2.3 Geological time scale

Dinosaurs, diprotodons and mammoths have come and gone. They are extinct, never to live on Earth again. Over 4.5 billion years, many fascinating organisms have lived on Earth. The fossil record of these organisms can be used to construct a likely time scale that tracks the history of life on our planet. New fossils are constantly being found that require adjustments to be made to this time scale.

Creating a time scale

Palaeontologists have constructed a time scale showing the sequence in which all the different fossil species are found in strata throughout the world. This time scale of past life and geology is called the **geological time scale**. By constructing it, scientists have tracked the history of life on Earth.

The geological time scale was constructed by combining relative and absolute dates.

- **Relative dates**: Stratigraphy and the index fossils of many different plants and animals (including the trilobites) were used to first construct a continuous sequence of rock strata back into the past. The particular time span covered by each set of index fossils was referred to as a geological period. Each period was given a name that referred to the place where that group of fossils was originally discovered.
- **Absolute dates:** the development of techniques such as radioactive carbon dating allowed palaeontologists for the first time to calculate the actual age of each index fossil and the rocks they were found in. These dates were added to the sequence of geological periods. The periods were further organised into sets based on major events such as dramatic changes in climate, which tied them together. The sets were referred to as eons, eras and periods.

The combined information from both dating methods became the geological time scale. You can see a simplified version of it in Figure 2.3.1. The scale starts at the bottom, which represents the formation of planet Earth itself 4.5 billion years ago.

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The Jurassic

The name Jurassic refers to the Jura mountains in Europe, where the fossils of the period were first named and described.

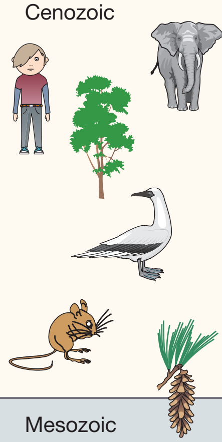
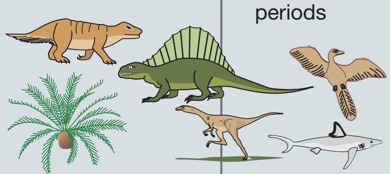
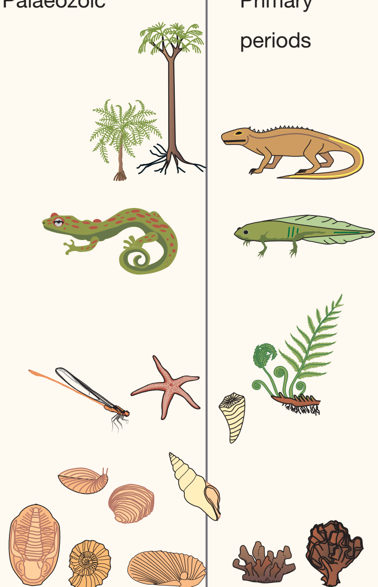
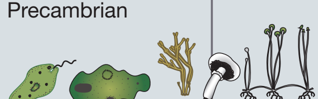
Cenozoic 	Quaternary periods	Holocene (current)	Some mammals disappear. Modern humans. Warmer climate	0.015
		Pleistocene	Ice ages. Large mammals. Primitive humans	2
	Tertiary periods	Pliocene Miocene Oligocene Eocene Paleocene	Life as we know it develops—birds and mammals increase Huge reptiles disappear Flowering trees and shrubs replace giant ferns and mosses Dinosaurs become extinct	5 23 36 53 65
Mesozoic 	Secondary periods	Cretaceous	Flowering plants	145–65
		Jurassic	Reptiles dominate—dinosaurs. First birds and mammals. Widespread lowlands	200–145
		Triassic	Vertebrates replace invertebrates Reptiles increase in number	251–200
Palaeozoic 	Primary periods	Permian	Many plants and ferns Dinosaurs evolve	299–251
		Carboniferous	Tropical coal swamps formed Giant insects dominate First reptiles	359–299
		Devonian	Vertebrates colonise the land. First insects Development of amphibians Land supports large tree plants	416–359
		Silurian	Primitive animal life First land plants	443–416
		Ordovician	Sea invertebrates (starfish, coral) Primitive fish	488–443
		Cambrian	First abundant fossils—trilobites, molluscs, sponges	542–488
Precambrian 		Many periods here	630 mya Ediacaran fauna—worms and jellyfish	2500–542
			Life develops: stromatolites and blue-green bacteria	3600–2500
			Formation of crust. No life	4500–3600

Figure 2.3.1 The geological time scale is divided into eras and periods based on the types of fossils found.

The earliest organisms

The geological time scale shows that there was a time in the Earth's history for which there are no fossils. This may be partly due to the difficulty of fossilising tiny, delicate creatures but it is more likely that it indicates that no life existed at all at that time.

Despite a lack of fossil evidence, palaeontologists have concluded that the very first forms of life on Earth would have been single-celled organisms like bacteria.

