2 Geological time

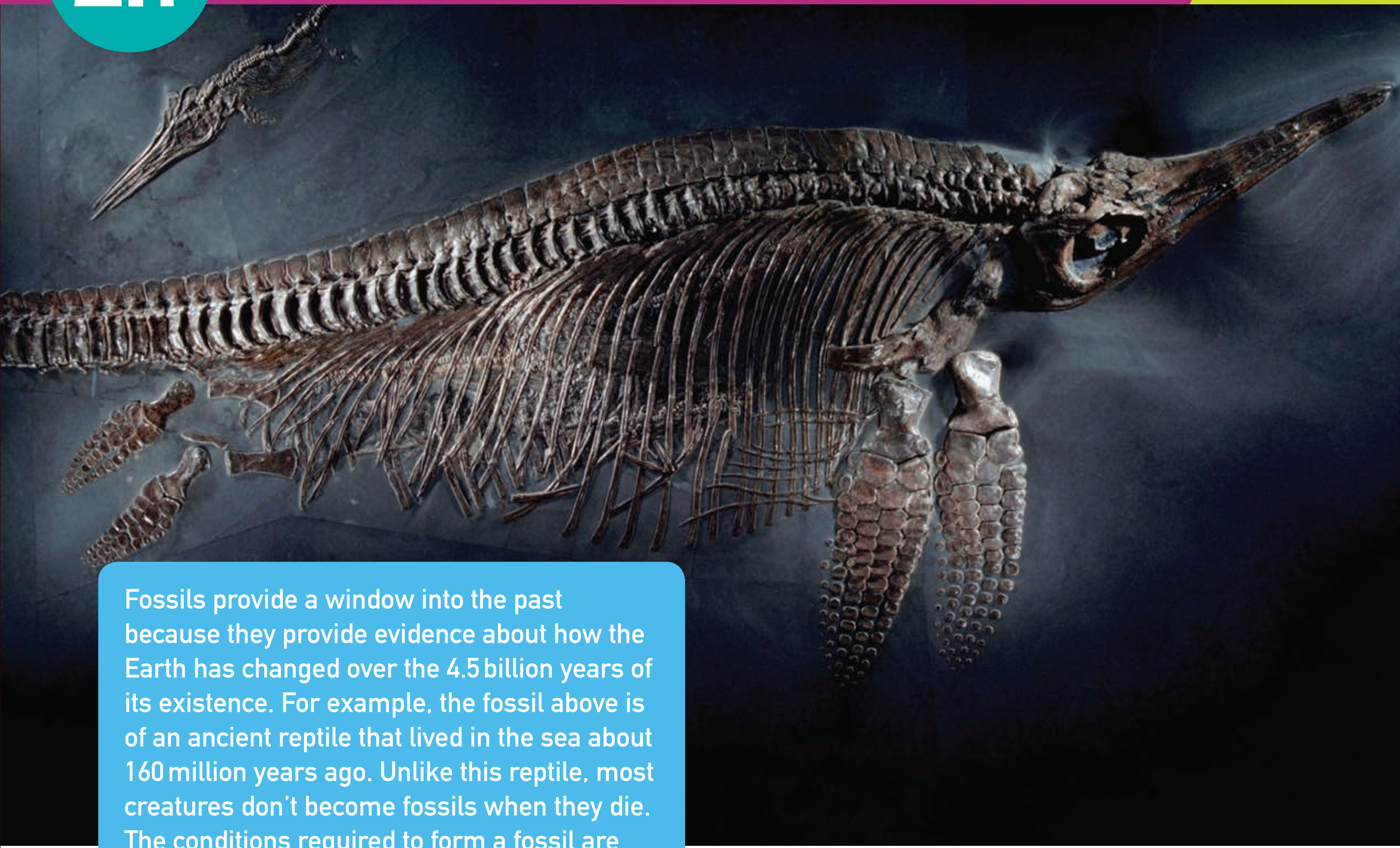
HAVE YOU EVER WONDERED…

- what life was like millions of years ago?
- where to find fossils?
- how we know when dinosaurs lived?
- how we know what a dinosaur would have looked like?
- how fossils form?

After completing this chapter students should be able to:

- evaluate evidence for evolution, including the fossil record, chemical and anatomical similarities and geographical distribution of species
- discuss the role of different sources of evidence for evolution by natural selection, including biochemical, anatomical and fossil evidence.

2.1 Fossils



Fossils provide a window into the past because they provide evidence about how the Earth has changed over the 4.5 billion years of its existence. For example, the fossil above is of an ancient reptile that lived in the sea about 160 million years ago. Unlike this reptile, most creatures don't become fossils when they die. The conditions required to form a fossil are relatively rare and so most organisms break down and decay after death, leaving no trace that they were ever there.

INQUIRY science 4 fun

Fossil kits

What can you tell from fossils?

No

Collect this …

- fossil kit

Do this …

Collect a fossil from the fossil kit. Handle it with care.

Record this …

Describe your fossil by sketching it and recording its name and age.

Explain how fossils like this tell you a little about past life.

What is a fossil?

Fossils are the preserved evidence in rocks or soils of organisms that once existed on Earth. The fossil may be the whole body of the organism, part of it or traces of its activities such as its burrows, tracks or dung (faeces). To be preserved as a fossil, the dead organism must not be eaten by scavengers and it must then decay very slowly. These two conditions are most likely to occur when dead organisms are covered in sediment, which then turns to rock.

Palaeontology is the study of past life, especially fossils. **Palaeontologists** are scientists who reconstruct past environments using fossils and geology.

Formation of fossils

The **fossil record** is a list showing all the species of living organisms that have been found as fossils as well as their location and age. The record can be thought of as a timeline of Earth, tracking the Earth's development since its formation 4.5 billion years ago. However, not all organisms are represented equally in the fossil record. This is because the soft parts of organisms decay much faster than the hard parts. For this reason, it is extremely rare for soft parts to be preserved.

Organisms that are only composed of soft parts, such as jellyfish, slugs, algae and mosses will be rare in the fossil record. Hard objects such as skeletons, shells, teeth and wood are most commonly found as fossils. Fossils of organisms with hard parts, such as dinosaurs, giant kangaroos, crabs, shellfish and trees, will be more common.

Being quickly covered by sediment will stop a dead organism from being eaten and will slow or even stop its decay. These conditions usually occur at the bottom of an ocean, lake or river. Sediments in the water sink to the bottom and cover any dead organism lying there. The sediment slowly builds up and natural cements and the drying of the sediment eventually turn it into sedimentary rock. This process is shown in Figure 2.1.1. A similar process can also happen on land if windblown sediment covers the dead organism.

Erosion and movements within the soil and rock can then expose the rock layers containing the fossil or bring them to the surface. Fossils are found in sedimentary rock and not in igneous or metamorphic rocks. The heat and pressure needed to form igneous and metamorphic rocks destroy any traces of organisms in them. In contrast, sedimentary rock traps the remains for possible future discovery.

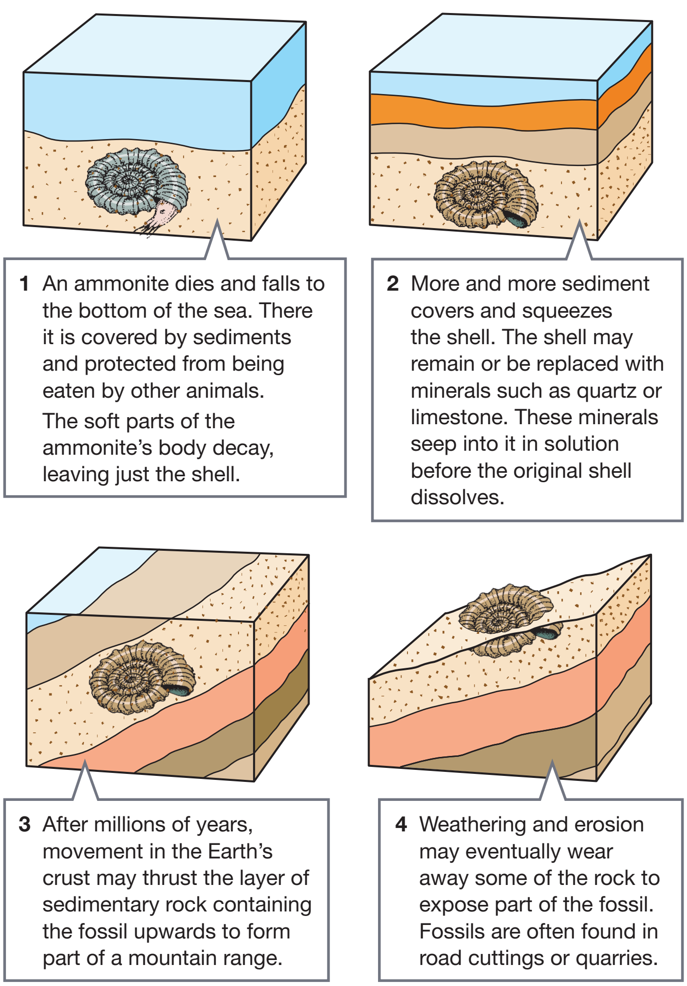


Figure 2.1.1 Fossilisation can happen when the remains of an organism are trapped in the layers of a sedimentary rock.

Types of fossils

The many types of fossils are due to the different ways in which they can form. The type of organism being fossilised also affects what the fossil will eventually be like. There are several different ways in which fossils can be classified, including:

- original
- replacement
- carbon film
- indirect fossils.

