

6. Fossils and Evolution

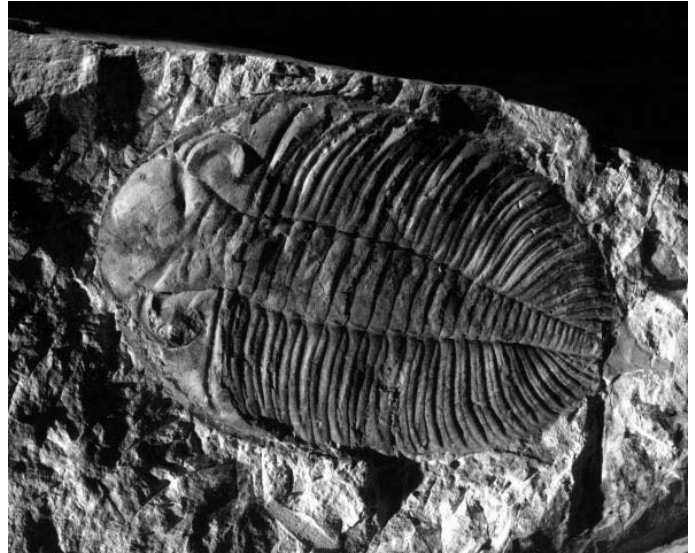
What evidence do scientists have to explain that life on earth has existed for millions of years? How are they able to determine evolutionary relationships between organisms? Until recently scientists relied upon the fossil record to provide vital clues on the evolutionary process. Over more recent times, carbon dating and DNA sequencing have enabled scientists to obtain further insights into the evolution of life on earth.

What are Fossils?

The word fossil comes from the Latin *fossilis* meaning 'dug up'. Fossils are the remains, moulds, or traces of organisms that died a long time ago and are usually preserved in sedimentary rocks such as sandstones, limestones, siltstones or shales.

When most animals or plants die, their bodies are attacked by decomposers until nothing remains. The chance of any dead organism being preserved as a fossil is quite small.

The fossil record provides only an incomplete record of the earth's past. This is because some organisms, in particular soft-bodied organisms, rarely form fossils. Many other fossils still remain hidden under layers of rocks and minerals. However, if the hard parts (bone, teeth, shells and wood) were covered by a sudden flood, sand or volcanic ash they might be preserved.



Trilobite fossil.
Source: Museum Victoria

Fossils are one of the most important sources of information about the Earth's past. They can tell us the age of the rocks in which they are found, what the environment was like when the fossilised organisms were alive, and even how the organisms functioned. They can also tell us about Earth movements, such as mountain building, about the former positions of continents (ancient geography), and about the evolution of life on Earth. Some of these uses for fossils are of economic importance, assisting in the search for oil and minerals.

Fossils as age indicators

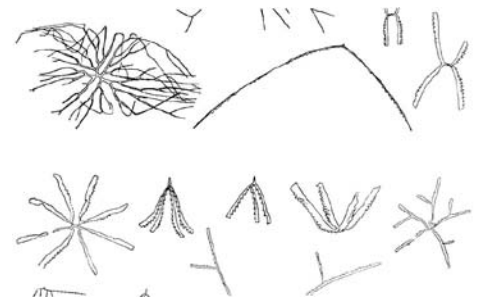
Fossils are the most important means of dating sedimentary rock sequences. However, they do not provide an absolute age measured in years, but rather a relative age expressed in terms of the relative Geological Time Scale. The use of fossils in this way relies on the fact that individual species evolved into others through time. If the time range of a species is known in one particular region, the occurrence of the same species in another region indicates that the rocks there are of the same age. This process of establishing the equivalence in age of two rock sequences in different areas is called *correlation*.

Not all fossils are of equal value in dating rocks; the most useful are called *index* or *zone fossils*. Ideally, index fossils should be common, readily preserved and easily recognisable. They should have spread rapidly and widely, and for accuracy of dating, they should have evolved rapidly so that individual species existed during only a short interval of time. Very few index fossils meet all of these criteria. Amongst the most important index fossils are graptolites, ammonites, foraminifera, pollen, conodonts and trilobites.

Victorian Graptolites

One of the most important groups of index fossils in the Palaeozoic rocks of Victoria is the graptolites. These were extinct marine animals that formed twig-like colonies composed of one or more branches. The colonies were originally three-dimensional but usually became completely flattened during fossilisation, though they are still easily recognisable. Some graptolite colonies may have been attached to the sea floor, but most floated freely in the sea. They are of most use in dating rocks ranging in age from Early Ordovician to Early Devonian.

The Ordovician rocks of central and eastern Victoria have one of the richest and most diverse graptolite faunas in the world. They have been used to subdivide the rock sequences into 30 intervals, and to correlate these intervals accurately with other sequences in New Zealand, Asia, Europe and North America.



Graptolites.
Source: Museum Victoria

Fossils as environmental indicators

Because fossils are the remains of once living organisms that were adapted to their environments, they can provide valuable information about what past environments were like. We can predict the environmental requirements of organisms in the past from those of closely related organisms living in the present day. Such predictions will be most reliable in the case of younger rocks which contain fossils having representatives alive today. As we go further back in geological time, the predictions become less reliable because we encounter fossils of extinct groups about whose environmental requirements nothing is directly known.

The environmental information obtained from fossils may be as simple as whether the rocks in which they occur were deposited in the sea, in a brackish water estuary, in fresh water, or on the land. For example, rocks containing fossils of corals, brachiopods, cephalopods or echinoderms must have been deposited in the sea because living representatives of those groups are found only in the sea today. Similarly, fossils of land-dwelling animals such as kangaroos indicate deposition on land or in an adjacent body of fresh water.

