GONDWANA GREENING

EVOLUTION

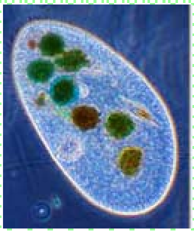
Congratulations! You are the end of a long line of parents; every single one of your ancestors has had at least one child. You are the product of an uninterrupted line of organisms that have passed their genes on to at least one offspring. This has been going on for more than 3 600 million years ago (mya) when the first living things were bacteria-like organisms. The Earth itself is about 4 600 million years old.

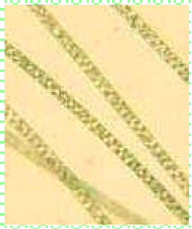
This is the same for every organism on earth, including plants, animals and fungi. We are all descended from the same primitive organisms. Every organism contains cells that contain DNA or RNA that contain the genes that are the blueprint for how each organism is made and functions. It is these genes that are passed on to each generation. Humans still carry many of those original genes, but what has made us change so much?

Humans, along with every other species, have changed or evolved so that the genes from each individual could have an improved chance of being passed on to future generations. This happens through a range of processes and influences that we are going to explore. We are going on a journey, signposted by fossils in rocks, that starts when the first life lived on the land about 420 mya, during the Silurian Period 436 million years ago. Until that time the land was barren and lifeless while life was evolving in the seas and waters.

For long stretches of geological time Australia was part of a supercontinent that we call Gondwana. This was largely made up of the Southern continents of Antarctica, Africa, South America and Australia. It also included India and islands such as New Zealand New Caledonia, Madagascar and parts of Indonesia. The name comes from India and means ‘Land of the Gond’. It was noticed in the 1870s that fossils that dated back to the Permian Period (286 – 245 mya) were very similar to fossils found in the same types of rocks from each of the Southern continents. This observation lead to the theory of continental drift. The reason why the fossils were very similar was because the continents were once joined and have since moved apart.

The first organisms were bacteria like?





More complex eucaryotic organisms later evolved? Some of those that could photosynthesise evolved to become the first plants.

Plant and animal species developed different adaptations in their evolution.

Trees and human beings are distantly related from those very early beginnings.

Palaeontologists have noticed that fossil plants and animals are usually found in association with collections of other fossils that represent the time and place that those organisms lived. These 'fossil scientists' can then build a picture of what whole ecosystems may have been like at various times of the earth's history. Each of these times has been given a distinct name and is referred to as a 'Period'.

At certain levels in the rock, the fossils change very suddenly, this is when the Period gets a different name. This suggests that something drastic must have happened between each Period that caused many species to die out and be replaced by a collection of very different species.

Layers of rock represent different times in the earth's history.
Plants and animals can become preserved as fossils as these layers build up.

By looking at the fossils in the rocks, Paleontologists gave the ages of the earth names like 'Age of the Dinosaurs' or 'Age of the Fishes' and more fancy names like 'The Jurassic Period' or the 'Devonian Period'. In between these 'Ages' or 'Periods' there seemed to be sudden changes in the types of fossils that could be found in the rock. This could be explained by great changes in the environment around the world. This may include climate change, volcanic activity or even events like the impact of asteroids.

One aspect of the world that is continually changing is the positions of the landmasses on the earth. All of the earth's continents, including Australia, have been moving around for millions of years. The positions of the continents affect how ocean currents move. Ocean currents have a very large effect on climate around the world. When the continents shift around, climates change over millions of years. In combination with volcanic effects and the possible occasional asteroid impact, the earth's environments have been constantly changing, sometimes slowly, sometimes very quickly.

This makes things interesting for organisms trying to make a living. The way that environments change has an impact on how species evolve.

Mass extinctions may have occurred from enormous volcanic events.

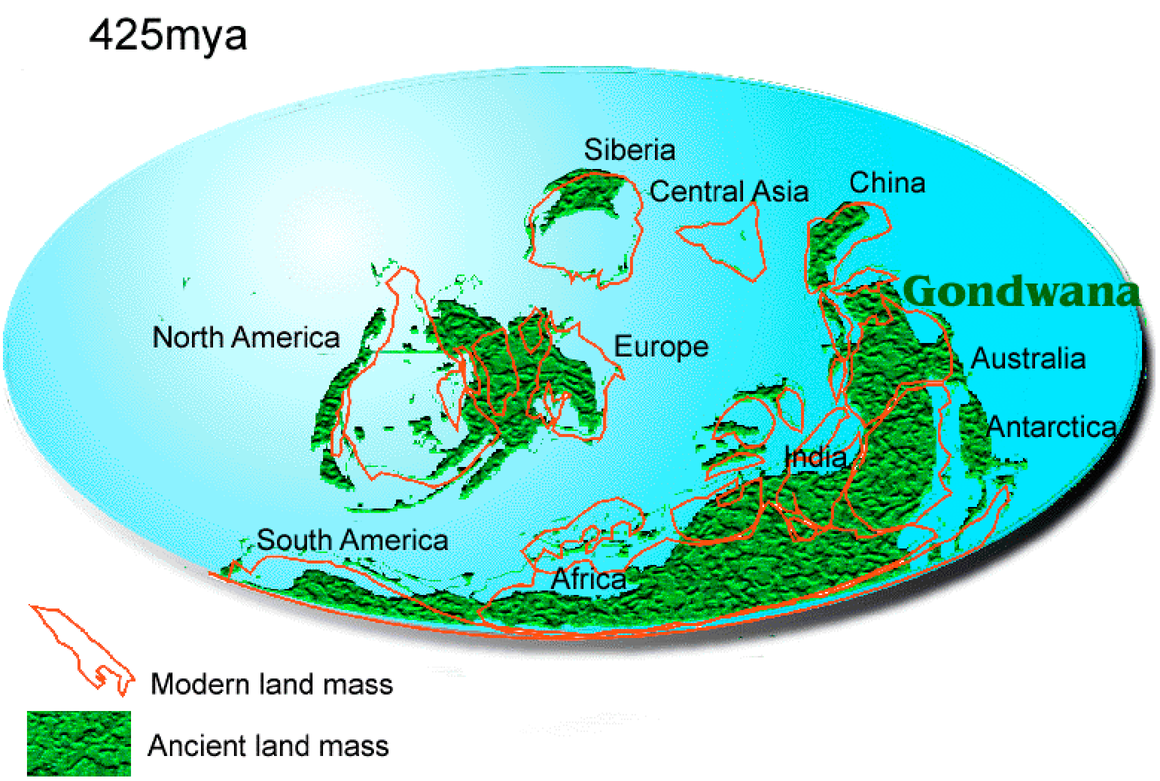
or from large asteroids that have hit the earth.