Original fossils

Original fossils form when a part of the organism is preserved, with its chemical composition being about the same as it was when it was living. An original fossil could be a complete skeleton, bones, a tooth (or teeth) or a shell. Bone is composed of minerals (such as calcium carbonate) that are resistant to decay and which scavengers find difficult to eat. The flexibility of living bone comes from proteins within it. These proteins normally quickly decay after death, leaving behind the minerals as hard but brittle bones. Common original fossils include:

- sea creatures that had shells, such as molluscs like scallops, mussels and clams
- vertebrates, because they had teeth and a bony skeleton. Examples are the remains of dinosaurs and of Australian megafauna such as 3-metre-tall giant kangaroos, sheep-sized echidnas, diprotodons, 3-metre-long wombats and marsupial lions, a skull of which is shown in Figure 2.1.2.

Figure 2.1.2 This is an original fossil. It was found on the Nullarbor Plain in Western Australia and is the remains of a marsupial lion that died 45 000 years ago. The fossil shows that it had large dagger-like teeth for catching its prey.

INQUIRY science 4 fun

Bendy bone

What is bone made of?

Yes

Collect this …

- chicken bone, cooked or fresh
- vinegar
- jar with lid or beaker covered with cling film
- tongs
- rubber gloves

SAFETY!

Wear gloves or wash your hands after handling raw or cooked chicken.

Do this …

1. Put the chicken bone in the vinegar. Leave it for 1–3 days depending on the thickness of the bone.
2. Next day, use tongs to hold the bone under running water to wash it thoroughly. Do not touch the water run-off or the bone until it is thoroughly cleaned.
3. Try to bend the bone. If the bone is thin enough, try to tie a knot in it.

Record this …

Describe what happened.

Explain why you think this happened.

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Turkana Boy

Original fossils of many early humans have been discovered, including the Turkana Boy. The fossil was found in Lake Turkana, Kenya, in 1984. This is a fairly complete skeleton of a young boy, his teeth indicating that he was about 9–12 years old. He lived about 1.6 million years ago.

Replacement fossils

A **replacement fossil** forms when a part of the organism is chemically changed into another mineral. This takes a long time to happen so most of these fossils date back to over 60 million years ago. Replacement fossils commonly form when the calcium carbonate found in shells and bony skeletons turns into another mineral such as silica, also called silicon dioxide (SiO_2). Silica is like sand. Sometimes the bone or shell even turns into opal, another form of silica. This means that the bone or shell is now a lump of solid silica or opal. This is what has happened in Figure 2.1.3.

Figure 2.1.3

This plesiosaur backbone is a replacement fossil. The bones have slowly been replaced by silica, turning into opal.

If the material being replaced and fossilised is wood, then scientists refer to the wood as being **petrified**. Sometimes whole tree trunks or stumps are petrified, having been turned into stone-like silica (Figure 2.1.4).

SciFile

Fake!

Some structures look like petrified tree trunks and roots but aren't. Despite this the structures at Cape Bridgewater (Victoria) and Cape Northumberland (South Australia) are commonly called 'petrified forests' when they are really just interesting formations of sand and rock.

Figure 2.1.4

Petrified trees are the replacement fossils of ancient trees. 'Forests' of petrified pine tree trunks exist near Lake Macquarie in New South Wales, in Arizona, USA, and on the island of Lesvos, Greece.

Carbon film fossils

Carbon film fossils occur when the dead body partially decays and leaves a thin black deposit of carbon. These fossils are also known as carbon trace fossils. Figure 2.1.5 on page 42 shows the carbon film fossil of an ancient fern. Plant fossils are commonly carbon film fossils. The traces of carbon left are still in the shape of the organism that decayed and often show its finer details. Coal is formed by this process, although no traces of the plants that were part of the coal can be identified in it.

Figure 2.1.5 These are carbon film fossils of ancient fern fronds.

Indirect fossils

Indirect fossils are not part of the organism itself but instead are preserved remains of things such as imprints of the body, (such as footprints and tracks), fossilised dung and burrows. Tracks, burrows and dung are also called trace fossils.

A **mould** is usually an imprint left in the rock showing the outside of an organism. A mould is a 'negative' image, meaning that it is a space where there is no body. Mollusc shells commonly form moulds. To form a mould, the shell is first covered in sediment, which then turns into rock. Then the original shell is dissolved by acids or other agents, leaving an imprint in the rock. This is common in the depths of the ocean because calcium carbonate dissolves faster at the higher pressures found there. Arthropods, such as crabs, lobsters and prawns, can also leave moulds. A fossil of an arthropod is shown in Figure 2.1.6.

Figure 2.1.6 These fossils are moulds of an ancient arthropod called a trilobite. The original animal has decayed and been lost. Only the imprint or shape is left in the rock.

It is possible to have a mould of the inside of an organism. This is referred to as an internal mould. For example, an internal mould could form if the shell from a sea snail fills up with mud, which then turns to rock. Then the shell breaks up and dissolves, leaving the rock behind. This rock will be a copy of the inside of the shell.

Good fossil footprints have been left behind by many organisms such as crabs, lizards, dinosaurs and early humans. One set of footprints found at Laetoli in Tanzania, Africa, provides evidence that 3.6 million years ago early human-like organisms walked upright on two legs, much as we do today. You can see them in Figure 2.1.7.

A **cast** forms when an organism in rock decomposes and the space in the rock fills with soil and turns to rock. This leaves a copy of the outside of the organism in a solid piece of rock. This is a positive image and is a three-dimensional 'model' of what the organism looked like in life.

Artificial casts can be made by pouring plaster into footprints or into fossil moulds. This gives a more realistic 3D 'positive' version of the organism than the 'negative' provided by the mould.

Figure 2.1.7 These fossil footprints at Laetoli in Tanzania, which are 3.6 million years old, were left by an animal that walked on two legs, much as humans do today.

1 p47 2 p47

Preserving environments

Hard parts such as skeletons and shells always have a better chance of surviving as a fossil than the soft parts of an organism. However, some environments will encourage the preservation of soft parts. These preserving environments include permafrost, amber, tar, peat and dry air.

Permafrost

Near the Arctic Circle, the land is permanently frozen. Bacteria and fungi that cause decay cannot grow if the temperature is below freezing. This has preserved some amazing original fossils. The most famous are the fossil mammoths of Siberia, Russia. In 2007, a baby one was found that had been preserved in the ice for about 40 000 years. You can see it in Figure 2.1.8.

Figure 2.1.8 This baby mammoth was preserved in permafrost for over 40 000 years.

Amber

Amber is solid plant sap or gum. Insects, spiders and even small vertebrates such as frogs and lizards get caught in the sticky sap, which seeps out of trees. When it sets and hardens, it can perfectly preserve whatever is entombed inside it, including the spider in Figure 2.1.9.

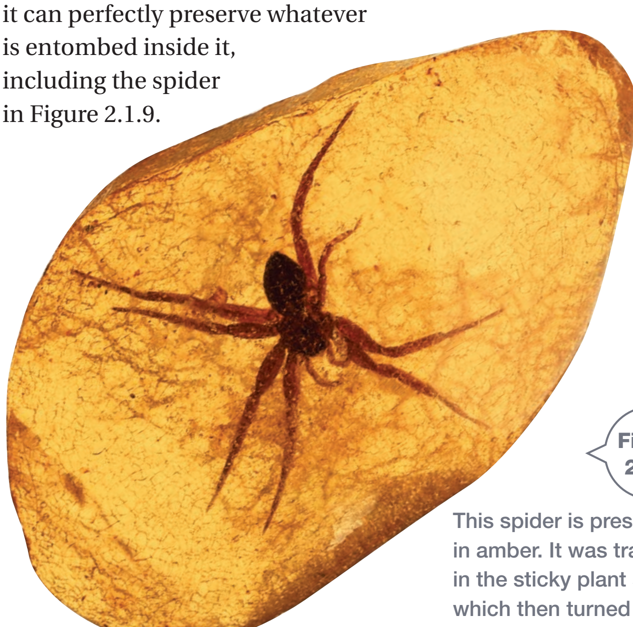


Figure 2.1.9 This spider is preserved in amber. It was trapped in the sticky plant sap, which then turned solid.

Tar

Tar pits occur where oil seeps naturally out of the ground and onto the surface. Tar pits are fairly rare, but the preservation of animals in them is spectacular wherever it occurs. Some of the best known have been found in the la Brea tar pits in Los Angeles, USA. Many animals such as mammoths, bison and sabre-toothed cats became stuck in the sticky tar. You can see a sabre-toothed cat in Figure 2.1.10.

Figure 2.1.10 This sabre-toothed cat was trapped by tar, died and was fossilised.

Peat

Peat is the partly decomposed remains of plants such as moss and is commonly found in swampy areas or bogs. The layers of peat can be very deep and oxygen and bacteria are often absent in the lowest layers. This gives the soft tissue trapped in these layers some chance of being preserved. The peat is generally acidic and this dissolves the hard minerals in the bone, making them very soft. In Europe, ancient human bodies have been found preserved in swamps. Tollund man is a good example. As you can see in Figure 2.1.11, his skin (and even the hair on his face) is well preserved.

Figure 2.1.11 Tollund man was found in a peat swamp which was acidic and had little oxygen. His remains were so well preserved that they even indicated how he died: he was hung and then thrown into the swamp in about 400 BCE!

Dry air

Bacteria and fungi need moisture to survive. As a result, extremely dry conditions can preserve a body too, since the bacteria and fungi that decompose soft tissues cannot live under these conditions. The dry air dehydrates the soft tissue, which fossilises, and turns it into a 'mummy'. This can occur in hot deserts, but also in cold frozen places where there is ice but no liquid water. The mummified skin then forms a mould in sediments.

