Australian Government
Geoscience Australia

AUSTRALIA'S GEOLOGICAL HISTORY

Department of Resources, Energy and Tourism

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CONTENTS

Introduction

The first edition of the publication was developed to complement the Geoscience Australia TimeWalk. This second edition has been updated to conform to the new international geological timescale which was released at the International Geological Congress, held in Brisbane in August 2012.

This booklet aims to provide an insight into the evolution of planet Earth and the life which occupies almost every part of its surface. The Earth is approximately 4600 million years old and it is through the study of geology that a greater understanding of the development of the planet has been obtained.

Each section in this publication discusses a single geological time interval, and outlines the major geological, climatic and biological events which occurred in that interval. Geological events include continental drift, the break-up and amalgamation of continental landmasses, mountain-building and major volcanic eruptions. Climatic events include changes in the composition of the atmosphere and the occurrence of ice ages. Biological events include the evolution of major groups of organisms, the invasion of the land and major extinctions. Other events include changes in sea levels and adaptation of plants and animals to climate change and major meteorite impacts. Each section also shows where rocks of a specific age are found in Australia and lists some of the continent's major mineral and energy resources formed during a particular time interval.

PRESENT DAY EARTH

Over the past 4600 million years the Earth has evolved from a ball of molten rock and iron to its current form. To assist readers in understanding past conditions on Earth, this publication compares them to those we experience on Earth today.

Today's atmosphere and temperature	
Average temperature	14–15°C
Atmosphere composition	
Nitrogen	78.08%
Oxygen	20.95%
Argon	0.093%
Carbon dioxide	0.038%
Water vapour	1%

SHAPING A NATION

This is a book that describes the geological history of the Australian continent and the interaction of tectonic and climatic drivers that have shaped where Australians live and how we have responded to the geological legacies to build a prosperous nation. The very long geological history of Australia has delivered a distinctive landscape and a great natural endowment of mineral, energy and groundwater resources. The story of Australia's nearly four billion years of geological processes and the continent's evolution with respect to human impacts and issues and our responsibilities to ensure the sustainability of resources is told in: *Shaping a Nation: A Geology of Australia* published by Geoscience Australia, 2012: http://www.ga.gov.au/products-services/publications/shaping-a-nation.html

FOR MORE INFORMATION:

Geoscience Australia website:
www.ga.gov.au

Geoscience Australia Classroom Resources:
www.ga.gov.au/education/classroom-resources.html

Australian Mines Atlas:
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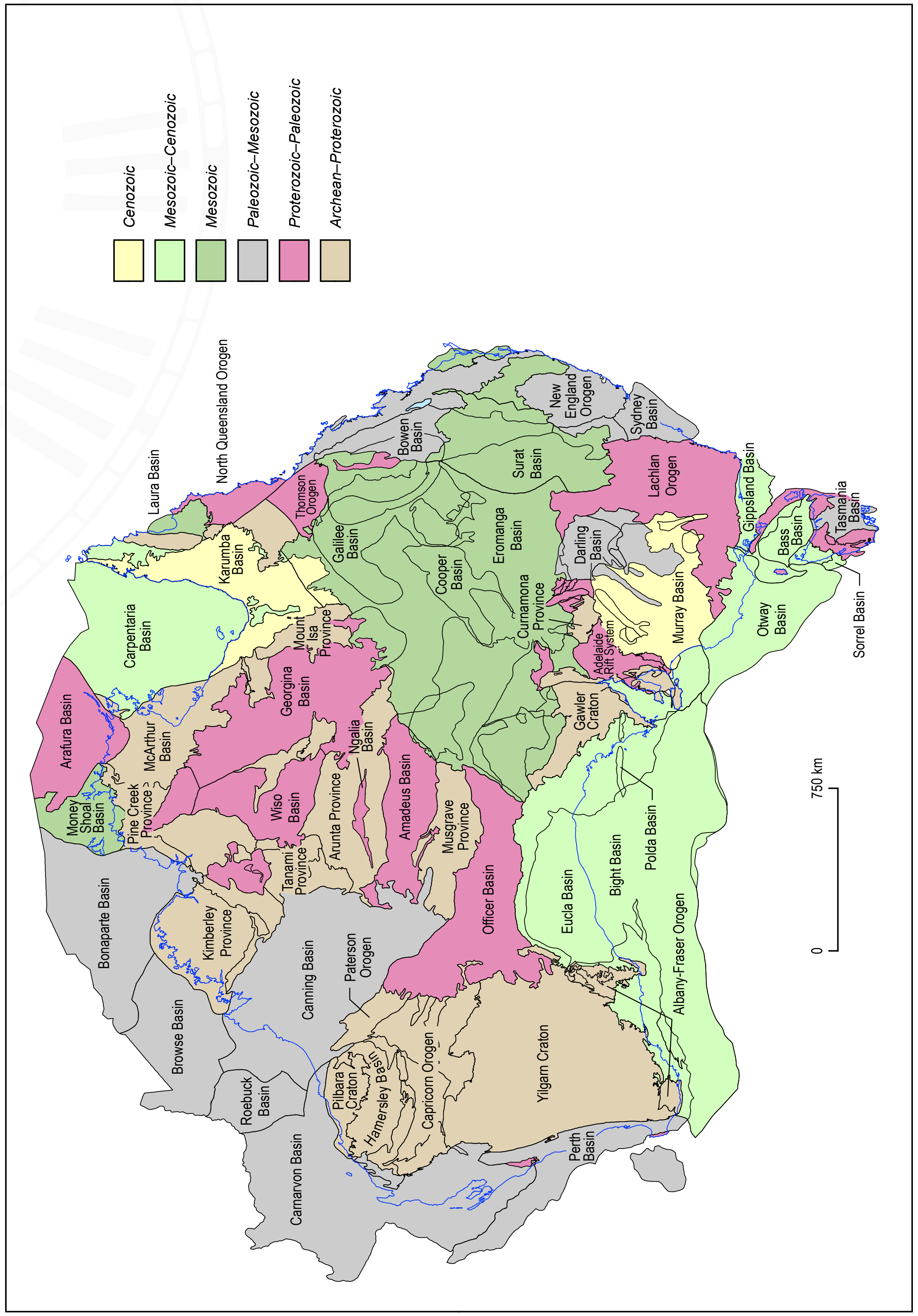
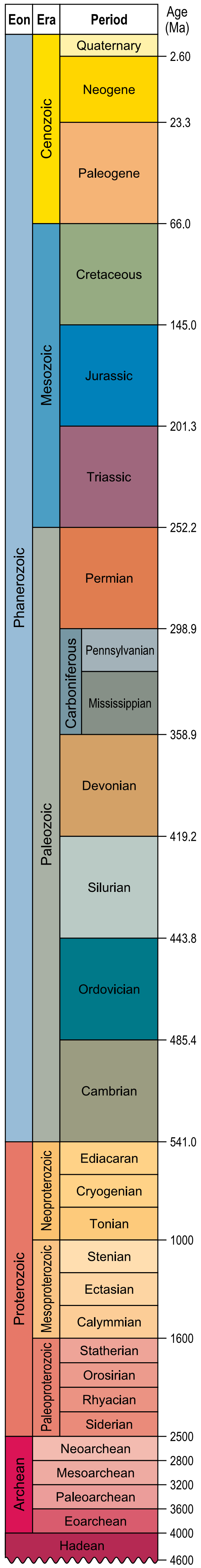
Geological Elements of Australia



Geological elements of Australia, coloured by age



GTS 2012 Timescale

Geological Time

INTRODUCTION

Geoscientists use geological time to describe events which have occurred over the history of the Earth. This information is useful in understanding the Earth's structure and how it has evolved, and enables us to better manage the Earth's environment and resources.

To calculate and communicate geological time, geoscientists use both relative and absolute scales. Relative time refers to the system of subdivisions based on relationships, such as where one layer of rock is described as being either younger or older than another layer. These subdivisions are given names and are recognised globally, usually on the basis of fossils. Absolute time refers to assigning a numerical age to a rock layer, usually in millions of years before the present (Ma). This is usually accomplished through radiometric dating of minerals in the rock. The Geological Timescale allows us to understand the succession of geological, biological or climatic events that have shaped the Earth as we know it.

The Geological Timescale used in this book was released at the International Geological Congress in Brisbane in August 2012. This standard Geological Timescale extends from the formation of the Earth approximately 4600 million years ago to today. The Geological Timescale is a hierarchical structured system, divided into eons, which are in turn divided into eras, periods, epochs and stages.

Eons: Eons are the largest unit of time, extending half a billion years or more. There are four eons in the Earth's history. From the oldest to the youngest, these are:

- **The Hadean (derived from Greek, meaning the underworld or hell).**
- **The Archean (derived from Greek, meaning the beginning).**
- **The Proterozoic (derived from Greek, meaning earlier life).**
- **The Phanerozoic (derived from Greek, meaning visible life).**

Eras: All eons (except the Hadean Eon) are subdivided into eras, which can be up to 900 million years long. The Archean Eon includes four eras, the Eoarchean, Paleoarchean, Mesoarchean and Neoarchean, while the Proterozoic has three, the Paleoproterozoic, Mesoproterozoic and Neoproterozoic Eras. The Phanerozoic has the Paleozoic, Mesozoic and Cenozoic eras.

Periods: Eras are divided into periods. The Paleozoic Era, for example, is divided into six periods, which, from oldest to youngest, are the Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian.

Epochs: Epochs are subdivisions of periods. Only periods of the Phanerozoic Eon have been subdivided into epochs which are usually tens of millions

of years long. This is because further division of periods historically has been based on fossil evidence, which is limited in rocks from earlier periods.

Stages (age): Stages are the smallest unit of time in the Geological Timescale, and are usually a few million years long. Most of the epochs in the Phanerozoic Eon are subdivided into stages.

Eons, eras, periods, epochs and stages are defined using a number of techniques, usually fossil species, magnetic reversals, major climatic events, isotopic shifts or, in the absence of these, numerical ages (chronometric). The numbers on the side of the Geological Timescale represent the numerical age (absolute time) in millions of years before present day (Ma). For example, the Cambrian Period began 541 million years ago and continued until 485.4 million years ago.

HOW THESE INTERVALS ARE DEFINED

Geological time intervals are defined using a number of techniques. Where the first appearance of a particular fossil species, a magnetic reversal or other event can be used to characterise the boundary, a point in a particular rock succession is selected to define the boundary. This point is termed a Global Stratotype Section and Point.

Fossils: Fossilised remains of plants or animals which existed during certain time intervals can be used to distinguish between rock intervals. For example, in the Silurian Period, the various epochs and stages are defined at the first appearance of particular species of graptolites, which are ancient marine animals.

Magnetic reversals: The Earth's magnetic field often reverses so that the north magnetic pole becomes the south magnetic pole and vice versa. The rocks laid down at a specific time are magnetised in harmony with the magnetic field prevailing at that time and reversals can be detected. For example, the start of the Piacenzian Stage, in the Neogene Period, is at the Gauss/Gilbert magnetic reversal.

Climatic events: Only the start of the Ediacaran Period is defined by the end of a climatic event, which was a glaciation. This differentiation is marked by a thin carbonate bed, signifying the end of the Marinoan glaciation.

Where there are no fossils or other features available to characterise the beginning of an interval, the boundary is defined chronometrically simply by selecting a numerical age to apply to the boundary. This numerical age is termed a Global Standard Stratigraphic Age. For example, the base of the Proterozoic Eon is defined as being 2500 million years ago.

