11 OTHER EVIDENCE OF EVOLUTION

UNIT 4 CONTENT

SCIENCE INQUIRY SKILLS

- conduct investigations, including the use of virtual or real biotechnological techniques of polymerase chain reaction (PCR), gel electrophoresis for deoxyribonucleic acid (DNA) sequencing, and techniques for relative and absolute dating, safely, competently and methodically for valid and reliable collection of data
- select, use and/or construct appropriate representations, including phylogenetic trees, to communicate conceptual understanding, solve problems and make predictions

SCIENCE AS A HUMAN ENDEAVOUR

- developments in the fields of comparative genomics, comparative biochemistry and bioinformatics have enabled identification of further evidence for evolutionary relationships, which help refine existing models and theories

SCIENCE UNDERSTANDING

Evidence for evolution

- comparative studies of DNA (genomic and mitochondrial), proteins and anatomy provide additional evidence for evolution; genomic information enables the construction of phylogenetic trees showing evolutionary relationships between groups
- the fossil record is incomplete and cannot represent the entire biodiversity of a time or a location due to many factors that affect fossil formation, the persistence of fossils and accessibility to fossilised remains
- sequencing a fossil record requires a combination of relative and absolute dating techniques to locate fossils onto the geological time line
- both relative dating techniques, including stratigraphy and index fossils, and absolute dating techniques, including radiocarbon dating and potassium–argon dating, have limitations of application

Source: School Curriculum and Standards Authority, Government of Western Australia

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The living things that exist on Earth today have all evolved from simpler forms that existed in the past. In Chapter 10 you learnt about how we can use DNA to show the gradual changes in an organism over time. However, our understanding of evolution started before we were able to analyse and compare DNA. One of the crucial pieces of evidence for evolution is the record of those changes left to us in the form of fossils.

11.1 FOSSILS

A **fossil** is any preserved trace left by an organism that lived long ago. Some fossils are bones, shells or teeth. However, fossils do not have to be a part of an organism; they also include footprints, burrows, faeces, or impressions of all or part of an animal or a plant. In the case of human ancestors, fossil remains are usually bones, teeth or sometimes footprints. Figure 11.1 shows the fossil remains of an ancestor of modern humans, *Australopithecus afarensis*, found in the Hadar region of Ethiopia. Such fossil remains are extremely important as they allow scientists to determine exactly what extinct species were like. Other material associated with the bones, such as the rock in which they were found and fossils

Alamy Stock Photo/Science Photo Library

FIGURE 11.1 The fossil hominin skeleton known as 'Lucy'

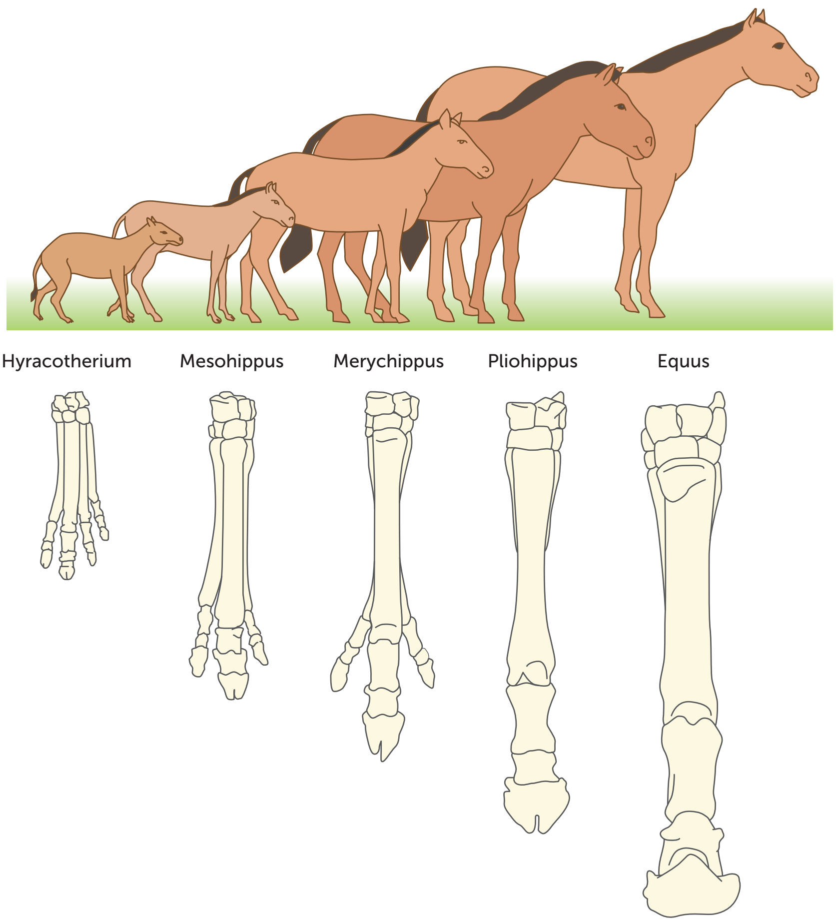

FIGURE 11.2 The evolution of the horse, showing how the leg bones appear to have changed as the animal increased in size

Horse evolution
This website provides more information about the evolution of the horse. Click on 'Gallery of horse fossils'.

of other plants and animals, allows the scientist to develop a picture of life in the past – what the organisms ate, what other organisms existed at that time and, sometimes, even what the climate was like.

There are many cases where the fossil record has allowed scientists to build up a sequence of the evolution of a particular plant or animal. One of the best known is the evolution of the horse, which can be traced through fossil remains from a small creature not much bigger than a small dog to the horses that we know today.

Fossil formation

When we consider the billions of organisms that have lived on Earth, the chance that a plant or animal will be fossilised is very small. Normally, dead organisms are decayed by micro-organisms and no trace of their existence is left. Parts of organisms may become fossilised when buried by drifting sand, mud deposited by rivers, volcanic ash or, in the case of some of the more recent human ancestors, other members of the species. If buried rapidly, conditions may not be suitable for the activity of decay organisms (decomposers), and decomposition may be slowed or prevented.

Effect of soil type on fossilisation

The nature of the soil is very important for the fossilisation of bone. In wet, acidic soils the minerals in the bone are dissolved and no fossilisation occurs. However, if such soil contains no oxygen, as in the case of peat, complete preservation of the soft tissues and bones of the animal may occur. Bones buried in alkaline soils produce the best fossils because the minerals in the bones are not dissolved. New minerals, often lime or iron oxide, are deposited in the pores of the bone, replacing the organic matter that makes up about 35% by weight of the bone. The bone becomes petrified (turned into rock), but the details of structure are still preserved.

Location of fossils

Fossils of human ancestors are often found at the edges of ancient lakes and river systems, in caves or in volcanically active areas. This is because the organism can be buried rapidly, preventing decomposition. Lakes and rivers build up sediments when flooding occurs or when the water flow slows rapidly. Many caves are in limestone, which consists of calcium carbonate. This chemical may be deposited around dead organisms, or the cave roof or walls may collapse, covering the bodies of animals. It is unusual for animals to be preserved near volcanic eruptions because heat from the volcanic material destroys the organism, but in East Africa ash falls have preserved fossils of many human ancestors.

Alamy Stock Photo/UPI

FIGURE 11.3 Fossilised remains of *Homo sapiens* were found in a cave called Jebel Irhoud in Morocco

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Discovery of fossils

Fossils are sometimes found by chance at the surface of the ground where they may have been uncovered by erosion, but more often the discovery of fossils is the result of slow and painstaking excavation of likely sites. Surface discoveries such as fossil fragments, or evidence of human occupation such as that found in many caves, are indications of places where excavations may prove fruitful. Scientists refer to an excavation as a 'dig'.

The area to be investigated is first surveyed and marked out in sections. Small hand tools are used to remove the soil gently so as not to damage any of the material. The soil removed is usually sieved so that even very small fragments are not overlooked. In the case of fossils of human ancestors, artefacts are often found in association with the fossils. **Artefacts** are objects that have been deliberately made by humans. They include items such as stone tools, beads, carvings, charcoal from cooking fires, and cave paintings.

Photographs are taken at every stage of a dig so that detailed studies of the positions of uncovered material can be carried out later. Each item is carefully labelled and catalogued for the prolonged study that follows the excavation of the site. In the laboratory, fossil bones are carefully scraped clean, broken parts are pieced together, measurements are taken, and plaster casts or latex moulds may be made.

Alamy Stock Photo/Ken Gillespie Photography

FIGURE 11.4 Archaeologists work with small hand tools to carefully uncover fossils and other artefacts at a site in Canada

Fossils show human migration
This website explains how recently discovered fossils show that humans migrated from Africa 180 000 years ago.

FIGURE 11.5 Cleaning prehistoric animal bones. These bones are from the jaw of a rhinoceros dating back 600 000 years

Science Photo Library/Pasquale Sorrentino

Key concept

Fossils are any preserved trace left by an organism that lived long ago. They form when organisms, artefacts or imprints are covered rapidly and left undisturbed, and conditions such as alkaline soils, a lack of oxygen and an absence of decay organisms prevent decomposition.

Questions 11.1

RECALL KNOWLEDGE

1 What is a fossil?
2 List the conditions needed for fossils to form.
3 Explain why fossils are often found near lakes and rivers.
4 Why are hand tools used to dig at excavation sites rather than bigger earthmoving equipment?
5 Describe artefacts, including at least one example.

APPLY KNOWLEDGE

6 Why are fossil remains of organisms usually bones or teeth, and not the skin, muscle or organs?
7 Fossils of soft tissue are most likely to be found in acidic soil, while the best fossils of bones are found in alkaline soils. Explain why this occurs, and include any other conditions that must be present for each of these fossils to form.

11.2 DATING FOSSILS

One of the major tasks following the excavation of fossils or artefacts is to determine the age of the material. This is known as **dating**. Knowledge of the age is crucial in finding out the sequence of changes that have resulted in present-day humans. Various methods of dating fossils and material associated with human ancestors have been devised. Dating can provide:

- **absolute dates** – the actual age of the specimen in years
- **relative dates** – a comparison of fossils to tell us whether one sample is older or younger than another.