Fossils of reef-building corals indicate that the rocks in which they occur were deposited in warm, shallow seas. At the present day, reef-forming corals are found in tropical seas and only at depths of less than 200 metres where sunlight can penetrate the water to reach the photosynthesising algae within their cells.

Koonwarra Fossils

The Koonwarra fossil bed of South Gippsland provides a good example of the use of fossils in reconstructing an ancient environment. This fossil bed has been dated at 115–118 million years old, and contains fossilised fish, plants, insects, crustaceans, spiders, bird feathers and a horseshoe crab. There are also bryozoans and a mussel. Palaeontologists have been able to work out that the deposit was formed in the shallow part of a large freshwater lake because the insects include mayflies that are similar to forms living today in cool mountain streams and lakes in Tasmania. The lake may have been frozen in winter because the many fish fossils show no signs of rotting. This conclusion is supported to some extent by the occurrence of a beetle that is similar to a modern species found only in alpine areas. The occurrence of fleas in the fossil fauna suggests that mammals may have been present on the adjacent land, and the occurrence of feathers shows that birds were also present. The small size of the fish suggests that they were juveniles or small adults, which inhabit shallow areas in modern bodies of fresh water. The insects are well preserved, even those that were not aquatic, suggesting that they were not transported great distances after death, so that the fossil deposits must have been formed close to the edge of the body of water.



Koonwarra fossil insects.
Source: Museum Victoria.

For more examples, visit <http://www.museum.vic.gov.au/prehistoric/fossils/koonwarra.html>

Fossils as indicators of Earth movements

The occurrence of fossils at a particular locality may provide evidence that there has been some movement of the Earth's crust since the fossils were deposited. The movement may have been only slight uplift of the land, as indicated, for example, by the occurrence of fossils of marine shells in cliffs around Port Phillip Bay. Alternatively, the uplift may have been on a much larger scale, as indicated by the occurrence of marine fossils far from present-day oceans and even in the middle of continents, or on high mountains, such as the Himalayas or the European Alps.

The Whitelaw Fault at Bendigo

Movement of the Earth's crust along faults or fractures may be indicated, even if the fracture itself is not evident, by the occurrence of fossils of very different ages at adjacent localities. For example, the Whitelaw Fault on the eastern outskirts of Bendigo is not marked by any obvious landform. Its presence is indicated by the occurrence of graptolites of Middle Ordovician age (about 470 million years old) on one side of the fault, in close proximity to Early Ordovician graptolites (about 493 million years old) on the other side.

Fossils as indicators of ancient geography

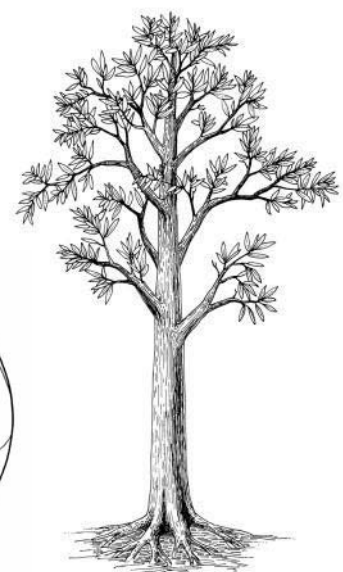
As long ago as the middle of the eighteenth century, it became apparent to some palaeontologists that there were sometimes striking similarities in the assemblages of fossils found in rocks of the same age in widely separated continents. The similarities could not be satisfactorily explained by the migration of organisms across vast expanses of ocean, because the fossils belonged to forms that lived only in shallow marine environments, in fresh water, or even on dry land. A few scientists suggested that these similarities were due to the fact that the continents were once joined together and later split apart, but this suggestion was rejected by most geologists because at that time there was no known mechanism by which the continents could move. The favoured explanation then was that organisms had migrated across 'land bridges', which had connected the continents in ancient times but which had later subsided to form part of the present-day ocean floor. We now know that this could not have occurred, because the Earth's crust on the floor of the oceans differs in composition from that of the continents. With the development of the theory of plate tectonics in the 1960s, leading to the widespread acceptance of continental drift, the similarities in the fossil faunas in different continents could be readily explained by the drifting apart of land masses that formerly lay together.

Gondwanan Fossils

One example of the fossil evidence that the continents were connected in the past is the distribution of the ancient seed-fern *Glossopteris* and related plants. The fossils of these plants are associated with coal deposits of Permian age in India, Australia, South Africa, South America and Antarctica. The rock sequences in which these coal deposits occur are remarkably similar on all of these continents. The distribution of these plants cannot be explained by wind dispersal of their seeds, as these are too large to have been carried across the ocean. A further line of evidence is the distribution of the reptile *Mesosaurus*, which is found in Brazil and South Africa at or near the Carboniferous-Permian boundary. *Mesosaurus* lived in fresh or perhaps brackish water habitats, so it is difficult to imagine that it could have found its way across an ocean as broad as the present day Atlantic.



Gondwana, 150 million years ago.
Artist: Karina H. McInnes / Source: Museum Victoria



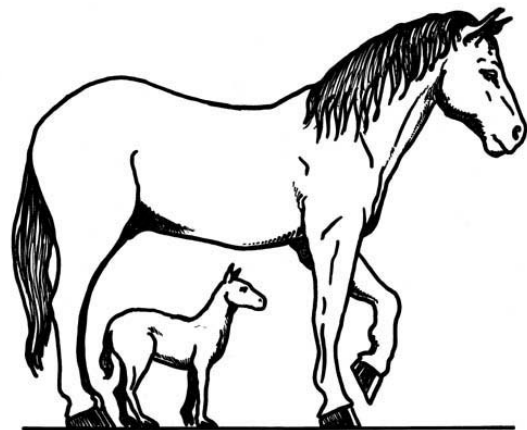
Glossopteris.
Artist: Kate Nolan / Source: Museum Victoria

Fossils as evidence for the evolution of life

Fossils are the main sources of information on the evolution of life on Earth. Without the information they provide, we would have no knowledge of extinct organisms such as trilobites and dinosaurs, and our knowledge of the history of the development and evolutionary relationships of the modern flora and fauna could be derived only from the living organisms themselves. We would also have no direct knowledge of the timing of critical biological events, such as the origin of life, the development of shells or skeletons, the colonisation of the land, the appearance of mammals and flowering plants, the development of flight, and major episodes of extinction.