All the oldest fossils found have been from the oceans, leading scientists to believe that life began there. The most ancient organisms for which there are fossil records were a type of bacteria called cyanobacteria (blue-green bacteria). They lived in the shallow waters of early seas, where they appear to have formed structures called **stromatolites**. These are circular rocky structures which grow as columns. Some are shown in Figure 2.3.2. These structures are found mainly in Western Australia, the most ancient preserved ones coming from the Kimberley region. Scientists have found living structures similar to stromatolites in several places in Western Australia at Shark Bay, Bunbury and Lancelin. These 'living relatives' have helped palaeontologists understand how the early stromatolites may have formed. These significant locations are recognised as world heritage sites.

Figure 2.3.2 Living stromatolites at Shark Bay. Stromatolites are some of the most primitive life forms ever to exist on Earth.

One study in 2006 claimed that the fossil stromatolites from the Kimberley are the most ancient life form discovered so far. The rocks are over 3400 million years old. You can see a cutaway section of a stromatolite in Figure 2.3.3. Palaeontologists have concluded that the black carbon layers are carbon film fossils of the bacteria that formed the layers.

The next major event on the geological time scale is the Ediacaran, followed by the appearance of the more complex Cambrian life forms such as the Burgess Shale communities. The Cambrian period and Burgess Shale were discussed in Unit 2.2.

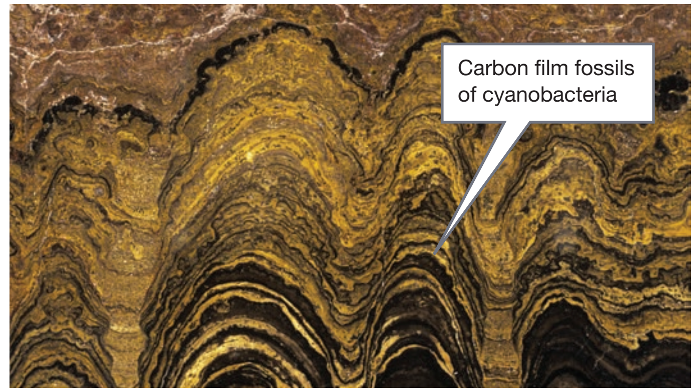


Figure 2.3.3 A cutaway section through a stromatolite

Vertebrate fossil history

Vertebrates are animals with a bony inner skeleton and include fish, amphibians, reptiles, birds and mammals. The earliest known vertebrate ancestors are primitive fish from the Cambrian era dated at about 525 million years. These were found at the Chengjian fossil site in China.

1 p64

Moving from water to land

The first land plants such as *Cooksonia* appeared in the fossil record in the Silurian period, about 416 million years ago. This was an extremely important event because it allowed life to spread from the sea to the land. The fossil record shows that animals such as insects and vertebrates followed soon after these first land plants.

Many fish belonging to a group called the **lobe-finned fish** have been discovered from the Devonian period about 400 million years ago. *Tiktaalik* is one example. Lobe-finned fish had bones in their fins similar to land animals. One example is *Eusthenopteron*, (shown in Figure 2.3.4). The current view is that some of these fish may have been able to pull themselves up onto land with their fins at least for a brief time. These fish probably had a lung, much like the modern-day **lungfish**. They are likely to have lived in shallow water in estuaries or rivers. Palaeontologists are fairly sure that the lobe-finned fish are the ancestors of the group of life forms that finally made the move to land.

SciFile

Coelacanths and lungfish

Not all lobe-finned fish lived in the shallows of rivers or estuaries. Two different species of lobe-finned fish of the group called **coelacanths** exist today. One lives in undersea caves off the Comoro Islands off Africa and the other is from Indonesia. This indicates that not all the lobe-finned fish moved onto the land. Lungfish are also lobe-finned fish and there are some species alive today. One species lives in the Mary River in Queensland.