Modern technology has enabled accurate estimates to be made of the absolute age of many samples. However, when that is not possible, knowing whether one fossil is older or younger than another is very important.

The age (or date) of a fossil or artefact is usually given in years before the present time. For example, a fossil may be said to date from 45 000 years BP, which is another way of saying it is 45 000 years old. BP stands for ‘before present’.

Absolute dating

Potassium–argon dating

Potassium is one of the most abundant elements in Earth’s crust, and is therefore found in some rocks. The **potassium–argon dating** technique is based on the decay of radioactive potassium to form calcium and argon. Potassium (chemical symbol K) is a mixture of three different isotopes. **Isotopes** are atoms of the same element with different numbers of neutrons. Isotopes of potassium all have 19 protons, but atoms of potassium-39 have 20 neutrons, atoms of potassium-40 have 21 neutrons, and atoms of potassium-41 have 22 neutrons. Potassium-40 is a radioactive isotope and decays to form calcium-40 and argon-40. Such decay takes place at an extremely slow, but constant rate, and so determining the amounts of potassium-40 and argon-40 in a rock sample enables the age of the rock to be calculated. As the rock ages, the proportion of potassium-40 decreases while that of argon-40 increases.

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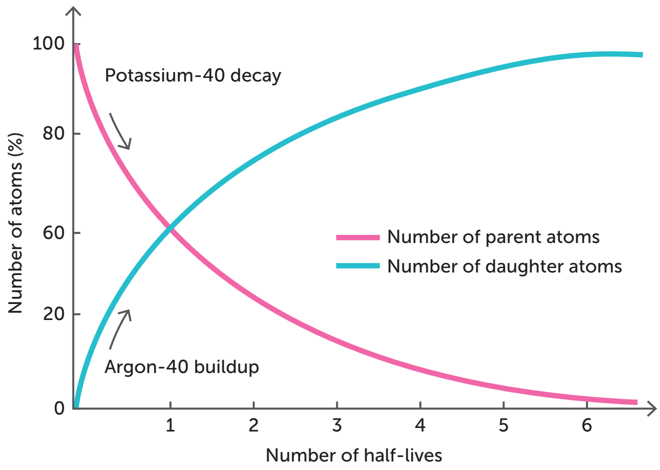

FIGURE 11.6 The levels of potassium-40 and argon-40 as a rock ages

Potassium–argon dating
This website provides more information about potassium–argon dating and some animated sequences on dating.

Potassium–argon dating has limited usefulness: not all rock types are suitable for this method of dating and it can only date rocks older than 100 000 to 200 000 years. The **half-life** of potassium-40 is 1250 billion years (1.25 x 10^9 years). This means that it takes 1250 billion years for half of the potassium-40 to decay. Therefore, after 100 000 years, only 0.0053% of the potassium-40 in a rock would have decayed to argon-40. Such a small amount pushes the limits of detection devices currently in use. Therefore, potassium–argon dating is most useful on samples that are older than 200 000 years.

To determine the age of a fossil using this method, some suitable rock of the same age as the fossil must be available. The age of the rock is determined using potassium–argon dating, and hence the age of the fossil is inferred. This situation can occur when rocks produced in volcanic eruptions bury bones.

Carbon-14 dating

The **carbon-14** or **radiocarbon dating** method is based on the decay of the radioactive isotope of carbon, carbon-14, to nitrogen. Carbon-14 is produced in the upper atmosphere by the action of cosmic radiation on nitrogen at about the same rate at which it decays. In the atmosphere there is a ratio of one carbon-14 atom to every million million (10^{12}) atoms of the stable isotope carbon-12.

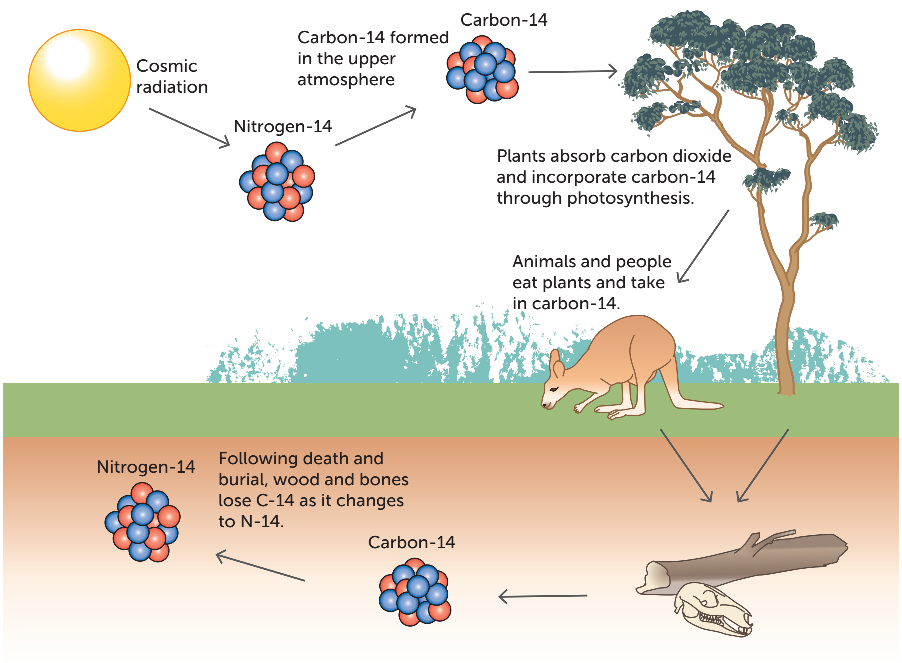

FIGURE 11.7 Summary showing how carbon-14 is formed, enters living things and decays

When green plants use atmospheric carbon dioxide in photosynthesis, one atom in every million million of the carbon atoms incorporated in the plant tissues is carbon-14. Should an animal eat the plant, the carbon-14 then becomes a part of the animal's tissues. With death, an organism's intake of carbon-14 ceases, but the carbon-14 already in the tissues of the organism continues to decay at a fixed rate. By measuring the amount of radiation liberated by a sample, the ratio of carbon-14 to carbon-12 can be estimated, and from this the age of the sample can be calculated.

Figure 11.8 shows the rate of decay of carbon-14. The ratio of radioactive carbon in the tissues of a living organism today is one carbon-14 atom to every 10^{12} carbon-12 atoms. This ratio declines to 0.5 in 10^{12} after 5730 years, to 0.25 in 10^{12} after another 5730 years, and so on. In other words, over a period of 5730 $\pm$ 40 years, half of any given quantity of carbon-14 breaks down. Therefore, 5730 $\pm$ 40 years is the half-life of radioactive carbon.

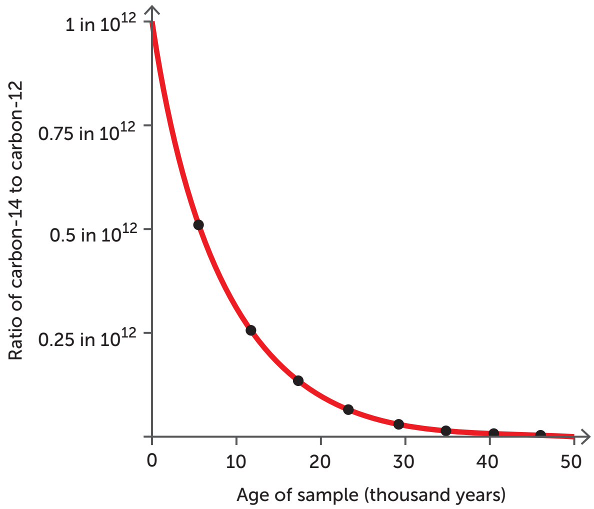

FIGURE 11.8 Rate of decay of carbon-14 to nitrogen. Each dot on the curve represents a period of 5730 years, the half-life of carbon-14

The normal method of radiocarbon dating requires at least three grams of organic material so that the rate of radioactive decay of carbon-14 in the sample can be measured. A more refined technique, known as **accelerator mass spectrometry (AMS) radiocarbon dating**, can be used to date a sample as small as 100 micrograms (0.0001 grams). This technique involves breaking the sample up into its constituent atoms so that the number of atoms of each isotope of carbon can be counted. Using AMS radiocarbon dating, it has become possible to date cave paintings accurately from tiny samples of pigment. It has been found that such pigments often contain organic material such as charcoal, while honey, milk, blood or oil seed may have been used to bind the pigment particles.

After about 70 000 years, the percentage of carbon-14 left is only 0.021%. This is too small to be able to measure accurately; therefore, radiocarbon dating method cannot be used to date back more than about 60 000 years. A further limitation is that the material to be dated must contain **organic compounds**, compounds from living things that contain carbon. Radiocarbon dating is nevertheless of great value in dating fossils of more recent origin and also in dating artefacts, because these are often found in association with charcoal left from cooking fires. By dating the charcoal found in ancient hearths, the approximate age of artefacts can be deduced.

There is another problem with using radiocarbon dating. It was once assumed that the ratio of carbon-14 to carbon-12 in the atmosphere was constant, but it is now known that the amount of carbon-14 in the atmosphere varies. Thus, radiocarbon dates must be treated with a certain degree of caution. Corrections for the fluctuations in the carbon-14 content of the atmosphere are, however, now possible for about the past 9000 years, by reference to other information such as tree-ring dating.

Each method of absolute dating is limited in its application because each depends on the occurrence of a particular set of circumstances before it can be used. Together, however, these and other methods do give the anthropologist a number of ways of determining the actual age of ancient material. New methods are being developed all the time and there is constant improvement in the accuracy of older methods. Table 11.1 shows the approximate time span applicable to the methods described and also those of some more recently developed techniques.

Carbon-14 dating
This website provides an animation of the use of carbon-14 dating.

How carbon-14 dating works
This website provides further explanation of the processes involved in carbon-14 dating.