The fossil record is incomplete

The fossil record is a list showing all the species that have been found as fossils. The fossil record is more complete for some organisms than others. Fossils form in sedimentary rock and so the best chance of an organism being fossilised is if it lives in water and if it has some hard body parts. Therefore, the most likely organisms to be fossilised and have a good fossil record are marine organisms with skeletons or shells. These include molluscs, corals, arthropods and vertebrates.

Marine organisms with soft bodies such as jellyfish and worms are unlikely to form fossils. They have delicate soft bodies, which decay quickly and squash under pressure. Despite this, there are some fossils of jellyfish and worm-like creatures in South Australia, one of which is shown in Figure 2.1.12.

Figure 2.1.12 This fossil is thought to be of a flat worm from Ediacara in the Flinders Ranges of South Australia. A new geological period called the Ediacaran was named after these fossils.

Land organisms with soft bodies are extremely unlikely to form fossils. This means that groups such as earthworms and slugs would rarely be fossilised. Land organisms with hard parts such as vertebrates (for example, mammals and reptiles) and arthropods (such as insects and spiders) may become fossilised if they die in water or where windblown sediment could cover them. However, this would not happen as often as water organisms dying and being covered by sediment.

2.1

Famous fossil sites

Famous sites with many fossils are:

- Ediacara, Flinders Ranges in South Australia
- the la Brea tar pits in Los Angeles, California, USA
- the Burgess Shale in Canada
- Chengjiang in China
- Solnhofen in Germany.

Ediacara and the Burgess Shales are particularly important because together they provide two consecutive chapters in the fossil record. The organisms of the Burgess Shales are very simple and many bear little resemblance to those in the earlier Ediacaran period and to those existing today. Figure 2.1.13 shows an artist's impression of two such organisms.

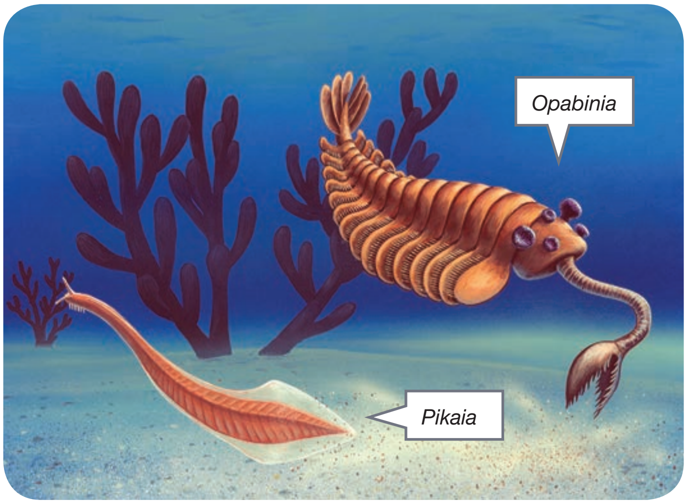
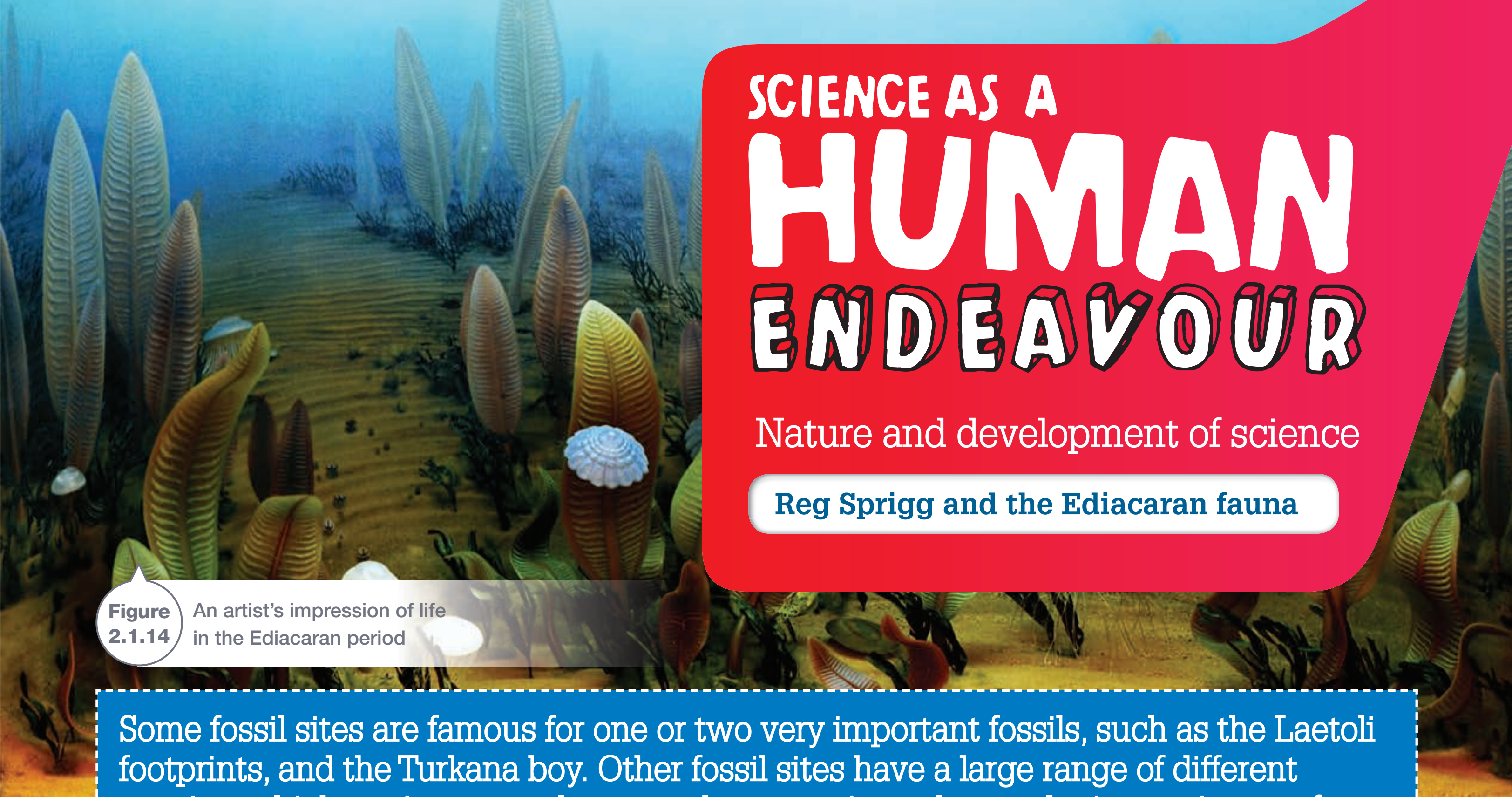


Figure 2.1.13 This is an artist's impression of two organisms from the Burgess Shale, which has some very well-preserved soft-bodied organisms.

SciFile

Spot the relative

Opabinia was about 7 centimetres long, had five eyes and a long proboscis (snout) with spikes on the end. It probably lived on the sea floor where it used its proboscis to hunt for animals hiding in the sediments. *Opabinia* died out, leaving no descendents. *Pikaia* had bilateral symmetry and a rod like structure running along its body. It may be one of the first chordates, the group to which humans belong.



SCIENCE AS A HUMAN ENDEAVOUR

Nature and development of science

Reg Sprigg and the Ediacaran fauna

Figure 2.1.14 An artist's impression of life in the Ediacaran period

Some fossil sites are famous for one or two very important fossils, such as the Laetoli footprints, and the Turkana boy. Other fossil sites have a large range of different species, which are important because they can give palaeontologists a picture of what the environment was like in the past.

In Australia, the most famous site for a wide range of fossils is the Ediacaran Hills in the Flinders Ranges of South Australia. A South Australian geologist, Dr Reg Sprigg (1919–94), discovered what is now believed to be the oldest group of multicellular organisms that are ancestors of all the life that followed. Artists' impressions of them are shown in Figures 2.1.14 and 2.1.15. Sprigg found the fossils in 1946 when he was just 26 years old, and published his findings.

In 2004, the International Commission on Stratigraphy finally recognised a new geological period, which they named the Ediacaran. The **Ediacaran** period is the first new geological period to be named in the past 120 years. It spans 635–542 million years ago and is the first ever to spring from the Southern Hemisphere. The Ediacaran Hills are now part of the Flinders Ranges National Park.

Figure 2.1.15 Reg Sprigg's contribution to palaeontology is recognised on a 50-cent stamp.