Evolution of the Horse

The role that fossils have played in deciphering relationships among organisms can be demonstrated by the evolution of horses, the family of mammals with probably the best fossil record. The development of the modern horse from its oldest known ancestors can be traced via a number of morphological changes, including body size, shape of teeth, and the structure of the feet. These morphological changes reflect changes in habitat and feeding. Browsing on soft leaves in forests was replaced by grazing on hard grasses on open plains. The oldest known horse, *Hyracotherium*, lived during the early Eocene (about 50 million years ago). It was a dog-sized creature with short-crowned teeth, and with four toes on the front feet and three toes on the back feet. Each toe had a small hoof. In descendants of *Hyracotherium*, there was a progressive increase in body size, to the size of the modern horse. The teeth developed long crowns with complex enamel ridges for grinding hard grasses, and the number of toes was progressively reduced to one on both front and hind feet.



Hyracotherium, compared with the modern horse.
Artist: Frey Micklethwait / Source: Museum Victoria

7. DNA and Evolution

Until quite recently organisms have been described mainly by their body structure – for example, the shape and size of teeth, number of chambers in the heart and the colour of body coverings. Research over the last few decades has enabled scientists to now consider genetic evidence. DNA sequencing has provided new information on the evolutionary relationships of organisms.

Ancient DNA

Small fragments of DNA can sometimes be found in the remains of long-dead plants and animals. Whether decades old or from thousands of years ago, this is called ancient DNA. When an organism dies its DNA is rapidly broken down into smaller and smaller fragments through the action of enzymes, oxygen and water. Sometimes this process is slowed, enabling small fragments of DNA to survive within the preserved remains of the organism.

Ancient DNA many thousands of years old can only be found in the remains of organisms preserved under extraordinary conditions. Plants and animals buried in volcanic ash, trapped in amber, frozen deep in the polar ice, or preserved in arid environments may retain fragments of ancient DNA because these environments lack oxygen and water. Ancient DNA also survives longer when combined with other substances. Hydroxyapatite (a calcium-containing compound found in bones and teeth), some proteins and sugars can all prolong the life of ancient DNA.

Ancient DNA has been found in the remains of extinct plants and animals, Egyptian mummies and even fossilised dung. However, the vast majority of fossilised plant and animal material does not contain ancient DNA.

Mitochondrial DNA

Mitochondria are small energy producing organelles found in the cytoplasm of cells. They contain an independent strand of DNA with genes specific for their function. When sperm and egg cells fuse to form a zygote during sexual reproduction, only the mitochondria in the egg survive. Those in the sperm are lost. This means that mitochondrial DNA (mtDNA) is passed through generations along the maternal line, in other words, from grandmother to mother to daughter. The fact that the tiny mitochondrial genome, unlike the much larger nuclear genome, is directly transmitted through the maternal line without mixing or recombination, makes it ideal to trace family lineages - local family groups, large cultural or racial groups and closely related species groups, such as closely related hominid species.



*Ancient DNA has been extracted from mummified human bodies ranging in age from 1200 to 5000 years old.
Source: Museum Victoria*

What DNA Tells Us

DNA (ancient DNA, mitochondrial DNA and modern DNA) provides an unbroken thread linking the history of all living things back to the origin of life. Scientists can obtain DNA from many living and even some once living things.

DNA can be used as a tool to study evolution. By comparing the DNA of different species we can see how closely related they are and sometimes trace the pathway through which they evolved. The more closely related two organisms are, the more similar their DNA will be. Conversely, species with very different DNA are not closely related. This DNA information gives us clues not only about how closely related two species are, but also how long ago they diverged from one another.

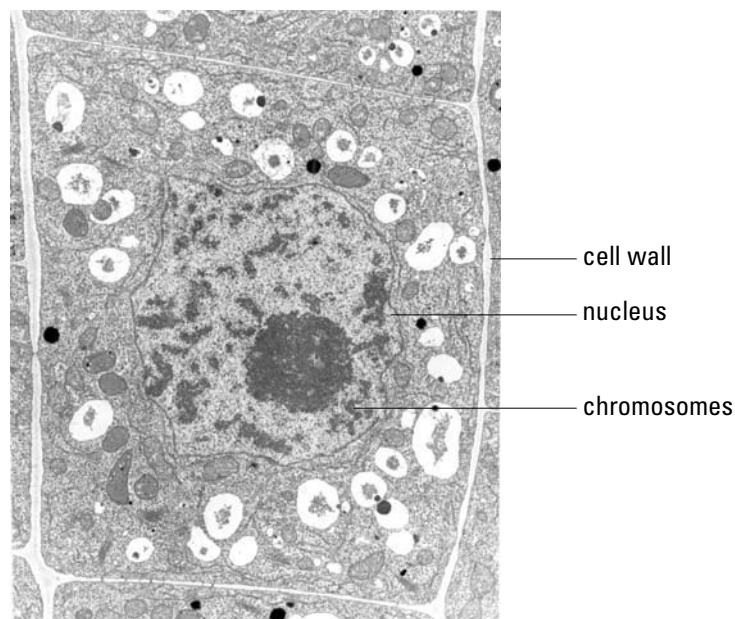
Scientists believe that DNA has been accumulating mutations at a fairly constant rate, just as a clock ticks away second by second. As a result they can use the number of differences between two otherwise similar DNA sequences to determine how long ago two species evolved.