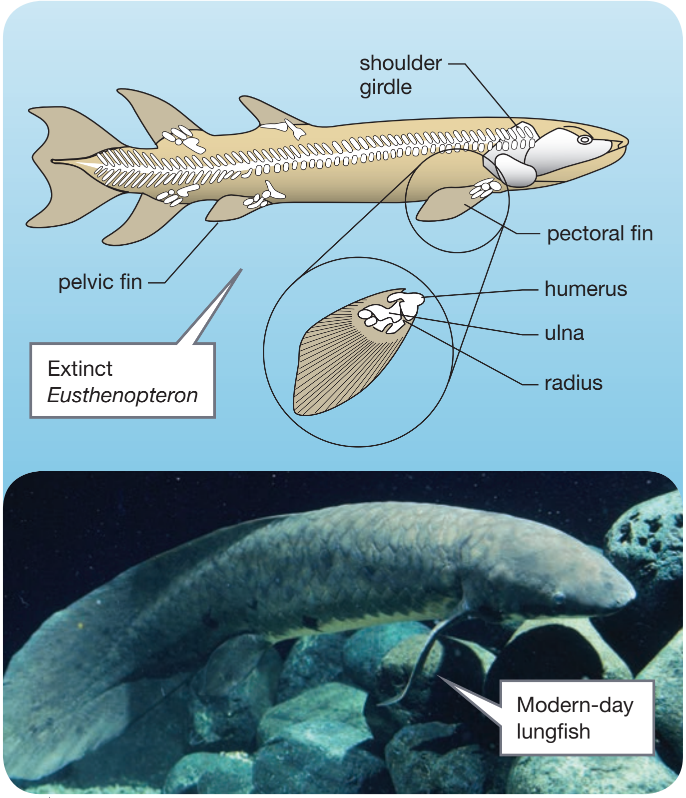


Figure 2.3.4 An extinct lobe-finned fish called *Eusthenopteron*. Lobe-finned fish are important because some of them probably represent ancestors of organisms such as lungfish.

Land vertebrates

The first land vertebrates in the fossil record were amphibian ancestors something like ***Ichthyostega*** shown in Figure 2.3.5. These early amphibians were the first of the group called **tetrapods** (meaning they have four limbs). Living tetrapods are now are classified as amphibians, reptiles, birds and mammals. Palaeontologists are searching for more fossils to fill in gaps in the fossil record to increase their understanding of how the change from land to water may have occurred.

2.4

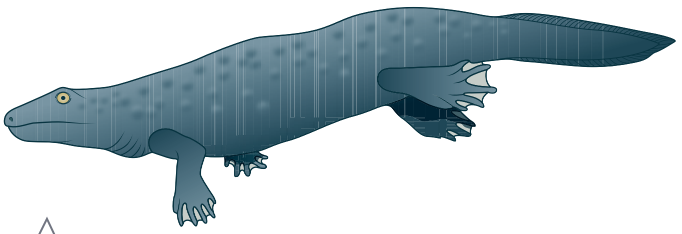


Figure 2.3.5 Ichthyostega was an early amphibian-like animal.

The fossil record shows reptiles appearing after the amphibians at around 315 million years ago in the Carboniferous period. The reptiles became the dominant animal group in the fossil record through the Triassic, Jurassic and Cretaceous periods of the Mesozoic era. This is when dinosaurs (Figure 2.3.6) appear and they were the dominant animal group from about 250 million years ago until about 65 million years ago.

Figure 2.3.6 Dinosaurs dominated the Earth in the Mesozoic era.

Birds

Bird-like animals appear in the Jurassic period around 200 million years ago. The oldest true birds date from about 110 million years ago. Birds shared many features with a small group of dinosaurs called **theropods**. These similarities have led most scientists to believe that birds probably developed from the dinosaurs. There are several different early bird-like creatures, which are like dinosaurs with feathers.

One early example was ***Archaeopteryx*** (which means 'ancient wing'), an amazing organism known from eleven fossils found in Germany. As Figure 2.3.7 shows, *Archaeopteryx* had feathers and a wishbone in the chest. Both these features are important for flight in modern birds.

Figure 2.3.7 This *Archaeopteryx* fossil shows the imprint of feathers.

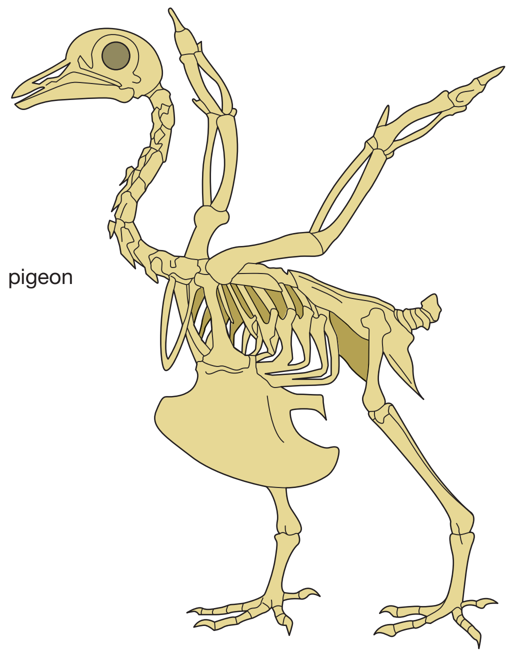
Figure 2.3.8 shows how similar *Archaeopteryx* was to a modern bird. However, *Archaeopteryx* had teeth, a long tail of bones and fingers at the tip of its front limbs. So this creature had features of both reptiles and birds. It probably could not fly as a modern bird can. *Archaeopteryx* is currently classified as the oldest known bird.

There are many more ancient bird fossils being found in China. These are much more like modern birds than *Archaeopteryx*, and yet they also clearly have some dinosaur-like features as well.

The earliest mammal-like fossils appeared in the Triassic period 190 million years ago. ***Hadrocodium*** is the oldest true mammal yet discovered. It is closely related to living mammals.