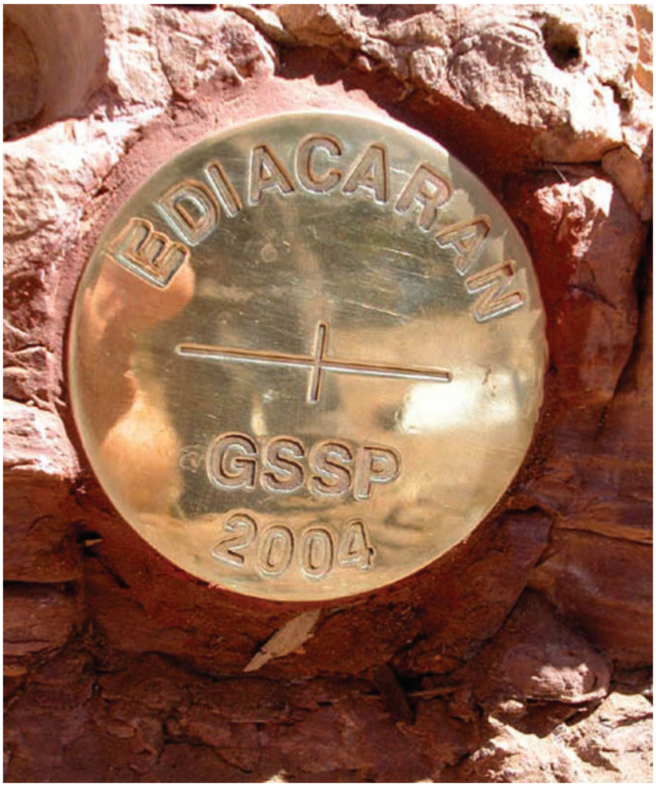


Figure 2.1.16 This point in a rock is the 'Golden Spike' marking the Ediacaran period. It is the reference point for defining the period and is officially known as the Global Stratotype Section and Point (or GSSP). Other sites around the world have since been discovered with similar fossils and these too are classified as Ediacaran.

2.1 Unit review

Remembering

1 **List** four types of fossils and give an example of each.

2 **State** what a palaeontologist does.

3 **Recall** the contribution that Reg Sprigg made to palaeontology.

Understanding

4 **Define** the term *fossil*.

5 **Describe** two environments which can preserve the soft parts of organisms.

6 **Describe** conditions that assist in the preservation of bone as a fossil.

7 **Outline** how fossils form in sedimentary rocks.

8 **Explain** why Tollund Man and the Siberian mammoths are so well preserved.

9 **Outline** how a replacement fossil forms.

10 **Explain** why the fossil record is good for marine organisms, but poor for many land organisms.

12 Imagine you found some worm burrows preserved in rocks. **Discuss** whether they are fossils or not.

11 **Explain** the significance of the Ediacaran fossil finds.

Analysing

13 **Compare** moulds and casts by listing their similarities and differences.

14 **Compare** tar and peat as environments that preserve the soft bodies of organisms.

15 Wood can be preserved as a replacement fossil and carbon film fossils.

- a **Compare** these two methods of formation.
- b **Describe** how you would distinguish between the fossils formed.

Evaluating

16 Sea reptile fossils have been found in the opal fields in South Australia. Palaeontologists believe that these fossils are extremely old. **Propose** reasons for this conclusion

17 a For each of the following pairs of organisms, **identify** which one is more likely to be fossilised.

- i a swamp plant or a woodland plant
- ii a cat or an earthworm
- iii a forest bird or a water bird
- iv a clam or a sea slug
- v a human or a frog
- vi a whale or a bat

b In each case, **justify** your answer.

18 The White Cliffs of Dover in England are limestone cliffs thought to have been formed in a shallow sea rather than the deep ocean. **Propose** what evidence leads geologists to think this.

Creating

19 **Construct** a sign to be erected at the site of the Golden Spike, identifying the importance of the Ediacaran fossil site. Your sign should show a title, position of any diagrams or photos, and where you would place the writing. Then provide the written information you would put on the sign.

20 **Design** an investigation to determine whether a fossil skeleton of a reptile is a replacement fossil or an original fossil.

Inquiring

1 Research two human fossils from different environments, such as ice or swamps, that preserved the soft tissues. Name the places where these different fossils were found, compare the appearance of the fossils and explain why they were so well preserved.

2 Research an important Australian fossil site other than Ediacara (such as Dinosaur Cove or Riversleigh) and explain why it is an important site.

3 Research the fossil known as the Lake Turkana Boy. Discuss where he was found, what fossils were found and what palaeontologists think he looked like when he was alive.

4 Western Australia was the first state in Australia to declare a fossil emblem to represent the state. It chose the Gogo fish. Research important fossils of your state or territory and produce an A4 poster that justifies the choice of the fossil as your state fossil emblem. If you live in Western Australia, then think of a fossil emblem for Australia and justify your choice.

5 The 'fossilised' remains of a few historic ships have been found buried deep in the mud they sunk into when catastrophe struck them. Research ships such as the *Mary Rose* to find out what stopped its wood, leather and steel from rotting and rusting away.

2.1 Practical activities

1 Making fossils

Purpose

To make fossil moulds and casts.

Materials

- modelling clay
- plaster of Paris
- margarine container
- objects to mould, such as shells and bones
- petroleum jelly
- wooden spatula for mixing plaster
- rubber gloves

SAFETY

Do not mix plaster with your bare hands. It can cause skin irritation and burns.

Wear safety glasses and rubber gloves.

Never tip plaster down the sink.

Procedure

1. Soften the modelling clay into a flat sheet about 1 cm thick.
2. Smear some petroleum jelly onto the shell or bone and then press it into the modelling clay.
3. Carefully remove the shell or bone without breaking the modelling clay. This imprint in the modelling clay is known as a mould
4. Using the spatula, mix some plaster and water in the margarine container
5. Pour the plaster mix into the mould in the modelling clay. Flatten the surface of the plaster.
6. Leave the plaster to set. When the plaster is solid, carefully remove it from the modelling clay. This is the cast.
7. If you have time, make another mould and cast from a different object.

Discussion

1. **Compare** your plaster cast and mould with the original shell or bone, indicating if they are accurate copies.
2. **Explain** whether the cast and mould tell us what the original organisms looked like.
3. Carefully **describe** how you think a mould could form naturally.
4. **Explain** what would have to happen for a cast to be made naturally.
5. **Explain** what information a cast gives that a mould may not give.

2 Modelling fossils

Purpose

To model the formation of different types of fossils.

Materials

- modelling clay
- plaster of Paris
- plastic container for mixing
- stirring rod
- variety of objects such as shells, leaves, bones, and nuts
- petroleum jelly
- newspaper for keeping the desk clean
- rubber gloves

SAFETY

Do not mix plaster with your bare hands. It can cause skin irritation and burns.

Wear safety glasses and rubber gloves.

Never tip plaster down the sink.

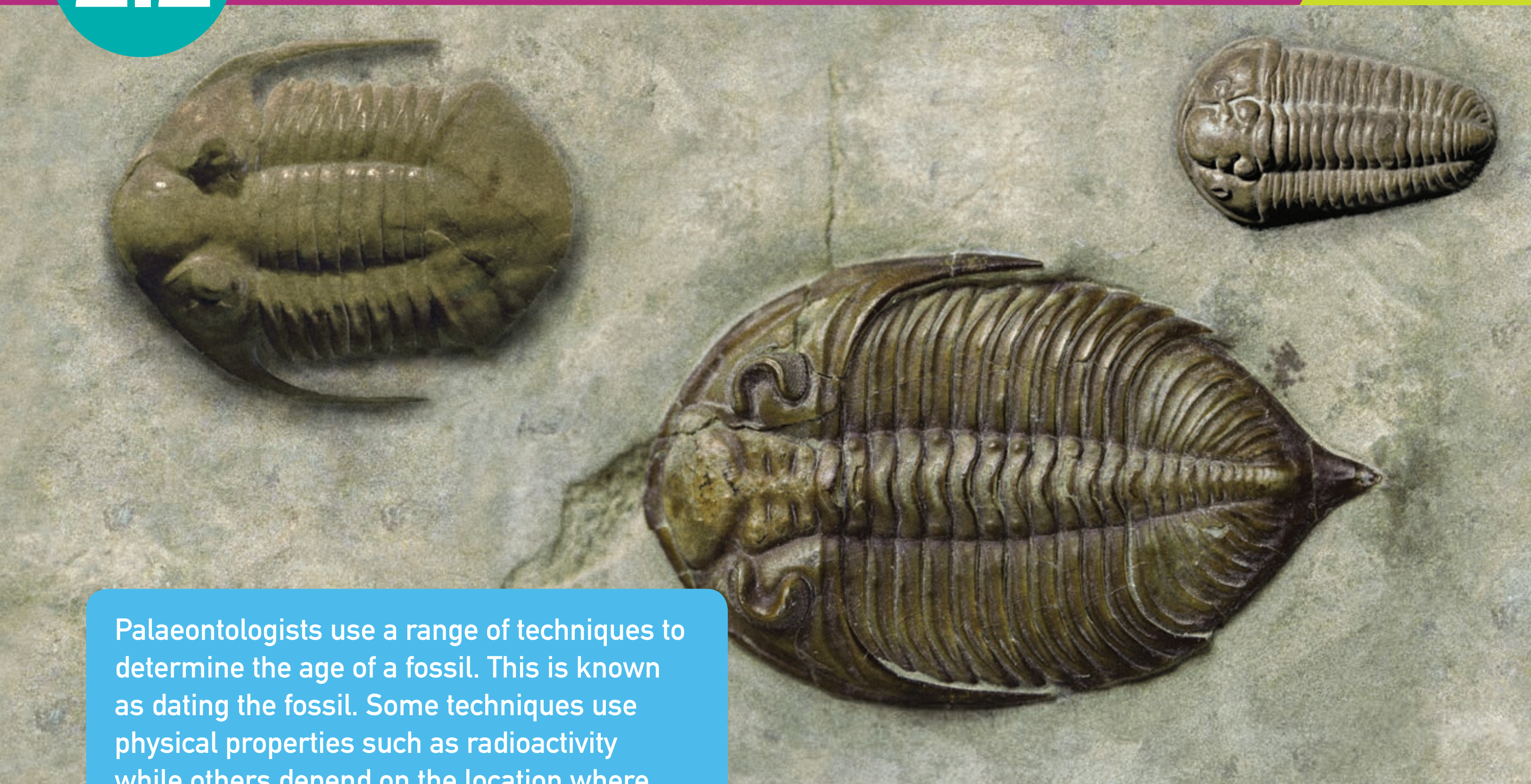
Procedure

1. Think of a way to model the process of forming some fossils, using only the materials you have been given. Each fossil has to be made in the plaster.
2. The fossils that you have to make in the plaster are a:
   - mould of the outside of one side of a leaf or shell
   - cast of the outside of complete shell (such as gastropod) or the outside of a eucalypt fruit (gumnut).
3. Describe or draw how you will make each fossil. Show it to your teacher and then make the fossil if your teacher agrees.