Activity 11.1
Investigating radioisotope methods of dating

Key concept

Absolute dating methods, such as potassium–argon dating and carbon-14 dating, allow the age of fossils to be identified. Potassium–argon dating is used to date rocks older than 200 000 years, while carbon-14 dating is used on organic matter less than 60 000 years old.

TABLE 11.1 Useful range of common absolute dating methods

DATING METHOD	MATERIAL USED	USEFUL RANGE (YEARS BP)
Tree growth rings (dendrochronology)	Wood	Up to 9000
Carbon-14	Carbon compounds	Up to 60 000
Protactinium	Sea sediments	Up to 250 000
Uranium–thorium	Sea sediments, coral	Up to 600 000
Potassium–argon	Volcanic deposits	200 000 And earlier
Electron spin resonance	Calcium carbonate (in shells, coral, teeth), also quartz and flint	Up to 100 000, possibly 300 000
Fission tracks	Minerals and glass	100 Years ago to 4550 million
Thermoluminescence	Sediments, lava, ceramics	300 Years ago to 100 000

Relative dating

When it is not possible to determine the actual age of a fossil or artefact, scientists can often determine whether it is older or younger than another sample, or whether it is older or younger than the rock or soil in which it is found. Such relative dating enables a sequence of events to be established.

Stratigraphy

Stratigraphy
This website provides more information about the problems that may arise with stratigraphy.

Stratigraphy is the study of layers, or strata. There are two ways in which stratigraphy can be useful in dating fossil material. The first is the **principle of superposition**, which assumes that in layers of sedimentary rock the layers at the top are younger than those beneath them. Thus, any fossils or other material found in the top layers will be younger than material found lower down. This principle must be applied with care because distortions of Earth's crust do occur, and a sequence of rock layers may be turned upside down. In addition, it is possible for fossils or artefacts to be buried by animals, or perhaps by early humans, some time after the deposition of sediment. In this case, the specimen may be younger than some of the layers above it.

The second use of stratigraphy is in the **correlation of rock strata**, which involves matching layers of rock from different areas. Matching of strata can be done by examining the rock itself, and also by studying the fossils it contains. Rocks that contain the same fossils may be assumed to be of the same age. Certain fossils, called **index fossils**, are of great value in this correlation work because they are widely distributed and were present on Earth for only a limited period of time. This makes the relative dating of strata more precise. Figure 11.11 (on page 304) shows how index fossils may be used to correlate strata from different localities, often hundreds, or even thousands, of kilometres apart.

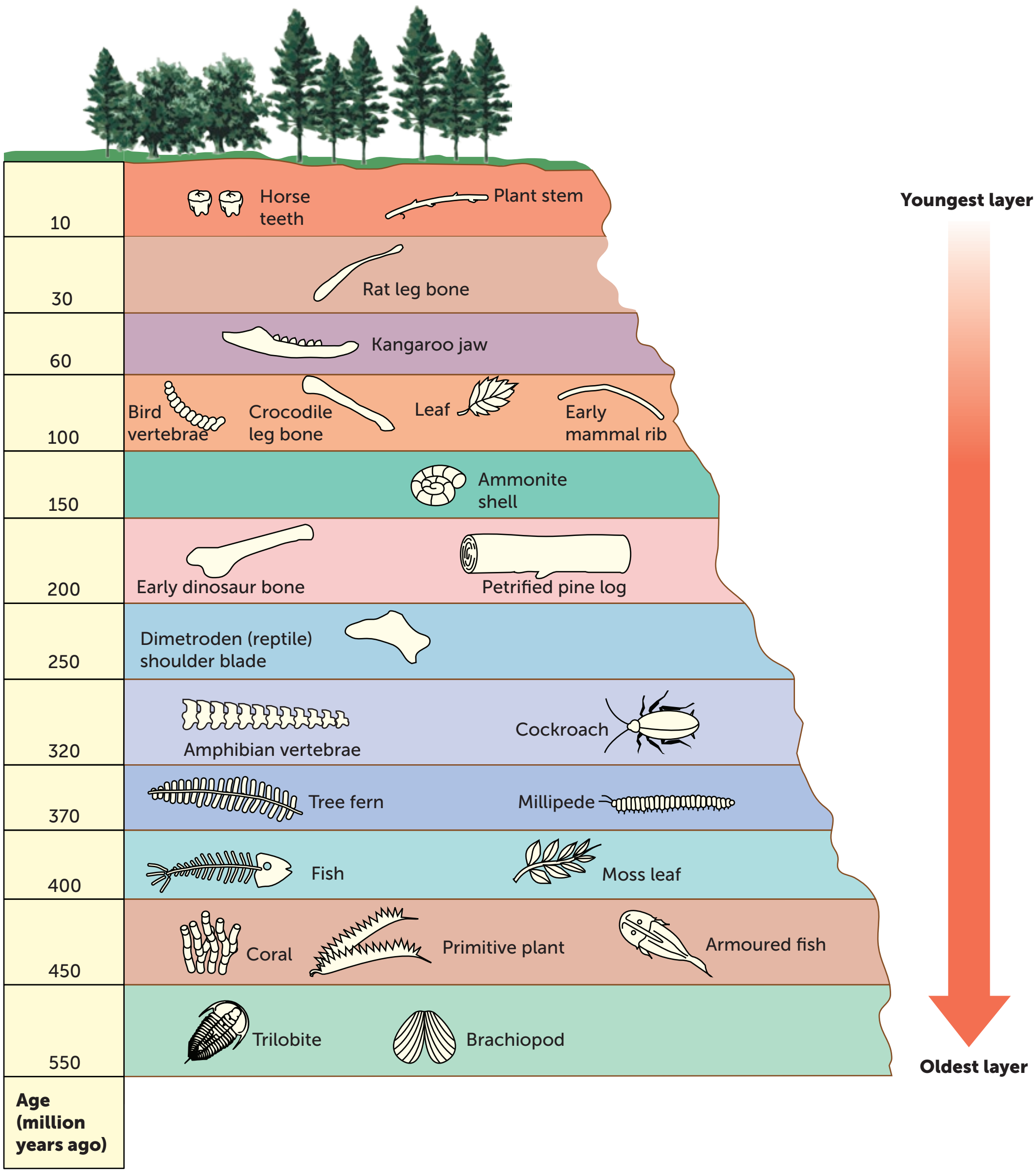

FIGURE 11.9 A section of rock strata containing fossils of different ages. The principle of superposition assumes that the younger strata are towards the top of the sequence

FIGURE 11.10 A trilobite fossil. The segmented form of the shell is clearly visible, with the head at bottom left. Trilobites make excellent index fossils as they lived between 500 and 300 million years ago before becoming extinct

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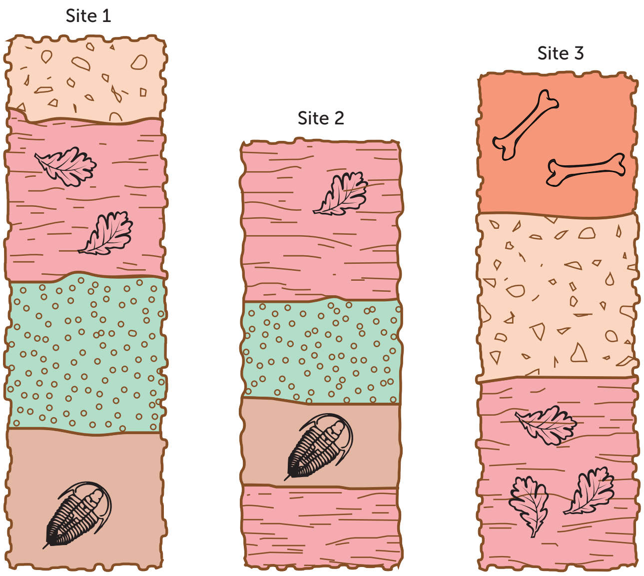


FIGURE 11.11 Three sets of rock strata, some containing fossils exposed in trenches at three different excavation sites. Which of the strata shown is the oldest?

Activity 11.2 Investigating stratigraphy

An analysis of fossilised pollen grains has developed into an important branch of science. Some fossil pollen grains are useful as index fossils but, even if they cannot be used in this way, the presence of preserved pollen grains in a soil or rock sample can enable a botanist to construct a picture of the type and amount of vegetation existing at the time the deposit was laid down. An idea of the climatic conditions prevailing at the time may then be worked out. This data can be used to confirm or refute relative dates arrived at by other methods.

Key concept

Relative dating, such as stratigraphy, allows the age of fossils to be compared. Stratigraphy is based on the principle of superposition, which assumes that layers of sedimentary rock are youngest on the top.

Problems with the fossil record

The fossil record is very incomplete as conditions for fossilisation do not always occur, or occur at irregular periods of time. For fossils to be formed, four conditions are usually required:

- a quick burial of the material
- the presence of hard body parts
- an absence of decay organisms
- a long period of stability – the organism needs to be left undisturbed.

Fossilisation is therefore a chance occurrence and there are many gaps in the fossil record because organisms have not been preserved.

Another reason for gaps in the fossil record is that only a very small proportion of the fossils that do exist have actually been discovered. Some are buried too deep in the ground to be found, or are in inaccessible places. Others may not have been recognised as fossils or may have been inadvertently destroyed by human activity such as agriculture or industry.

Even when fossils are found, dating the fossil material can be problematic. To use carbon dating techniques, material containing carbon must be present, and the material can only be dated back to 60 000 years or so. To date material older than this, the age of the fossil is determined by the sediments in which it is found. For example, the use of potassium–argon dating relies on suitable material, such as volcanic lava, being present.

It is unusual to find a fossil of an entire organism, or the whole skeleton of an organism. This is particularly true of fossils of human ancestors. Often, from just a few fragments of bone, scientists have to reconstruct what the organism may have looked like. Figure 11.12 shows a reconstructed skull of *Homo ergaster*. Found in Kenya, the fragments were dated at around 1.8 million years old, and were pieced together like a jigsaw puzzle. Areas shown in black are parts of the skull where bones are missing. Experts have estimated the shape of the face and upper jaw in order to complete the reconstruction. Such reconstructions are only approximations based on the experience of the scientists involved. Other scientists may disagree with the interpretation and this can lead to considerable controversy. The only resolution to such disagreements is to find more fossils; but as we have seen, even if there are more fossils, the chances of finding them are often slim.