Scientists have been studying ancient DNA to find out:

- What types of plants and animals lived at a particular time in the past.
- What extinct animals ate.
- How similar (genetically) extinct plants and animals were to living species.
- What animals were hunted by ancient humans.
- How ancient human cultures lived.
- What types of disease were present in ancient human populations.

A timeline of Ancient DNA Time-line showing the age of specimens used in attempts to extract DNA is available on the Museum Victoria website, at http://www.museum.vic.gov.au/scidiscovery/dna/ancient_dna.asp. Most attempts to extract ancient DNA from specimens older than 100 000 years have failed. In many cases no DNA was found. In others, the extracted DNA was actually a combination of human and bacterial DNA contamination. This is quite a problem because fragments of DNA from living and recently dead organisms of all types is very widespread.

Unfortunately, most fossils older than 100,000 years do not contain DNA suitable for analysis. Any DNA that could be recovered would be so poorly preserved that we would only have tiny fragments of the animal's genetic code.



*Plant cell showing cell wall and DNA in the form of chromosomes within the nucleus.
Source: Museum Victoria*

8. Evolutionary Milestones

- Human Evolution (Segment 'Hominid Evolution', Darwin to DNA exhibition))

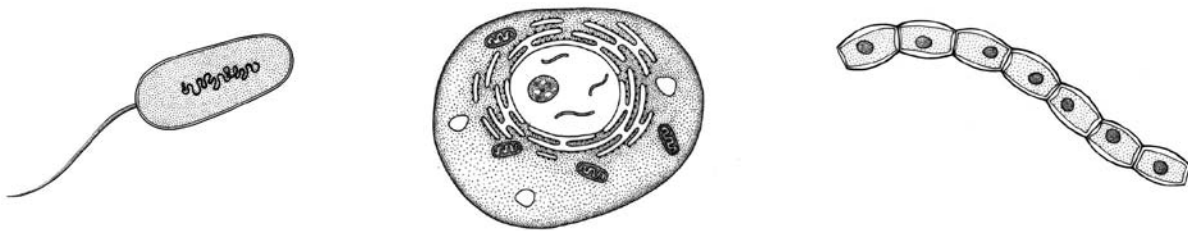
The oldest evidence for life on Earth

Simple life forms existed on the Earth 3,500 million years ago. Fossils thought to be evidence of once-living cells have been discovered in rocks of this age in Western Australia and South Africa. The fossils are of two types: finely layered structures called stromatolites; and microscopic spheroidal or thread-like structures. These fossils show that life originated within the first 1,000 million years of the Earth's existence.

Primitive cells, complex cells and multicellular organisms

The very earliest organisms in the fossil record are cells of a very simple, primitive type where the DNA is free within the cell, and the cell is without internal structures. Cells of this type, called **prokaryotes**, are represented by bacteria and some other single-celled organisms living at the present day.

By 1,700 million years ago other cells had appeared, called **eukaryotes**. Most of the DNA of eukaryotes is contained in a nucleus, and the various functions of the cell are carried out by separate internal structures, some of which contain their own DNA. Eukaryotes compose over 99% of organisms living today, including all multicellular organisms. The appearance of eukaryotes was therefore one of the most significant evolutionary developments within the living world. Fossils of eukaryotes are known from Western Australia, in rocks dated at about 1,500 million years old, and from 800 million year old rocks from central Australia.



Prokaryotic cell

Artist: Kate Nolan / Source: Museum Victoria

Eukaryotic cell

Multicellular organism

Multicellular organisms evolved from single-celled eukaryotes. The first multi-cellular organisms were seaweeds, known from 1,300 million year old rocks from the United States. Multi-cellular animals, or metazoa, seem to have appeared somewhat later. The first evidence for them is found in rocks 900 million years old and consists of burrows made by worm-like animals, though the animals themselves are not preserved. The oldest known fossils of the bodies of multicellular animals are about 600 million years old.

Ediacaran fauna

In 1946 a South Australian geologist, Reg Sprigg, discovered fossil impressions of the oldest known multi-cellular animals, in the Ediacara Hills, north of Adelaide. Similar fossils have since been found at other localities in Australia, and in South Africa, Europe, Asia, North America and possibly South America. These fossils, which are known collectively as the Ediacaran fauna after the locality where they were first found, are all between 580 and 650 million years old. They include a variety of circular, leaf-like, frond-like or segmented organisms, all of them entirely soft-bodied. It is still uncertain what types of animals these fossils represent. Some have been interpreted as jelly fish, worms, soft corals, echinoderms and arthropods, but some scientists now believe they may belong to types of organisms no longer surviving at the present day. It is clear, however, that the animals of the Ediacaran fauna are not the ancestors of the shelled animals that first appear in the fossil record in younger rocks of Cambrian age, around 570 million years ago.

Oxygen in the atmosphere

The Earth's original atmosphere was formed from gases released during cooling of the planet. It would have contained little or no oxygen, and so could not have supported animal life. Scientists agree that, as a result of photosynthesis, the level of oxygen in the atmosphere gradually increased during the Precambrian. Photosynthesis is a chemical process where plants, and some bacteria, use sunlight to make chemicals (such as sugars) for energy, from carbon dioxide and water, at the same time releasing oxygen as a waste product. Present-day stromatolites are photosynthetic, and scientists think that stromatolites from 3,500 million years ago were too. Oxygen had apparently reached moderate levels in the Earth's atmosphere by 2,000 million years ago.

Stromatolites

Stromatolites are sheet-like, mound-like or columnar structures formed by primitive bacterial communities. These structures are made of a hard limestone-like substance, and range in size from a centimetre to several metres across. Inside, they are made of many fine concentric layers. Stromatolites are the most noticeable fossils known in Precambrian rocks, and were most common between 2500 million and 700 million years ago. They are rarer in younger rocks, probably due to the evolution of grazing invertebrates such as snails, which ate the bacteria depositing the stromatolites. Though rare at the present day, modern stromatolites can still be found in environments where grazing invertebrates are uncommon.