Discussion

1. **Assess** whether your method worked well and if you could improve on it.
2. **Identify** the material that you are simulating with the plaster.

2.2 Dating techniques



Palaeontologists use a range of techniques to determine the age of a fossil. This is known as dating the fossil. Some techniques use physical properties such as radioactivity while others depend on the location where the fossil was found. Dating fossils allows palaeontologists to construct a timeline showing when each organism lived on Earth. These fossils are of trilobites, a group of organisms that can be used to compare the age of rocks in different places.

Relative dating

Relative dating is a technique that compares the age of one fossil or rock with another to determine which is older. Relative dating relies on two basic facts:

- Sedimentary rocks form in layers.
- Fossils are the same age as the rocks in which they are found.

Layer by layer

Sedimentary rock forms in layers called **strata**. A single layer is called a stratum. Sediment always settles and so the first and oldest stratum is found at the bottom. Newer sediment then settles on top. This means that lower strata are usually older than strata above them. This gives a way of determining which organisms lived earlier than others. The fossils from the bottom layers of rock should be oldest.

Sometimes, however, the lowest stratum will not be oldest. This is because the layers of rock have folded over each other and been turned upside down by earth movements.

Index fossils

Evidence from the fossil record and rock strata indicates that most species only existed on Earth for a relatively short time. Each fossil species is only found in a narrow band of the rock strata in any one location. For example, a species of arthropod that appears in a particular layer in the sequence of rock strata in Victoria will also be found in a particular layer in the sequence of strata in New South Wales. This fossilised arthropod can then be used to compare the age of the two strata in Victoria and New South Wales.

The fossilised arthropod only lived at a certain time in the past and so rocks containing the same fossils must be of the same age. This would be true even if the rocks are different, such as limestone and shale. This is relative dating. It allows palaeontologists to determine how old one fossil is relative to another, but not the actual age for each.

Fossils that can be used to compare the ages of strata in different locations are called **index fossils**. To be used as an index fossil, the species must:

- have been fairly widespread in where it lived
- have lived in a fairly narrow period of time
- have been abundant (there were many of them)
- be easy to identify.

Index fossils allow rock layers in different locations to be compared and dated. Comparing layers like this is called **stratigraphy**.

2.2

Using stratigraphy

Deeper rock layers are usually older than shallower ones. Index fossils within the rock layers can be used to determine the relative ages of the fossils and the rock layers they appear in.

In Figure 2.2.1, layers A3, B1 and C5 contain the same long shell-like fossil species. Hence, these layers are the same age.

Locality C has four layers above C5. This implies these four layers are younger than C5, with C1 being the youngest.

The same round, shell-like fossil is in A5 and B4. Hence, these layers are the same age.

Locality B has one layer below B4, implying that B5 is older than B4 and A5 (which contains the same species).

Hence, the oldest rock layer is B5 and the youngest is C1.

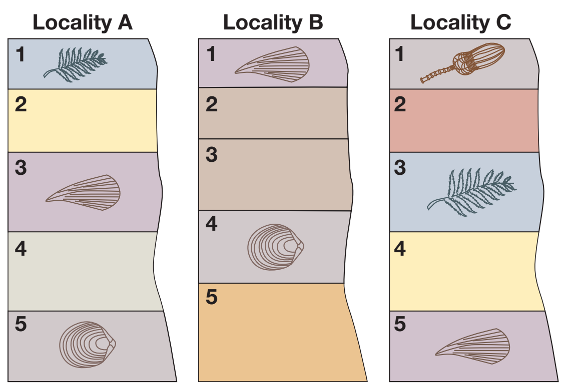


Figure 2.2.1 Rock layers can be compared in different places by using index fossils.

Examples of index fossils

There are many types of index fossil. Two animal groups that make good index fossils are trilobites and ammonites. Trilobites are now extinct, but are classified as arthropods because of their external skeleton and jointed limbs. This places them in the same phylum as current-day insects, crabs and spiders. A reconstruction of what trilobites were like is shown in Figure 2.2.2.

Not all structures are preserved in every trilobite fossil. The legs and antennae are often not preserved because they were so delicate. Many trilobite fossils do not seem to have any legs or antennae because of this.

SciFile

Three lobes

Trilobites have two furrows that run along their bodies from head to tail. This makes them look as though they were made from three lobes, so the words *tri* and *lobe* were combined to name them.

SciFile

Trilobite eyes

Scientists have discovered that trilobites were the first organisms to have complex eyes. X-ray images of these eyes show that they had a special type of lens to help them focus.

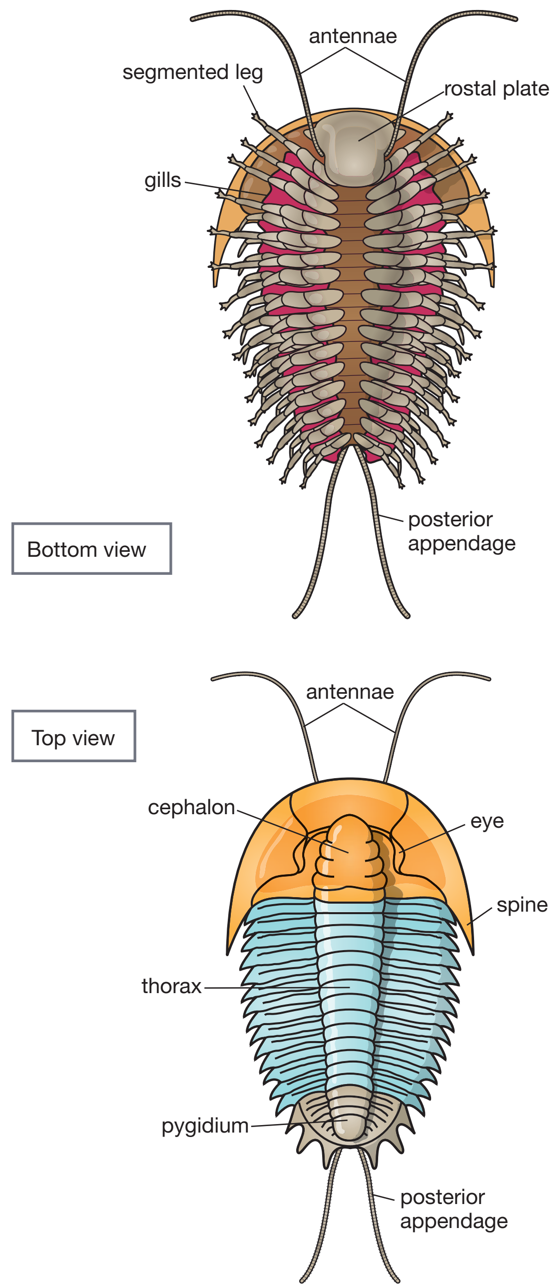


Figure 2.2.2 Trilobites are useful index fossils.

Trilobites as index fossils

Figure 2.2.3 on page 50 shows the order in which different trilobites lived. It was constructed by studying many different rock strata around the world. These same trilobites kept occurring in the same order, with *Ceraurus* and *Isotelus* consistently lowest (and therefore oldest) in the rock strata. Hence, rocks with *Ceraurus* in them can be considered to be older than rocks with *Dalmanites* in them.

Geologists have given each of the layers names, such as Silurian and Devonian.

Dalmanites and *Calymene* occur in rocks in New South Wales and Victoria, which were covered by an ancient sea at the time when the trilobites were fossilised. The trilobites on page 48 belong to these species. Geologists finding rocks with these trilobites in them would then classify the rocks as being the same age. They would classify the rocks as Silurian.