FIGURE 11.12 The reconstructed skull of *Homo ergaster*

Evidence for evolution
This website provides a review of evidence for evolution that has been discussed in this chapter and the previous one.

WS
11.1 Fossil evidence for evolution

Key concept

There are gaps in fossil records because fossils only form in certain conditions, they may be accidentally damaged, they may not yet have been found, or it may not be possible to date them.

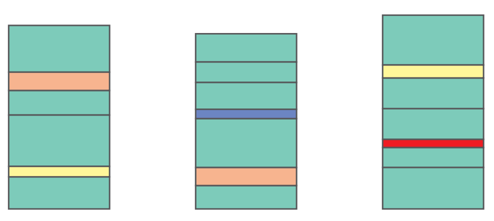
Questions 11.2

RECALL KNOWLEDGE

1. Describe the difference between absolute dating and relative dating.
2. Define 'isotopes' and list three isotopes of potassium.
3. Explain how the amount of potassium-40 can provide information about the age of the sample.
4. What types of samples are able to be dated using potassium–argon dating?
5. What types of samples are able to be dated using carbon-14 dating?
6. Define 'half-life' and state the half-life of carbon-14 and potassium-40.
7. What type of dating could be used to determine the age of a wooden artefact?
8. Explain why the principle of superposition cannot be considered without taking other factors into account.
9. Describe index fossils and explain their relevance to relative dating.
10. List the reasons that there are gaps in fossil records.

APPLY KNOWLEDGE

11. Compare and contrast atoms of potassium-40, calcium-40 and argon-40. Use this to suggest what happens when potassium-40 decays to form calcium-40 and argon-40.
12. Explain why dating using carbon-14 is also called radiocarbon dating.
13. Explain why carbon-14 dating can only be used to determine the age of samples that were once living.
14. The diagram below shows a sample of soil taken from the same area. The colours represent fossils found in particular layers. State the age of the fossils from the youngest to the oldest.



11.3 COMPARATIVE ANATOMY

Fossil evidence and current observations can provide information about the anatomy of organisms. This allows scientists to compare the structural features of related animals to ascertain the degree of similarity between them. Similarities in structure often suggest that species have a common ancestor. In discussing comparative anatomy, we will focus on three areas:

- **embryology** – comparing the very early stages of the development of organisms
- **homologous structures** – structures that are similar in structure but may be used in different ways
- **vestigial structures** – structures that may once have been important but have lost or changed their function.

Embryology

How fudged embryo illustrations led to drawn-out lies
Learn how *Haeckel's Embryos* misled people about comparative embryology.

Comparative embryology provides evidence for evolutionary change over time by comparing the early stages in the development of organisms. Although it is relatively easy to distinguish between the adults of different species, it is frequently far more difficult to tell the difference between embryos. In vertebrates, comparing the embryonic stages reveals a remarkable similarity between different species at different times.

At one point in their development, the embryos of humans and chickens have slits and arches in their neck. These are similar to the gill slits and arches in fish, but do not develop into gills. However, their similarities indicate a common ancestor.

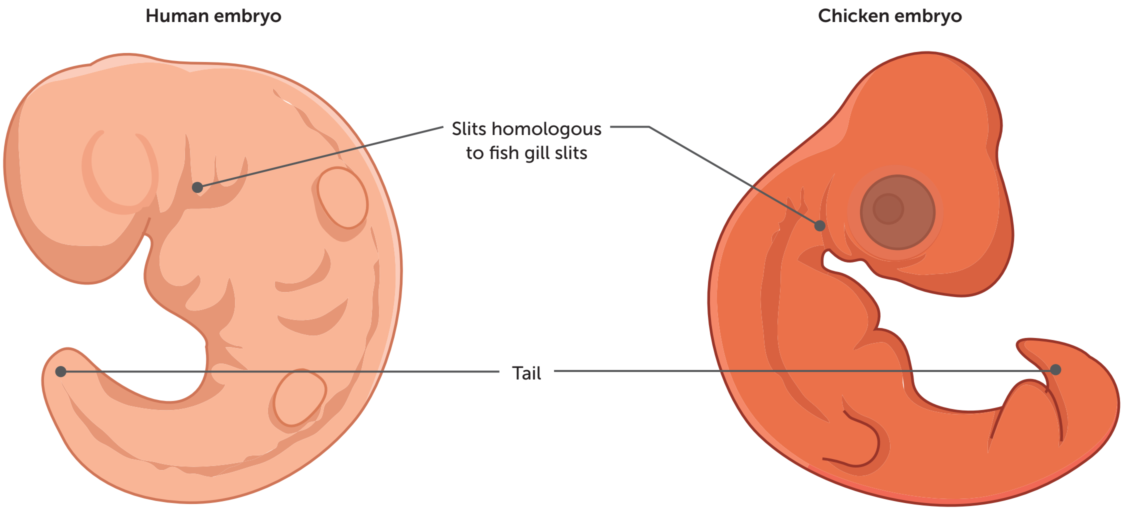


FIGURE 11.13 Comparing the human and chicken embryo at one stage of development

Additional features common to vertebrate embryos at one stage are the presence of a tail, a two-chambered heart and similar brain development. This all adds up to striking evidence for a common ancestry with later evolution along different pathways.

Homologous structures

One of the classic examples used to illustrate similarity in anatomy is the forelimbs of vertebrates. The same bones appear in various forms throughout the vertebrates: the feet of amphibians and reptiles, the wings of bats and birds, the leg of a horse, the flipper of a whale or seal, and the human hand. The degree of similarity between the bones can be seen in Figure 11.14. In every case the bones are arranged in a similar way, even though some have developed different functions. These forelimb bones are described as homologous structures because they possess a similar structure. Organisms possessing homologous structures are likely to have a common ancestor. Therefore, the arrangement of the bones of the forelimb in such a range of vertebrates is convincing evidence that they have all evolved from a common ancestor.

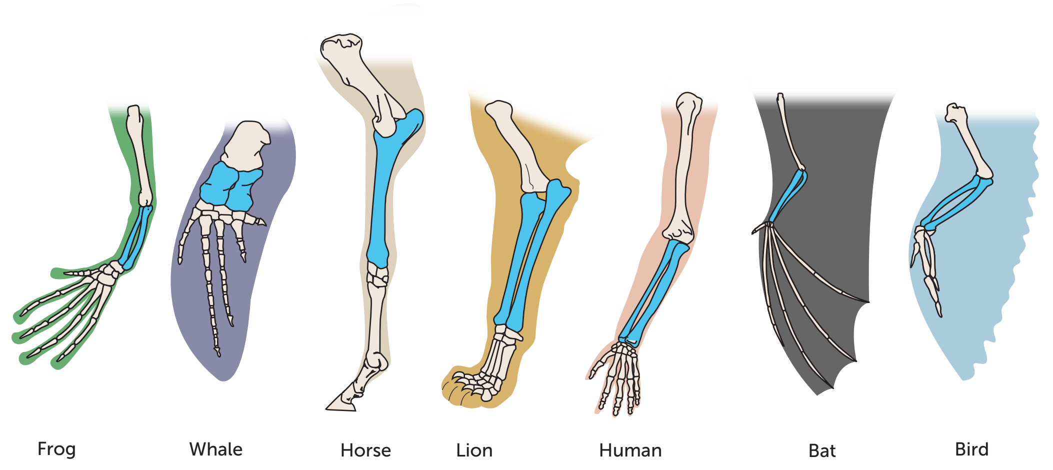


FIGURE 11.14 Left forelimb bones of seven vertebrates; from left to right: frog forelimb, whale flipper, horse forelimb, lion forelimb, human arm, bat wing, bird wing

Anthropoids, the human-like primates, show a great many anatomical resemblances. The number of traits shared and the degree of similarity between the shared traits is remarkable, especially considering the range of habitats occupied. Figure 11.15 shows the skeletons of a human and a gorilla; Figure 11.16 shows the arrangement of muscles in their legs. Note the high degree of similarity between them. These two species share a common ancestor and are therefore closely related. This will be discussed further in later chapters.