BIOSTRATIGRAPHY

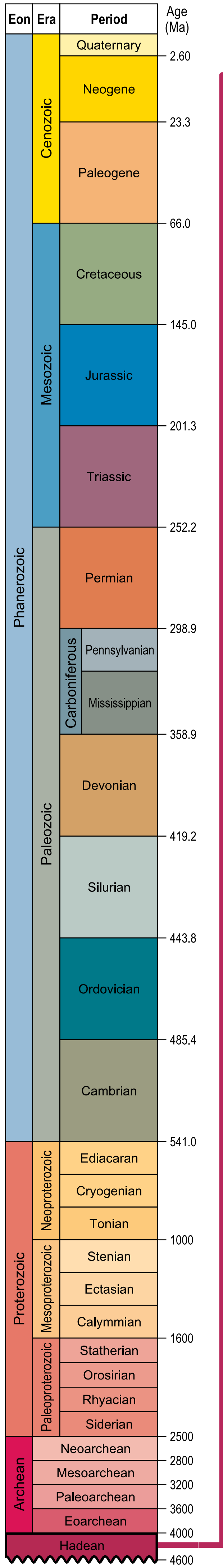
Early in the history of modern geology (1790s), it was realised by the English surveyor William Smith that rock layers in a particular area were arranged in a sequence and that their relative positions were predictable. He also noticed that each of these rock units often contained the same types of fossils, no matter where the rock unit was sampled. Smith went on to publish the first national geological map of Britain in 1815.

The *'Law of Superposition'* states that when sediments are deposited, those that are older will be at the bottom while the younger layers will be at the top. This law, coupled with Smith's *'Principle of Faunal Succession'*, which states that fossils succeed each other in a specific, reliable order, enables geologists to determine the relative age of sedimentary rock layers by their contained fossils. This is the discipline of biostratigraphy. For example, if the same fossil species is found in widely scattered rock units, this indicates that these rock units are about the same age.

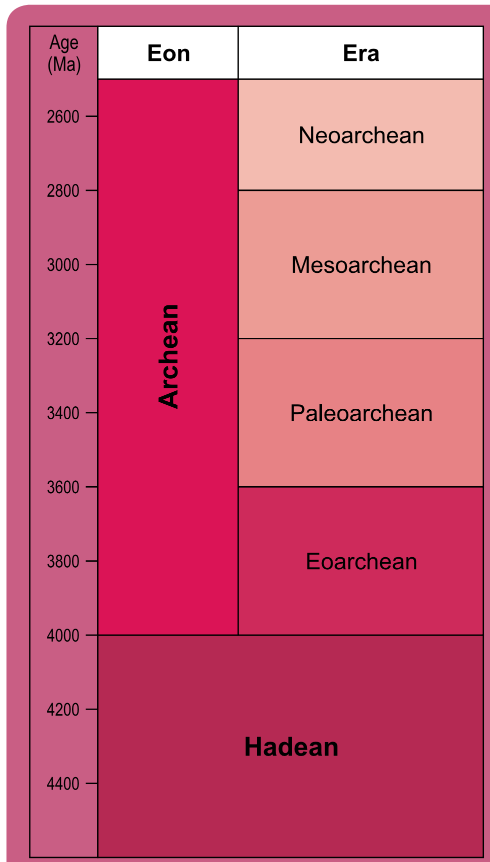
RADIOMETRIC DATING

In 1906, a breakthrough came with the realisation that radioactive decay of uranium in some minerals could be used to determine the absolute age of rocks. This is termed radiometric dating.

One method used for radiometric dating is the uranium-lead method. A radioactive isotope of uranium (the parent) spontaneously decays at a known constant rate by losing particles from its nucleus to form an isotope of lead (the daughter). The ratios of the two isotopes are measured and the age determined. The constant rate of decay of a particular isotope is conveniently expressed by that isotope's 'half life', which is the time it takes for half the number of atoms of that isotope to decay. For one of the isotopes of uranium (uranium-238), this half-life is about 4460 million years. The science of dating rocks is called 'geochronology' and has been a very useful tool for the development of the Geological Timescale. The numbers along the side of the Geological Timescale (Ma) have been determined using radiometric dating, and are referred to as absolute time.



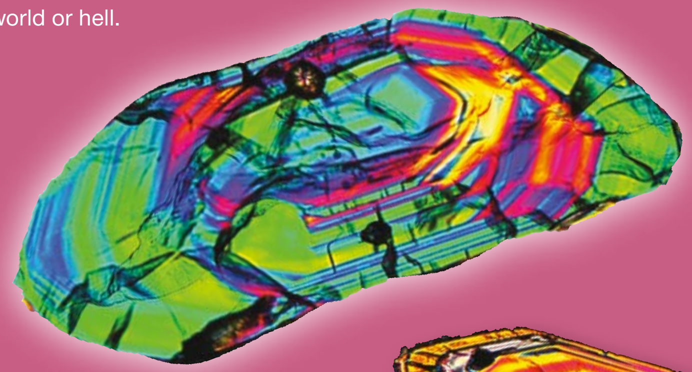
Hadean Eon (4600–4000 Ma)

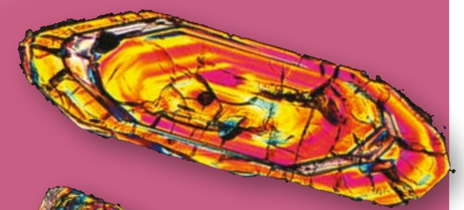


HOW OLD IS THE EARTH?

Using radiometric dating techniques, rare zircon crystals found in younger conglomerates from the Jack Hills in Western Australia have been dated to be up to 4404 million years old. The Earth's formation predates these, but preserved remnants of the original crust have not yet been found. Fortunately, fragments of the earliest rocks in the Solar System have periodically fallen to Earth as meteorites. Along with the Earth, the Sun and the other planets, meteorites are a product of the event which created the Solar System. Several meteorites preserving remnants of the original matter have been dated at 4560 million years old. This is the formation age of our Solar System and of planet Earth.

The name 'Hadean' is derived from the Greek word 'hades', meaning the underworld or hell.





Zircon grains are found in very small quantities in most rocks. Zircon is highly resistant to weathering and therefore is the most commonly used mineral to date rocks. The oldest zircons on Earth, dated to be 4404 million years old, are found in younger conglomerates in the Jack Hills, Western Australia.

INTRODUCTION

The Hadean Eon is the oldest eon in geological time and has not been subdivided. The Hadean Eon is considered to have started when the Earth formed, approximately 4600 million years ago, and spans 600 million years until the beginning of the Archean Eon.

Conditions on Earth at this time were harsh, with the planet beginning as a ball of molten rock and iron undergoing continual meteorite bombardment.

MAJOR EVENTS

- **The major event during the Hadean Eon was the formation of planet Earth, about 4600 million years ago.**
- **A collision between a Mars-sized planet and the Earth created the Moon.**

The formation of planet Earth

The Sun, Earth and other bodies in the Solar System originated from a cloud of interstellar gas and dust left when an older star exploded. Consequently, we and everything around us began as stardust.

Approximately 30 million years after its formation, the Earth collided with a planet named 'Theia' which was approximately the size of Mars. This collision melted the entire surface of the Earth and resulted in considerable quantities of material from both planets being scattered and ejected. It is believed that some of this ejected material condensed over a short period of time to form the Moon.

The current tilt of the Earth towards the Sun (of around 23.5°) is also evidence that the two planets collided. This tilt is responsible for the seasons we now experience. In addition, the chemical composition of both the Earth and Moon provide evidence to support this theory of how the Moon formed. Following the Moon-forming collision, the Earth continued to develop, with the more dense iron and nickel sinking towards the centre to form the core while less dense, but still molten, rocks remained at the surface. As the planet cooled, the surface solidified to form a crust.

Throughout the Hadean Eon, meteorites continually bombarded the Earth. However, toward the end of the Hadean Eon and at the start of the Archean Eon, a period of more intense meteorite bombardment occurred. This was termed the 'Late Heavy Bombardment'. Evidence of this event has been found mainly on the Moon because few rocks of this age have been found on Earth.

CLIMATE

Temperature

At the beginning of the Hadean Eon, surface temperatures were likely to have been around 2000°C, but, by its end, had decreased to around 55–85°C, which is at least 40°C hotter than the current average surface temperature.

Atmosphere

The atmosphere in the Hadean Eon was made of greenhouse gases, including methane, carbon dioxide and water vapour, along with other gases such as ammonia and nitrogen.

Sea levels

As the planet cooled, water condensed to form the oceans.

PALEOGEOGRAPHY

Conventional thought considers it unlikely that continents existed during the Hadean Eon. However, strongly debated evidence from rare minerals of Hadean age suggests that the Earth may have already had some crustal formation processes involving water.

LIFE

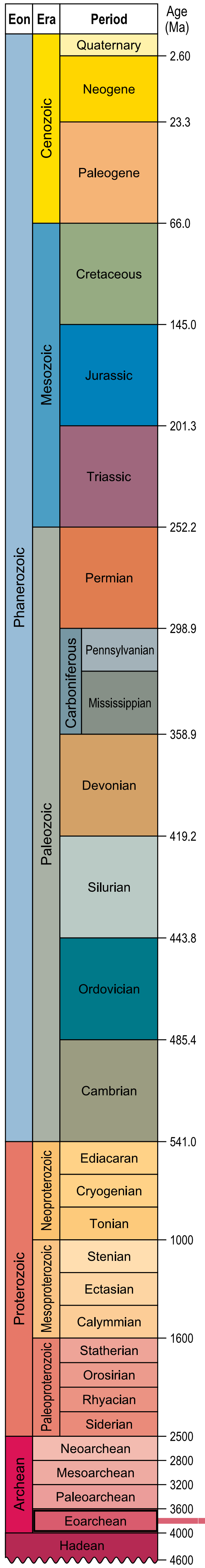
There is no evidence that life existed during the Hadean Eon.

HADEAN ROCKS

The oldest rocks on Earth are from Canada, dated at 4030 million years old. There are no rocks of this age in Australia. However, the oldest minerals ever dated on Earth come from much younger rocks in the Jack Hills of Western Australia. These are zircons which were radiometrically dated as having crystallised around 4404 million years ago.

HADEAN RESOURCES IN AUSTRALIA

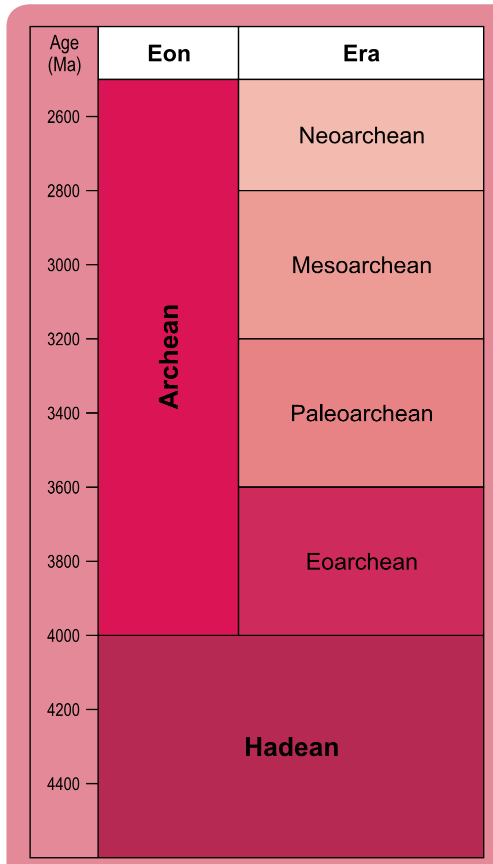
No resources are known from this time.