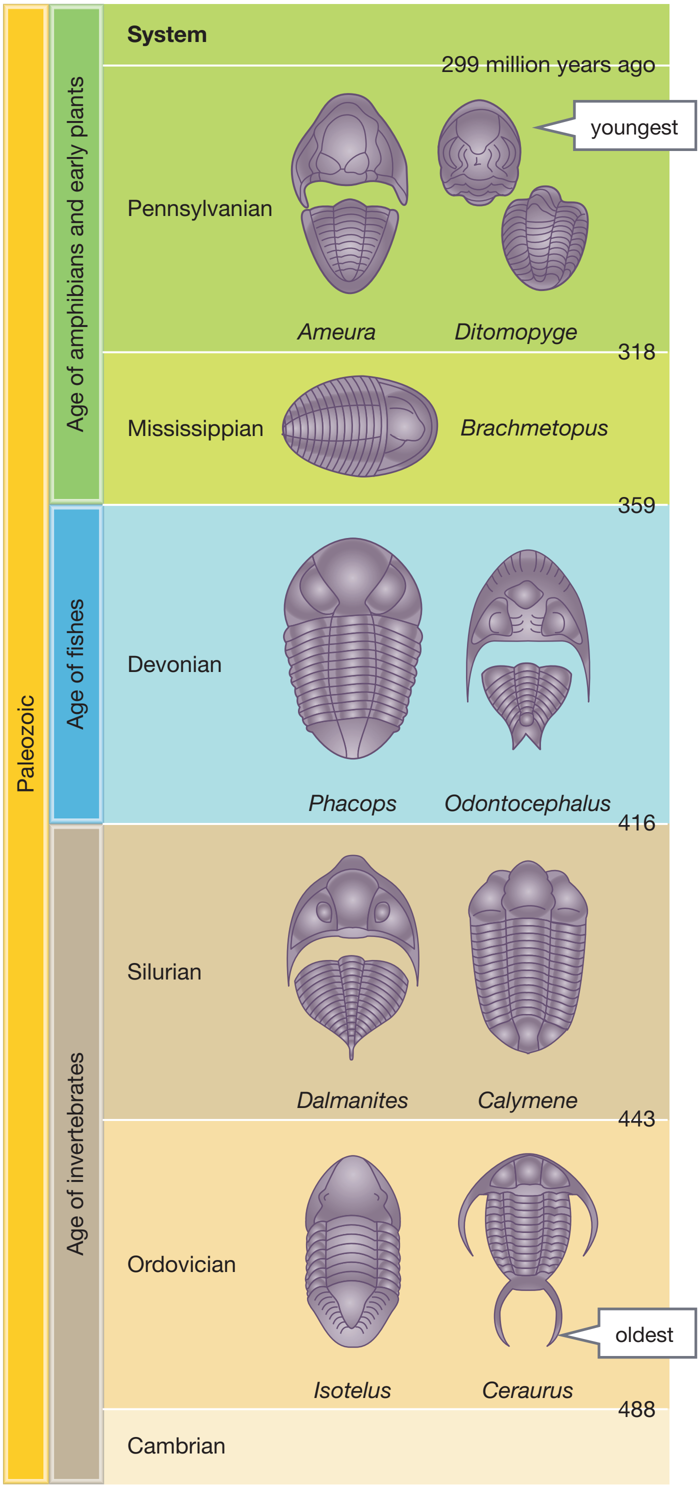


Figure 2.2.3 Trilobites are good index fossils because they were relatively common, widespread and different species existed at different times.

SciFile

Naming rock layers

The names of the rock layers came from the places where the fossils were first discovered. Devonian, for example, is named after a part of England called Devonshire. The Silurian is named after an ancient Welsh tribe called the Silures, because the rock strata were found in Wales, now part of the United Kingdom.

Fluorine analysis

Fluorine dating is another relative dating method. It compares the amounts of fluorine in different bones found in the same rock. Bones absorb fluorine from the water in the surrounding rock. This happens at a slow rate and depends on how much fluorine is in the water surrounding the bone. The technique was used to show that the famous Piltdown Man skull was a forgery (Figure 2.2.4). The Piltdown Man consisted of bone fragments collected in 1912 from a gravel pit at Piltdown, England. The palaeontologists who discovered them claimed that the bones were the fossilised remains of an early human. Others were sceptical. In 1953, fluorine analysis proved that the bones came from different layers of the rock, and therefore could not be part of the same animal.

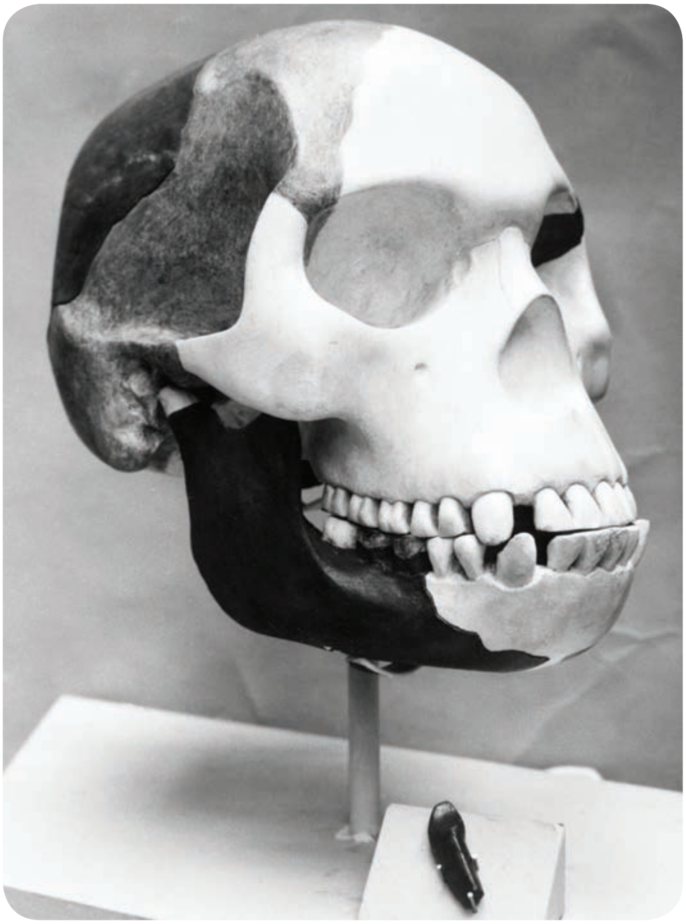


Figure 2.2.4 Fluorine analysis proved Piltdown Man to be a forgery. These bones came from three different animals. No one knows for certain who was responsible for the hoax.

Absolute dating

Dating methods that give the actual age of rocks and fossils are called **absolute dating** methods. There are many methods of absolute dating, including radioactive dating and tree rings.

Radioactive dating

Radioactive dating is a method that uses the natural rate of decay (breakdown) of radioactive isotopes. The process is shown in Figure 2.2.5. **Isotopes** are atoms of an element that have different numbers of neutrons and so have different atomic masses. For example, the element carbon exists as three isotopes, each with six protons but a different number of neutrons. Almost all carbon is carbon-12, with a small amount being carbon-13 and even less being carbon-14. Carbon-14 is radioactive, but carbon-12 and carbon-13 are not. Likewise, naturally occurring potassium is made up of potassium-39 (93%), potassium-40 (0.012%) and the rest potassium-41. Potassium-40 is radioactive, but the other two isotopes are not.

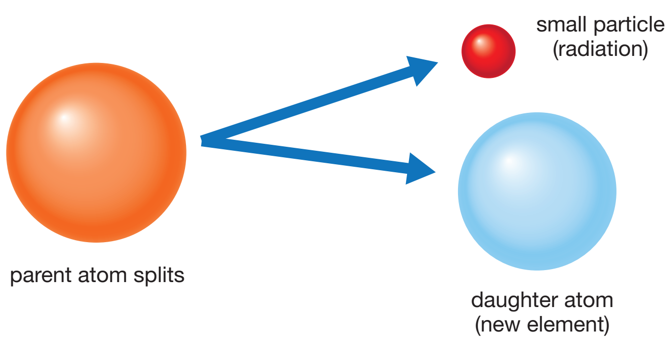


Figure 2.2.5 Radioactive elements break down to form new elements and release radiation.

Radioactive elements decay at a known rate and release particles that form radiation. This radiation can be detected by equipment such as Geiger counters. The elements that decay turn into new elements, the amount of which can then be measured.

This decay allows scientists to estimate how long ago the rock was laid down. There are many elements that can be used, depending on the type of fossil and the type of rock. Radioactive potassium-40 is found mainly in rocks containing volcanic ash. Potassium-40 decays into argon, which can be measured. By measuring how much argon has been formed in the rock and how much potassium-40 is left, you can calculate an age for the rock. This can be done by using a graph called a decay curve. You can see the potassium–argon decay curve in Figure 2.2.6.

From a decay curve, you can estimate the element's **half-life**. The half-life is the time it takes for half of a radioactive sample to decay. For example, the half-life of potassium-40 is 1251 million years. Carbon-14 has a much shorter half-life of 5730 years, so carbon-14 radioactivity disappears much more quickly from a fossil than potassium-40.

1 p55

Carbon dating uses the decay of carbon-14 to determine the age of **organic matter**. Organic matter is made of chemicals that contain a very small amount of radioactive carbon-14. A fossil may still retain some of the original chemicals from its body tissue and so the amount of carbon-14 remaining can be used to measure the age of the fossil. Carbon dating is useful as far back to less than 40 000 years. However, beyond that, the method is not reliable as the amount of carbon-14 remaining is too small to measure.

2.3

WORKED EXAMPLE

Problem

If the potassium to argon ratio in a sample of rock containing a fossil was 0.8, how old is the fossil?

Solution

Using the graph in Figure 2.2.6, run a horizontal line across from 0.8 on the vertical axis. Where it meets the plotted line of the graph (the green line), draw a vertical line down to the horizontal axis. This gives an answer somewhere between 400 and 450 million years.