Humans

Humans belong to the order of mammals called **primates**. Other members of this group are apes, monkeys and gibbons. The oldest known primate fossils date to about 60 million years ago. The earliest members of the human sub-tribe date to about 4 million years ago from Africa. These are ape-like creatures called *Australopithecines* (which means 'southern ape'). There are many other similar creatures found in the fossil record from around this time, one of which may well be our ancestor. The oldest known fossils of our species, *Homo sapiens*, date to over 130 000 years ago in Africa. Figure 2.3.9 compares the skulls of some primates.



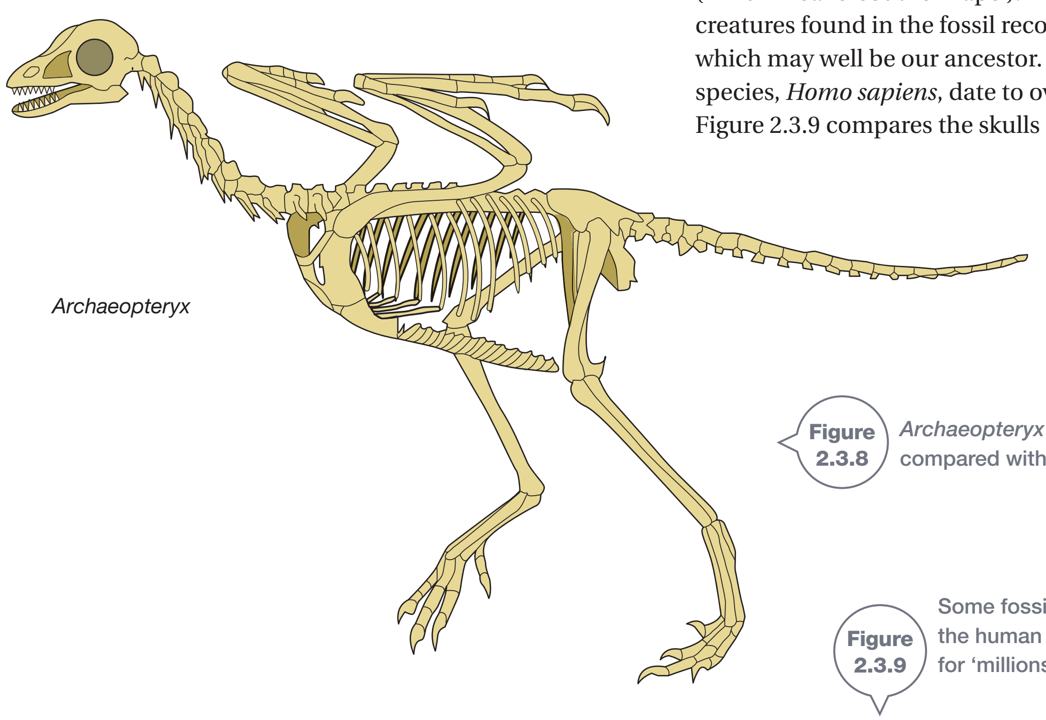
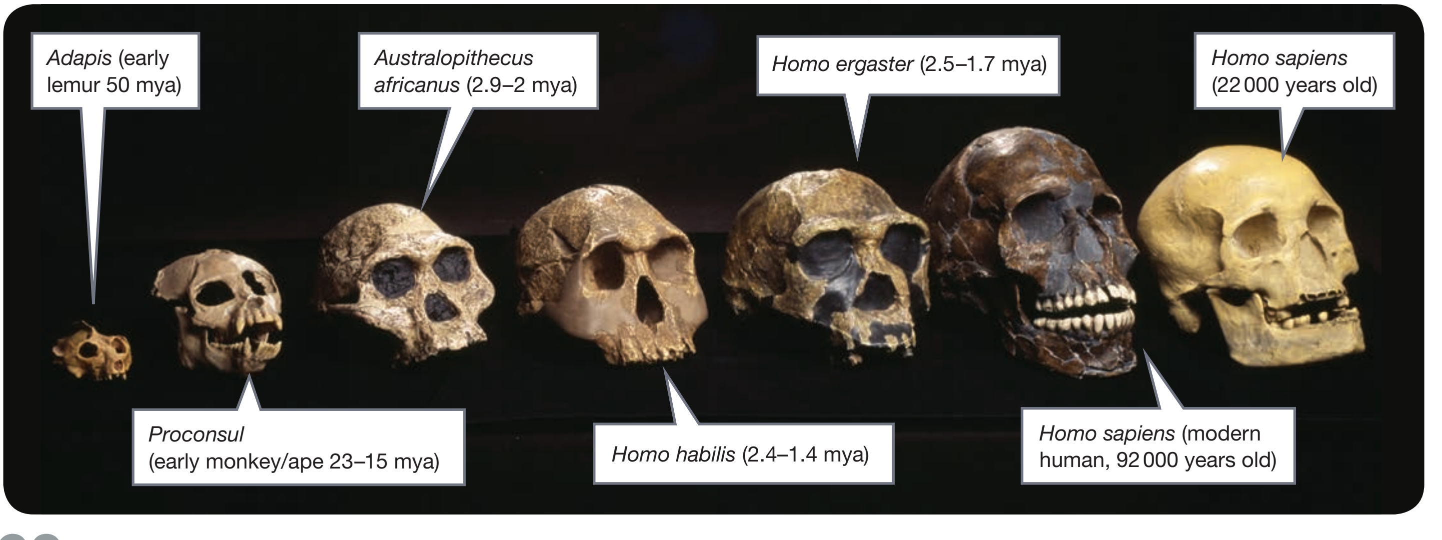


Figure 2.3.8 *Archaeopteryx* skeleton compared with a modern bird

Figure 2.3.9 Some fossil primate skulls, including members of the human family. The abbreviation mya stands for 'millions of years ago'.