GTS 2012 Timescale

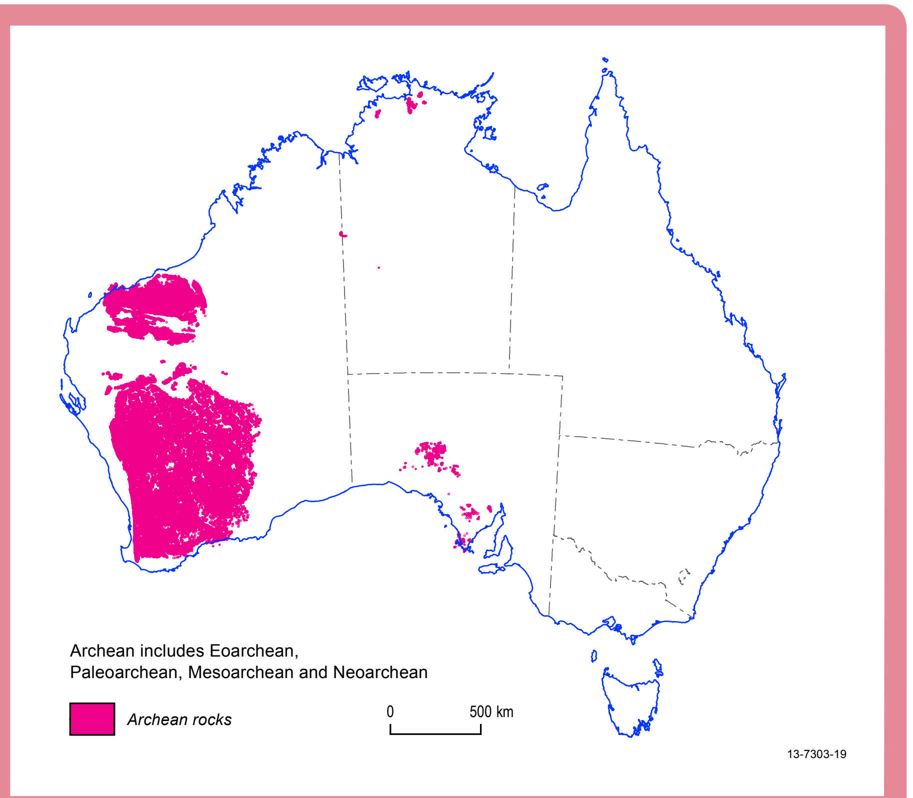
Eoarchean Era (4000–3600 Ma)

EON: ARCHEAN



The name 'Eoarchean' is derived from a combination of the Greek words 'eos', meaning dawn and 'arkhe', meaning beginning.

Meteorite fragments, including those found in the Henbury Craters, Northern Territory, were originally used to help date the formation of the Earth at about 4560 million years old.



HOW DO WE DATE ROCKS?

The Australian designed and built Sensitive High-Resolution Ion MicroProbe, or SHRIMP, is a mineral dating machine. The SHRIMP measures the age of rocks by analysing the uranium and lead isotopes in a tiny portion of single mineral grains. Some minerals contain a trace amount of uranium when they form in the Earth's crust, but it slowly decays over geological time to become lead. Minerals, especially a mineral known as zircon ($ZrSiO_4$), are extracted from geological samples by crushing the rocks and separating minerals according to their density and magnetic properties. The SHRIMP focuses a beam of ionised oxygen onto a spot within a single zircon grain. This beam has sufficient energy to remove a small portion of the grain including any uranium and lead within the crystal structure. The uranium and lead isotopes are then separated within the instrument before being measured. These measurements, along with known values for the natural decay rates of uranium, are used to calculate the age when the mineral originally formed.

INTRODUCTION

The Eoarchean Era is the first and oldest era of the Archean Eon. It lasted for 400 million years, from 4000 to 3600 million years ago.

During the Eoarchean Era, crust formation which began during the Hadean Eon continued and the intense meteorite bombardment ceased.

MAJOR EVENTS

- **The last part of the 'Late Heavy Bombardment' by huge meteorites occurred during the early Eoarchean Era and ended about 3800 million years ago.**
- **The oldest rocks still in existence in Australia are gneisses, a highly deformed rock, from Western Australia.**

The Late Heavy Bombardment

The 'Late Heavy Bombardment' was a time when the Earth, the Moon and other inner planets were bombarded by meteorites. This is evidenced by large impact craters on the surface of the Moon and other inner planets. Evidence of this bombardment on Earth is scarce because it has been mostly erased over time by weathering and tectonic processes.

Information from Mars, Mercury and the Moon indicates that the bombardment was intense, with the equivalent of a 50 kilometre wide meteorite hitting the Earth every century. Impacts such as these would have partly boiled the oceans. Larger impacts also had the capacity to melt the surface of the Earth, which, possibly, is why there are so few rocks of this age remaining.

Rocks of this age are only found today in Australia, Antarctica, Canada and Greenland. The oldest rocks in Australia are Eoarchean gneisses from near Mount Narryer in Western Australia, which have been dated at 3730 million years old.

CLIMATE

Temperature

Little is known about the surface temperature during the Eoarchean Era. However, the Sun was dimmer than it is now and consequently there was much less solar radiation to heat the surface of the Earth.

Atmosphere

The atmosphere comprised greenhouse gases, including methane, carbon dioxide and water vapour, along with other gases such as ammonia and nitrogen. During the 'Late Heavy Bombardment' a large amount of water vapour would have evaporated from the oceans into the atmosphere.

Sea levels

During the Eoarchean Era, most of the surface of the Earth was probably covered by oceans which, in the early part of the era, may have intermittently boiled as meteorites bombarded the planet.

PALEOGEOGRAPHY

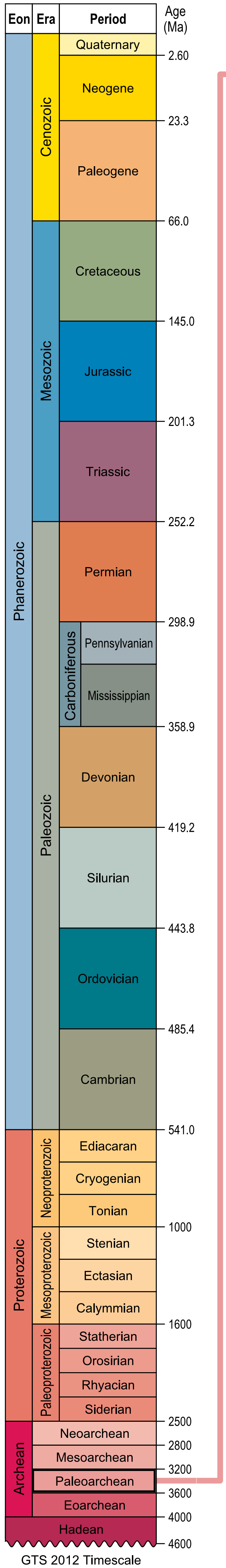
Continental blocks are believed to have existed. However, because of the scarcity of Eoarchean rocks, it is impossible to tell how significant they were, or their distribution.

LIFE

There is very little evidence of the existence of life during the Eoarchean Era, but given that stromatolite and bacterial fossils are known from the Paleoarchean Era, it is possible that life existed at this time.

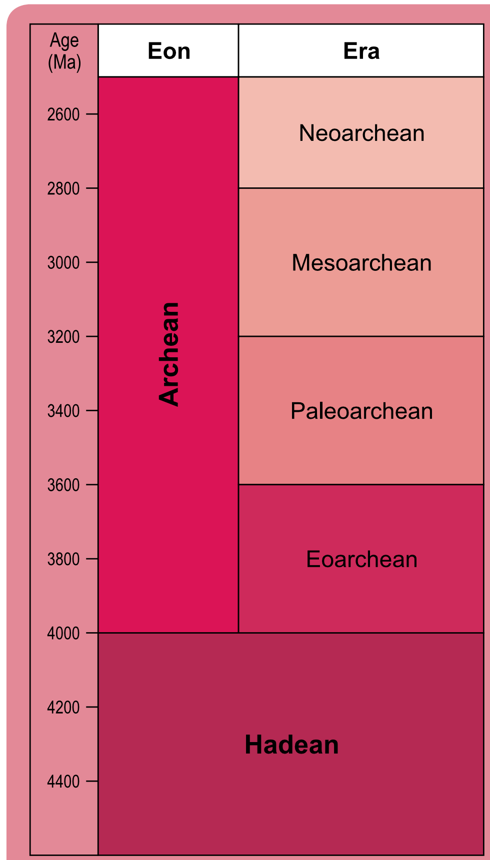
EOARCHEAN RESOURCES IN AUSTRALIA

No resources are known from this time.

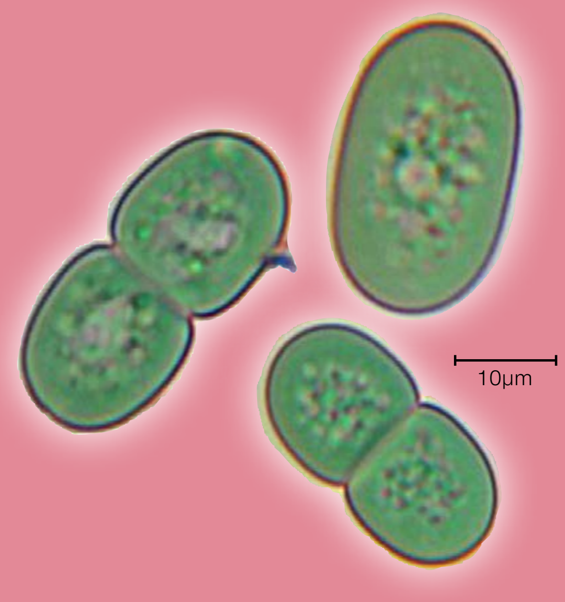


Paleoarchean Era (3600–3200 Ma)

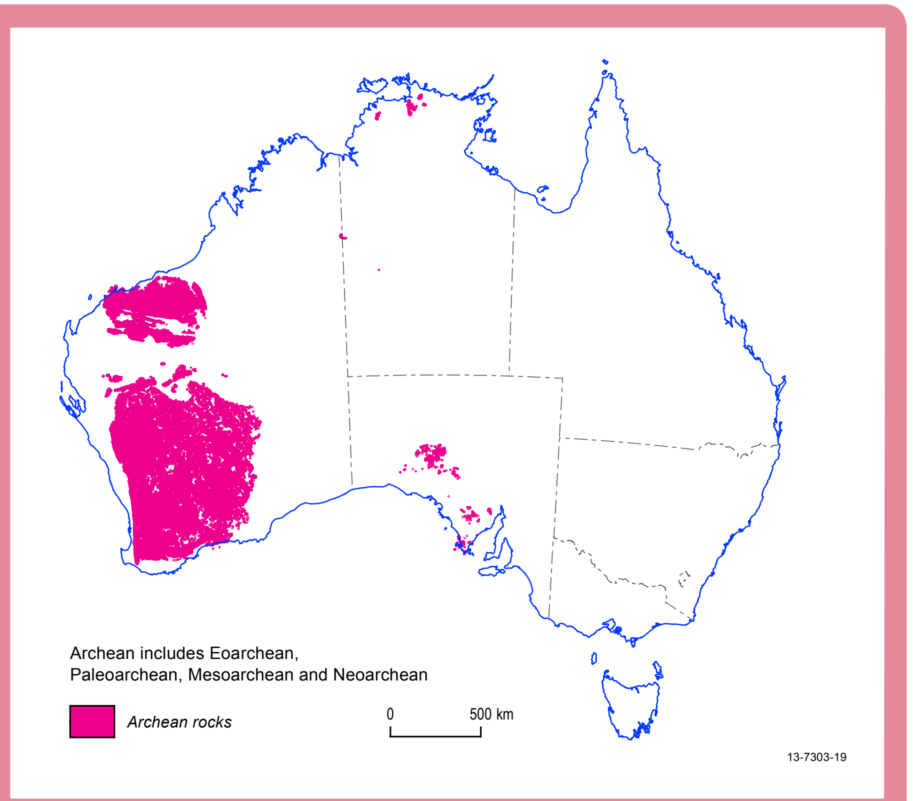
EON: ARCHEAN



The name 'Paleoarchean' is derived from the Greek words, 'paleo' meaning old and 'arkhe' meaning beginning.



Single-celled Cyanobacteria were the first organisms to generate oxygen by photosynthesis. Their common, but incorrect name is blue-green algae.



INTRODUCTION

The Paleoarchean Era is the second era in the Archean Eon and lasted 400 million years, from 3600 to 3200 million years ago.

Stromatolite and bacterial fossils from Western Australia indicate that life had appeared on Earth early in the Paleoarchean Era. Some continents had formed by the Paleoarchean Era, but most of the surface of the planet was covered by ocean.