*Stromatolites at Shark Bay, W.A.
Photographer / Source: Malcolm Wallace*

Banded iron formations

Banded iron formations are sedimentary rocks made up of alternating layers of iron-rich minerals and chert, a form of quartz. These formations are the source of most of the iron ore mined in the world, such as in the Hamersley Ranges in Western Australia. Banded iron formations are believed to have formed by iron minerals dissolved in sea water combining with oxygen, and falling out, or precipitating from the water. This is evidence that there was enough oxygen in the atmosphere at that time to cause iron minerals to precipitate. Banded iron formations reached their maximum development about 2,000 million years ago.

Life Develops in the Sea

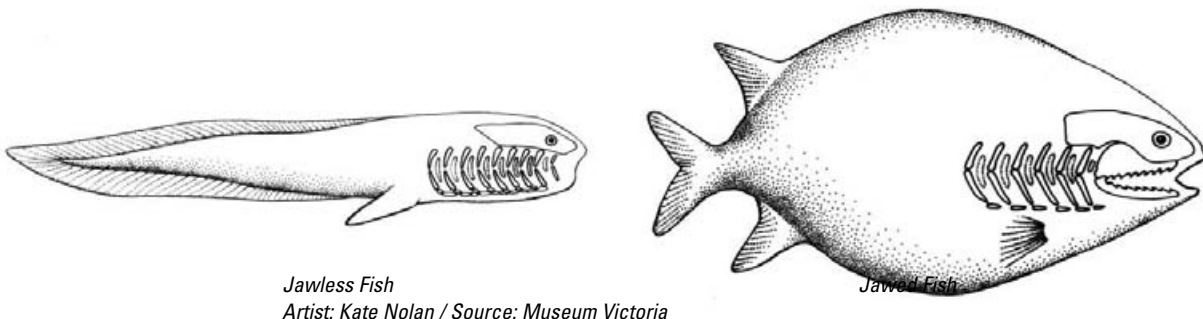
At the beginning of the Palaeozoic 570 million years ago, a great explosion in the diversity of life occurred. The seas became populated with a wide variety of animals in a very short period of time. By the end of the first period of the Palaeozoic, the Cambrian, all of the major groups (phyla) of animals alive today, had evolved. In later periods, fish evolved and diversified. For the first several hundred million years of the Palaeozoic, animals were found only in the sea.

The first animals with hard body parts/ Cambrian explosion

Animals with hard body parts, such as shells or other skeletal elements, appeared at the beginning of the Cambrian period, around 570 million years ago. Organisms may have evolved hard body parts as a protection from predators. The evolution of hard body parts may also have been helped by an increase in the amount of phosphate or carbonate in the oceans, as these are the minerals used by organisms for making hard parts. The ability to build hard parts was a major evolutionary development that led to a spectacular diversification of life in the seas. During this period almost all the major groups (phyla) of animals alive today appeared, including arthropods, brachiopods, molluscs, echinoderms and sponges. The fossilised hard parts from the Cambrian reveal a great diversity of marine life at a very early stage in the history of multicellular life.

Evolution of Jaws in fish

The earliest fish, from the Ordovician and Silurian, had no jaws, just a mouth opening which sometimes contained teeth. Fish with jaws first appeared during the Devonian Period about 400 million years ago. Their jaws evolved from modified gill arches, which are the bones that support the breathing structures (gills) of fish. Jawless fish are thought to have fed by sucking food from the ocean floor, although modern jawless fish (lampreys and hagfish) suck the blood of other fish. Having jaws made many different ways of life available to fish that were not available to jawless species. With the evolution of jaws, there was a great explosion in the diversity of jawed fish species during the Devonian. At the same time, most of the jawless fish species disappeared.



Jawless Fish
Artist: Kate Nolan / Source: Museum Victoria

Jawed Fish

Invasion of the Land

The biggest problem that organisms faced when they first colonised the land, was the air. In the water, organisms 'breathed' by absorbing oxygen through their body surfaces or through delicate structures such as gills, which needed moisture to operate. On land, these ways of breathing would not work. Air also dried out the surfaces of organisms. The third problem they faced on land, was that air did not support their bodies against gravity as much as water did. To live successfully on land, organisms needed to evolve to combat the problems that a life in the air presented.

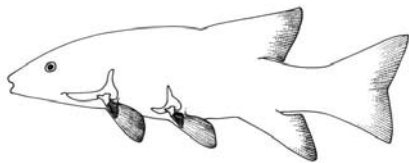
First Land Invertebrates

The first animals to move out of the seas were probably the eurypterids, or water scorpions. These were fearsome predators that reached lengths of two metres or more, making them the largest arthropods that have ever lived. Many of them had large claws for grasping prey. The oldest known eurypterids, from the Ordovician Period (510 to 439 million years ago), were marine, but by Silurian times (439 to 409 million years ago) some had migrated into brackish or freshwater environments, and some were even amphibious as shown by their development of lungs. However, none became adapted completely to a life on dry land.

First Land Vertebrates/The Evolution of Limbs

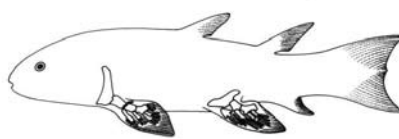
The first fossils of land dwelling (terrestrial) vertebrates are found in the Late Devonian Period (around 370 million years ago). These early land dwellers evolved from bony fishes.