TV shows often reconstruct what dinosaurs might have looked like.

Figure 2.3.10

SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Reconstructing dinosaurs

Palaeontologists use evidence to reconstruct the appearance of organisms. TV documentaries often show how dinosaurs moved, what they ate, how they raised their young, who ate who and if they were 'warm blooded' or not. Some critics suggest that these representations are just made up. However, there is evidence to support much of what is portrayed about dinosaurs.

Appearance

The techniques used to reconstruct a dinosaur are similar to those used in forensic science. The dinosaur's appearance can be predicted from its skeletal structure.

One problem in reconstruction is missing bones. This can sometimes be overcome if there is a similar bone on the other side of a skeleton. For example, a missing legbone such as a femur can be copied from the other leg. Another technique is to study living species that are related to the specimen and use their bones as a guide. Anatomists can relate bone size to body mass using well-known research data. For example, bones become larger and stronger as body size increases.

When as much as possible of the skeleton is present, it is arranged in a posture suggested by the bones. Then the bones are carefully studied for marks left by muscle attachment. This can indicate how large the muscles were and where they were positioned. This is shown in Figure 2.3.11. The muscle bulk of living relatives can also be used as a guide.

Skin is then placed on the muscle masses and a texture and colour pattern given to it, or the fur or feathers that covered it are reproduced. That is done by studying the colour patterns of the nearest living relatives. The skin covering is known for some dinosaurs. A few dinosaurs had feathers, and some were slightly furry. Fossil moulds indicate that some dinosaurs had leathery skin.

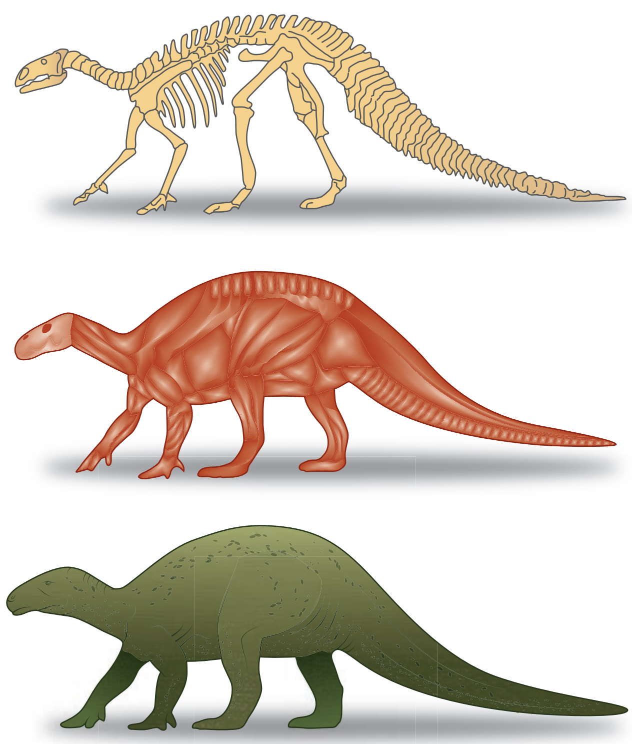


Figure 2.3.11 Constructing dinosaurs using clues from the skeleton to work out muscle size and position

ENDEAVOUR

Figure 2.3.12 This dinosaur baby had just hatched out of the egg when it died and was fossilised.

Reproduction

Dinosaurs laid eggs. Scientists know this because many eggs and nests have been found. Intact eggs can be studied with X-rays. There are some examples of eggs just hatching. You can see one in Figure 2.3.12. Some fossils even show parents guarding nests.

Movement

Estimates of how fast dinosaurs could move are based partly on their fossilised footprints (Figure 2.3.13). They are also based on computer simulations. By measuring the distance between footprints and comparing this with body size, scientists can estimate the dinosaur's running speed.

