIVE BREEDING OF DOGS
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throats of many individuals in the population. Antibiotics prevent these cells from repairing or producing new cell walls, causing the cells to die rather than reproduce. In some populations, random mutations caused *Staphylococcus aureus* cells to be unaffected by antibiotics. These bacteria are resistant.

When a person has a bacterial infection, a doctor will often prescribe an antibiotic. If there is a single bacteria present that is able to resist the antibiotic for a short time, then it will survive longer than the rest of the bacteria. If the person feels better and stops taking the antibiotic, that partially resistant bacteria will start reproducing again through a process called binary fission. This makes the person sick again, so they take the rest of the antibiotics. Once again the partially resistant bacteria slows its growth, but this time another random mutation causes a fully resistant bacteria to start growing. This bacteria is not affected by the antibiotic and can easily spread to other patients in a hospital. MRSA is such a bacteria. The misuse of antibiotics by humans selected the bacteria for its resistance (Figure 2.33).

Some bacteria do not have to wait for a random mutation to develop resistance to antibiotics. Sometimes the gene for antibiotic resistance can be transferred from one bacteria to another in a process called **horizontal transfer**. Because bacteria reproduce so quickly, they evolve very quickly.

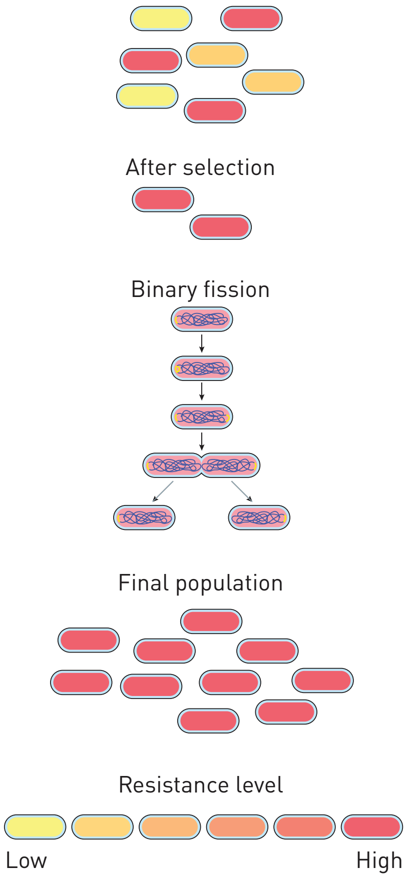

Figure 2.33 Frequent use of antibiotics selects for bacteria that are resistant to antibiotics. This increases the allelic frequency of resistance.

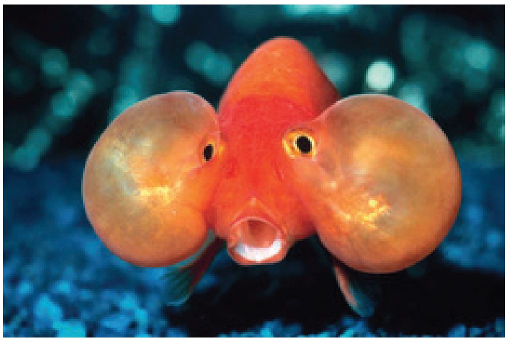

Figure 2.34 The bubble-eye goldfish can have problems with buoyancy, which affects their ability to swim. Could these fish survive in the wild?

Figure 2.35 Selected for its hairless coat, the sphynx cat was recognised as a new breed in 2008. Would these animals survive in the wild?

Check your learning 2.7

Remember and understand

1. What is selective breeding?
2. Give an example of how selective breeding was used to produce an animal.
3. What is MRSA?

Apply and analyse

4. How can misusing antibiotics contribute to the existence of MRSA?
5. A student claimed that artificial selection has interfered with nature. Provide two reasons to support their claim. Provide two reasons that disagree with their claim. Which view do you agree with?

//SCIENCE AS A HUMAN ENDEAVOUR//

2.8 Natural selection affects the frequency of alleles

Sickle cell anaemia is a disease that affects the structure and function of red blood cells. Sufferers have sickle-shaped cells that are unable to carry oxygen effectively around their body. Sickle cell anaemia is caused by a mutated gene for haemoglobin. Carriers of the sickle cell allele cannot contract malaria (a deadly disease that is contracted through mosquito bites). The number of sickle cell anaemia carriers is much higher in countries with a higher incidence of malaria. Therefore, malaria is a selection pressure for the sickle cell anaemia allele.