The evidence we have of extinct organisms is in the rocks.

SILURIAN PERIOD 436 – 408 MYA

THE LAND INVASION

The Earth is 4.6 billion years old. There is fossil evidence that suggests that life was around in the seas, as bacteria-like organisms, at least 3.4 billion years ago. It wasn't till another 3 billion years later, in the Silurian Period, that life appeared on dry land. There was a lot of evolving going on in the seas before land was colonised. During the Silurian, Australia was part of one large southern continent called Gondwana. The Australian part was close to the equator and was probably quite warm.



One thing that made it difficult for life to come out of the water earlier was that there was no protection from the deadly solar radiation. Photosynthetic organisms in the seas, such as algae and bacteria, had now been producing enough oxygen to create an ozone layer to filter out the harmful radiation.

The first living things to find their way onto land were probably green slimes that consisted of a combination of algae, fungi and bacteria. It would have existed around the edges of seas and lakes. At this stage the rest of the land was completely barren and rocky. There wasn't even any soil, which is only created with the presence of plants and other organisms.

A reconstruction of *Cooksonia,* one of the very first land plants. (Mary White 'The Greening of Gondwana')

There are fossil plants that have been found in Victoria near Yea called *Baragwanathia*. It would have looked very similar to a living club moss called *Lycopodium*. This was a huge discovery. It suggested that plants evolved from slime to a highly structured organism relatively quickly. It seems that once plants were able to colonise land, there was a race to take advantage of the clear sunlight that they could use out of the water. Another early land plant was *Cooksonia* (named after the Australian paleobotanist Isabel Cookson who discovered the *Baragwanathia*). These were very simple leafless plants that resemble the existing plant *Psilotum*.

Where plants grow, animals are sure to follow as the plants provide food and shelter. The animals that came on to land at this time were arthropods. Their exoskeletons could protect them from the sun's radiation and from drying out. There are fossils that reveal extinct creatures called eurypterids.

Silurian plants lived near water. They relied on the presence of free water for reproduction, as male sex cells needed to travel through water to get to female sex cells. Most plants also did not have a vascular system, including roots, so they could not easily transport water to all their cells. They therefore had to be small and live close to moisture.

Baragwanathia* would have resembled living clubmoss, or tassel ferns, such as this *Lycopodium

MUTATION

For evolution to happen there has to be variation between the organisms in a species. This means that there are differences in the genes between individuals. So, where do these differences come from? Genes in the DNA of sex cells can change, like typing errors in the code. Usually these changes are bad, even lethal, for the organism. Often they make no noticeable difference. More unusually they will improve the organisms chances of survival. This means those new genes have a better chance of getting passed on to future generations.

A living fossil. *Psilotum nudum*. Similar to the first land plants like *Cooksonia*.

A living lycopod, *Lycopodium squarrosum*.

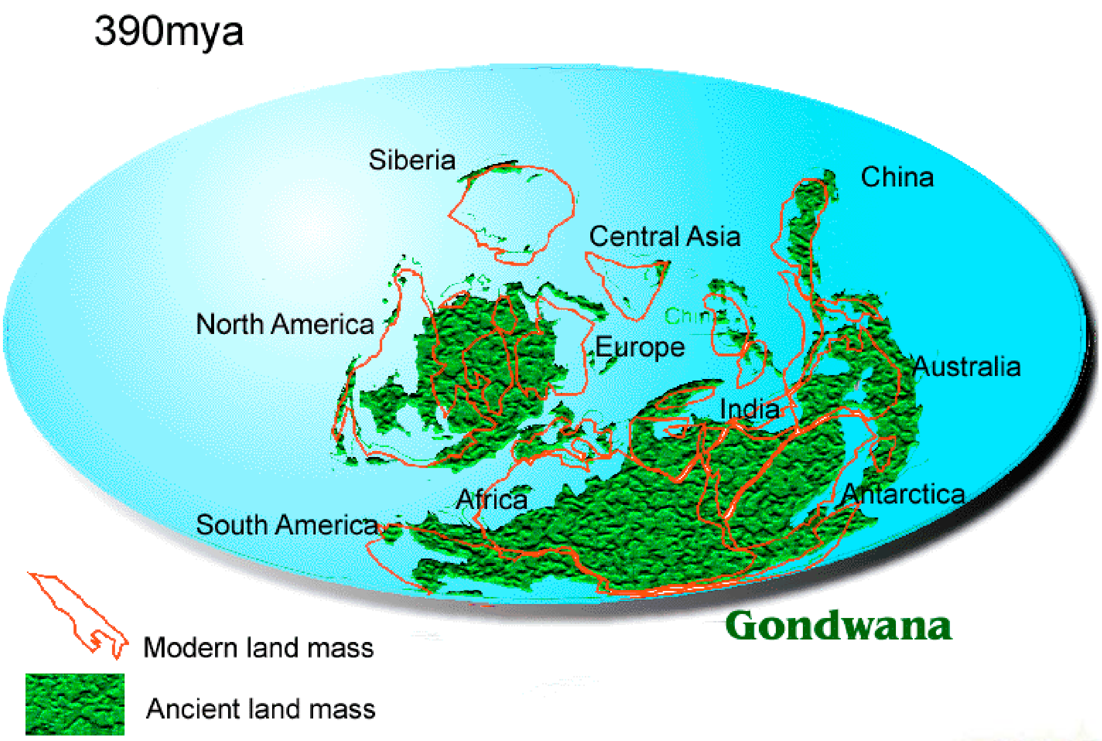
A fossil of a stem of Baragwanathia.

Eurypterids were arthropods that were around in the Silurian

DEVONIAN PERIOD 408 – 360 MYA

GETTING BIGGER

Since the Silurian, the Australian part of Gondwana had been moving south from the equator. At this time the whole world was warm and wet. Towards the end of the Devonian the world's climates became arid as seas retreated, exposing new land. It was also at this time that volcanoes in what is now Eastern Australia were creating new land. In the earlier part of the Devonian the world's flora didn't vary across different parts of the world, it was fairly consistent. This would have been a reflection of a consistent warm, wet world climate and that most of the worlds continents were joined or close to each other.



To get larger, plants had to have some sort of system to transport water and food to all of their cells. This is called a vascular system, which allows water to be transported from the ground through roots to every other part of the plant. It also allows the transport of sugars that are produced in the green photosynthetic part of the plant to feed every cell, including those in the roots.

There was now a lot of competition for light, so there was an advantage in being taller than your neighbour. So instead of only low ground hugging plants, there were forests of giant horsetails and giant clubmosses. However, they still had to live in moist, swampy areas rather than dry land. Today, horsetails and clubmosses are small, low growing plants.