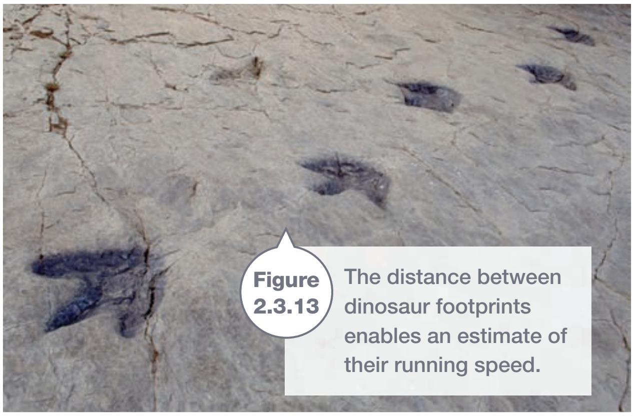


Figure 2.3.13 The distance between dinosaur footprints enables an estimate of their running speed.

Body temperature

There is disagreement on whether dinosaurs were able to control their body temperature like mammals and birds can. Some dinosaurs (most likely the small, fast-moving ones or large predators) may have been warm blooded. Fossilised bone structure is inconclusive at present, although the bone does look more like warm-blooded birds and mammals than reptiles. More research needs to be done in this area before we will know for certain.

Social behaviour

Dinosaur tracks are a good guide that many dinosaurs lived in groups. There are some very good fossil sites that show a herd of dinosaurs' footprints.

Diet

Teeth are a good guide to diet. Carnivores have many sharp teeth, whereas herbivores generally have flatter teeth to grind plant material. So scientists are fairly sure what type of food each dinosaur ate. Another guide to diet is the fossilised dung of dinosaurs, which is known as coprolites. These showed that herbivorous dinosaurs mainly ate plants called gymnosperms. The carnivorous dinosaurs often ate each other, according to fossil sites showing dinosaurs that died in a battle with each other.

2.6 2.7

2.3 Unit review

Remembering

1 **State** the term that means 'the time scale of life and geology in the past'.

2 **State** what geological eras are divided into.

3 **State** two possible reasons why the early part of the geological time scale does not show any living organisms.

4 **List** the sequence and time of appearance in the fossil record for the current classes of vertebrates.

Understanding

5 **Explain** how the geological time scale was constructed

6 **Define** the term *stromatolite*.

7 **Explain** why stromatolites are important in the history of life

8 **Explain** why lobe-finned fish are important in the history of life.

9 **Explain** why scientists think some dinosaurs and birds are related.

Applying

10 *Archaeopteryx* would not be a useful index fossil. **Demonstrate** why.

Analysing

11 **Use** Figure 2.3.8 on page 60 to **compare** the skeletons of *Archaeopteryx* and modern birds, listing their similarities and differences.

Evaluating

12 **Propose** why plants would need to spread to the land first before animals could live on land.

13 Some major differences between amphibians and reptiles are their method of respiration, how the young are born and what the body is covered with.

Amphibians are thought to be the ancestors of reptiles. **Use** the table below to **propose** why reptiles were successful in moving into a wide range of habitats on land.

Feature	Amphibian	Reptile
Respiration	Live in water as young and breathe by gills. Develop lungs as adults and breathe air	Live on land and breathe by lungs
How young are born	Eggs with thin membrane easily dehydrated. Laid in water and hatch into water	Eggs with waterproof flexible membrane. Hatch in air
Body covering	Thin moist skin	Thick leathery scaly waterproof skin

Creating

14 **Construct** a notice to be posted at the Shark Bay stromatolite site detailing reasons why tourists should protect the area.

15 In a group, **construct** a timeline for geological time on A3 paper or butcher's paper. Use a scale of 1 mm to 1 million years. Make the paper at least A4 width (about 30 cm) and at least 9 A3 pages long (about 3.7 metres). On your timeline add the names of the geological eras and periods. Write the major fossil groups for each era or period and highlight important events such as life on land. Add diagrams or drawings of some of the major fossils.

Inquiring

1 Research the living coelacanths and lungfish and explain why they are so important.

2 Research the latest finds of fossil birds and bird-like dinosaurs in China, describing the fossils and what they tell us about the origin of birds.

3 Research the primitive fish from the Cambrian era dated at about 525 million years ago, which have been found at the Chinese fossil site called Chengjian. Explain why they are considered important fossils.

4 Research three theories about the extinction of the dinosaurs. Rate which one you think is most likely to be true.

5 Imagine you found some moulds of footprints of a bipedal dinosaur in mudstone. They are about the size of a human footprint. The tracks go for 50 metres. Design a method you could use to determine its speed. Check your method with your teacher and run your experiment if you get their approval.

2.3 Practical activities

1 Vertebrate skeletons

Purpose

To compare different vertebrate skeletons.

Materials

- skeletons of human, cat, bird, frog, bony fish and lizard
- If actual skeletons are not available, then there are excellent images on the internet.

Procedure

1. Copy Tables 1 and 2 shown in the Results section into your notes.
2. Carefully observe each specimen and complete Table 1 by placing a tick in the table if the feature is present.
3. Use Table 1 to complete Table 2 in your notes. You can observe the animals again if necessary. Record the animals that are most alike and least alike for each of the features.