There are two major groups of fishes: (a) *sharks and rays*, which have a skeleton of cartilage; and (b) *bony fishes* that have a skeleton of bone. Bony fishes can be divided into two groups: (i) the *ray-finned fishes* whose fins are supported by delicate rods only; and (ii) the *lobe-finned fishes* with a few large bones as well as rods, in their fins. Today, the ray-finned fishes plus the sharks, skates and rays dominate the sea and freshwater, but it was the lobe-finned fishes which gave rise to terrestrial vertebrates. The bones in the fins of the lobe-finned fishes were able to support the weight of the first vertebrates to venture onto land, and in time evolved into the limbs of terrestrial vertebrates.

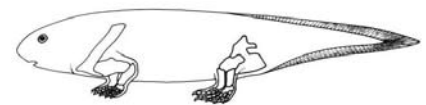


Ray-Finned fish

Artist: Kate Nolan / Source: Museum Victoria



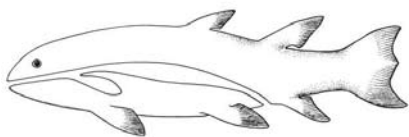
Lobe-Finned Fish



Primitive Amphibian

Evolution of Lungs

Lungs first evolved in fishes about 400 million years ago as simple air sacs that helped to control buoyancy. In a few groups of fishes, the air sacs developed blood vessels that allowed the exchange of gas between the air and fishes' bodies. Some palaeontologists think that fishes used these primitive lungs to survive in stagnant pools and during droughts.



Air sac

Artist: Kate Nolan / Source: Museum Victoria



Primitive lung

First Land Plants

The first plants that colonised the land needed support against gravity, protection from dehydration, and a way to move nutrients throughout their bodies. To carry out these functions, almost all land plants evolved rigid hollow (vascular) tubes inside, that provided a rigid framework, and moved liquids and nutrients to all parts of the plant. As well, small openings in the plants' surface (called stomata) evolved which could be opened and closed to regulate the flow of gases and water. Plants with these stomata and vascular tubes are known as vascular plants, and include almost all of the present day species of land plants.

Baragwanathia is one of the earliest land plants known, and at over half a metre in length, was one of the largest plants of its time. It has been found in late Silurian period rocks, around 415 million years old, from many sites in eastern central Victoria. *Baragwanathia* is thought to have lived in swampy areas with its roots in the water, much like the present day lycopods (clubmosses). The earliest land plants elsewhere are quite rare and very small.

Early Amphibians

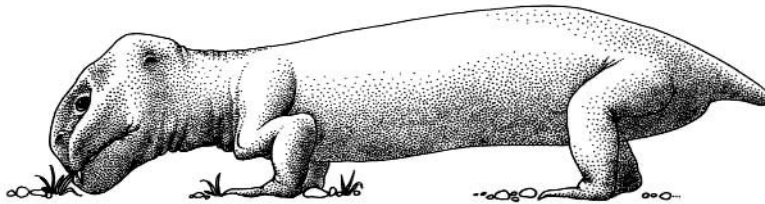
Amphibians evolved from fish near the end of the Devonian period, about 370 million years ago. In Australia, we have evidence of these early amphibians from fossilised trackways from Genoa, in eastern Victoria, as well as a fossilised bone from New South Wales. These early amphibians, known as Labyrinthodonts, did not look like present day amphibians; they were large animals with long snouts and tails, more like an alligator in appearance. Fossil amphibians from the late Devonian have also been found in other parts of the world.



Genoa amphibian.
Artist: Kate Nolan / Source: Museum Victoria

Mammal-like Reptiles

During the late Palaeozoic, the dominant land vertebrates were the mammal-like reptiles. Mammal-like reptiles appeared about 295 million years ago during the Carboniferous period, and became extinct 165 million years ago in the middle of the Jurassic period. They were most common during the Permian (290 to 245 million years ago), and the early Triassic. True mammals evolved from mammal-like reptiles in the Late Triassic about 210 million years ago.



Dicynodon.
Artist: Kate Nolan / Source: Museum Victoria

Life in the Mesozoic

Dinosaurs were the largest and most dominant land animals during the Mesozoic, but they were not the only animals from this time. Crocodylians, lizards, snakes, frogs and mammals were all found in the Mesozoic, and now-extinct reptile groups such as ichthyosaurs and pterosaurs dominated the sea and air. Invertebrate groups in the sea, and on land, continued to diversify, with some groups, such as ammonites, becoming prevalent throughout the Mesozoic.

Development of the Egg

The evolutionary development of an egg that could be laid on land and survive, was a key innovation in the history of vertebrates. Amphibian and fish eggs both need to be laid in water, as they have no protecting skin against drying out. Reptile eggs were protected from drying out by a shell that could regulate the exchange of gases and moisture between the egg and the outside atmosphere, and by a membrane, the amnion, which held a fluid in which the developing young floated. This kind of egg, called the amniotic egg after the fluid-containing membrane, enabled reptiles to become non-dependent on water for reproduction, helping them to expand into new, drier habitats. This development occurred about 300 million years ago. Fossil dinosaur eggs have been found in Mongolia and many other parts of the world, but not yet in Australia or Antarctica.

Evolution of Birds

Archaeopteryx is the oldest known bird. It lived in Germany 150 million years ago, during the late Jurassic. Except for the presence of feathers, it is remarkably similar to a small carnivorous dinosaur found in the same deposits, *Compsognathus*. Like *Compsognathus*, *Archaeopteryx* had an elongated tail with bones along its whole length, and a mouth filled with teeth. However, one important difference was that the elongated tail of *Archaeopteryx* was covered with feathers while that of *Compsognathus* was bare.

Because, among other things, both birds and small carnivorous dinosaurs have a wishbone, or furculum (essential for flight), it is thought that birds are descended from dinosaurs like *Compsognathus*. Modern birds differ from *Archaeopteryx* in several ways, including having an enlarged breastbone (the sternum) which anchors the flight muscles, and reduced bones in the tail.