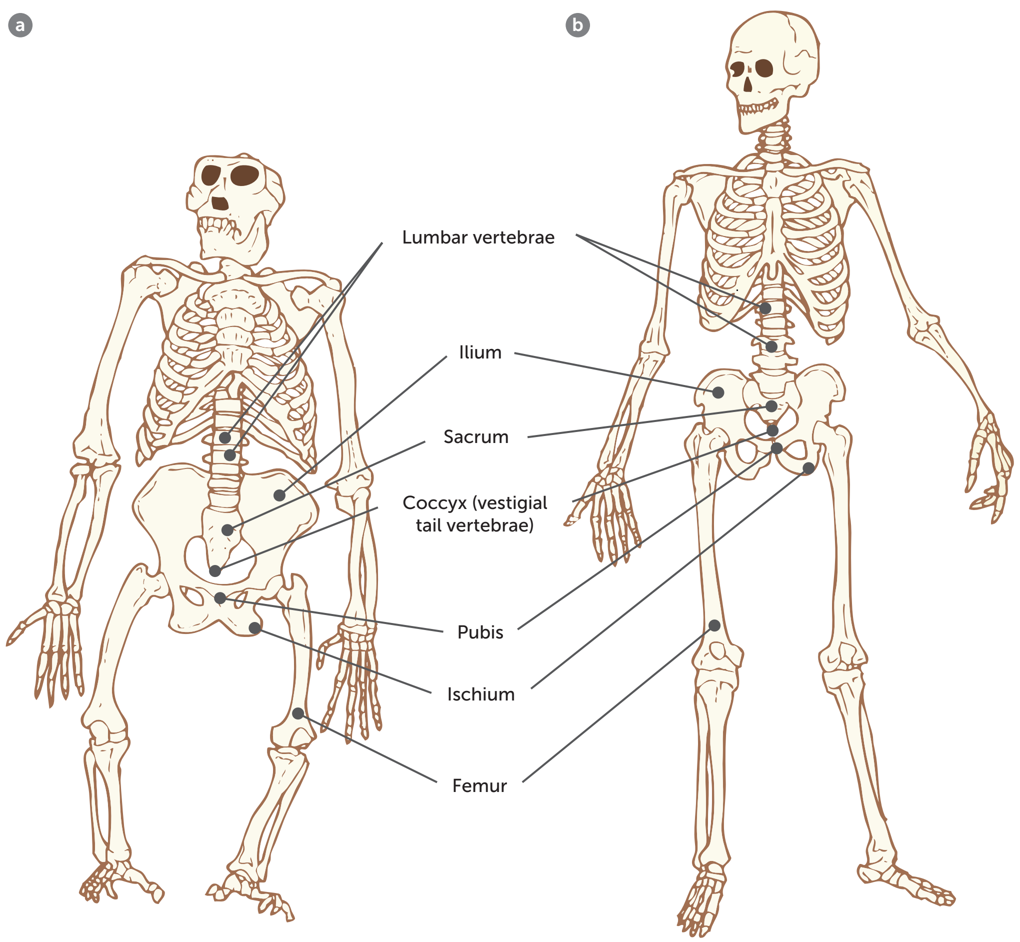


FIGURE 11.15 Skeleton of **a** a gorilla and **b** a human

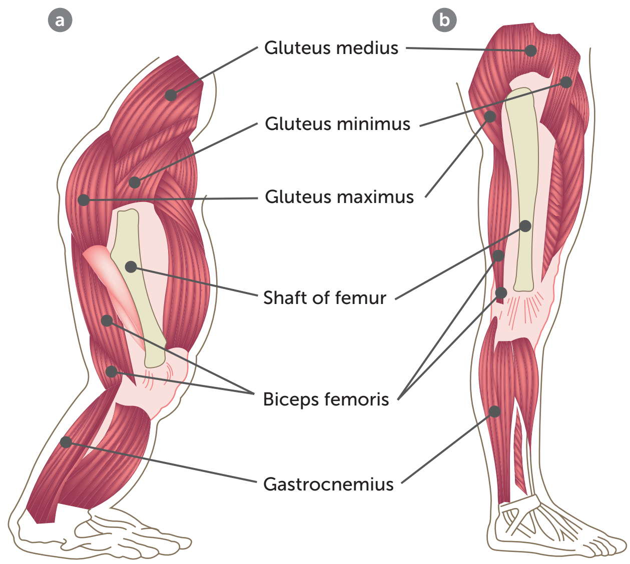


FIGURE 11.16 Musculature of the right leg of **a** a gorilla and **b** a human

Vestigial structures

Vestigial structures are structures that have changed during evolution to the point that they no longer fulfil their origin function. They are common in vertebrate species and form an intriguing aspect of comparative anatomy. Humans may have as many as 90 of these structures. Keep in mind that vestigial structures are largely or entirely functionless when their original role is being considered. However, some may retain lesser functions or develop new ones.

- The **nictitating membrane**, or transparent third eyelid, found in cats, birds, frogs and other vertebrates is able to cover the eye for protection. In humans, it is only represented by a pinkish membrane located at the inner corner of each eye that is unable to cover the eye. Therefore, it cannot fulfil its original function. However, it does have some use in maintaining tear drainage.

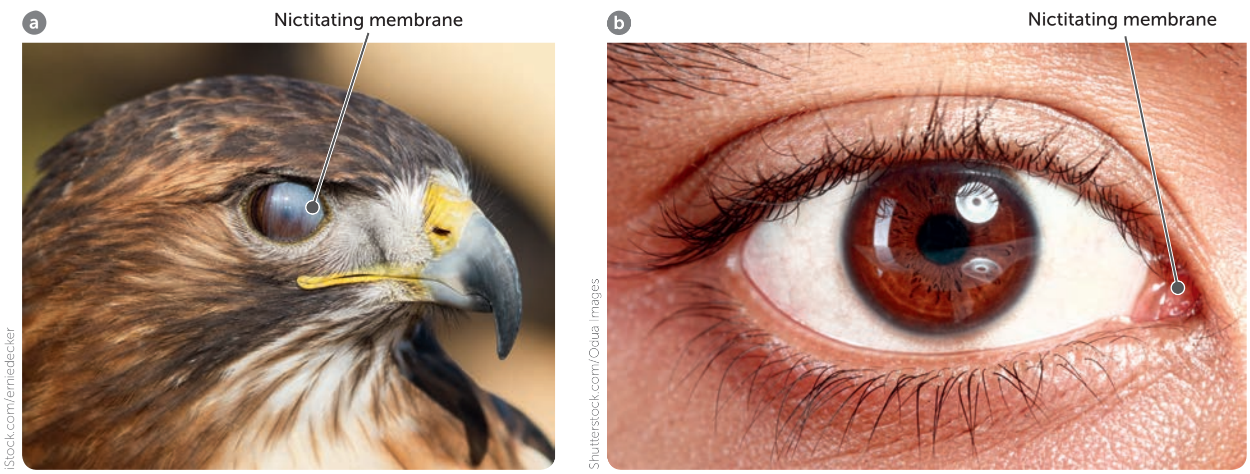


FIGURE 11.17 a The nictitating membrane of falcons protects the eye while diving at high speeds; **b** The nictitating membrane of humans is considered a vestigial structure as it does not fulfil its original function

- The muscles that move the external ears of many mammals are reduced to such an extent in humans that, in most individuals, they will not move the ears at all.

- In most humans the third molars, or wisdom teeth, erupt abnormally and cannot be used in mastication. Frequently, they are removed before eruption so that they do not become painful. About one-fifth of the population are spared any discomfort because the third molars do not develop at all.
- About one-fifth of the population do not develop the muscles that lie above the pubic bone, the pyramidalis muscles. These muscles, if present, do not make any difference to muscular performance.
- Humans still have the vertebrae for a tail, fused to form the coccyx.
- Males have nipples on their chests, although some would argue that these should not be termed vestigial, as they had no function in the first place. They appear to be retained in males because all human foetuses develop from the same basic genetic form, and nipples do have an important function in females.
- The muscles at the base of hairs are considered to be vestigial in humans. In mammals with fur or spines, and in birds with feathers, these tiny muscles pull the hair or feather upright, creating a layer of insulating air to protect against the cold. However, human hair is so fine that it is not capable of such a function and the contraction of the muscles is seen as goose bumps.
- In humans the appendix has commonly been considered a vestigial structure. In herbivorous vertebrates the appendix plays a role in the digestion of tough plant matter. It is thought that it played a similar role in ancient humans, whose diet was more herbivorous. With the change in diets of humans to more easily digested food, the appendix is no longer needed for its original function. Many humans have their appendixes removed following inflammation known as appendicitis. As there does not appear to be any negative effects of the removal, scientists used to think that the appendix does not have any function in present-day humans. However, research is now indicating that the appendix actually has a role in the immune system, and that it produces and stores good gut bacteria. Based on this information, there is now debate about whether the appendix is actually a vestigial structure.

Evolutionary mechanisms can be used to explain the existence of many of these structures that appear to have no function. They are what remain of organs that were functional in ancestral forms. Over time, and with changing environmental conditions, such organs were no longer essential to survival and were gradually reduced to vestigial remnants. As these remnants are not harmful in any way, they have not been completely eliminated. However, natural selection has reduced the organs to non-functional remnants because it would have been a waste of the organism's energy and resources to maintain useless structures. Such organs will probably disappear altogether as there is no selection pressure to retain them.

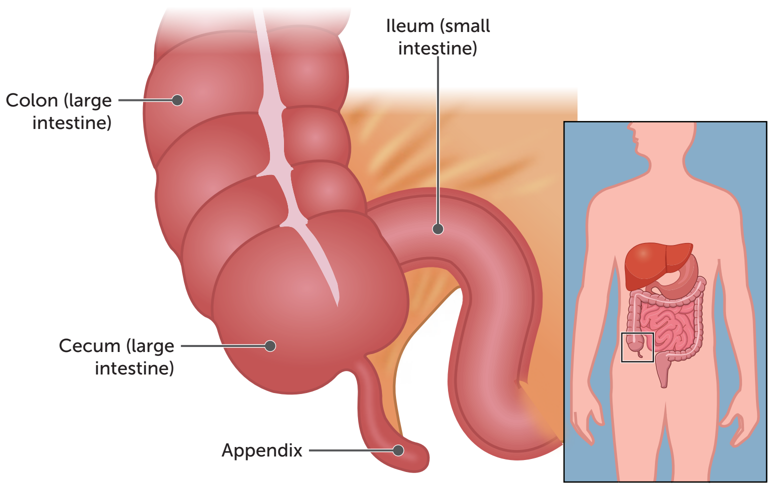


FIGURE 11.18 Location of the appendix

Why do humans have an appendix?
This website has more information about the appendix in humans.

Vestigial organs
This website provides more information about vestigial organs.

7 vestigial features of the human body
This website explains seven vestigial features in humans.

Evidence for evolution
This website provides a good overview of the evidence for evolution.

Key concept

Comparison of the anatomy of embryos, homologous structures and vestigial structures provides evidence for evolution.

WS

11.2 Evidence for evolution

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Questions 11.3

RECALL KNOWLEDGE

1 Define 'homologous structures' and 'vestigial structures'.

2 Describe how comparing the structure of embryos at different stages of development can provide evidence for evolution.

3 Describe how a comparison of homologous structures provides evidence for evolution. Include an example in your explanation.

4 List five vestigial structures of humans.

APPLY KNOWLEDGE

5 Explain the importance of fossils in providing evidence for evolution.

6 Explain how our developing understanding of the functions of the appendix has led some scientists to believe that it is not a vestigial structure.