Results

Table 1 Vertebrate skeletons

Animal	Skull	Vertebral column	Ribs	Front limbs	Rear limbs	Front limb girdle	Rear limb girdle
Human							
Cat							
Bird							
Frog							
Bony fish							
Lizard							

Table 2 Comparing vertebrate skeletons

Feature	Most alike	Least alike
Skull		
Vertebral column		
Ribs		
Front limbs		
Rear limbs		
Front limb girdle		
Rear limb girdle		

Discussion

1. Using Table 2, **deduce** which two animal skeletons seem to be most alike, and which two are least alike.
2. Fish live in the ocean and the rest of these animals live on land. Look very carefully again at the specimens and note how the fins and limbs are attached to the rest of the skeleton. **Propose** how the large differences in these parts of the skeletons are related to the environment in which these creatures live.
3. Most of these animals have remarkably similar skeletons. They have many bones that are in the same places and doing the same jobs. **Describe** some examples of this.
4. **Propose** why these animals have skeletons which are so similar.
5. If fossil bones from the limbs of these creatures were discovered, then **discuss** whether you think you could easily identify which of these creatures the bones belonged to.
6. The fish fins were very different from the frog limbs. **Discuss** whether there is any evidence of fish fins having bones in them as land animals do.

Chapter review 2

Remembering

1 **List** the sequence of appearance for the vertebrate groups in the geological time scale.

2 **Name** a major event from the geological record for each of the following.

a	Ediacaran	b	Cambrian
c	Devonian	d	Permian
e	Triassic	f	Jurassic
g	Cretaceous	h	Pleistocene

Understanding

3 **Define** the following terms.
- a fossil
- b index fossil
- c radioactive dating
- d geological time scale

4 **Describe** five different types of fossils and how they form.

5 **Explain** why the fossil record is incomplete.

6 **Describe** how the age of a fossil or rock can be determined.

7 **Explain** how the geological time scale was constructed using absolute and relative dating methods.

8 **Describe** how a replacement fossil of a trilobite may form.

9 **Outline** how you could reconstruct the appearance of a dinosaur from a fossilised skeleton, but with half the bones missing.

10 **Modify** the following statements to make them correct.
- a Only a preserved body part can be considered a fossil.
- b Palaeontologists cannot interpret fossils to determine the appearance of an organism.
- c There is no way to tell how long ago a particular fossil was formed.
- d All species lived at all times throughout the history of the Earth.
- e All species were equally distributed over the Earth in the past.
- f The fossil record would be complete if all the sedimentary rocks with the fossils could be exposed.
- g Palaeontologists should stop looking for fossils because they already know the history of life on Earth.
- h The geological time scale will not change as new fossils are discovered.

Applying

11 Some scientists have estimated that only 25% of the dinosaurs that existed have been discovered as fossils. **Use** your knowledge of fossils to **explain** why we will never find examples of all the dinosaurs.

12 **Use** the decay curve for potassium to argon in Figure 2.2.6 on page 51 to **calculate** the age of a fossil that had one-tenth of its potassium-40 remaining.

Analysing

13 Birds and bats that fly over swamps can sometimes be exposed to poisonous gases. **Analyse** how this may affect their chances of being fossilised.

14 **Compare** relative and absolute dating.

15 **Contrast** a fossil mould and a cast.

Evaluating

16 Scientists have extensive knowledge of trilobites, ammonites, molluscs, coral and fish, but know very little of ancient marine worms, earthworms, bats and desert plants. **Propose** reasons why.

17 a Refer to Figure 2.3.1 on page 57 and **assess** which are the ten most important events in the history of life on Earth.
- b **Justify** your choice.

Creating

18 **Use** the following ten key terms to **construct** a visual summary of the information presented in this chapter.

fossil
preserving environments
fossil record
absolute dating
relative dating
index fossil
stratigraphy
geological time scale
vertebrate history
dinosaurs

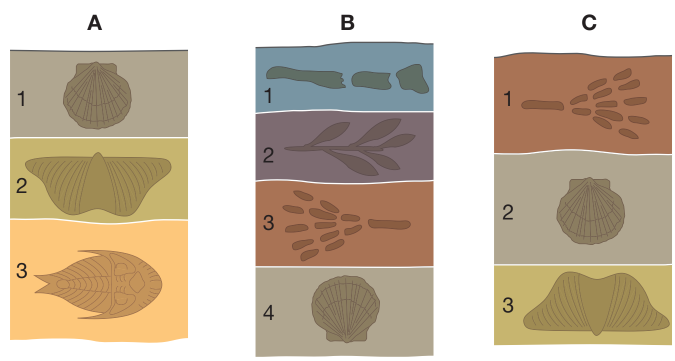
2.8

Thinking scientifically

Q1 In which of the following environments are soft-bodied animals least likely to form fossils?

A In a peat swamp
B In a rain forest
C In the ice of the tundra
D In dry deserts which have strong winds and dust storms

Questions 2 to 5 are based on the following diagram showing ten strata in three different locations, A, B and C. The strata are numbered.