Drawing of *Archaeopteryx fossil*, Berlin specimen, 1877. Artist: H. v. Meyer (1861)

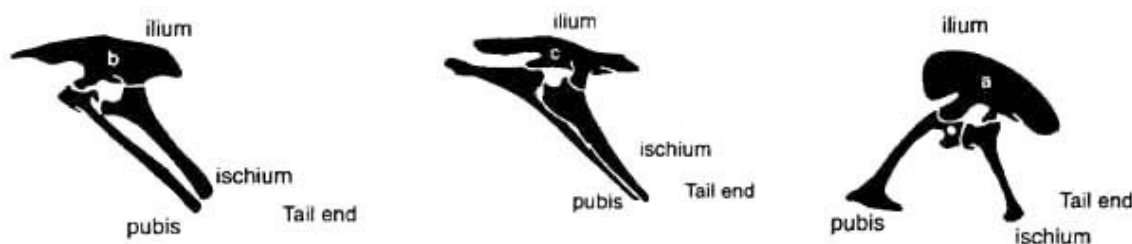
Warm Bloodedness

Warm-bloodedness, or homeothermy is the maintenance of a high, constant body temperature by the use of food energy. Animals' bodies work best when they are at a certain temperature range; too hot or too cold, and their bodies cease to function. In the present day, only mammals, birds and some fish use homeothermy to keep their body temperature constant. Other animals (known as ectotherms) maintain body temperatures by using environmental sources of energy, through behavioural adaptations such as moving between sunny and shaded areas, or living in an environment of constant temperature, such as the polar sea. Being homeothermic can be an advantage for animals, as it allows them to be active at all times, unlike ectotherms which are less active and slower when their environmental source of energy is absent. However, to keep their body temperature constant, homeotherms need to eat around ten times as much food as an ectotherm of a similar weight.

Homeothermy or developed at least twice in vertebrates once among the ancestors of mammals about 280 million years ago and again, amongst the ancestors of birds about 160 million years ago. It probably also developed amongst the pterosaurs or flying reptiles, and amongst the small predatory dinosaurs such as *Deinonychus*, which, from their skeletons appear to have been quite agile and from their brains, quite intelligent. At the other extreme of dinosaurs, the huge sauropods like *Mamenchisaurus* were probably not homeothermic.

Dinosaurs

The dinosaurs evolved about 230 million years ago and became extinct 65 million years ago. Although they were reptiles, they had a number of quite unique characteristics which separated them from other reptiles like turtles, lizards, snakes and crocodilians. These characteristics included their upright stance, the ball-like head on the thighbone or femur, the presence of no more than three bones in the fourth finger, and the pattern of weight-saving 'windows' in their skulls. Dinosaurs have been divided into two groups based on the structure of the pelvis: the *Ornithischia* or 'Bird-Hipped' dinosaurs which were all herbivorous; and the *Saurischia* or 'Lizard-Hipped' dinosaurs which included all the carnivorous species such as *Tyrannosaurus* and *Tarbosaurus*, and the long-necked herbivorous species like *Mamenchisaurus*.

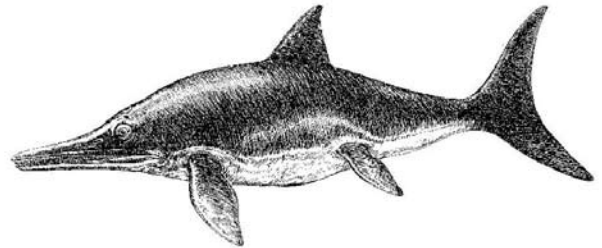


Pelvic structure of the three groups of dinosaurs – Early Ornithischia Late Ornithischia Saurischia. Source: Museum Victoria

Ichthyosaurs

Ichthyosaurs overlapped in time with the dinosaurs. They evolved slightly earlier and became extinct about 30 million years before the dinosaurs. Ichthyosaurs look much like dolphins and yet we are more closely related to dolphins than they were. This is because ichthyosaurs were reptiles while dolphins and humans are both mammals.

The ancestors of both ichthyosaurs and dolphins lived on land and returned to the sea – but one ancestor was a reptile and the other, a quite unrelated mammal. Ichthyosaurs and dolphins look so much alike because they both breathed air and became adapted to a way of life where a fish-shaped body was highly suitable. Cases in which two totally unrelated organisms evolve from quite different ancestors and yet look so much alike because their mode of life is so similar, is called convergent evolution.



Ichthyosaur.
Artist: Frey Micklethwait / Source: Museum Victoria

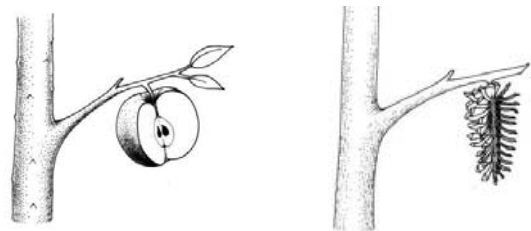
Mammals

Mammals evolved at about the same time as the dinosaurs, 225 million years ago, and throughout the Mesozoic, were small, presumably nocturnal animals. Little is known about Mesozoic mammals within Australia. We know, from an early Cretaceous jaw found at Lightning Ridge, that the egg-laying monotremes were present. Marsupials, which dominate the living mammalian fauna of Australia, were not present, but have been found in Mesozoic rocks from North America. The partial jaw of a small mammal, found at Inverloch in Victoria and named *Ausktribosphenos*, may be from a placental mammal. *Ausktribosphenos* is unique in Australia's Mesozoic fossil record, as it is the only non-monotreme or non-marsupial mammal fossil known from this time.

Evolution of Flowering Plants

Many of the plants we see around us today are flowering plants or angiosperms. The first angiosperms appeared in the fossil record, in the Cretaceous over 100 million years ago. Angiosperms differ from other vascular plants in the specialized vascular tubes that flowering plants evolved to transport water and food around their bodies.