A reconstruction of the giant clubmoss *Leptophloeum*. (Mary White 'The Greening of Gondwana')

Mosses and liverworts, which don't have a vascular system, must always be small so that each cell has access to water and sugars.

The giant horsetails and clubmosses still relied on spores to reproduce hence the necessity to live in moist environments. These spores were, as they are in their modern relatives, produced in capsules at the end of their stems.

The world became drier during the Devonian, so new environments of dry land were being created. Plants that reproduced by producing seed were now evolving. These plants had a great advantage. A seed is not as reliant on free water because fertilisation occurs within a specialised structure such as a cone. A seed contains a multicelled embryo with food reserves sealed up in a capsule. This protects it from drying out.

A variety of arthropods also lived on the land. Amphibians were the only land vertebrate.

There were not many land vertebrates but there were fish such as this lungfish that were precursors to them

NATURAL SELECTION

When there is enough variation in a population, some individuals survive better than others do especially when resources, like light, water or nutrients are limited.

Every generation more and more individuals that are good at surviving and reproducing pass on their successful genes. It's as if nature has selected what types of organisms should survive and which ones shouldn't.

When the first land plants lived on land, as soon as it got crowded it was a great advantage to be taller than your neighbour. The tallest plants got more sun, had a better chance of survival and so reproduced more tall plants. In the mean time, individuals that had a mutation for even taller genes also contributed to the whole species getting taller and taller.

Horsetails today are low growing, tough textured plants that grow in moist areas.

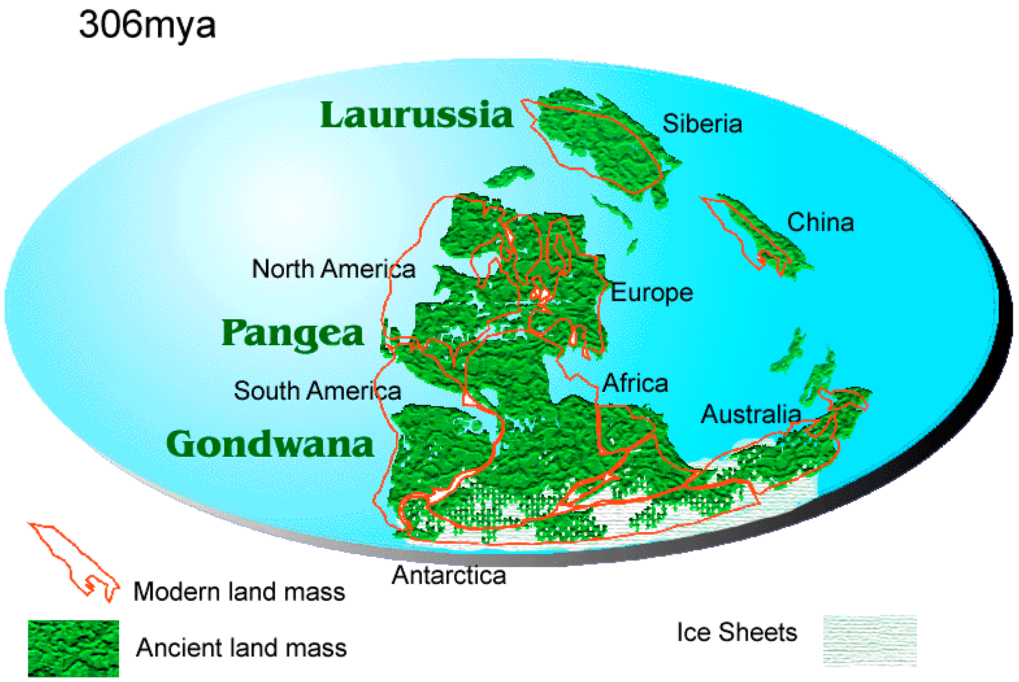
This bar shaped rock is a fossilised piece of giant horsetail (5cm thick) about 300million years old.

A reconstruction of a giant horsetail or *Equisetum* (Mary White 'The Greening of Gondwana')

CARBONIFEROUS PERIOD 360 – 286 MYA

THE BIG FREEZE

Gondwana and other landmasses were joining up to form the supercontinent of Pangea. Gondwana occupied the south polar regions where the southern lands, including Australia, experienced frigid conditions. Large areas were covered in ice. The more northern continents were nearer the equator and had much warmer climates.



Life on land was still restricted to moist swampy places because plants had generally not developed adaptations that allowed them to reproduce away from moist environments. The warmer continents had lush forests of ferns, giant horsetails and clubmoss and early species of seed plants called seed ferns.

The name Carboniferous refers to the coal deposits in the northern hemisphere that are the remains of these ancient plants. No coal was produced in Australia from this time because it did not have lush forests. It was experiencing an ice age. The only plants that lived there were small clubmosses and seedferns at the fringes of the ice. Through the Carboniferous Period, seedferns were becoming more dominant as they competed more successfully with the clubmoss and horsetails. This Period is sometimes referred to as the Age of the Ferns. This is because of .the prominence of ferns in the Carboniferous fossil record.

A reconstruction of the giant clubmoss *Lepidodendon*. (Mary White 'The Greening of Gondwana')

Ferns, clubmoss and horsetails were, and still are, spore producing plants. Spores are haploid cells that are produced by small structures called sporangia.
In ferns they appear as brown spots or lines underneath the fronds from where they are released. Spores have tough coats to protect them from drying out. The fern spore germinates to form the second generation of a fern called a prothallus. This is a small heart shaped individual. This haploid generation produces the gametes- the sperm and the egg. The sperm needs to swim to get to the egg, so there needs to be moisture around for it to get there.
Once fertilised, the egg becomes the next generation of diploid fern, which grows up to become the spore producer.

In seed producing plants the second haploid generation is not a separate individual. It all occurs within the safe, moist confines of reproductive structures such as cones or flowers. Sperm are contained inside tough little capsules called pollen grains. When they reach a female cone or flower, the sperm are guided into where the eggs are without having to swim around outside. The fertilised eggs undergo mitosis to become an embryo, which is later released within a protective covering as a seed.

ADAPTATIONS

Having variation within a species means that individuals are all different. This means that there are differences in features that help an organism to survive.
These useful features, or adaptations, have evolved to suit the species to their environment. These are genetic traits that can be passed on to future generations.
As plants were evolving on land, they developed further adaptations:

- **To protect them from the drying effects of the air (a protective cuticle),**
- **To move water and food through their bodies (vascular system)**
- **To reproduce without water (production of seeds)**

Angiopteris is a primitive treefern from tropical Australia

Sporangia beneath the fronds of a fern.