MAJOR EVENTS

- **Life on Earth had evolved by the early Paleoarchean Era.**
- **The earliest stromatolites may have contained cyanobacteria during this era.**
- **During this era, there were major eruptions of komatiites and basalts.**

CLIMATE

Temperature

The Earth's average surface temperature was higher than today's. The large amount of greenhouse gases counteracted the effect of the Sun being dimmer than at present. Greenhouse gases warm the Earth's atmosphere by absorbing infrared radiation.

Atmosphere

The atmosphere consisted mostly of the greenhouse gases, methane, carbon dioxide and water vapour, and other gases such as ammonia and nitrogen. There was still no free oxygen in the atmosphere.

Sea levels

Many scientists believe that, at this time, there were possibly islands of emergent continental crust scattered throughout the Earth's oceans.

PALEOGEOGRAPHY

Rocks from this era are scarce, which makes understanding the Earth's geography of the time very difficult. There are two parts of the Southern Hemisphere which still contain continental crust from the Paleoarchean Era, the Pilbara Craton in Western Australia and the Kaapvaal Craton in southern Africa. Evidence suggests that these two cratons once formed part of a single supercontinent called Vaalbara.

The Paleoarchean Era was dominated by submarine volcanoes of komatiitic (komatiites are very high temperature ultramafic rocks that are common in Archean rocks) and basaltic rocks.

Many of the volcanic rocks erupted underwater and formed characteristic 'pillows'. In between volcanic eruptions banded iron formations, siltstones, sandstones and carbonates were deposited.

LIFE

The oldest stromatolite and bacterial fossils identified on Earth have been found in Paleoarchean rocks from the Pilbara Craton in Western Australia, indicating that bacteria had started to form colonies during this era. Another domain of life, the archaea, had most likely evolved by this time.

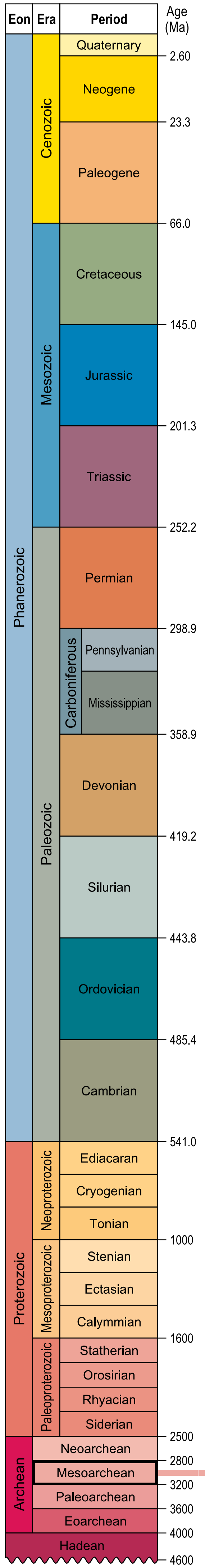
PALEOARCHEAN RESOURCES IN AUSTRALIA

All known mineral resources from Paleoarchean rocks are found in the Pilbara Craton of Western Australia.

FIRST LIFE

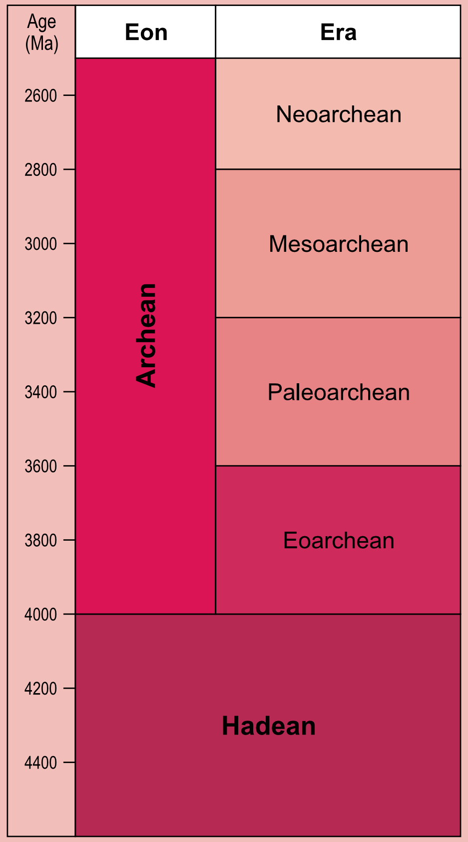
Stromatolites are laminated mound-like sedimentary structures which form over time as filamentous cyanobacteria and other single-celled organisms bind layers of sediment grains together. Stromatolites were the Earth's first reef building structures and dominated the fossil record for the first 2500 million years of life on Earth. Stromatolites were most abundant and diverse during the Proterozoic Era but declined in the Phanerozoic Era as more complex life forms evolved. They are extremely rare today, but still exist in places such as Hamelin Pool in Shark Bay, Western Australia.

The North Pole barite deposit, formed 3481 million years ago, is the oldest ore deposit in Australia. Other mineral resources include Panorama (zinc-lead-copper) and Spinifex Ridge (molybdenum-gold).

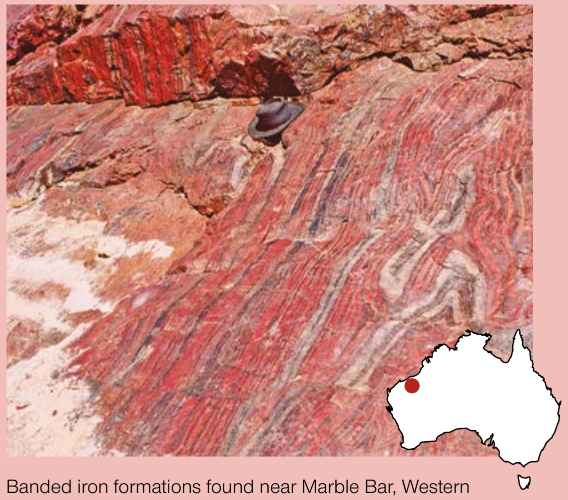


Mesoarchean Era (3200–2800 Ma)

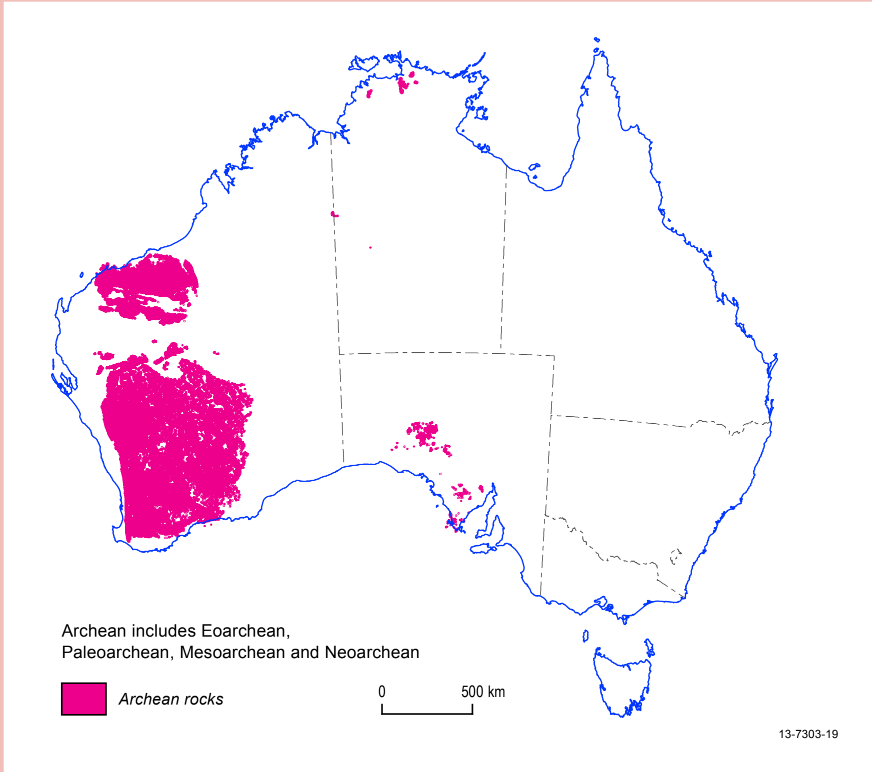
EON: ARCHEAN



The name 'Mesoarchean' is derived from the Greek word 'meso,' meaning middle, and 'arkhe' meaning beginning.

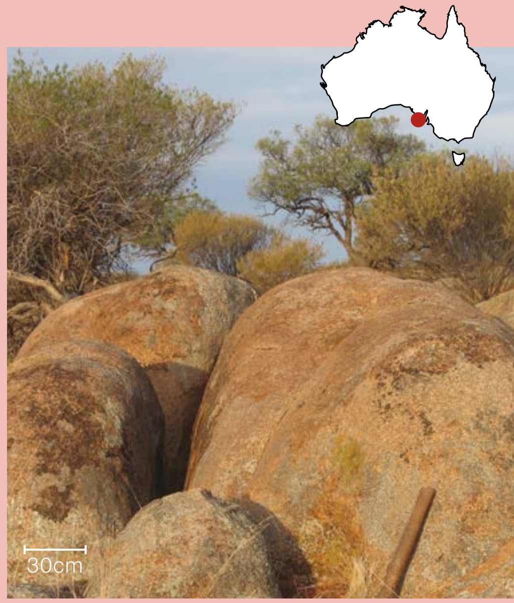


Banded iron formations found near Marble Bar, Western Australia were deposited in the Mesoarchean Era and later transformed into iron ore.



EYRE PENINSULA

In 2008, rocks from Eyre Peninsula were dated at 3150 million years old, extending the knowledge of South Australia's geological history by 500 million years.



INTRODUCTION

The Mesoarchean Era is the third era of the Archean Eon and lasted for 400 million years, from 3200 to 2800 million years ago.

During the Mesoarchean Era, development of continents continued. The oceans were more iron-rich than at present, giving rise to banded iron formations.

MAJOR EVENTS

- **The earliest economic banded iron formations in Australia were deposited.**
- **In the middle of this era, large volumes of igneous rocks were extruded onto the western Yilgarn Craton of Western Australia. These rocks host copper and zinc mineralisation.**

CLIMATE

Temperature

The Earth's average surface temperature was probably roughly similar to today, with the large amount of greenhouse gases counteracting the effect of the Sun's weaker radiation. Greenhouse gases warmed the Earth's atmosphere by absorbing infrared radiation.

Atmosphere

Oxygen was being generated by photosynthetic cyanobacteria, but little of this made its way into the atmosphere. The atmosphere consisted mostly of greenhouse gases, including methane, carbon dioxide and water vapour, and other gases such as ammonia and nitrogen.

Sea levels

Little is known of actual sea levels during the Mesoarchean Era, but most known sedimentary rocks of this time were deposited under water.

PALEOGEOGRAPHY

Little is known about the distribution of the continents on the Earth during this era.

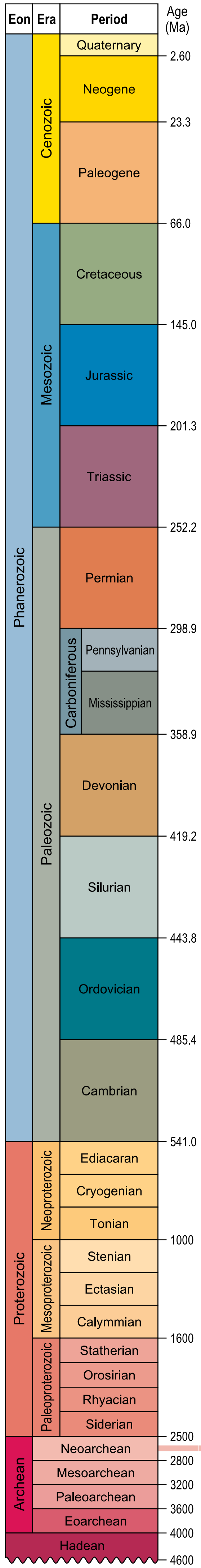
Rocks of this age occur in Western and South Australia. Submarine volcanoes were abundant and banded iron formations, sandstones and shales were deposited.