Angiosperms also differ from other plants in the way they protect and nourish their seeds. The seeds of non-flowering plants are bare while those of flowering plants are enclosed in fruit. As they evolved, it is thought that angiosperms became more and more efficient at transporting food and water, and devoted more and more resources into producing successful seeds. These are some of the adaptations that may have helped angiosperms to become the most diverse and common plant group on the planet.



Angiosperm and Non-Angiosperm.
Artist: Kate Nolan / Source: Museum Victoria

Human Evolution

(See 'Hominid Evolution' displays, in Darwin to DNA exhibition)

The taxonomic order Primates refers to the placental group of mammals that include all apes, humans and monkeys. Primates share a suite of physical features suited to arboreal life (associated with trees). As a group they have a tendency towards upper body erectness associated with sitting, standing, and leaping. The collarbone (clavicle) allows flexibility of the shoulder joint. Five digits on the hands and feet are usually well developed for grasping, and the thumb and big toe (except *Homo*) are opposable to other digits. Digits have nails rather than claws. They have forward facing eyes with well developed, and often, stereoscopic vision and excellent hand eye co-ordination. Primates have relatively large brains, well developed parental care and relatively complex social behaviours. Anthropoids are a sub-order of Primates including lemurs, orangutans, gorillas, chimpanzees and humans. They share characteristics, relative to other primates, including: larger brains, short jaws resulting in flat faces, four upper and lower incisors, fully opposable thumbs and no tail.

Hominid refers to a group of Anthropoids that are more closely related to humans than to any other living species, including chimpanzees or gorillas. Generally, it refers to all species of hominid along the human line following the last common ancestor of Humans and Great Apes. Fossil evidence suggests that many species of hominid have existed at one time or another since then. Some of these ancient species appear to have lived at the same time and some appear to have co-existed alongside one another. Humans (*Homo sapiens*) are the only hominid species alive today.

With the discovery of more and more fossil evidence over the past decade, and with recent advances in DNA studies, protein comparative studies and dating techniques, ideas about the branching pattern of Anthropoids has changed dramatically. The 'clock-like' properties of DNA, with accumulated mutations marking elapsed periods of time, has been used to revise the evolutionary divergence maps of hominids and other primates (See section *Mitochondrial DNA* on page 21).

Current estimates, using the DNA clock, suggest that:

- Orangutans (The Pongo lineage) diverged and evolved from the common ancestor of Great Apes around 15 million years ago;
- Gorillas diverged around 10 million years ago; and
- Chimpanzees and early hominids diverged somewhere between 5 and 7 million years ago.

This makes chimpanzees the closest genetic relative of modern humans. By comparing the skeletal and muscular anatomy of humans and chimpanzees, we can speculate about characteristics that belonged to the common ancestor of humans and chimpanzees; and the anatomical and behavioural changes that were pivotal in evolution for the transition of hominids to modern humans.

In the past two decades the pace of discovery of hominid fossils and artefacts has increased dramatically and the human family tree is now thought to be far less linear and far more branched than was once believed. The recent emerging view of hominid evolution suggests that a series of adaptive radiations have occurred at different times, resulting in many unique species adaptations and diverging hominid branches. One prediction of this model is that some of the anatomical features that we tend to believe characterise our human lineage – bipedalism, increased dexterity, and even a bigger brain – may have been acquired and lost in more than one species of an adaptive radiation.



Chimpanzee, the closest genetic relatives of modern humans. © Steve Bloom /Source: stevebloom.com

Human Diversity

The last few years have seen an extraordinary number of studies on the relationships of human population groups throughout the world. These studies have approached important questions, not the least of which is how long ago the great native populations of Africa, Europe, and Asia diverged from each other. The genetic markers used for these studies, naturally enough, are mitochondrial DNA.

Information encoded in the mitochondrial DNA of modern humans provides evidence to support the idea that modern humans originated in Africa around 200,000 years ago. There are two groups of mtDNA in Africa today – one uniquely African while the other is closely related to the mtDNA found all around the rest of the world. This information suggests that all other populations around the world derived from common ancestors who initially migrated from Africa. This population group would have carried only a part of the genetic diversity present in the ancestral populations at the time.

This mtDNA analysis tells us that we are all members of the one race and that there is no evidence of separate origins in Africa, Asia, Europe and the Indo-Pacific. In fact the mtDNA in Africa can be more similar to an individual in Europe than elsewhere in Africa. In the past, humans were divided into races on the basis of differences in appearance, but these differences are not reflected in our DNA.

Features that characterise people of different cultures have evidently arisen very recently in our evolutionary history. They do not appear to be the result of changes accumulated over millions of years, as was once thought. It seems that physical appearance in humans, like many other animals, is not always a reliable guide to our evolutionary relationships.

Evolution Today

Evolution is a continuing process. New species are evolving as a result of environmental changes and the creation of new niches. Extinctions are also occurring, but other species that have been in existence for hundreds of millions of years are continuing to thrive.

One characteristic of evolution today is that human intervention in the process is significant in many regions of the world. For example, environmental change induced by human activity is threatening the existence of species and increasing the rate at which extinctions occur. Widespread clearing, large-scale agriculture and selective breeding are diminishing areas where 'natural' and complex ecosystems once flourished. Species that are of economic benefit to humans are being favoured over others, and simplified ecosystems that may be vulnerable to serious instability are being created. Often these ecosystems can only be maintained by the use of large amounts of pesticides, herbicides and antibiotics. These are directed against various target 'pests' that are continually evolving into more resistant forms.

The evolutionary changes and extinctions that are occurring today seem quite momentous. However, whether the changes to species diversity are sufficient to mark a new era in the history of life on Earth remains unclear. Are we witnessing the end of the Cenozoic Era, or will the present changes be of little consequence in the long term?