Dragonflies were among the early examples of insects that proliferated during the Carboniferous.

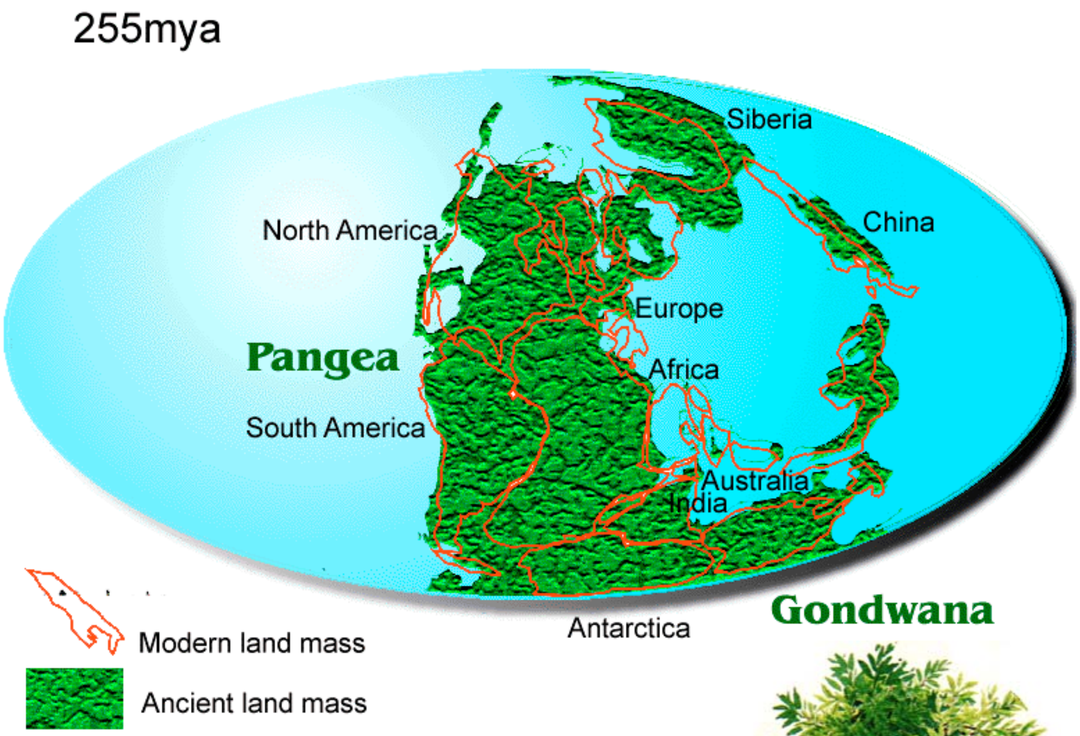
This low growing clubmoss, *Selaginella*, is similar to what was growing near the frozen parts of Gondwana.

PERMIAN PERIOD 286 – 245 MYA

EVOLUTION EXPLOSION

Gondwana was still part of Pangea. The northern part of the supercontinent aggregated while the earth's climate was warm and moist. The fossil records suggests that by the end of the Permian there were large-scale extinctions of species. This may have been due to a decrease in shallow water environments or an increase in volcanic activity. As the earth's climates warmed up the ice retreated in Australia. The sea levels rose and large area s of land in Australia were flooded

Even though Australia was no longer covered in ice, it was still close to the South Pole and so conditions were very seasonal. This meant that winter days were very short and warm while summer days were very long and warmer.



As the new habitats were being created a burst of evolution followed. The vegetation that came to dominate Gondwana in this time were seed plants called Glossopterids. The prolific growth of these trees produced the coal swamps from which black coal is mined today. In the swamps of the Permian, clubmosses and ferns were still prominent. The fossils of *Glossopteris* include many leaves in a way that suggests the trees must have been deciduous and dropped all of their leaves during the colder months. This would make sense, as it is a common adaptation for trees in very seasonal climates that experience winters with short daylight hours.

Reconstruction of a *Glossopteris* tree. (Mary White 'The Greening of Gondwana')

Glossopteris fossils were one piece of evidence that lead to the theory of Continental Drift. It was initially difficult to accept that the earth's landmasses are all moving around but it became the best way to explain many relationships between the plants and animals and geology of continents that are now widely separated. *Glossopteris* fossils were all found in rocks of the same age in Australia, Antarctica, Africa, South America and India.

The Glossopterdids were not only dominant but diverse. Their reproductive structures show similarities to what might be early attempts at more modern structures such as flowers. This has lead to the suggestion that they may even be ancestors to flowering plants, southern conifers and cycads.

Glossopteris was succeeded by cycads, southern conifers, seed ferns and ginkgos that could survive on dryer land. At the end of the Permian all of the species of *Glossopteris* vanished in what was the greatest mass extinction ever. Only 10% of all species of living things survived. There were also other types of plants that were living at this time. They included ferns, clubmoss, horsetails, ginkgos and another seedfern called a cordaite.
Amphibians were dominant but there are plenty of reptiles as well as insects that have appeared in Permian fossils.

Amphibians such as this Diplovertebron were the dominant vertebrates

SPECIATION

Before sex was invented there were no species. Every organism was an individual that reproduced by cloning itself. The only variety was from accumulated mutations. Sex increases diversity by shuffling the genes of two organisms so that their offspring is not a clone; it is a new individual. For this to happen, the two sex cells need to be fairly similar in their genes and chromosomes. Speciation occurs when individuals between populations of one species become so different to each other that they can no longer sexually reproduce successfully. This can occur if the populations are isolated from each other and evolve separately in different environments.

A twig of a Glossopteris showing the male cone. (Mary White 'The Greening of Gondwana')

A fossilised piece of a Glossopterid trunk.

Treeferns and other ferns were also abundant in the Permian.