LIFE

Stromatolites occur in rocks from the Mesoarchean Era and indicate that bacterial colonies were present. These stromatolites contained photosynthetic cyanobacteria.

MESOARCHEAN RESOURCES IN AUSTRALIA

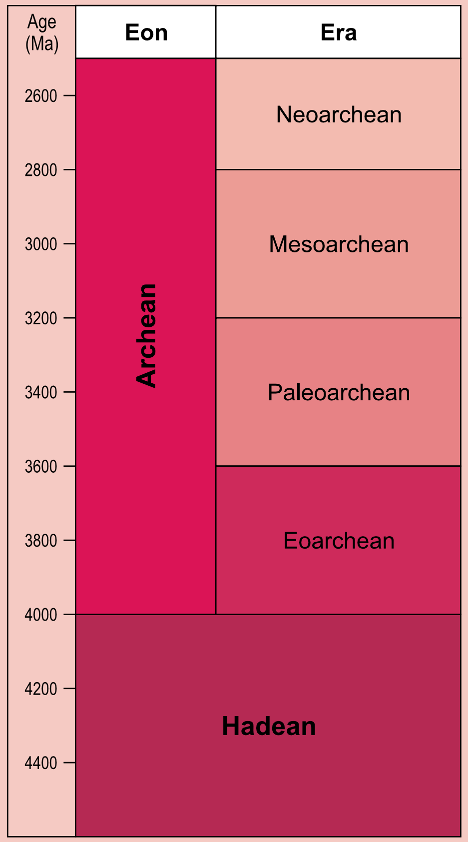
Mineral resources from Mesoarchean rocks are all located in Western Australia and include Golden Grove, Whim Creek (zinc-copper-lead-gold), Radio Hill (nickel-copper-platinum) and the world class Wodgina (tantalum-tin) deposits.



GTS 2012 Timescale

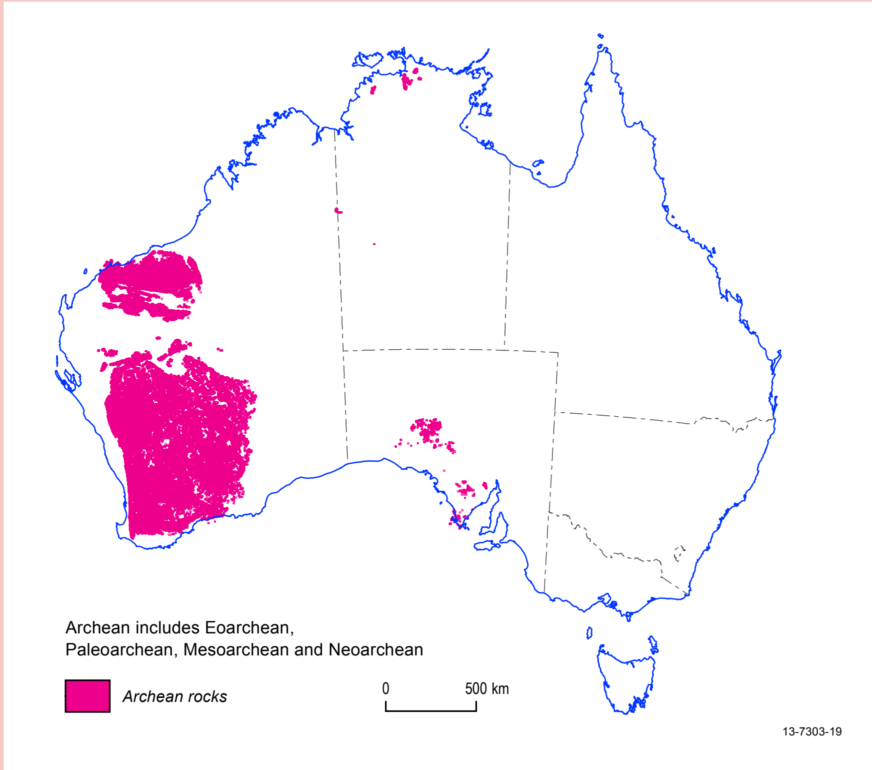
Neoarchean Era (2800–2500 Ma)

EON: ARCHEAN



The name 'Neoarchean' comes from the Greek words 'neo', meaning new and 'arkhe' meaning beginning.

Gold from near Kalgoorlie, Western Australia.
Kalgoorlie is one of the largest gold deposits in the world.



In March 2009, geoscientists identified a rock from west Arnhem Land, Northern Territory, as being 2671 million years old. This is the oldest rock identified so far in the Northern Territory.

INTRODUCTION

The Neoarchean Era is the youngest era in the Archean Eon and lasted for 300 million years, from 2800 to 2500 million years ago.

During the Neoarchean Era, continental blocks continued to grow and world-class gold and nickel deposits in Western Australia were formed.

MAJOR EVENTS

- **Continental blocks continued to grow.**
- **Large volumes of igneous rocks which host many world-class mineral deposits were emplaced in Western Australia.**

CLIMATE

Temperature

The Earth's average surface temperature was roughly similar to today's, with the large amount of greenhouse gases counteracting the effect of the Sun's weaker radiation. Greenhouse gases warmed the Earth's atmosphere by absorbing infrared radiation.

Atmosphere

Oxygen was still being generated by photosynthetic cyanobacteria during the Neoarchean Era, but very little of this made its way into the atmosphere. This is because, as a highly reactive gas, most oxygen generated was consumed by chemical reactions in the oceans and atmosphere. The atmosphere consisted mostly of greenhouse gases, including methane, carbon dioxide and water vapour, and other gases such as ammonia and nitrogen.

Sea Levels

Little is known of actual sea levels during the Neoarchean Era.

PALEOGEOGRAPHY

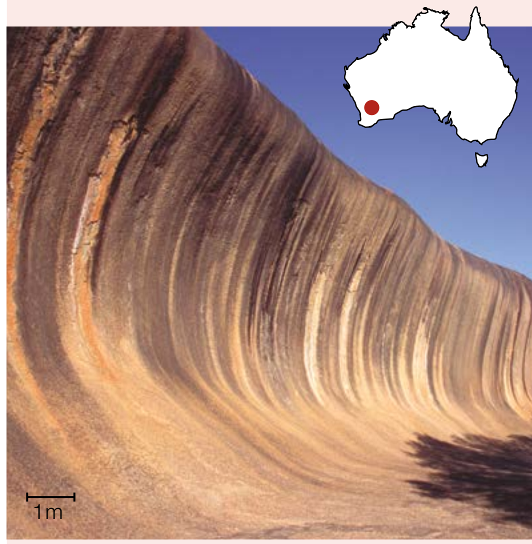
The surviving Neoarchean rocks of Australia indicate that at this time they were covered by a shallow sea. Underwater volcanic eruptions continued, and, in some emergent areas, there were volcanic flows and wide river deltas which merged into submarine fans at the coastline. Towards the end of the Neoarchean Era, major banded iron formations were precipitated on deeper shelf environments in the Hamersley Basin, Western Australia and in parts of South Australia.

LIFE

Stromatolites continued to be widespread in rocks from the Neoarchean Era, and indicate that photosynthetic cyanobacteria were still the dominant form of life. The only other forms of life which were widespread were other bacteria and Archaea.

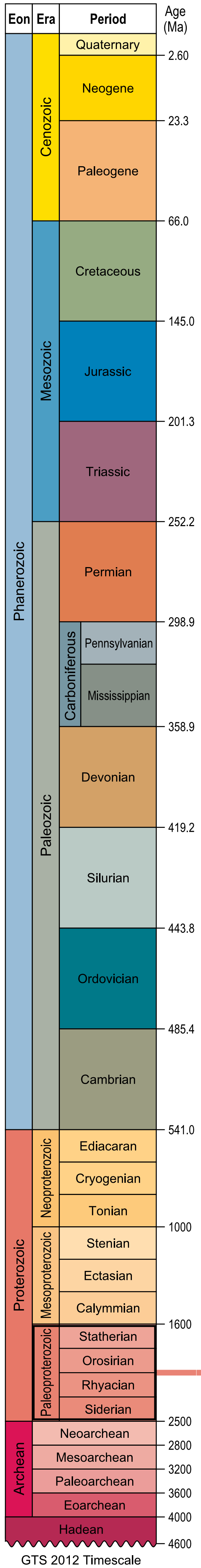
NEOARCHEAN RESOURCES IN AUSTRALIA

Mineral resources from Neoarchean rocks are all in Western Australia and include the world-class Mt Keith, Kambalda, Perseverance (nickel), Boddington (gold-copper) and Kalgoorlie (gold) deposits. In addition, there is world-class tantalum and lithium at Greenbushes and significant iron ore at Marra Mamba.



WAVE ROCK

Formed during a major igneous event, Wave Rock in Western Australia is 2630 million years old. It stands 14 metres high, and 110 metres long. The granite cliff, resembling a wave about to break, is on the northern face of a large erosional remnant called Hyden Rock. This curved cliff face has been rounded by weathering and water erosion.



Paleoproterozoic Era (2500–1600 Ma)

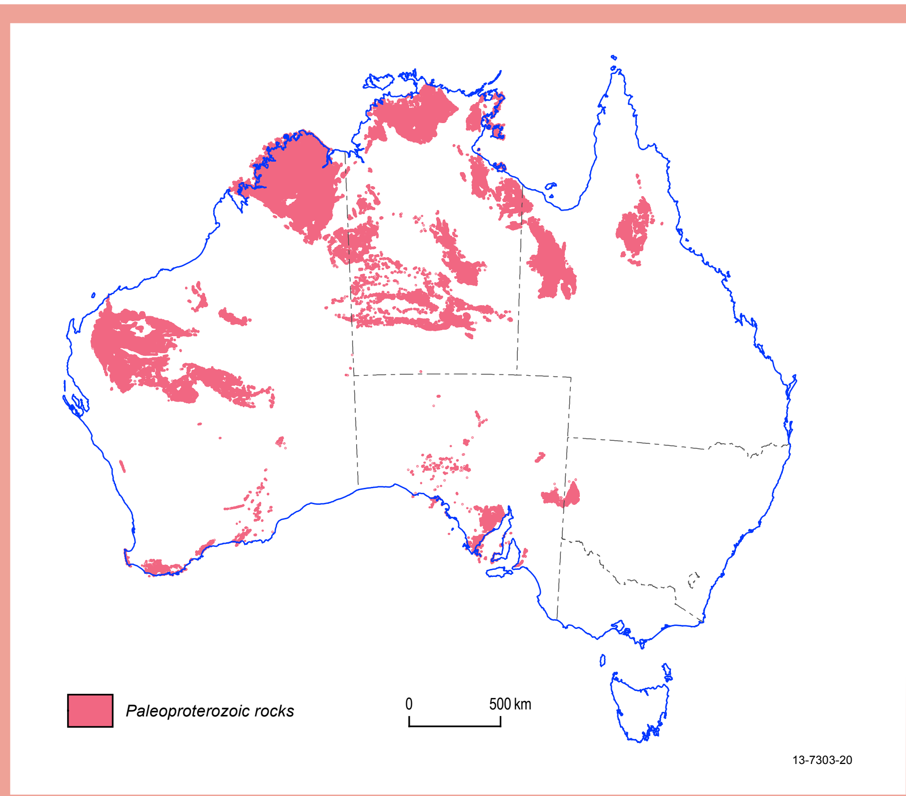
EON: PROTEROZOIC

Age (Ma)	Era	Period
1700	Paleoproterozoic	Statherian
1800		
1900		Orosirian
2000		
2100		Rhyacian
2200		
2300		Siderian
2400		

HAMERSLEY BASIN
BANDED IRON FORMATIONS

Many of the major banded iron formations of Australia in the Hamersley Basin, Western Australia, were deposited between 2640 and 2480 million years ago. During this era, the oceans were more iron rich and were inhabited by photosynthetic bacteria that caused the precipitation and settling of layers of iron oxide amongst other sediments. This process gave rise to the 'banded' pattern in the rocks.