11.4 PHYLOGENETIC TREES

The techniques described in this and the previous chapter enable scientists to work out the likely evolutionary relationships between groups of organisms. The probable relationships can then be represented as a diagram, called a phylogenetic tree. A **phylogenetic tree**, also called a **dendrogram**, represents the evolutionary relationships between a number of organisms derived from a common ancestor. The ancestral organism forms the base of the tree, and those organisms that have arisen from it are placed on the ends of 'branches'. Relationships between the various organisms are shown by the distance between them on the tree, with closely related groups positioned on 'branches' close to one another. However, keep in mind that these are only inferred relationships; different researchers may come up with different 'trees' to fit their interpretations of the data.

Phylogenetic trees are often used to simplify more complex relationships, in order to enable them to be more easily understood. For example, in Figure 11.19 the tree on the left, labelled 'a', shows a hypothetical ancestral population that has divided to form two separate populations; each of these has divided further to produce four descendant species, A, B, C and D. Notice that the branches are thick and curving to represent the variation that may have existed in the past, and that there are side branches that have died out over the period represented. The tree on the right, labelled 'b', is a simplified representation using thin, straight lines to show the lineages of just the four descendant species A, B, C and D.

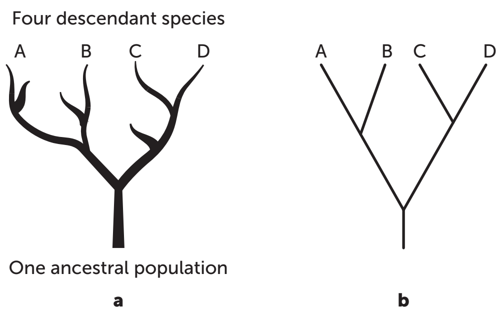


FIGURE 11.19 A simple phylogenetic tree representing one ancestral population and four descendant species

Activity 11.3 Investigating phylogenetic trees

Phylogenetic trees are useful for representing relationships as well as organising knowledge of genetic diversity and structural classifications. They are particularly useful for showing evolutionary pathways and have been used as such since the time of Charles Darwin.

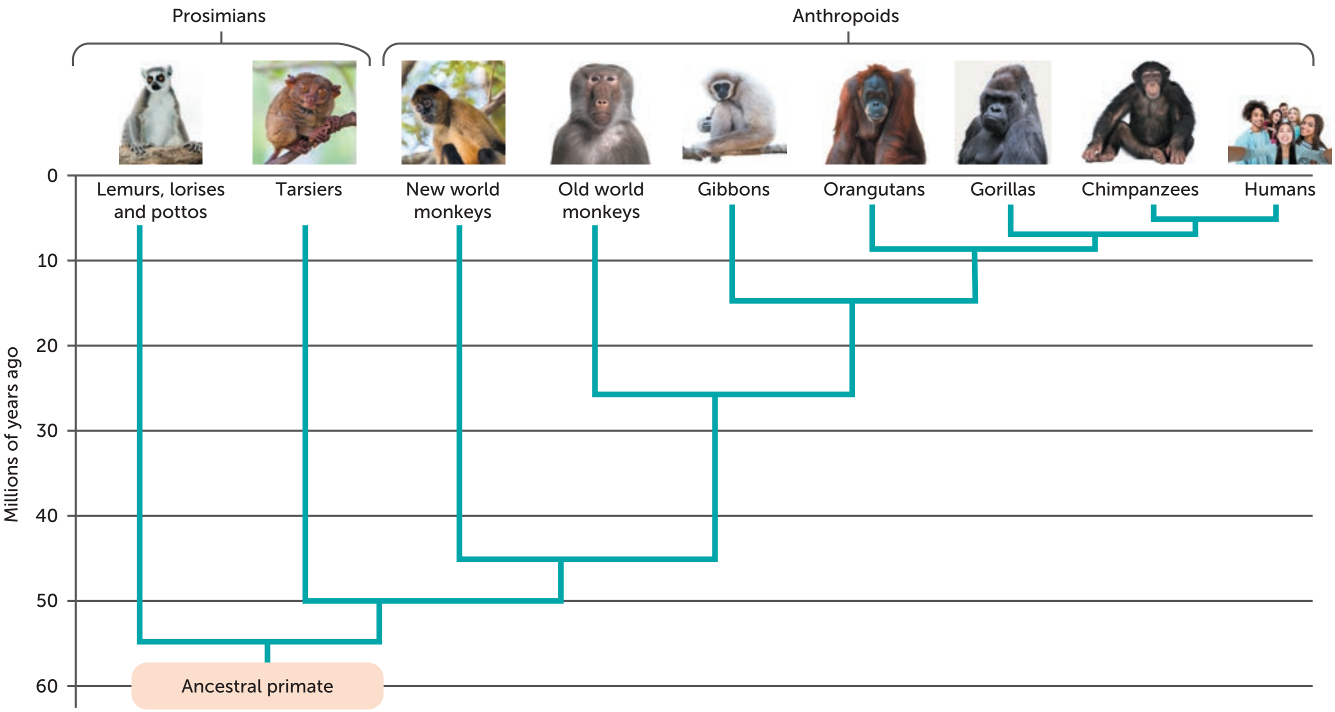


FIGURE 11.20 A phylogenetic tree of primates

Key concept

A phylogenetic tree shows the evolutionary relationship between species, with species with more recent common ancestors diverging further up the tree.

Drawing phylogenetic trees

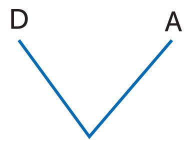
A variety of information can be used to draw phylogenetic trees, including the presence (or absence) of traits and the number of similarities (or differences) in DNA or amino acid sequences. In all cases, species with the greatest similarities are drawn with branches closer together, while those with the most differences are drawn with branches the furthest apart.

We will use data about the number of differences in amino acids in a protein found in five fictional species, named A, B, C, D and E, to draw a phylogenetic tree. This data is shown in Table 11.2.

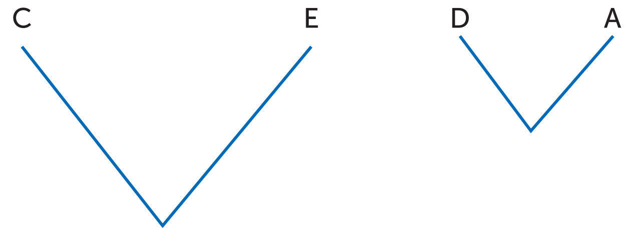
TABLE 11.2 The number of differences in amino acids in a protein in fictional species

	A	B	C	D	E
A		41	26	1	31
B			15	40	20
C				25	5
D					30
E					

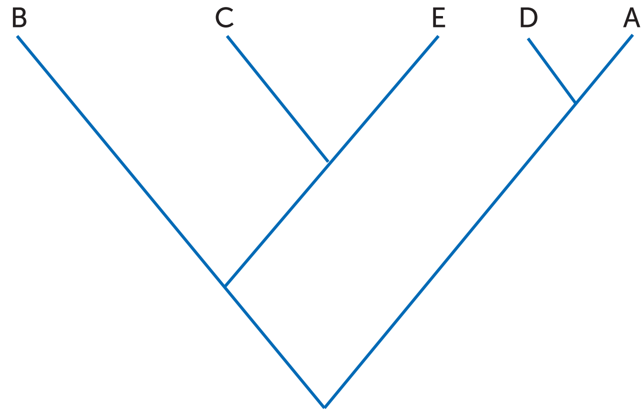
STEP 1: Identify species with the most similarities (A and D). Draw these joined by short branches showing a recent common ancestor.



STEP 2: Identify the species with the next most similarities (C and E). If these are also similar to the species identified in step 1, draw them branching underneath the most recent branch showing the recent common ancestor. If they are not similar to them, join them by branches independent of the others. In this example, C and E are similar to each other, but not A, B or D. Therefore, they are joined independent of the other species. (Note that the branch for C and E is lower than A and D, representing less similarity and, therefore, a more distant common ancestor.)



STEP 3: Identify which of the branches the remaining species is the most similar to. In this example, B has more similarities to C and E than to A and D. Therefore, it has a more recent ancestor with C and E, and so their branches separate higher up than where B branches from A and D.



NOTE: All species that live in the present are drawn level with each other. If the species was extinct the branch would end lower down.

STEP 4: An axis is drawn to show the progress of time, as shown in Figure 11.20.

Questions 11.4

RECALL KNOWLEDGE

1 Define 'phylogenetic tree'.

2 Describe what phylogenetic trees are used for.

APPLY KNOWLEDGE

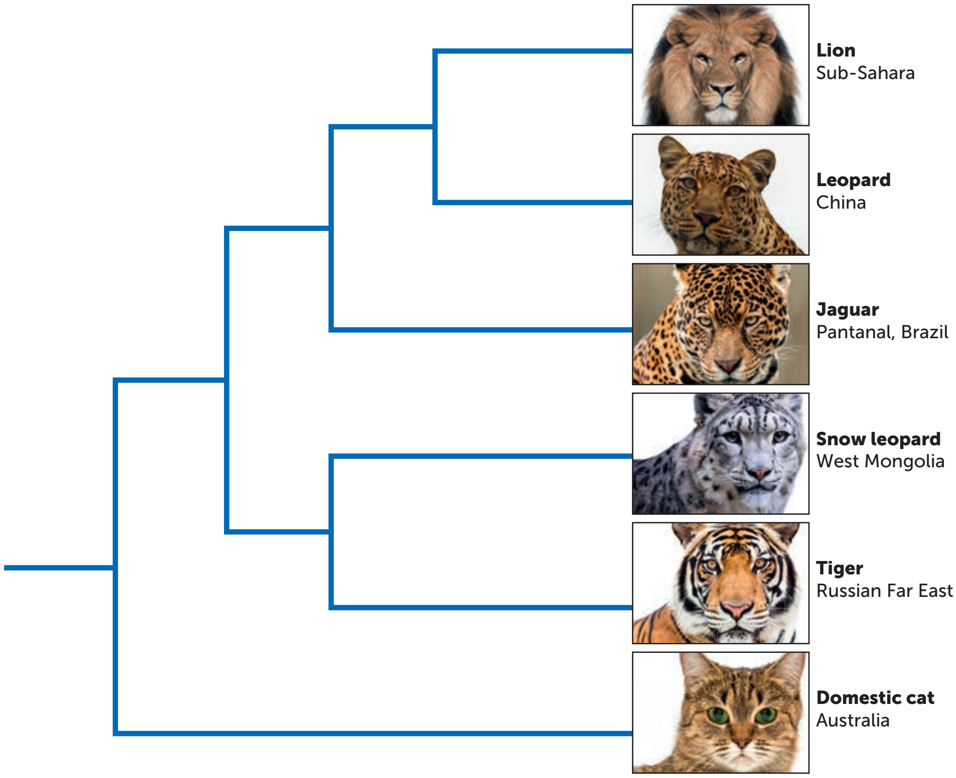
3 Suggest why phylogenetic trees are so named.