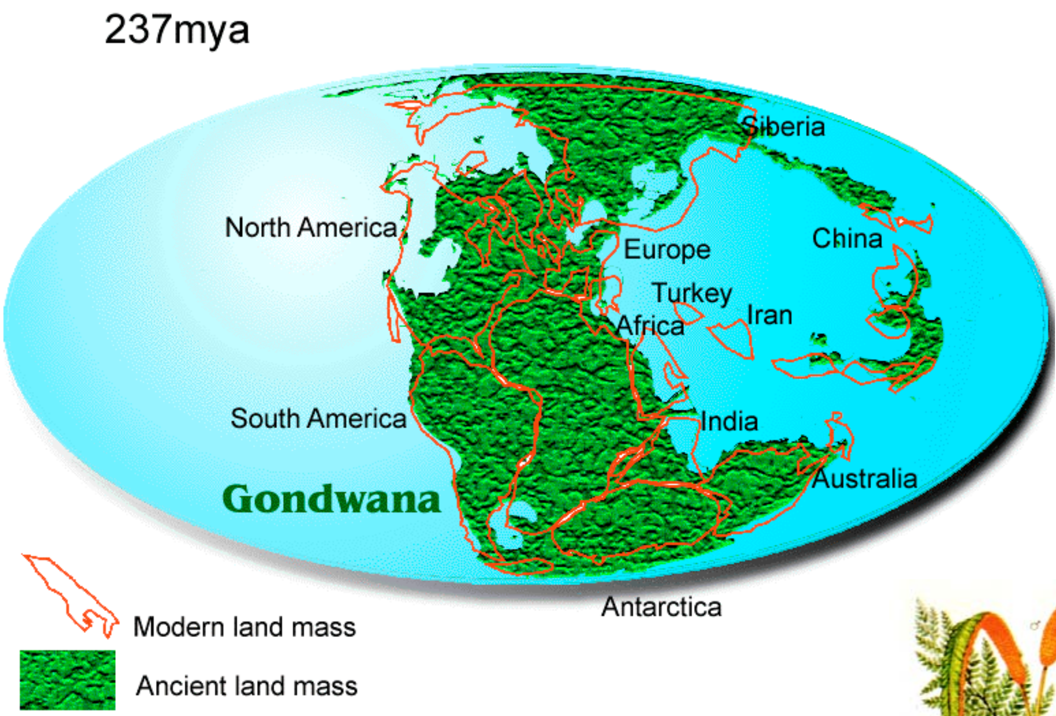
TRIASSIC PERIOD 245 – 208 MYA

THE GREAT DYING

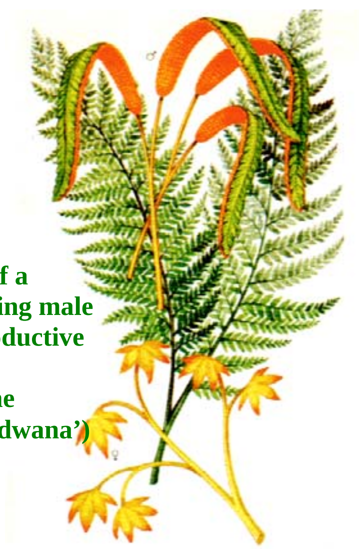
The end of the Permian is defined by what has been described as the 'Great Dying'. About 90% of species became extinct. It is not known exactly why but it may well be a combination of events including great volcanic activity and climate change.

During the Triassic, Gondwana became the southern part of one huge supercontinent - Pangea. It stretched from the North Pole to the South Pole so that the rest of the earth was covered in one great ocean called Panthalassa. Pangea blocked ocean currents from circling the globe so that warm water from the equator mixed with cool water from the poles. This meant that the earth's climates were consistently warm.

The earth also became much drier, particularly closer to the equator. In the north and south conditions were more humid. There was also a great decline in shallow water environments because of the merging of landmasses and a great drop in sea levels. The sudden decline of these environments may have been one reason for the mass extinctions.



Because Australia was very close to the South Pole it stayed fairly humid. The flora of Southern Gondwana evolved in isolation to the flora of northern Pangea because a large arid belt of desert at the equator separated it. A seed fern called *Dicroidium* dominated Australia. Its distribution was similar to that of *Glossopteris*- around the South Pole. This suggests that



Reconstruction of a *Dicroidium* showing male and female reproductive structures. (Mary White 'The Greening of Gondwana')

Dicroidium is well adapted to very seasonal environments also.

The foliage of Dicroidium was very fern-like and preserved well as fossils because of the presence of a thick cuticle. This would have been an adaptation to hot dry climates. While their leaves appeared fern-like they had more elaborate reproductive structures and produced seeds on the surface of hand-shaped structures. Other species had structures that were more helmet shaped. Male structures are tassel-like arrangements or 'catkins'. Fossils don't reveal what the structure of the whole plant looked like but it was probably a relatively low growing plant.

As the climate grew hotter and drier, other new groups also became more prominent such as cycads, ginkgos and conifers. These groups, which survive today, were able to survive in areas where water is not a constant presence. Amphibians were still dominant though increasing numbers of reptiles appeared as things got drier. The first dinosaurs also appeared in the Triassic.

Some seed ferns had a shield shaped structure where the seeds grew underneath.

EXTINCTION

The mass extinction at the beginning of the Triassic was the greatest in the history of life on earth, even bigger than that of the dinosaurs. There has been evidence to show that the dinosaur extinction at the end of the Cretaceous (66 mya) was due to a large asteroid that hit Mexico. This could have been the case with the end of the Permian but it was more probably a combination of catastrophes that caused it, including asteroids. There is evidence in Russia that the biggest ever volcanic eruptions occurred at this time. We know also that there were dramatic climate changes that were mainly the result of the position of the continents. A combination of catastrophes happening around a similar time seems unlikely, but mass extinctions don't occur too often.

While extinctions would seem to be a disaster, they do create opportunities for the surviving species. At the beginning of the Triassic many new environments would have opened up, waiting to be colonised by species that have the adaptations to survive there. If one particular species thrives in areas that contain a variety of niches or environments, different populations will be better adapted in different environments. If these different specialised populations are isolated enough it can lead to a burst of speciation.

A reconstruction of cyclomeia, a Lycopod that lived early in the Triassic before it got too dry (Mary White 'The Greening of Gondwana')

A Ginkgo (*Ginkgo biloba*) with fruit. Ginkgos were once diverse and common all over the world. There is now only one species that is now virtually extinct in the wild in China.

A fossil of Dicroidium showing its ferny foliage.

An early crocodile-like reptile

JURASSIC PERIOD 208 – 144MYA

STAGNATION

The super continent of Pangea started to split, forming the northern continents of Laurasia and the Southern continents of Gondwana. Conditions became uniformly warm and moist and promoted luxuriant plant growth. even climate at the poles was warm temperate. This was the age of the dinosaurs.
Australia has moved further away from the South Pole so conditions are less dramatically seasonal as they were in the Triassic.

Not only was the climate fairly constant around the world, during the Jurassic, so was the vegetation. Dominant plant groups included conifers, cycads, ferns, ginkos, seedferns, horsetails, clubmosses and mosses.
The dominant conifers included the Kauri pines (*Agathis*), plum pines (podocarps) and araucarias (pine trees that include bunya bunyas, monkey-puzzles and hoop pines). These are termed the southern conifers because of their current distribution in rainforests of Australia, New Zealand, South America, Africa and New Caledonia. These groups are regarded as living fossils because of the way they seem to survive in remnant pockets of habitat, usually in warm moist conditions.