Banded iron formations are sedimentary rocks, which are one of the most important precursors to the formation of economic sources of iron ore. During the Paleoproterozoic Era, around 2000 million years, silica and carbonate were removed from the banded iron formations leaving behind enriched iron ore.



The name 'Paleoproterozoic' replaces the informal 'early Proterozoic' and is derived from the Greek word 'paleo' meaning old.

INTRODUCTION

The Paleoproterozoic Era is the oldest era of the Proterozoic Eon. It lasted 900 million years, from 2500 to 1600 million years ago and is the longest era in the Earth's history.

In the early part of the Paleoproterozoic Era, free oxygen began to accumulate in the atmosphere. This is known as the 'Great Oxidation Event'. Soon after, the Earth experienced its first severe glaciation.

During the Paleoproterozoic Era continental rocks amalgamated to form the supercontinent known as Nuna. The supercontinent had started to break apart by the end of the Era.

MAJOR EVENTS

- **The 'Great Oxidation Event' occurred, which increased free oxygen levels in the Earth's atmosphere.**
- **The first series of major glaciations, known as the Huronian Glaciations began early in the Paleoproterozoic Era.**
- **Some of the world's largest deposits of iron, lead, zinc, silver and uranium were formed in Australia later in the Paleoproterozoic Era.**

CLIMATE

Temperature

Little is known about the climate of the Paleoproterozoic Era, except that at the start of this era there were a series of major glaciations called the Huronian Glaciations. Cooling, which led to these glaciations, may have been caused by oxygen removing the greenhouse gas methane from the atmosphere.

Atmosphere

During this era, photosynthetic cyanobacteria and algae increased in diversity, leading to the first free oxygen

entering the atmosphere. By the end of the early Paleoproterozoic Era, oxygen made up about 1% of the atmosphere. Although this is called the 'Great Oxidation Event', the amount of oxygen was still only about one-twentieth of today's levels. However, this event was irreversible and impacted significantly on the evolution of life on Earth.

Sea levels

Little is known about actual Paleoproterozoic sea levels, but it is likely that they fell during the severe Huronian Glaciation.

PALEOGEOGRAPHY

The parts of the Australian continent which existed at this time are thought to have been positioned just south of the Equator and were moving relatively quickly around the tropics.

Early in the era, precipitation of banded iron formations continued in the Hamersley Basin. Evidence of the Huronian Glaciation is found in the Pilbara Craton, Western Australia. For the rest of the era, shallow seas covered most of northern Australia.

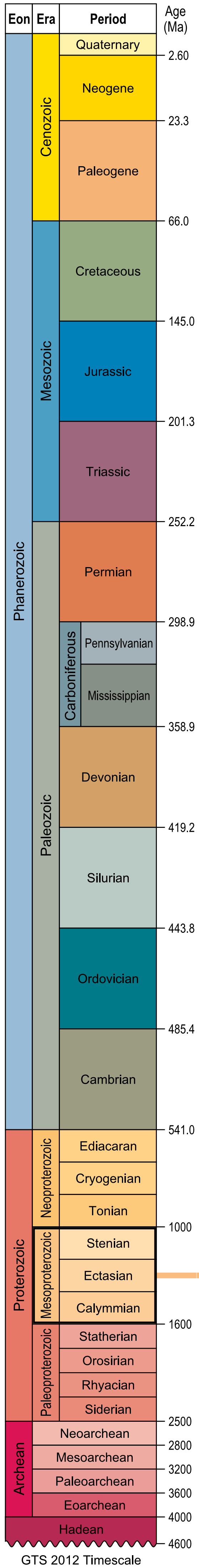
Previously separate parts of the Australian continet are thought to have amalgamated as part of the Nuna Supercontinent during this era.

LIFE

Photosynthetic cyanobacteria dominated early in the era. The third domain of life, the eukaryotes, evolved later as single-celled algae when several different organisms joined together, paving the way for modern plants, animals and fungi. It is possible that multicellular algae evolved later in the Paleoproterozoic Era.

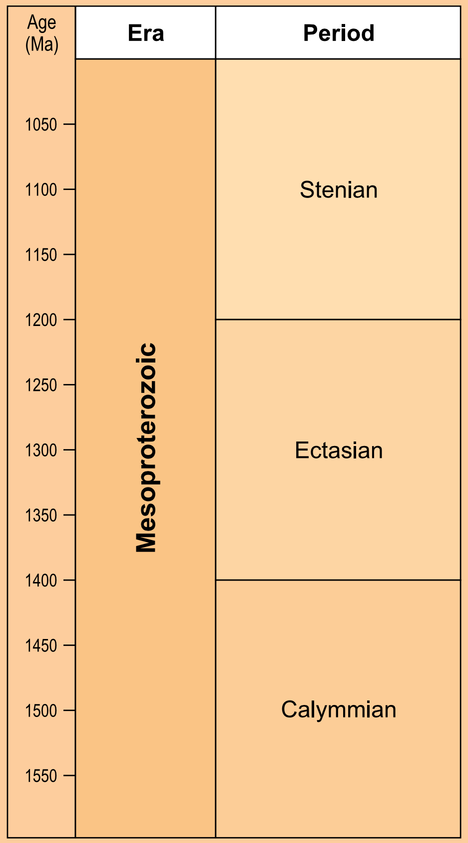
PALEOPROTEROZOIC RESOURCES IN AUSTRALIA

World-class lead, zinc and silver resources are found in Paleoproterozoic rocks at Broken Hill, New South Wales and at Cannington and Mount Isa, Queensland. The Northern Territory hosts significant Paleoproterozoic deposits at McArthur River (lead-zinc-silver), Tanami (gold), Tennant Creek (gold-copper-bismuth), Ranger and Jabiluka (uranium). Major iron ore deposits occur in the Hamersley Basin, Western Australia. The world's oldest oil is found in Paleoproterozoic rocks in the Northern Territory, but is uneconomic.



Mesoproterozoic Era (1600–1000 Ma)

EON: PROTEROZOIC

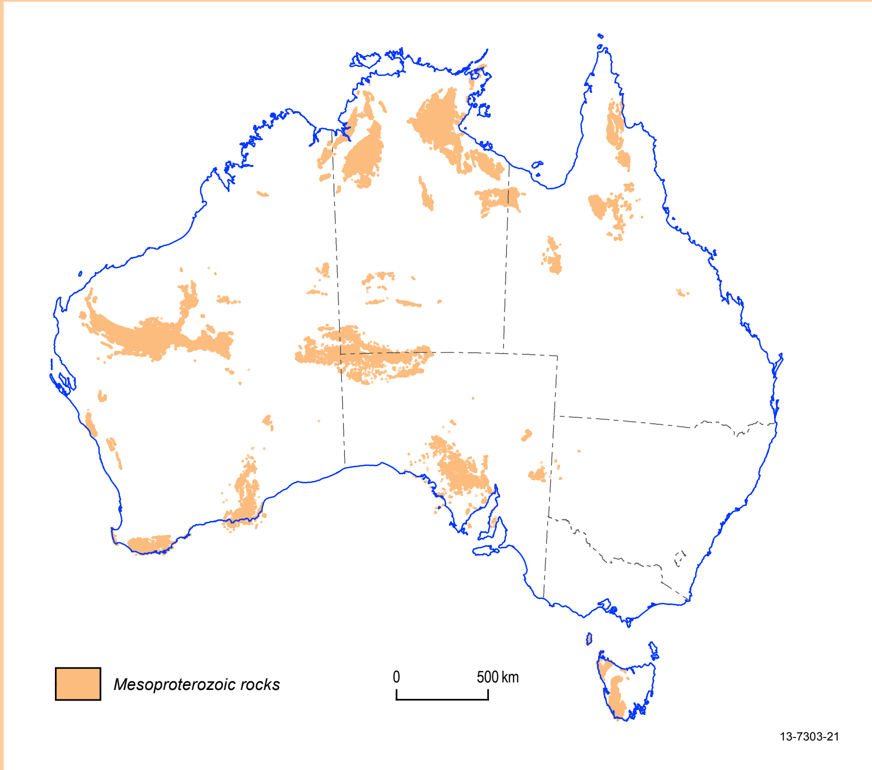


The name 'Mesoproterozoic' replaces the informal 'middle Proterozoic'. However, it means the same thing because 'meso' is Greek for 'middle'.

ARGYLE DIAMONDS

Diamond is the hardest naturally occurring mineral and comprises a cubic crystal lattice of carbon. The strong chemical bonds between the carbon atoms are what make it so hard. Diamonds form under a combination of very high pressure and temperature. Natural diamonds form in the Earth's mantle mostly beneath the thick, old, stable continental crust, at depths of 140 to 200 kilometres.

The diamonds are brought from the Earth's mantle to the surface by deep-source volcanic eruptions, which travel along near-vertical 'volcanic pipes'. The magma, which transports the diamonds, are of two types and these cool to form kimberlite or lamproite rock. Argyle diamonds, found in the Kimberley region of Western Australia are hosted by a lamproite pipe of Mesoproterozoic age (below).



INTRODUCTION

The Mesoproterozoic Era is the second era of the Proterozoic Eon and lasted 600 million years, from 1600 to 1000 million years ago.

The Mesoproterozoic Era saw further rearrangement of continents. Following the break-up of the Nuna supercontinent, continental blocks amalgamated near the end of the era to form the supercontinent known as Rodinia. Life was still confined to the ocean.

MAJOR EVENTS

- **Early in the era, major volumes of granite were intruded in South Australia and Queensland and hosts significant deposits of uranium, copper, gold and molybdenum.**
- **Towards the end of the era the supercontinent Rodinia formed.**

CLIMATE

Temperature

Little is known about the climate during the Mesoproterozoic Era.

Atmosphere

At the beginning of the era, oxygen had not significantly increased since the early Paleoproterozoic Era, and formed only about 1% of the atmosphere. By the end of the Mesoproterozoic Era it had still reached only about 2%.

Sea levels

Little is known about actual sea levels during this era.

PALEOGEOGRAPHY

The supercontinent Rodinia, which formed at the end of the era, was mainly located in the Southern Hemisphere and was surrounded by a large ocean.

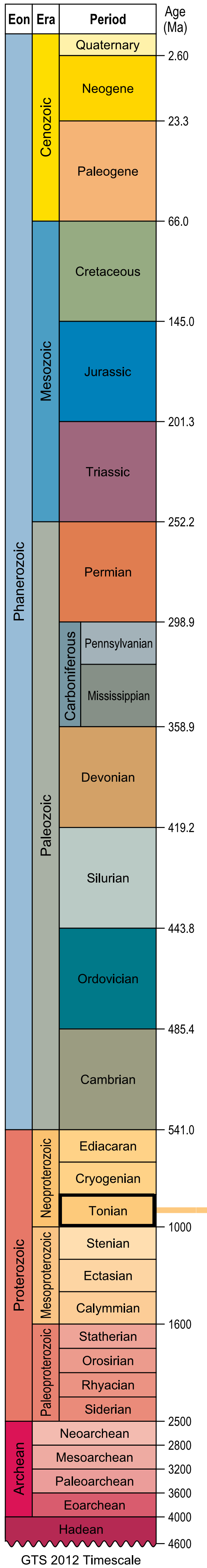
In Australia, early in the Mesoproterozoic Era, major eruptions deposited volcanic rocks over wide areas in the Gawler Craton, South Australia and in the Georgetown area, northern Queensland. In the middle part of the era, much of Australia was submerged under a wide, shallow sea. However, by the late Mesoproterozoic Era, this sea had receded to a small area in central Western Australia.

LIFE

Cyanobacteria continued to diversify and formed even more types of stromatolites. Algae also continued to diversify and by the end of the Mesoproterozoic Era, red algae had evolved. A number of possible fossils of multicellular algae have been noted from the Mesoproterozoic Era.