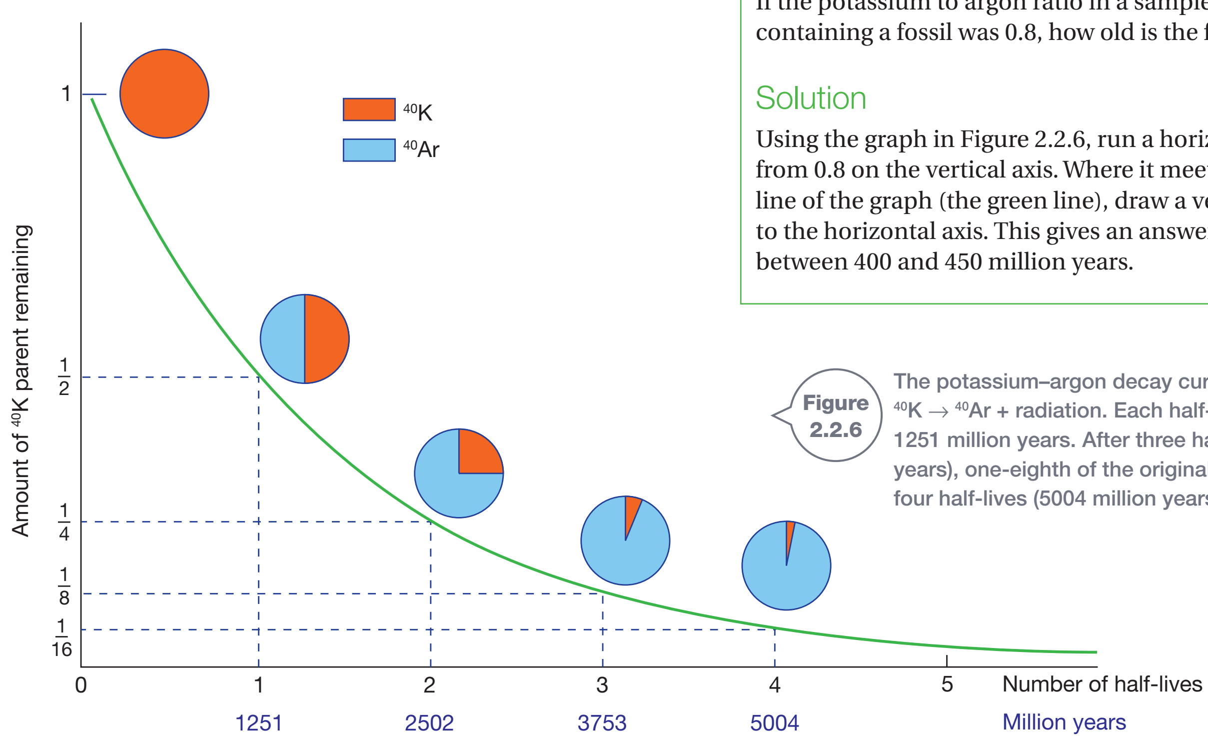


Figure 2.2.6 The potassium–argon decay curve: $^{40}K \rightarrow {}^{40}Ar$ + radiation. Each half-life is equivalent to 1251 million years. After three half-lives (373 million years), one-eighth of the original ^{40}K is left. After four half-lives (5004 million years) $\frac{1}{16}$ is left.

Tree rings

A useful method of absolute dating for wood is **tree ring dating**. This method can give a date to several thousand years ago. Tree ring dating involves counting growth rings in the woody trunks of trees. Many woody trees grow by adding layers on the outside of the stem each year. This leaves a line in the wood that is easy to see. Tree rings (like those in Figure 2.2.7) are visible whenever you cut down a tree or cut off a branch or if you drill through the tree to form a cross-section of the piece of wood.

In this way, the growth rings in pieces of old or fossilised wood can be compared with a standard scale of growth rings. The standard scale is constructed by analysing many different trees in a particular region and devising a pattern to show the growth rings. The process is shown in Figure 2.2.8. This method can only be used by comparing wood with trees from the same climatic region, because the climate affects how trees grow. For example, a piece of wood from Australia cannot be dated by using tree growth rings from another country. You could not even compare a piece of wood from Victoria with one from the Northern Territory because they have different climates and so different growth rates.

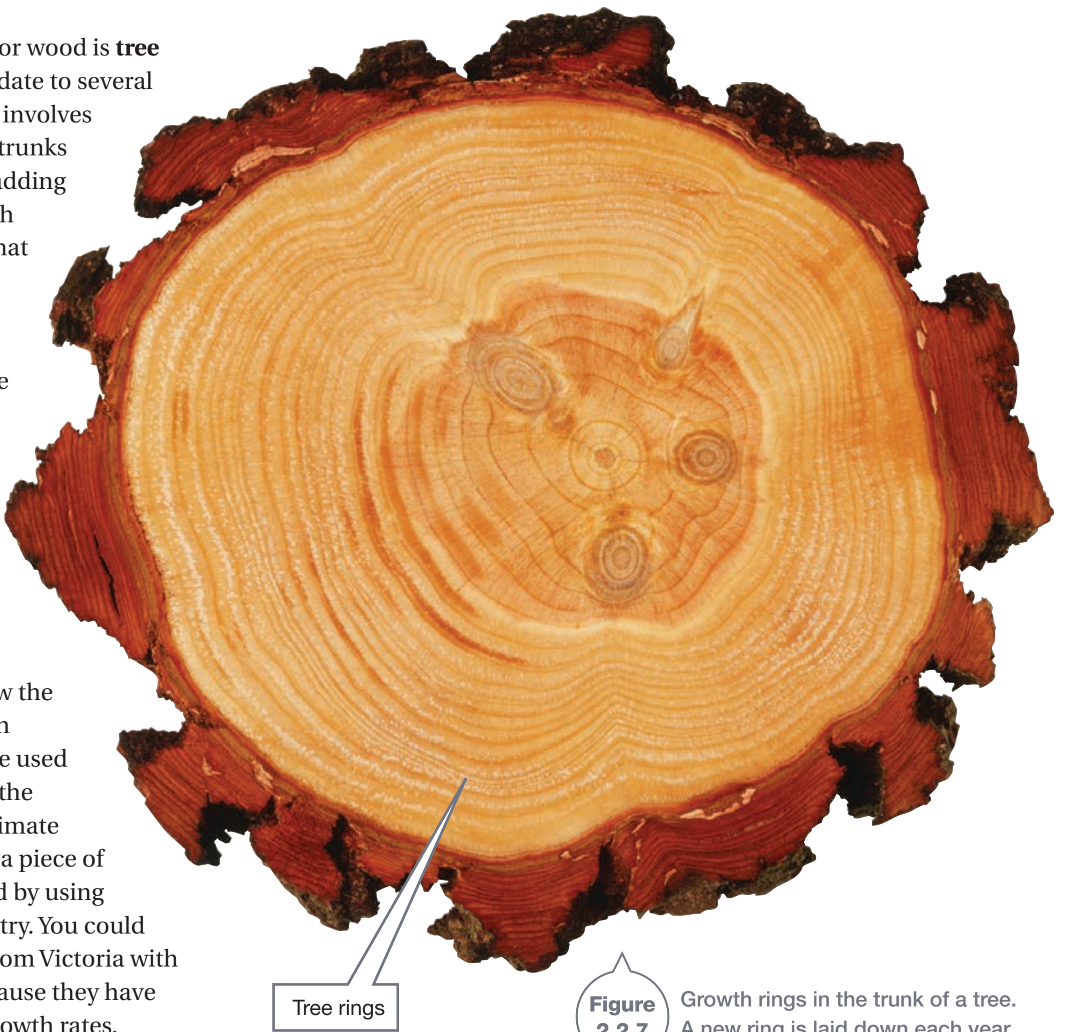


Figure 2.2.7 Growth rings in the trunk of a tree. A new ring is laid down each year.

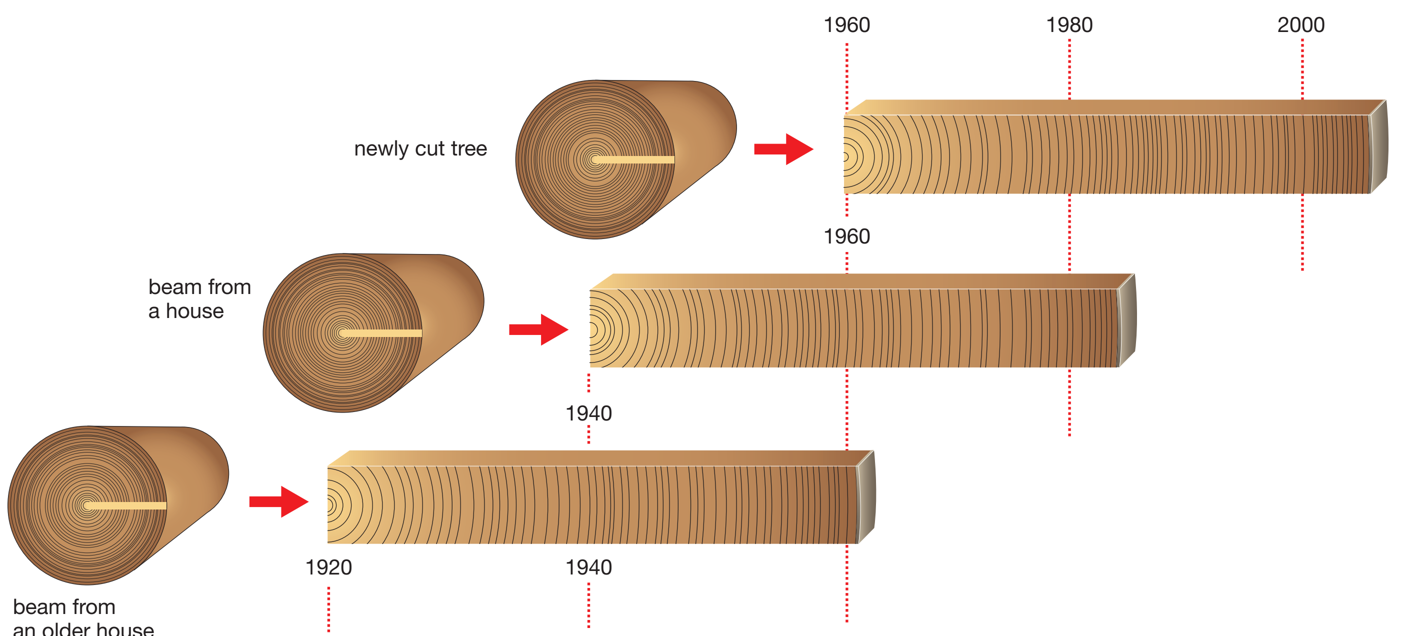


Figure 2.2.8 Growth rings are compared to find an age. By starting with a piece of wood of known age, similar spaced rings in different samples of wood can be matched and overlapped. In this way, a continuous record can be produced that extends back many thousands of years.