Reconstruction of the cycadophyte *Pentoxylon australica* showing male and female parts. (Mary White 'The Greening of Gondwana')

The consistency of the Jurassic environments created few selective pressures. Species adapted well to the conditions and there was no advantage in changing. The dominant plants and animals stayed dominant for millions of years. One of the driving forces of evolution is environmental change and genetic diversity. In the case of the Jurassic, the conditions stayed unchanged for so long that the dominant species were not well adapted to new environmental conditions when changes finally did happen. As we can see now with living conifers, seeds are produced in female structures called cones. Pollen is produced in smaller male cones. The pollen is produced in huge amounts and is carried by the wind till some of it reaches an egg in a female's cone. The seed is then produced within the scales of the cone from where it is released, usually by the wind.

Plum pines (podocarps) and gingkos have cones that more resemble the fruit of flowering plants. Plum pines have a single seed attached to a sweet, fleshy attachment. Ginkgos have a single seed inside a fleshy yellow covering that smells like rancid cheese. These characteristics appear to be adaptations to attract animals to eat the fruit and so disperse the seed. Most conifers rely on wind. Using animals for dispersal means larger seeds can be carried away, with more reserves for the developing embryo. The question is what type of animal were they attracting? There were no birds or mammals to speak of but there were plenty of dinosaurs and other reptiles. Perhaps their rather smelly fruits were very appealing to certain types of dinosaurs. Not too many animals these days, apart from humans, are interested in it. Perhaps this has contributed to the fact that ginkgos are now almost extinct in the wild.

COMPETITION

Another big driver of evolution is competition between individuals. The phrase 'survival of the fittest' means that the individuals who compete the best, survive to pass on their genes to the next generation. If there are two species in the same environment who rely on the same resources to survive, eventually the species with the better adaptations will get to those resources first and take over. Weeds are an example of plants that can compete very well in disturbed environments. Their introduction into a natural environment can bring about the extinction of other species. The weeds can change the nature of the environment and out-compete some natural species for space, light, water and nutrients.

A female cone from a Kauri pine (*Agathis robusta*)

Trunk and foliage of a Kauri pine.

Dacrycarpus dacrydioides or white pine, a type of podocarp or plum pine. Could these 'plums' have been dinosaur food?

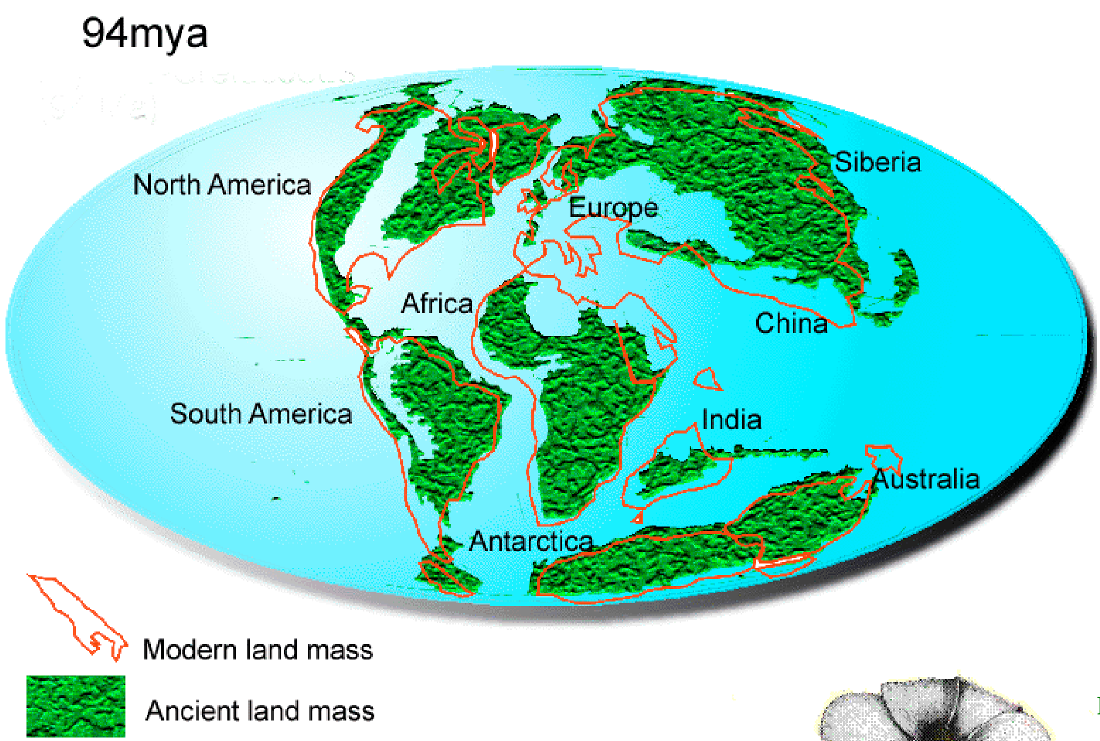
The giant dinosaur diplodocus.

CRETACEOUS PERIOD 144 – 66 MYA

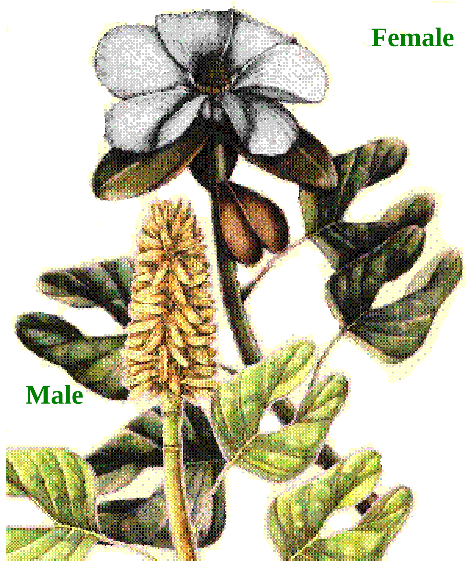
THE BIG SPLIT

The super continents start to break up much more. Gondwana is breaking into pieces while Australia stays attached to Antarctica near the South Pole. Climates also started changing. Things got much colder then warmed up again. This contributed to rising sea levels and the inundation of land all over the world. Inland seas divided Australia into four pieces. The new shallow seas created a big increase in swampy environments. When these seas subsided, new environments were left for colonisation.

As continents broke up, rift valleys were formed where they split. These rift valleys were also places of change and increased shallow water environments.