Sickle cell anaemia

Sickle cell anaemia is a genetic disease that causes swelling of the hands and feet, fatigue and pain. It is an autosomal recessive disease (see Chapter 1) that affects the haemoglobin protein found in red blood cells. The haemoglobin protein is made from four genes found on chromosome 11. It is responsible for carrying oxygen around the body. Most people have normal versions (or alleles) of the haemoglobin genes. Some people have a mutated allele, which causes the haemoglobin to clump together (Figure 2.36). A single copy of the mutated allele will not affect the quality of a person's life. However, two copies of the mutated allele will cause all the haemoglobin to clump together and the red blood cells to become shaped like a sickle (a curved cutting instrument).

These sickle-shaped cells can become stuck in the blood vessels, causing strokes or damaging the joints and organs of the body. People suffering sickle cell anaemia must be treated regularly to prevent infections. Thirty years ago, sufferers would die by the age of 20. Today, life expectancy is approximately 50 years.

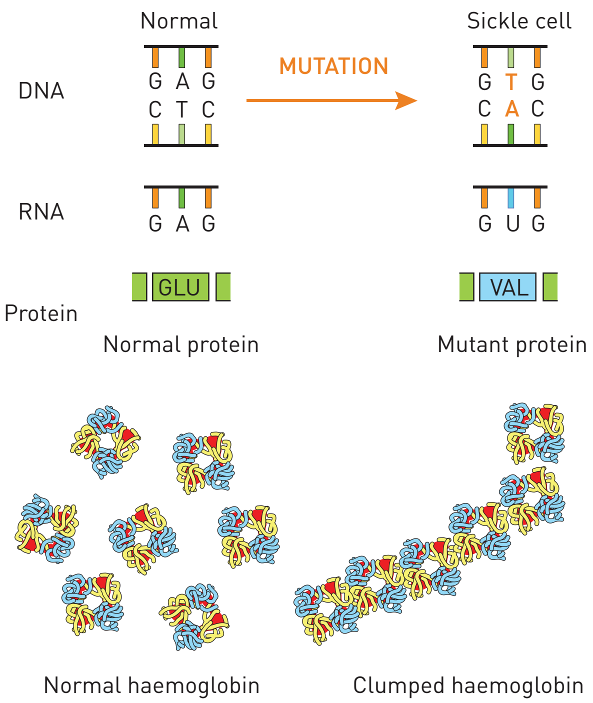

Figure 2.36 A single change in the nucleotide sequence causes a change in the amino acid sequence of haemoglobin. This causes the haemoglobin to clump together in people with sick cell anaemia.

Selection pressures

The rate of sickle cell anaemia is very low in Australia. It is thought that only 5% of the world's population is a carrier for sickle cell anaemia. This means they have one copy of the sickle cell allele and one copy of a normal

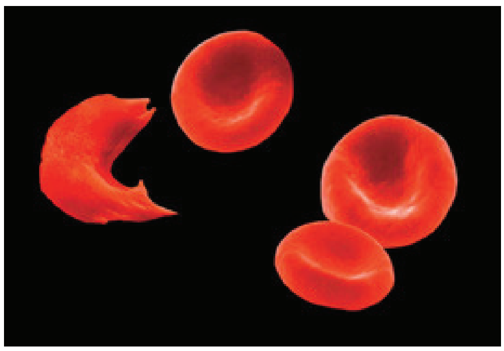

Figure 2.37 A person with sickle cell anaemia has crescent-shaped red blood cells (left) that are unable to effectively transport oxygen around the body.

EXPERIMENT 2.8: SELECTING FOR SICKLE CELL ANAEMIA
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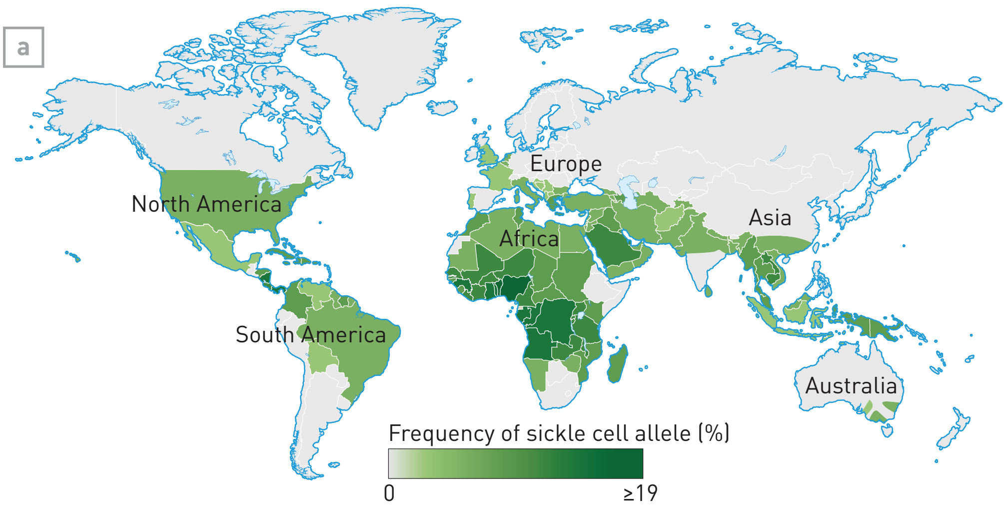
haemoglobin allele. However, in some areas the rate of carriers for anaemia is closer to 25% (Figure 2.38). This is because a person who is a carrier for sickle cell anaemia is protected from contracting malaria (an infectious disease that is contracted through mosquito bites). This means that people who:

> are not carriers of the allele for sickle cell anaemia are at risk of catching malaria and dying
> are carriers of the sickle cell allele do not get sickle cell anaemia or malaria
> have two copies of the sickle cell allele have sickle cell disease and may die young.

Malaria is the selection pressure that selects for the sickle cell carriers.



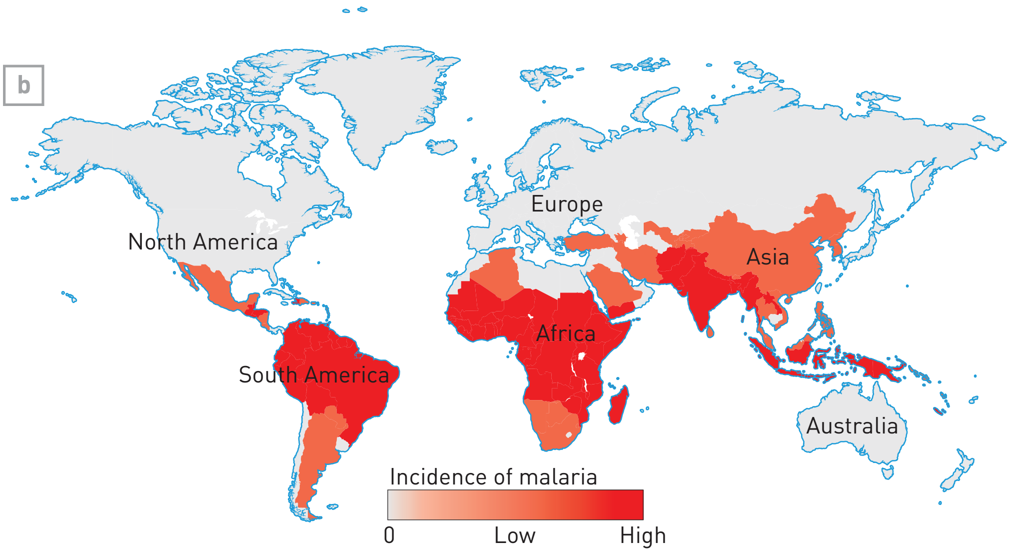


Figure 2.38 There is a strong correlation between (a) countries that have a high number of carriers for the sickle cell anaemia allele and (b) countries that have a high incidence of malaria.

Extend your understanding 2.8

1 How does sickle cell anaemia get its name?
2 What are the symptoms of sickle cell anaemia?
3 What does being a 'carrier for sickle cell anaemia' mean?
4 What is a selection pressure?
5 How does malaria select for carriers of sickle cell anaemia?
6 Research the cause and symptoms of malaria. Why is resistance for malarial drugs increasing in some areas? Use natural selection to explain your answer.

*REVIEW

2

Remember and understand

1 What is the difference between a hypothesis and a theory?
2 What is natural selection and what are the four essential factors for this process?
3 Explain the difference between incorrectly suggesting an organism has evolved as opposed to correctly suggesting that a population of organisms has evolved.
4 Define the term 'gene pool'.
5 What is the professional title for a person who studies the fossil record and geological time periods?
6 *Archaeopteryx* had features of both birds and lizards. What term is applied to fossils that show the evolutionary progression between two very different forms?
7 What is or was Gondwana?
8 The layering of sedimentary rocks is useful in relative dating. What is the basic principle of comparative dating?
9 Distinguish between the terms 'transitional fossil' and 'living fossil'.
10 Explain precisely how fossils provide evidence for evolution.