2.2 Unit review

Remembering

1 **List** two types of relative dating.

2 **Name** two animal groups commonly used as index fossils.

3 **List** three characteristics a fossil must have to be useful as an index fossil.

4 **List** two types of absolute dating.

5 **State** the meaning of half-life in radioactive decay.

Understanding

6 **Define** the terms:

a relative dating

b stratigraphy

c absolute dating.

7 **Explain** why fossils in the lower layers of rock are usually older than ones in higher layers.

8 **Outline** how trilobite fossils could be used to compare the relative ages of two rock layers from different countries.

9 **Explain** how fluorine analysis is useful in relative dating.

10 **Explain** how radioactive isotopes can be used to date the age of a rock.

Applying

11 **Use** Figure 2.2.3 on page 50 to **identify** two trilobites which lived towards the end of trilobite history.

12 Figure 2.2.9 shows a trilobite called *Ptychagnostus atavus*. This is one of the earliest trilobites yet discovered. It was only a few millimetres long and was blind because it had no eyes. Scientists have concluded that it lived in the depths of the ocean. Fossils of this species have been found in Australia, Vietnam, China, Korea, Russia, Scandinavia, Great Britain, Greenland, Canada and the US. Dating by stratigraphy placed the first appearance of this species to 506 million years ago. In 2005, scientists agreed to make this trilobite an index fossil for this time in the Earth's history. The species was shown to only occur in strata from 500–506 million years ago.

a **Use** Figure 2.2.3 on page 50 to **identify** the name of the time period in which this species lived.

b **Identify** two trilobite species that appeared in the fossil record not long after this species.

c **List** the rules for index fossils and **demonstrate** how they apply to this trilobite species.

Figure 2.2.9 *Ptychagnostus atavus*

Analysing

13 At Emu Bay on Kangaroo Island, South Australia, is a world-famous well-preserved Early Cambrian fossil site. One species called *Anomelocaris* is identical to those found at the Burgess Shale and Chengjiang in China. Several trilobites found at Emu Bay also occur at Chengjiang. However, Emu Bay also has some unique trilobites that have not been found anywhere else. They are called *Emuella* and are shown in Figure 2.2.10.

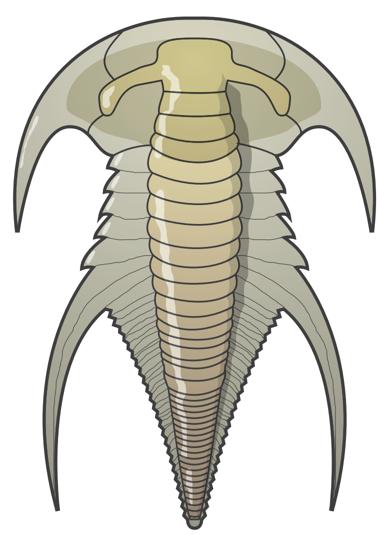


Figure 2.2.10 *Emuella polymera* fossil

a **Analyse** the information here and discuss how Emu Bay could be dated.

b **Critically analyse** the information and comment on whether *Emuella* could be used as an index fossil.

14 **Compare** tree ring dating and radioactive dating as possible methods for wood preserved as a:
 a carbon film fossil
 b replacement fossil.

Evaluating

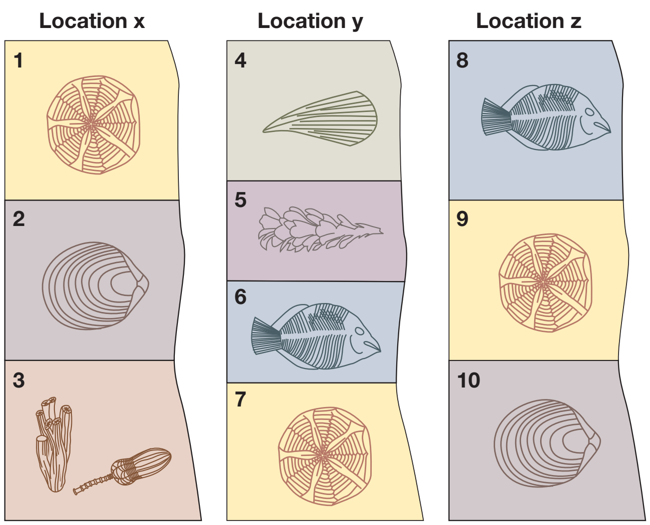


Figure 2.2.11

15 a **Deduce** the strata that are of the same age in Figure 2.2.11.
 b **Explain** how you decided this.
 c **Deduce** the layers in order from the oldest to the youngest.

16 **Justify** why trilobites are suitable as index fossils and birds and humans are not.

17 **Propose** a suitable method of dating for each of the following situations.
 a Showing that two bones were not from the same cave
 b Proving a piece of wood was about 30 000 years old
 c Dating a wooden box found in an Egyptian tomb
 d Dating a primitive looking stone tool found in a rock layer near an extinct volcano
 e Showing that the skeletons of two suspected murder victims buried in the same place had been there for different amounts of time
 f Comparing two rock layers from different countries that cannot be radioactively dated but which contained fossils such as trilobites and ammonites

18 **Propose** reasons why all trilobite fossils would not look like Figure 2.2.2 on page 49.

19 **Propose** why tree rings may not be able to be used to date wood found in an ancient sunken ship.

Creating

20 Artefacts are objects made by humans, such as stone tools, ceramic containers and paintings. Index artefacts have been identified and are regularly used to determine the age of human remains. For example, stone tool cultures such as Mousterian and Acheulian are used for indexing.
 a **Identify** what you think could be used as an index artefact for the 21st century. Imagine that many thousands of years into the future another civilisation will look back at us and use the artefact to place our time on a scale compared with earlier centuries. Your index artefact needs to have the same requirements as index fossils.
 b **Construct** an argument for your artefact as an index artefact for the 21st century.

Inquiring

1 Research the ammonites as a group of animals. Describe what they looked like and explain how they are useful as index fossils.

2 There is a primitive crablike creature alive today called a horseshoe crab. Find images of the crabs and compare them with trilobites. Research any features these groups share and discuss whether palaeontologists think trilobites may be related to the horseshoe crab.

3 Pollen can be a good index fossil. Petroleum geologists use it to find new oil and gas. Research and explain how they do this.

4 Design a way of determining the age of a twig or a small branch from a tree.

2.2 Practical activities

1 Radioactive decay

Purpose

To simulate radioactive decay and draw a decay curve.

Materials

- 100 counters or similar with one side marked
- container to shake up counters
- graph paper

Procedure

1. Shake up your 100 counters in your container so that they are thoroughly mixed. Tip the counters onto the bench. Spread them out so that none is being covered by another.
2. The counters that have their marked face showing are decayed atoms. Put these in a pile on a piece of paper labelled 'Time 1'. On your piece of paper write the number of decayed atoms and the number of undecayed atoms. Because there are 100 counters, this figure will be a percentage.
3. Leave the decayed atoms on the paper until the end of the experiment. Return the remaining counters (the undecayed atoms) to your container and shake them thoroughly again. Repeat step 2 but put this pile of counters on a different sheet of paper labelled 'Time 2'. Again record how many decayed and undecayed atoms there are on the paper.
4. Repeat these steps until all atoms are decayed.

Results

1. Copy and complete the following table by writing in your results from the record sheets. The first two entries should be 0 and 100. Your table will start like the one shown here, but have many more rows.

Time	% Undecayed
0	100
1	
2	

2. Collect results from the whole class and obtain a class average for the table.
3. Use the class results to construct a line graph with Time number (0, 1 etc.) on the horizontal axis and Per cent undecayed on the vertical axis (from 0 to 100).

   Your graph should be similar to Figure 2.2.12.

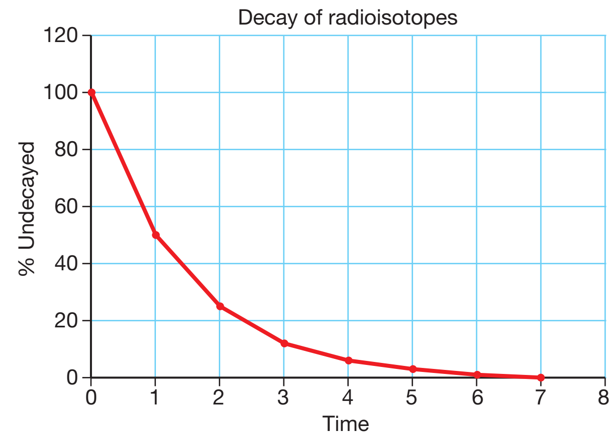


Figure 2.2.12

Discussion

1. In this experiment, **identify** what represents a decayed atom.
2. a **Describe** the shape of your graph.
   b **Compare** its shape with Figure 2.2.6 (page 51).
3. Use the graph to **estimate** how many throws it took for half (50%) of your atoms to decay. This is the half-life of your radioactive source.
4. The half-life in this experiment should have been one unit of time (i.e. 1 throw), because every counter had a 50% chance of decaying. So half of the counters should have decayed. **Compare** your estimate from the graph with what was expected.
5. **Propose** how you could make this experiment more accurate.