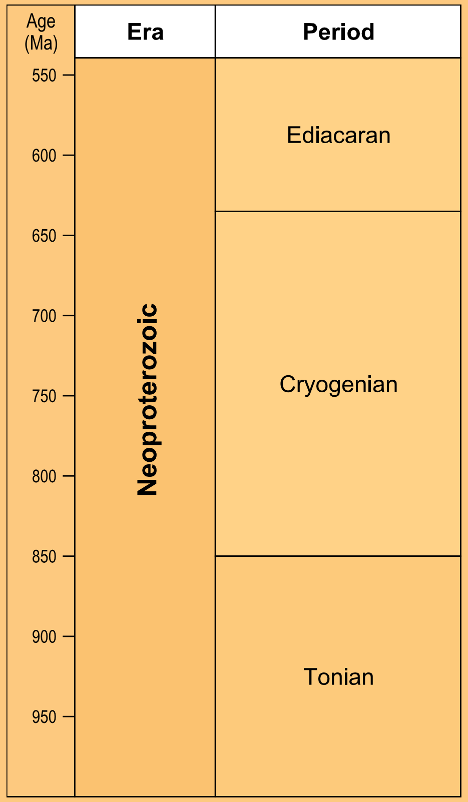
MESOPROTEROZOIC RESOURCES IN AUSTRALIA

Mineral resources from Mesoproterozoic age rocks include: Argyle (diamonds), Western Australia; Olympic Dam (uranium-copper-gold), South Australia; and Century (lead-zinc), Mount Isa (copper) and Merlin (molybdenum) in northwest Queensland.



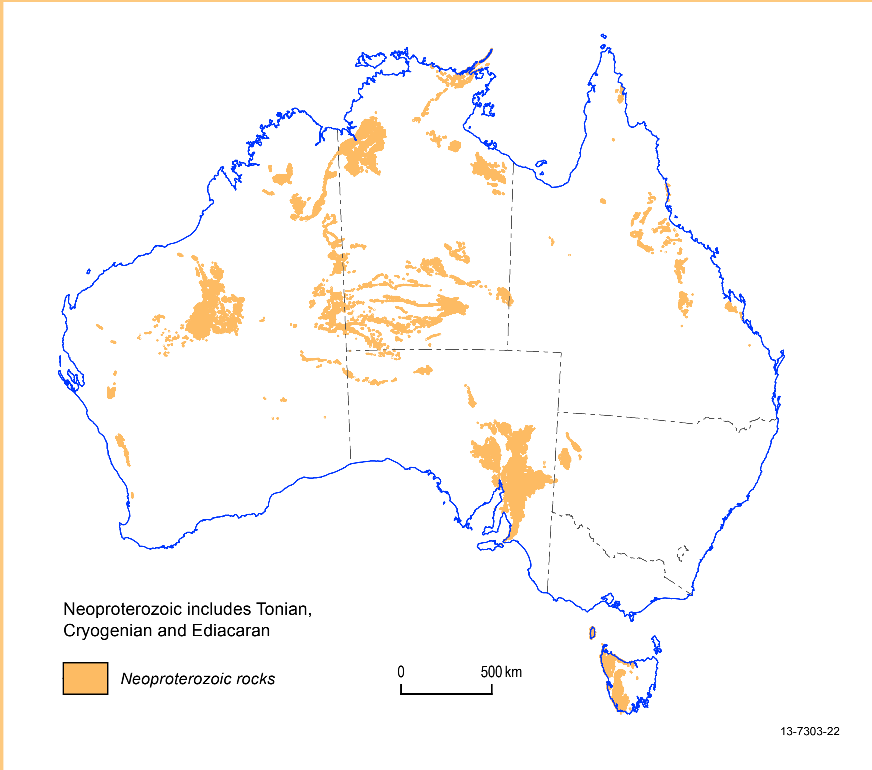
Tonian Period (1000–850 Ma)

EON: PROTEROZOIC **ERA:** NEOPROTEROZOIC



The name 'Tonian' comes from the Greek word 'tonos', which means 'stretch', a description chosen because it was during this period that the supercontinent Rodinia began to break up.

Ripple-marked quartzite from the Rocky Cape Group northwestern Tasmania. The Rocky Cape Group is one of the rare Tonian rock groups in Australia.



INTRODUCTION

The Tonian Period is the first of three periods of the Neoproterozoic Era. It lasted 150 million years, from 1000 to 850 million years ago.

During the Tonian Period, the supercontinent of Rodinia included most of the Earth's continental crust. There are very few positively identified Tonian rocks in Australia.

MAJOR EVENTS

- **The supercontinent of Rodinia had reached its maximum size by the beginning of the Tonian Period and by its end had started to break up.**
- **There are very few positively identified rocks of Tonian age in Australia.**

CLIMATE

Temperature

Little is known about the climate of the Tonian Period, but it is likely to have been relatively cold, about 10°C cooler than today.

Atmosphere

In the Tonian Period, the concentration of oxygen in the atmosphere was approximately 2% and had not increased since the Mesoproterozoic Era.

Sea levels

Very little is known about the actual sea levels during the Tonian Period.

PALEOGEOGRAPHY

The supercontinent Rodinia was surrounded by a large ocean throughout this period, but by the end it had rifted and started to break up.

Because Tonian rocks are scarce in Australia, it is difficult to determine just where Australia was within the supercontinent Rodinia. However, most of Australia was emergent in the Tonian Period, with the exception of a marine shelf in the Rocky Cape area of western Tasmania.

LIFE

Single-celled green algae underwent their first major diversification during the Tonian Period. There is some evidence also of multicellular algae in rocks of this age. Although no fossil animals are known from Tonian rocks, there is some evidence that small worm-like animals may have existed.

TONIAN RESOURCES IN AUSTRALIA

There are no known resources of Tonian age in Australia.

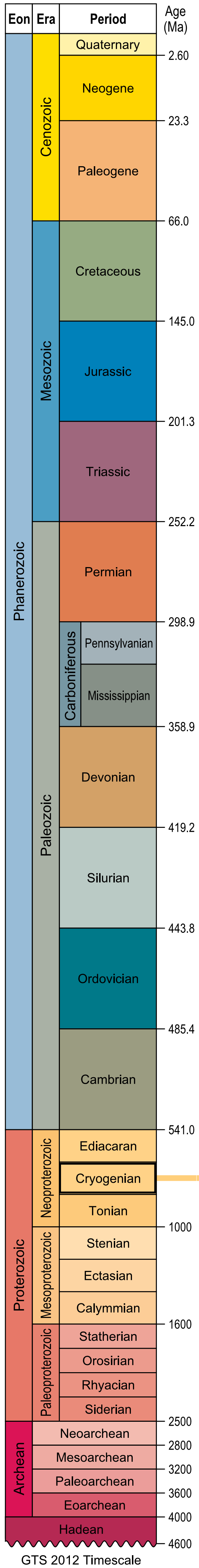
SUPERCONTINENTS

A supercontinent is a landmass formed by the amalgamation of most or all of Earth's continental landmasses. Smaller landmasses containing more than one continent or craton are called supercratons.

The 'supercontinent' theory proposes that during the Earth's history, supercontinents have formed through the process of plate tectonics. The supercontinent cycle is characterised by an amalgamation phase when continents collide together culminating in formation of the supercontinent, and a subsequent breakup phase, when the supercontinent rifts and breaks apart into smaller continental fragments. Over the past 3000 million years, at least six supercontinents (and supercratons) are thought to have formed and split apart—though there is less certainty with older proposed supercontinents.

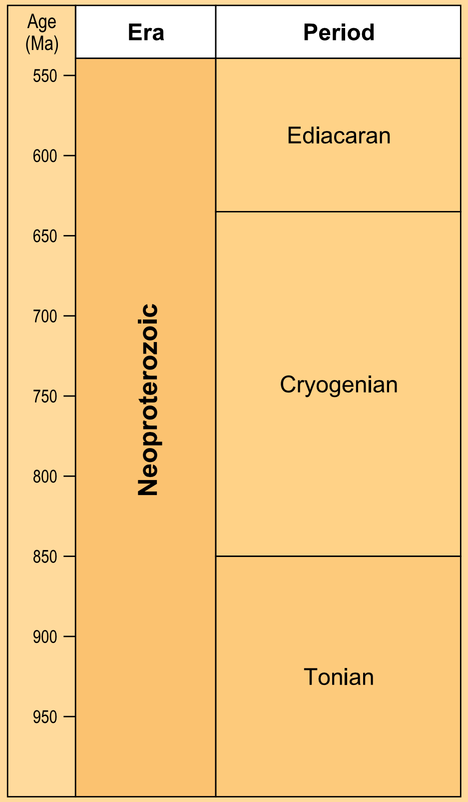
The earliest suspected supercraton was Vaalbara which formed more than 3100 million years ago, and broke up around 2800 million years ago. The next supercraton, Kenorland, was formed approximately 2700 million years ago and broke up around 2500 million years ago. The first well documented supercontinent, Nuna (also known as Columbia), formed and rifted apart during the period from 1900 to 1500 million years ago.

The supercontinent Rodinia, formed at around 1100 million years ago and began to rift roughly 750 million years ago into three fragments: East Gondwana, West Gondwana and Proto-Laurasia. Plate tectonics then brought the fragments of Rodinia back together in a different configuration around 300 million years ago, forming the best-known supercontinent, Pangaea. At around 180 million years ago, Pangaea subsequently broke up into the northern and southern landmasses of Laurasia and Gondwana.



Cryogenian Period (850–635 Ma)

EON: PROTEROZOIC **ERA:** NEOPROTEROZOIC

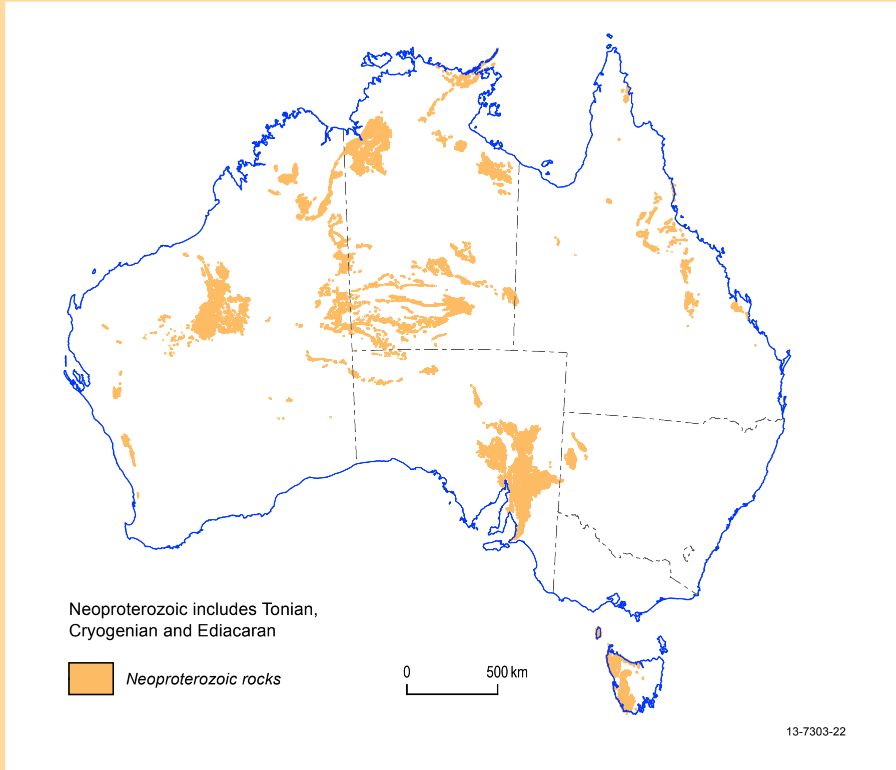


The Cryogenian Period was named in 1990. During this period two of the most severe ice ages in Earth's history occurred. The word 'cryo' is Greek for 'icy cold'.