4 Consider the phylogenetic tree for cats shown below.

a Which cats have the most recent common ancestor?

b Do tigers or jaguars have a more recent common ancestor with lions?

c Suggest why the domestic cat has more differences than the other cats.



Top to bottom, all Shutterstock.com: Eric Isselee; The inspired Eye; AP Photographie; andamanec; Suwin; Galyna Andrushko

5 Use the fictional values below comparing four species named A, B, C and D to construct a phylogenetic tree.

SPECIES	PERCENTAGE OF DNA IN COMMON
A and B	80
A and C	65
A and D	62
B and C	75
B and D	72
C and D	98

CHAPTER 11 ACTIVITIES

ACTIVITY 11.1 Investigating radioisotope methods of dating

Radioisotopes are the basis of two of the absolute dating techniques described in this chapter. Isotopes are the different forms of atoms of the same elements. Atoms are composed of particles called electrons, protons and neutrons, and the number of electrons and protons determines the type of atom.

Some isotopes are stable, but other isotopes are unstable, meaning they change into atoms of another element. This is known as decay, and causes radioactivity to be emitted. It is for this reason that they are called radioisotopes.

Radioactive isotopes have a half-life, which is the time it takes for half the atoms to decay, forming atoms of another elements. In the first half-life, half the atoms decay. In the second half-life, half the remaining atoms decay, leaving one quarter of the original material. In the third half-life, half again decay, leaving only one eighth of the original material, and so on.

Radioisotope methods of dating assume that the decay rate of a given isotope is constant and has always been so. Only if nuclear decay rates are constant can the method be used to reliably estimate the age.

You will need

Graph paper; pencils; ruler; eraser

A RADIOCARBON DATING

Radiocarbon dating is based on the decay of the radioactive isotope of carbon, carbon-14 (^{14}C), to nitrogen. When this occurs, radioactivity is released. The decay rate of ^{14}C in material from living organisms or from those that have recently died is 15.6 disintegrations per second per gram of material. After one half-life, 5730 years, the number of disintegrations will be 7.8 disintegrations per second per gram of material (abbreviated to nuclei/s/g).

What to do

1 Draw up a table like the one below and fill in all the gaps.

Decay rate of carbon-14

HALF-LIFE	AGE (YEARS)	RADIOACTIVITY (NUCLEI/S/G)
0	0	15.6
1	5730	7.8
2		
3		
4		
5		
6		
7		
8		
9		
10		

2 On your sheet of graph paper, plot a decay curve for carbon-14 to show the relationship between decay rate and time, up to a maximum of 60 000 years.

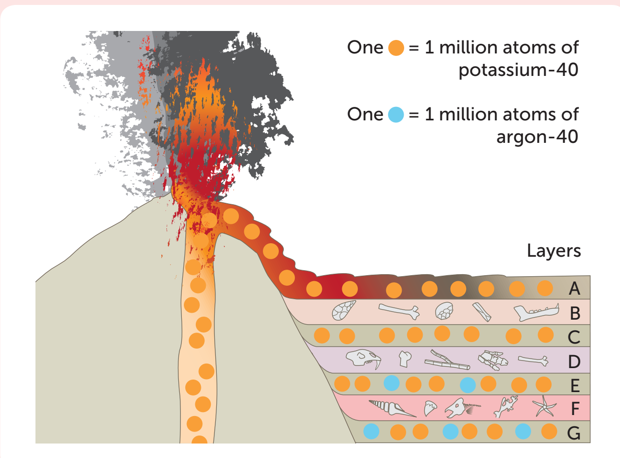
3 Use your graph to answer the following questions.
   a Charcoal remains from a hearth in a cave occupied by Australian Aborigines were found to have a decay rate of 8.9 nuclei/s/g of charcoal. How old was the charcoal?
   b A piece of wood buried in a cave in Europe was found alongside stone tools that were considered to be about 9000 years old. If the wood were the same age as the tools, what decay rate would you expect from the piece of wood?
   c If the piece of wood from question **b** was found to be considerably older than 9000 years, what explanations can you offer for the fact that it was at the same level in the cave deposits as the tools?
   d If the piece of wood was found to be considerably younger than 9000 years, suggest reasons to account for the fact that it was at the same level in the cave deposits as the tools.
   e A fossil bone was discovered and when tested had a decay rate of 1.5 nuclei/s/g. How old was the fossil bone?
   f A piece of fossilised wood was dated using the tree-ring method at 4000 years old. What decay rate would you expect it to display when it was subject to carbon-14 analysis?

B POTASSIUM–ARGON DATING

Potassium–argon dating is based on the decay of radioactive potassium (^{40}K) to form calcium (^{40}Ca) and argon (^{40}Ar). This decay is very slow as potassium-40 has a half-life of around 1300 million years, so the material to be dated must be very old, usually more than 200 000 years. Argon-40 is not normally found in rocks unless it is trapped in solid lava from volcanic eruptions. This occurs when potassium-40 decays. Because the rate at which potassium-40 breaks down into argon-40 is known, it is possible to determine the age of the lava by measuring the ratio of potassium-40 to argon-40.

What to do

Study the following figure carefully, and then answer the questions below. Layers A, C, E and G are lava and contain trapped atoms of potassium-40 and, in most layers, argon-40.



This volcano has erupted periodically for millions of years

1 Explain why there is no argon-40 in layer A.
2 Determine the ratio of potassium-40 to argon-40 in layer E.
3 Rock layers B, D and F are composed of the same material. What type of material do you think this would be? Explain how it has come to be between the alternating layers of lava.
4 Explain why there are no fossils in layers A, C, E and G.

5 Layers B, D and F all contain fossils. For this to have occurred, conditions must have been suitable for fossilisation. Describe the conditions that assist the process of fossilisation.
6 Anthropologists working at this site believe that layer B was formed around 40 000 to 70 000 years ago. This date is too early to use the potassium–argon dating technique. Suggest at least two ways in which they could determine the age of layer B. Explain how each of these methods works.

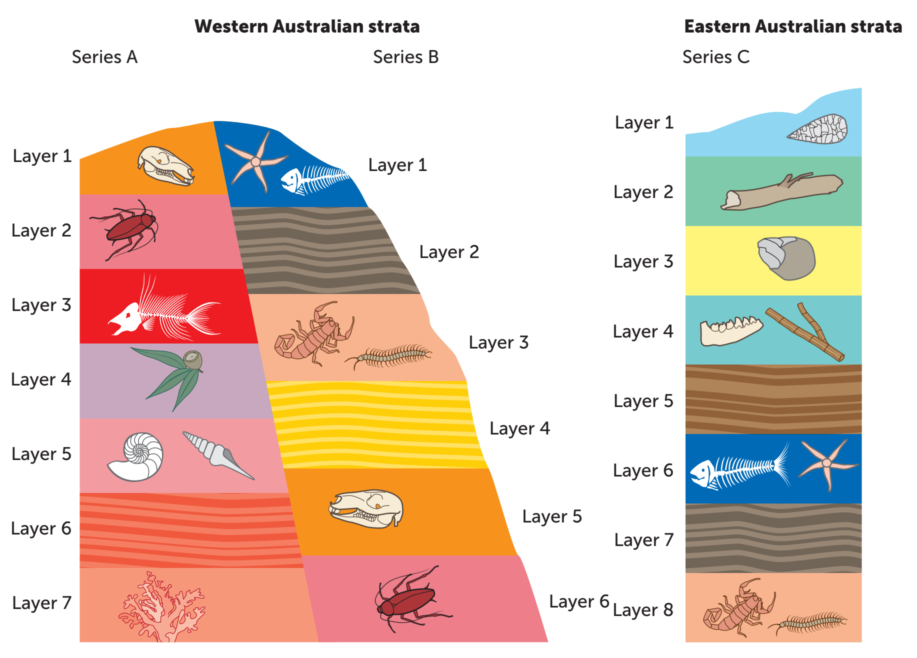
ACTIVITY 11.2 Investigating stratigraphy

Observation of rock strata from various sites around the world has indicated that, in many cases, similar strata contain very similar or identical fossils. In this activity, you will examine three series of hypothetical strata from two locations in Australia. The different strata are shown in three series in the figure below.

What to do

Study the figure carefully and then answer the following questions.

1 How do you think these sediments were formed?
2 The various layers in series A and series B no longer align with each other. Explain how this may have happened.
3 Of all the strata shown in series A, B and C, which is the oldest? Explain how you arrived at your answer.
4 Of all the strata shown, which is the youngest? Explain how you arrived at your answer.
5 Layers A2 and B6, and B1 and C6, contain the same types of fossils. Would these be index fossils? List the criteria that must be met for a fossil to be considered an index fossil.
6 A fossil in layer A4 was dated at 45 000 years using carbon-14 dating. What can you infer about the relative ages of layers B6 and C8?
7 Could layer A6 be dated using the potassium–argon technique? Give reasons for your answer.
8 Do you think dendrochronology could be used to determine an absolute date for layer C2? Give reasons for your answer.



Strata from two locations in Australia

ACTIVITY 11.3 Investigating phylogenetic trees

The increasing number of techniques in biotechnology is providing scientists with a wealth of data that can be used to examine the evolutionary relationships between species. In this activity, you will use some of this data to construct phylogenetic trees.