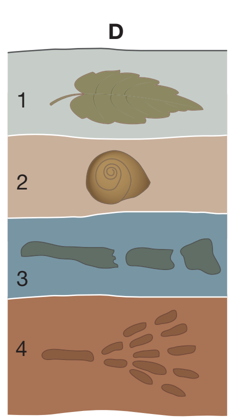
Q2 Which of the following strata are the same age?

A A1, B1, C1
B A3, B4, C3
C A1, B4, C2
D A2, B3, C3

Q3 Which is the oldest layer of the ten strata?

A A3
B B4
C C3
D B1

Q4 At location D, the following strata and fossils were discovered.



Which layer found in location B appears to be missing from location D when it would have been expected to be found at D?

A B1
B B2
C B3
D B4

Q5 Which is the youngest layer in the four sites?

A A1
B B4
C C1
D D1

The following information applies to questions 6 and 7.

The half-life for a radioactive substance is the time it takes for half of the original radioactive material to break down. The half-life for dating using carbon-14 is 5730 years. Carbon-14 decays to form nitrogen-14. For the decay of potassium-40 to argon, the half life is 1251 million years. Fossil birds date from about 150 million years ago. House roof beams are usually no older than a few hundred years even if the timber is recycled.

Q6 Which of the following is a correct deduction using the above information?

A Potassium-40 decays faster than carbon-14.
B Potassium-40 could not be used to date rocks older than 500 million years.
C Carbon-14 could not be used to find the age of the oldest fossil bird discovered.
D Carbon-14 would not be useful to date wooden beams from a house.

Q7 How many years would it take before a 1 gram sample of carbon-14 decayed to a mass of less than 0.1 gram?

A less than 11 460 years
B between 11 460 and 17 190 years
C between 17 190 and 22 920 years
D more than 22 920 years

Glossary

Unit 2.1


Carbon film fossil

Carbon film fossil: when the dead body partially decays and leaves a thin black deposit of carbon

Cast: when an organism in rock decomposes and the space in the rock fills with soil that turns to rock

Ediacaran: time period on the geological time scale when complex life forms were developing

Fossil record: a list showing the classification of all the species that have been found as fossils


Fossils

Fossils: the preserved evidence in rocks or soils of organisms that were once alive

Indirect fossils: preserved remains of things such as imprints of the body (such as footprints), fossilised dung and burrows

Mould: an imprint of the outside of the body in rock

Original fossils: when a part of the organism such as a skeleton is preserved and remains in its original form


Replacement fossil

Palaeontologist: scientist who studies prehistoric life

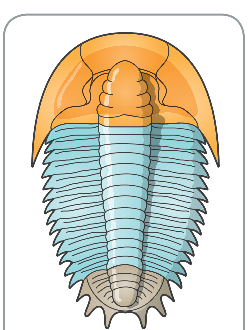
Palaeontology: the study of prehistoric life

Petrified: when wood is replaced by minerals and fossilised

Replacement fossil: when a part of the organism is changed into another mineral

Unit 2.2

Absolute dating: a way of determining the actual age of rocks and fossils

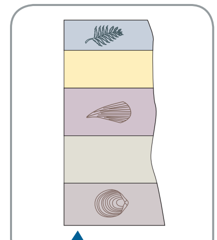

Index fossil

Fluorine dating: finding a relative age for two bones from the same area by comparing the amount of fluorine in them

Hadrocodium: the oldest true mammal yet discovered

Half-life: the time it takes for half of a radioactive sample to decay

Index fossil: fossil that can be used to compare the relative age of rock strata in different locations


Stratigraphy

Isotope: different forms of the same element with different numbers of neutrons, and so different atomic masses

Organic matter: chemicals such as proteins that were made by a living thing

Relative dating: comparing the age of one fossil or rock against another to see if one is older or younger than the other


Tree ring dating

Strata: layers of sedimentary rock

Stratigraphy: comparing strata in different locations to determine their relative ages

Tree ring dating: counting growth rings in the woody trunks of trees to find their age

Unit 2.3

***Archaeopteryx*:** bird-like dinosaur that had feathers

Coelacanths: ancient group of fish related to the lobe-finned fish ancestors of the amphibians

Geological time scale: a scale showing the history of life and geology

***Ichthyostega*:** early amphibians which were the first of the group called tetrapods

Lobe-finned fish: fish with bones in their fins similar to land animals

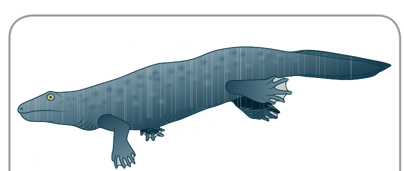
Lungfish: relatives of the lobe-finned fish that made the move from sea to land

Primates: order of mammals to which humans belong


Stromatolite

Stromatolite: circular rocky structures thought to be the earliest evidence of living organisms called the cyanobacteria

Tetrapods: land animals with four limbs. Living tetrapods are now classified as amphibians, reptiles, birds and mammals


Tetrapod

Theropods: a dinosaur group closely related to birds and from which birds probably developed