Vegetation was still dominated by conifers, cycads and ferns for much of the Cretaceous but as the environments of the world changed, new species were getting a chance.
The rift valleys that were forming at the splits between continents provided new environments that increased selection pressures. This encouraged more rapid evolution of species.
Cycads were still a prominent seed plant group and had been since the Permian. It was once thought that, like conifers, pollen from cycads was distributed by wind to the female cones. It has been noticed more recently that pollen is mainly distributed by beetles. For such an



A reconstruction of *Archaeanthus*, one of the very first fossil examples of a flower that was found in China.

ancient group of plants this seems like a modern innovation. This method of pollination is much more effective than relying on the wind because it is much more direct. Not so much pollen gets wasted by getting blown away.

Flowering plants were the big newcomers at this time. They made their appearance during the Cretaceous and diversified very rapidly – though ‘rapidly’ in geological time still takes millions of years. One of the big successful adaptations of flowering plants was their co-evolution with animals, including insects. As flowering plants diversified, so did insects. They evolved together, one benefiting by the direct pollination, the other by the offering of food in the form of nectar or the pollen itself.

Charles Darwin described the origin of flowering plants as an ‘abominable mystery’. The origin and dramatically quick diversification (over about 10 million years) of flowering plants is still a mystery. One well-regarded theory is that the first ones evolved in the rift valley that was created when South America and Africa was splitting apart.

Dinosaurs were still abundant till the end of the Cretaceous. Mammals were around but not so obvious. Birds were waiting to take advantage of the flower explosion and the insects that came with it.

***Leaellynasaurus*, note the large eyes for seeing during the dark winter months near the South Pole.**

ENVIRONMENT CHANGE

Another driving force in evolution is change. During the Jurassic, without a lot of change in the environment, there was no advantage in a species being variable. Variability in the gene pool of a species can give it some tricks up its sleeve for when things do change.

When the changes came, during the Cretaceous, the species that were more variable were better able to cope with the changes, compete better and diversify into new species occupying different niches.

A cycad showing a female cone with seeds.

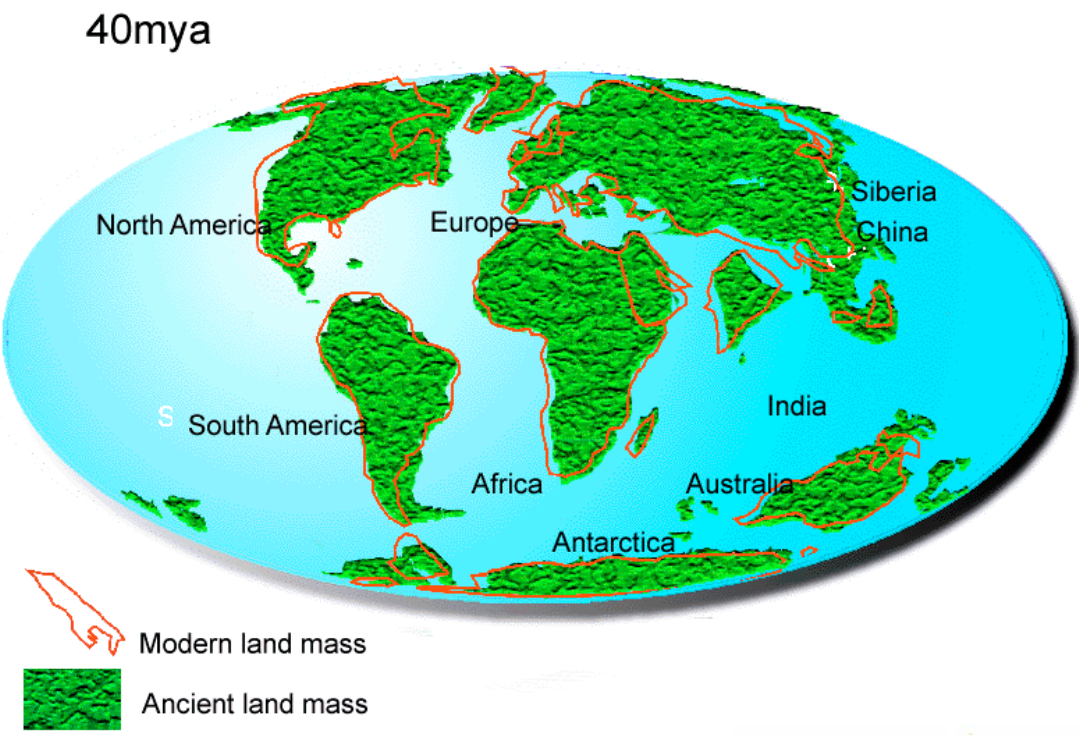
The Bunya Bunya pine (*Araucaria bidwillii*) of Queensland

Water lilies (Nymphaeas) are among the earliest types of flowers.

TERTIARY PERIOD 66 – 1.6 MYA

THE FLOWER EXPLOSION

Australia was the last part of Gondwana to break away from Antarctica. Its break away had a great influence not only on the climate of Australia itself, but also on the climate of the entire earth. When Antarctica was finally isolated, the circum-polar current cut Antarctica off from warmer water spreading from the Equator. This had a freezing effect on Antarctica and this influenced climates around the world. Australia starts the Tertiary Period close to the South Pole but is now moving north on its own. It is now isolated from the rest of the world.
Australia also starts off being rather moist but as the poles get colder Australia gets drier.



Life in Australia is now evolving separately from the rest of the world. We have an idea of what sort of environment it was like where Australia and Antarctica split. Fossils show that there were fossils of araucarias and plum pines and also forests of flowering plants such as *Nothofagus* (myrtle beech). *Nothofagus* forests can still be seen in cool rainforests of Victoria, Tasmania, New Zealand and South America. They seem to have thrived in the very seasonal and moist conditions in a similar way that the Glossopterids did in the Permian.

Magnolia type flowers like this *Liriodendron* are regarded as one of the most primitive flower forms.

For most of this time Australia was covered in forest. The rainforests of Queensland are today like a time capsule of life at this time but as conditions became drier and drier these communities shrank to pockets that remained reliably moist.

Flowering plants were now taking over. One theory is that they started evolving around the rift valley between Africa and South America. Many of these early flowering plants, such as water lilies and palms, were able to spread around to all the equatorial regions of the world before Gondwana completely split up. These plants still thrive in the same warm, moist conditions today.

The changing nature of the world's climates and environments spelled trouble to all the species that were not well-adapted to change. Flowering plants were in an ideal position to diversify through mutation and natural selection. There was a radiation of species, meaning that new species formed to take over different niches in each new environment.