What to do

1 Refer to Table 10.2 in Chapter 10 (page 280), which shows the relationship between humans and great apes using DNA differences. Using this information, construct a phylogenetic tree to show diagrammatically the evolutionary relationships.
2 Refer to Table 10.4 in Chapter 10 (page 283). This table shows the differences in amino acids in cytochrome C between humans and a number of other species. The more similarity there is between two molecules, the more recently they have evolved from a common ancestor. Using this information, construct a phylogenetic tree to show the evolutionary relationships between the species listed.
3 Refer to Table 10.5 in Chapter 10 (page 285), which shows the amino acid sequences in the haemoglobin of five mammalian species. Using the data presented in the table, construct a phylogenetic tree to show the evolutionary relationships between the species shown.

Studying your data

Compare the trees you have constructed with those of other members of the class and then answer the following questions.

1 How much variation was there among the phylogenetic trees constructed by different class members? Explain any similarities and differences with the ones you have created.
2 In the three trees you have drawn, does one animal appear to be more closely related to humans?
3 In which of the three trees do you have the most confidence as a good representation of evolutionary relationships? Why did you select this tree?
4 When a phylogenetic tree is constructed, it can be considered a way of presenting a hypothesis. Explain why.

Drawing phylogenetic trees
These websites look at how to draw phylogenetic trees.

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CHAPTER 11 SUMMARY

- Fossils are preserved traces left by organisms that lived a long time ago. They may be bones, shells, teeth, faeces, artefacts or impressions. Fossils give us evidence for evolution.
- Fossils form when parts of organisms become buried quickly in conditions that prevent their decomposition. Therefore, fossils are found in soils near lakes, rivers, caves or volcanoes that are alkaline and low in oxygen.
- Absolute dating gives an actual age of a fossil specimen, while relative dating compares the age of different specimens.
- Potassium–argon dating uses the decay of potassium-40 to form argon-40 and calcium-40. As the decay occurs at a constant rate, the proportion of postassium-40 and argon-40 in a rock allows the age of the specimen to be determined. This method is used for rocks that are older than 200 000 years. Fossils can be dated by the age of nearby rocks.
- Carbon-14 is an absolute dating method that uses the decay of carbon-14 to form nitrogen. When organisms die, the carbon-14 that decays is not replaced as it is in living organisms. Therefore, the ratio of carbon-14 to carbon-12 can be used to calculate the age of the sample. This is useful for samples from living things that are less than about 60 000 years old.
- Stratigraphy is used in relative dating. The principle of superposition states that the layers, or strata, of sedimentary rock on top are younger than those beneath.
- Index fossils, such as some pollen grain fossils, are those that were only present on Earth for a limited time. Therefore, their presence in strata from different areas indicates that the rock in both areas is the same age.
- The fossil record is incomplete, as fossilisation does not always occur; therefore, it is a chance occurrence. It is also difficult to find fossils, as they are buried. Those that are found may be hard to age and may be only part of an organism.
- Fossils and observations of living species allow the anatomy to be compared, providing evidence for evolution by identifying the changes that have occurred.
- Embryological comparisons indicate common ancestors of vertebrates through the presence of slits and arches, a tail, a two-chambered heart and similar brain development.
- Homologous structures – for example, the forelimb bones of vertebrates – have similar structures despite different functions and indicate a common ancestor.
- Vestigial structures have changed during evolution and no longer fulfil the same function. The changes can be used to indicate the degree of separation from common ancestors. Examples in humans are the nictitating membrane, muscles of the ears, wisdom teeth, tails, nipples on males, and muscles at the base of hairs.
- The appendix in humans is often considered a vestigial organ. However, it is now thought that the appendix plays an important role by storing beneficial bacteria and contributing to the immune system.
- Phylogenetic trees, or dendrograms, are used to represent the evolutionary relationships between species. Branches are used to indicate species that have a common ancestor. The closer the branching, the more recent the common ancestor.

CHAPTER 11 GLOSSARY

Absolute date The actual age (in years) of a fossil or artefact

Accelerator mass spectrometry (AMS) radiocarbon dating A technique used to give radiocarbon dates for very small samples of material

Artefact An object made or modified by humans

Carbon-14 The radioactive isotope of carbon

Correlation of rock strata The process of matching rock strata from different places

Dating Determining the age of excavated artefacts or fossils

Dendrogram *see* phylogenetic tree

Embryology The study of the early development of an organism; in humans, from fertilisation to the end of the eighth week of pregnancy

Fossil Evidence of, or remains of, an organism that lived long ago

Half-life The time required for half of any quantity of radioactive material to decay into stable non-radioactive material

Homologous structure Structures with a similar structure but not necessarily a similar function

Index fossil Fossils or organisms that were on Earth for only a short period of time and are therefore useful in the relative dating of rock strata

Isotope One of two or more atoms of the same element with the same atomic number and number of protons, but different numbers of neutrons

Nictitating membrane A transparent fold of skin (third eyelid) that protects the eyes of birds and reptiles; in humans, it occurs as a vestigial organ in the corner of the eye

Organic compound A compound made up of large molecules that contain carbon

Phylogenetic tree A diagram showing evolutionary relationships between related organisms; also called a dendrogram

Potassium–argon dating A method of calculating the age of a fossil or artefact using the known rate of decay of radioactive potassium

Principle of superposition In a vertical sequence, the principle that the sedimentary rock layers on top will be younger than those lower down

Radiocarbon dating The calculation of the age of a fossil or artefact using the known rate of decay of radioactive carbon

Relative date The age of a fossil or artefact relative to another fossil or artefact (i.e. whether older or younger)

Stratigraphy The study of the sequence of rock layers as a means of relative dating

Vestigial structure A structure of reduced size that appears to have no function; for example, the ear muscles of humans

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CHAPTER 11 REVIEW QUESTIONS

Recall

1 a Define 'fossil'.
  b Give examples of five different forms of fossils.
2 a Explain the difference between a fossil and an artefact.
  b What is an index fossil? Could there be such things as index artefacts?
3 a What soil types are best for the preservation of fossils?
  b Why is it that fossilised soft tissue, such as muscle, is rarely found by those searching for fossils?
4 a What do you understand by the terms 'relative dating' and 'absolute dating'?
  b Why is relative dating used when a number of good methods of absolute dating are available?
5 Draw up a table with three columns, listing in the first column the methods of absolute and relative dating described in this chapter. In the second and third columns, list the advantages and limitations of each method.
6 a What is the principle of superposition?
  b Does this principle always apply? If not, explain why.
7 What are phylogenetic trees and why are they used?
8 a What are homologous structures?
  b Using an example, describe how homologous structures provide evidence for evolution.
9 a What is a vestigial organ? Describe four human vestigial organs.
  b Describe the significance of vestigial organs to the theory of evolution.

Explain

10 Explain the principle behind radioisotope methods of dating.
11 Describe why potassium–argon dating cannot be used to date fossil bones.
12 a How is it that the bodies of plants and animals have radioactive carbon-14 in them?
  b What does it mean to say that carbon-14 has a half-life of 5730 years?
  c Why is it not possible to use radioactive carbon dating on artefacts?
  d What is AMS radiocarbon dating?
13 a Explain how index fossils can be used to compare strata from different locations.
  b Describe the different ways in which fossil pollen grains can be of use to the anthropologist.
14 How does a study of embryology assist in supporting the theory of evolution? Give examples to illustrate your answer.

Apply

15 Anthropologists excavating the floor of a cave found, at a depth of 50 centimetres, a deposit of charcoal that they concluded was the site of an ancient hearth. Next to the hearth, at the same depth, was a stone tool. Radiocarbon analysis of the charcoal showed that the ratio of carbon-14 to carbon-12 was 0.25 in 10^{12}. Further excavation uncovered, at a depth of 95 centimetres, a fragment of human jaw bone and the thigh bone of another animal.

a What would be the estimated absolute age of the stone tool?
b What evidence would suggest that the jaw bone and thigh bones were the same age?
c Further testing showed that the thigh bone was younger than the jaw bone. How could this be possible?

16 The sand dunes around the Australian coast consist of alkaline soil. If an animal were buried in the dunes by drifting sand, would its bones become fossilised, provided they were left undisturbed for long enough? Explain the reasons for your answer.

17 In the peat bogs of England, Denmark and other parts of northern Europe, human bodies up to 4000 years old have been found. The hair, skin and other soft tissues have been so well preserved that the fingerprints can still be seen on the skin of the hand, and food in the alimentary canal is complete enough to indicate the nature of the last meal eaten.
a Describe the types of conditions that must be present in peat bogs to allow preservation of these tissues for such a long period of time.
b Would you expect the skeletons of these 'bog people' to be preserved? Why, or why not?

18 Riversleigh, in north-west Queensland, is one of the world's most important and abundant fossil sites. Fossils found at Riversleigh include kangaroos, wombats, bandicoots, possums, koalas, platypuses, crocodiles, snakes, turtles, lungfish, birds, frogs, snails and insects.
a From this list of some of the fossils found at Riversleigh, write a description of what the area must have been like when the fossil animals were alive.
b What conditions must have occurred at Riversleigh for so many organisms to have been fossilised?

19 Homologous organs are so called because they have a similar structure. However, the basic structure may be modified substantially to carry out a different function. Describe the changes that have taken place to the vertebrate forelimb for it to become:
a a flipper
b a wing
c an arm.

Extend

20 In this chapter, the forelimb was used as an example of homologous structures. What other structures found in vertebrates could be used to illustrate homology?

21 In 1893 a German anatomist, Robert Weidersheim, compiled a list of 86 vestigial organs. On his list were the valves in veins, the tonsils, the pituitary gland and the thymus. Why must scientists be very careful about describing an organ as vestigial?

22 More than 135 years ago, Charles Darwin predicted that fossils of the ancestors of modern humans would be found in Africa. Suggest what evidence Darwin would have used as the basis for making that suggestion.

23 New techniques in establishing an absolute age for a fossil or artefact have been developed in recent years. Three of these are uranium–thorium dating, electron spin resonance and thermoluminescence. Find out:
a the principle on which these techniques are based
b the uses to which the techniques have been put
c limitations to the use of these techniques.