Apply and analyse

11 Use examples to illustrate the two critical deductions that Darwin made – the struggle for existence and the survival of the fittest.
12 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers. Instead, the stem keeps growing out past the old flower. Consequently, a mature plant may contain the ripe seeds of numerous years in its branches. How has this adaptive feature enabled *Callistemon* to exploit the current Australian environment?
13 Connect the terms 'allopatric speciation' and 'gene flow'.
14 Suggest why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

Evaluate and create

15 The tortoises of the Galapagos Islands either have a domed shell and a short neck (on islands with significant rainfall) or a shell with the front flared up and a long neck (on islands that are more arid). The tortoises feed on prickly pear cactus. On islands with no tortoises, the prickly pear plant is low and spreading, but on islands with long-necked tortoises, the prickly pear plant is tall and has harder spines protecting it.
   a Why might the tortoises have two very different phenotypes?
   b Would the tortoises that originally reached the islands be likely to resemble any of the tortoises that live there today?
   c Using the terms 'variation' and 'survival of the fittest', explain why the prickly pear plant is so different on islands with long-necked tortoises compared with those plants growing elsewhere.
   d What type of speciation is occurring on these islands?
16 Only two species of native non-marine mammals (both bats) existed in New Zealand before the Polynesians introduced rats and dogs 1500 years ago. This unusually small number of mammal species, along with New Zealand's separation from Gondwana 60–80 million years ago, has led many to speculate on which land mass mammals originally evolved. The earliest known mammal-like fossil remains are over 160 million years old. Considering this information, explain whether a Gondwanan origin for mammals is likely.
17 How does the study of DNA sequences help in our understanding of evolution?

Ethical understanding

18 Through selective breeding, humans are able to make speciation occur. Discuss the various scenarios in which this has occurred in the past and may occur now and in the future. Provide three examples of human intervention being positive and three examples of detrimental intervention. Support your choices.

Critical and creative thinking

19 Research the various explanations for changes in the natural world before evolutionary theories. Select one example and present your findings and analysis to the class in an appropriate and interesting format.

20 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. Prepare a three-part cartoon strip for each theory that clearly identifies the similarities and differences between these theories.

21 Present the strengths and weaknesses of the various forms of evidence that support evolution.

22 To appreciate how different people can hold different views on the theory of evolution, select a team of three to role-play the following, presenting and defending a range of perspectives on the theory of evolution validated with evidence-based reasoning: An atheist who accepts the evidence of evolution, a creationist who does not accept the evidence of evolution and a person who accepts the evidence of evolution and maintains a religious faith of any denomination.

Diversity and evolution

23 In what ways are the terms 'diversity' and 'evolution' linked? How does one rely upon the other? Can evolution occur without diversity? Can diversity occur without evolution?

Research

24 Choose one of the following topics for a research project. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

Darwin and the Galapagos Islands
Much of Darwin's theory developed while he was visiting the Galapagos Islands. Which new species did he find there? What was so unique about these species? How did Darwin's findings help him develop his ideas?

Modern-day evidence for evolution

There is evidence of current populations evolving by natural selection all around us. Research one of the following topics and see whether you can find evidence of evolution by natural selection occurring today.

- Can controlled breeding modify organisms?
- When fewer predators are present, how does brighter colouration evolve?
- How does natural selection lead to pesticide resistance?

> **Climate change and natural selection**

How do you think climate change will affect species on Earth? Which species do you think will be most affected? Why is this? What could these species do to avoid becoming extinct as a result of changing habitats? How could they do this? Would all species be able to avoid the effects of climate change? Do you think new species may evolve as a result of climate change?

Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in general agriculture are monitored closely. Why are these examples important? Why do they need close monitoring? Why do these organisms demonstrate evolution at such a fast rate?

KEY WORDS

2

absolute dating
a method that uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

amino acids
small molecule that makes up a protein

analogous structures
structures in organisms that perform the same function but are structurally different

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

continental drift
the continuous movement of the continents over time

converge
the boundary between two tectonic plates that are moving together

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

diverge
two species can experience different selection pressures, and gradually become more different; may lead to the two species becoming reproductively isolated.

evolution
gradual change in the genetic material of a population of organisms over a period of time

evolutionary relationship
an evolutionary relationship refers to how two species or populations are related with respect to their evolutionary descent

fossil
the remains or traces of an organism that once existed

fossilisation
the process of an organism becoming a fossil

gene flow
genes will flow from one generation to the next or one population to the next as different families or groups in the population choose partners and mate

gene pool
all the genes or alleles in the entire population

half-life
the time it takes the radioactivity in a deceased organism to decrease by half

homologous structure
a structure that is found across organisms and has a similar pattern but different function

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) between different bacteria

isolation
the division of a population into two groups

living fossil
an existing species of ancient lineage that has remained unchanged in form for a very long time

mutation
change that occurs at the DNA level that may add, delete or rearrange genetic material

pentadactyl limb
a limb with five digits

protein
chain of amino acids that are an essential part of any cell

selection pressure
environmental factors that affect an organism's ability to survive

speciation
process that results in the creation of a new species

transitional fossil
a fossil or an organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

vestigial structure
a structure in an organism that no longer has an apparent purpose