Apart from their capacity to change, flowering plants had other advantages. Their reproductive structures provided more protection and nourishment for their developing seed. They also evolved in association with insects and birds to pollinate flowers and disperse seeds. These relationships also increased the degree of speciation that could occur. Flowering plants also evolved a great variety of chemicals that could serve to deter or attract animals by being poisonous or having a beautiful perfume. They also evolved a great variety of forms including herbaceous plants, climbers, epiphytes, parasites, shrubs or trees. Flowering plants rapidly dominated the earth.

Dinosaurs were now gone. Marsupials and birds became dominant in Australia.

Butterflies evolved in association with flowering plants.

DIVERGENCE

Some groups of flowering plants that evolved early in the southern part of Gondwana, diversified separately as the southern continents broke apart. This includes plants of the Proteaceae family (Banksias, Proteas etc.). As related species become increasingly separated, they may adapt to different conditions and become very different to each other. Banksias in Australia have evolved differently to their relatives the Proteas in South Africa.

Ephedra is a living fossil. These structures are not quite flowers but they are getting close.

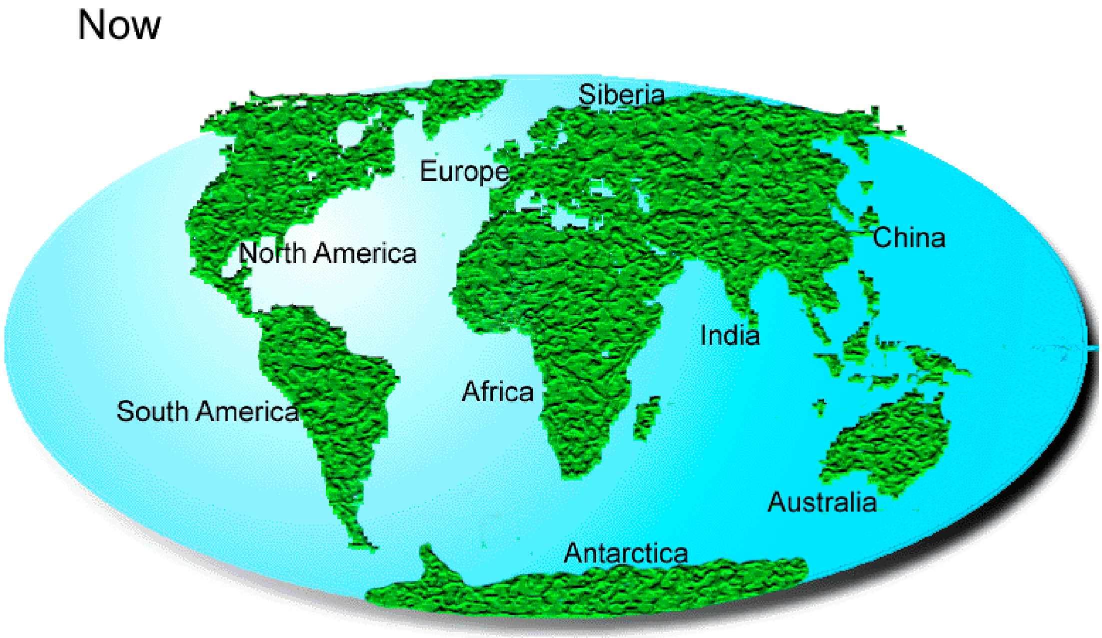
Euchryphia is an early Gondwanan flowering plant that still lives in rainforests of Australia, New Zealand and South America

Nothofagus was a dominant forest tree in Southern Gondwana.

QUATERNARY 1.6 MYA TO NOW

AUSTRALIA BROWNS OFF

In the Quaternary, the continents moved to where they are today. It is the time of a great ice age in the Northern Hemisphere while in the south; Antarctica is covered in ice. Australia has been moving north and is now ploughing into Indonesia. This has resulted in a mixing of plants and animals that had previously evolved in isolation to each other. The connection between North and South America has also allowed an even greater interchange between floras and faunas that had evolved separately for millions of years.
This is also the time of *Homo sapiens* (humans). Our species has had a huge impact on life on earth. Will it become as big as what led to the Great Permian Extinction?



Life in Australia now had to cope with increasing aridity as well as a higher frequency of fire. Two genera that most successfully adapted to these new, dry environments were *Eucalyptus* and *Acacia*. Between them they include many species and dominate most of the whole continent. One of the few environments they don't dominate is the rainforests which more resemble the ancient Gondwanan forests of the Cretaceous.

Eucalypts have a number of adaptations that make it well suited to a dry continent. Its tough leaves have a thick waxy cuticle that reduces water loss. They generally hang down vertically to minimise direct exposure to the sun.

They have the capacity to produce new shoots after a fire that would kill most other plants. They possess a

***Eucalyptus* now dominates much of Australia. Many animals have evolved to rely on it for food and shelter.**

lignotuber, an underground storage organ that provides the energy to bounce back from drought or fire.

Eucalyptus oil, which gives gum trees their distinctive smell, is actually a toxic chemical that acts as a defense mechanism against armies of animals that would eat the leaves. The fact that there are plenty of animals, including insects, that eat gum leaves shows the animal kingdom has evolved with adaptations to counter the harmful effect of the poison. This is highlighted by the way *Eucalyptus* trees grow more luxuriantly outside of Australia where they have no natural predators. Animals everywhere else have not evolved to cope with eucalyptus oil.

Having tough leaves is useful to reduce water loss but it is also an adaptation to survive nutrient deficient soils. Australia has very old soils and is also a low-lying continent where much of it was covered in seas for significant periods. Soils made from old, deeply weathered rocks lack nutrients that plants need for growth. Australian plants have adapted well to this, particularly those in the Proteaceae family such as Banksias, Grevilleas and Hakeas. This may explain why there are now only two Proteaceae species left in New Zealand where the soils have been enriched by volcanic activity.

Many birds have co-evolved with flowering plants, particularly honeyeaters in Australia.

CONVERGENCE

Most forests in Australia are referred to as sclerophyll forests. This means, literally, tough leafed. It is not only eucalypts that have such leaves but plants from a number of different plant families including Acacias, Banksias, Casuarinas, grass trees (*Xanthorrhoea*), kurrajongs (*Brachychiton*) and salt bush (*Atriplex*). Unrelated plants with similar adaptations, like sclerophylly, may appear more similar to each other than to related plants with different adaptations. This phenomenon of unrelated species evolving the same adaptations or appearance is 'convergent' evolution.

Banksias are a Gondwanan group with adaptations to Australian conditions.

Grass trees (*Xanthorrhoea*) are endemic to Australia. They are found nowhere else having evolved in isolation to the rest of the world.

Olearia belongs to the daisy family (Asteraceae) which is regarded as a more recently evolved group of flowering plants.