SNOWBALL EARTH

In the second half of the Cryogenian Period during the Sturtian and Marinoan glaciations, the climate was thought to be so cold that ice caps covered the entire surface of the Earth, even at the Equator. This is the hotly debated 'Snowball Earth' hypothesis.

The world-wide Sturtian and Marinoan glaciations are named after rock successions in the Flinders Ranges, South Australia which show clear evidence of both of these glaciations. These were first identified in 1906 by Sir Douglas Mawson, a then lecturer in Geology at the University of Adelaide and later an Antarctic explorer.



AUSTRALIA'S COLD PAST

In the Cryogenian Period, parts of Australia were just north of the Equator, with little elevation above sea level. Unlike the tropical conditions experienced at the Equator today, conditions at the Cryogenian Equator would have looked much more like Antarctica does today.

INTRODUCTION

The Cryogenian Period is the second of three periods in the Neoproterozoic Era. It lasted approximately 215 million years, from 850 to approximately 635 million years ago.

During the Cryogenian Period the supercontinent Rodinia finally broke up and two great ice ages occurred. The oldest fossil single-celled animals are found in Cryogenian rocks.

MAJOR EVENTS

- **There were two major ice ages during the Cryogenian Period, the Sturtian Ice Age between about 720 to 700 million years ago; and the Marinoan Ice Age at the end of the period (i.e. 660 to 635 million years ago).**
- **The first fossil evidence of animals (single-celled amoebas) comes from rocks deposited in the Cryogenian Period.**

CLIMATE

Temperature

Temperatures during the Cryogenian Period were quite mild initially, but became extremely cold during the ice ages, even at the Equator. These glaciations are believed to be the most severe in the Earth's history.

Atmosphere

The concentration of oxygen in the atmosphere rose slightly to about 3% or 4%, which is one-fifth of today's level.

Sea levels

Actual sea levels are unknown for most of the Cryogenian Period, but during the extensive Sturtian and Marinoan glaciations, they would have been quite low.

PALEOGEOGRAPHY

During the early Cryogenian Period, Rodinia continued to break apart into three smaller supercontinents; East Gondwana, West Gondwana and Proto-Laurasia. About the time of the Marinoan glaciation, Australia was part of East Gondwana and was located just north of the Equator.

Early in the Cryogenian Period, much of Australia became submerged forming the central Australian basins. Initially the basins were filled by large river systems and later the sea encroached. As the climate cooled, ice sheets and glaciers began to cover Australia.

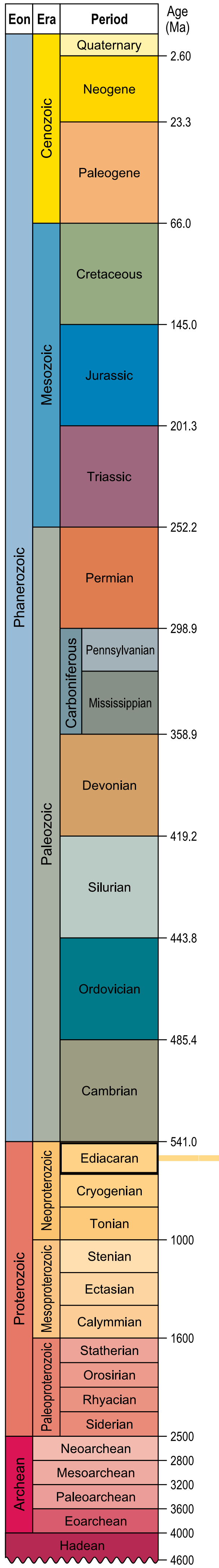
LIFE

Fossil amoebas, the oldest fossil single-celled animals, have been found in rocks from the Cryogenian Period. No complete fossils of multicellular animals are known from this period. However, fossils of molecules produced only by sponges have been found in rocks of this age, indicating that primitive marine sponges had evolved.

Cyanobacteria were still widespread during this time. Green algae were common and some formed the earliest multicellular plants which were similar in appearance to seaweed filaments.

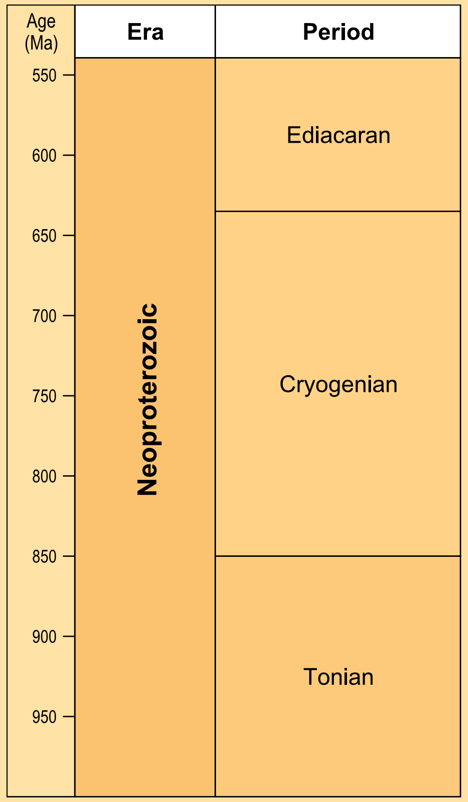
CRYOGENIAN RESOURCES IN AUSTRALIA

Mineral resources from Cryogenian rocks include the Western Australian deposits at Telfer (gold), Kintyre (uranium) and Nifty (copper), Nolans Bore (rare earth elements-phosphate-uranium) in the Northern Territory, and Burra (copper) in South Australia.



Ediacaran Period (~635–541 Ma)

EON: PROTEROZOIC **ERA:** NEOPROTEROZOIC

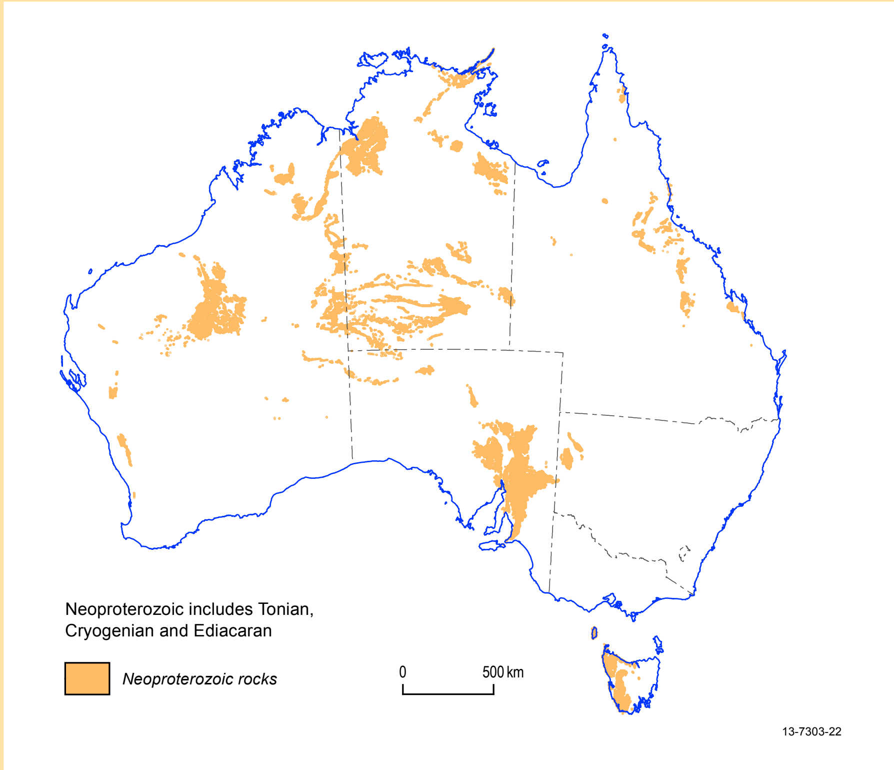


The Ediacaran Period was named in 1990 after the Ediacara Hills in South Australia, where fossils of some of the earliest multicellular animals were found.

EARLY LIFE

The Ediacaran Period is famous for its association with the 'Ediacara biota', marking the first appearance of large, architecturally complex organisms in Earth's history. The marked and rapid increase in abundance, size and diversity of lifeforms during the Australian Ediacaran shows that it was a period of major evolutionary change.

Left, *Dickinsonia costata* (length 8.5cm) and right, *Tribrachidium heraldicum* (diameter 2.5cm).



INTRODUCTION

The Ediacaran Period is the third and last period of the Neoproterozoic Era. It lasted approximately 94 million years, from approximately 635 to 541 million years ago.

After the glaciations of the preceding Cryogenian Period, conditions were warmer. Multicellular animals appeared in the oceans in the middle of the Ediacaran Period and towards the end, the first shelled animals appeared.

MAJOR EVENTS

- **The first multicellular animals appeared during the middle of the Ediacaran Period and are known as the 'Ediacara Biota'.**
- **In the middle of the Ediacaran Period a very large meteorite hit the Gawler Ranges in South Australia leaving a crater about 90 kilometres in diameter, which today contains Lake Acraman.**
- **A mass extinction event which wiped out nearly all the Ediacara Biota occurred towards the end of the period.**

CLIMATE

Temperature

The Ediacaran Period begins at the end of the Marinoan Glaciation, when the Earth warmed rapidly as the glaciation eased. Evidence suggests that the Ediacaran Period's climate was warm and arid towards the Equator, and warm and humid towards the poles. At the end of the period the Earth's climate cooled slightly.

Atmosphere

The average oxygen content of the atmosphere increased to about 8%, which was still less than half of today's level. Carbon dioxide content of the atmosphere averaged about 0.45% which is about 12 times greater than today's level.

Sea levels

Sea levels rose sharply with the melting of the ice caps at the end of the Cryogenian Period. This resulted in higher sea levels through most of the Ediacaran Period.

PALEOGEOGRAPHY

Towards the end of the Ediacaran Period, West Gondwana and East Gondwana collided to form the supercontinent known as Gondwana.

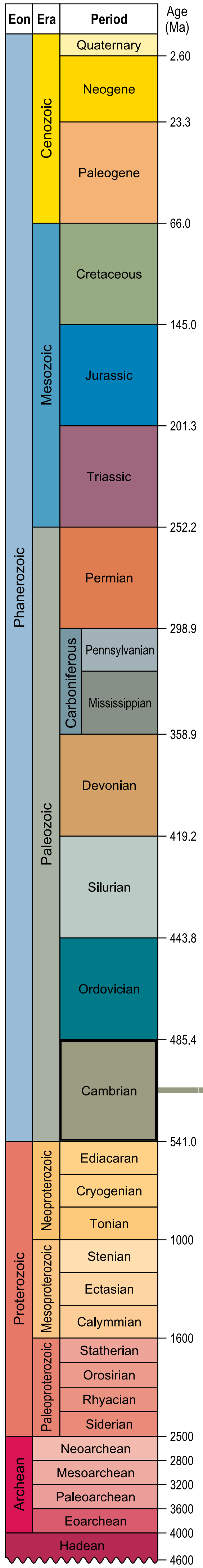
Following the glaciations of the Cryogenian Period, sea levels rose and much of central and southern Australia was covered by a shallow sea. In some areas deep marine canyons developed, similar to those found on some continental shelves today.

LIFE

It is likely that animals existed at the beginning of the Ediacaran Period, but it was not until late in the period that animals, known as the 'Ediacara biota', appear in the fossil record. This biota included jellyfish, worms and sea pen-like animals, arthropod-like organisms and sponges. Towards the end of the period the first animals with shells appear in the fossil record. However, the extinction event at the end of the period wiped out most of the Ediacara biota.

EDIACARAN RESOURCES IN AUSTRALIA

There are no known economic natural resources in rocks of Ediacaran age. Sub-economic natural gas has been sourced from Ediacaran rocks in the Northern Territory.



GTS 2012 Timescale

Cambrian Period (541–485.4 Ma)

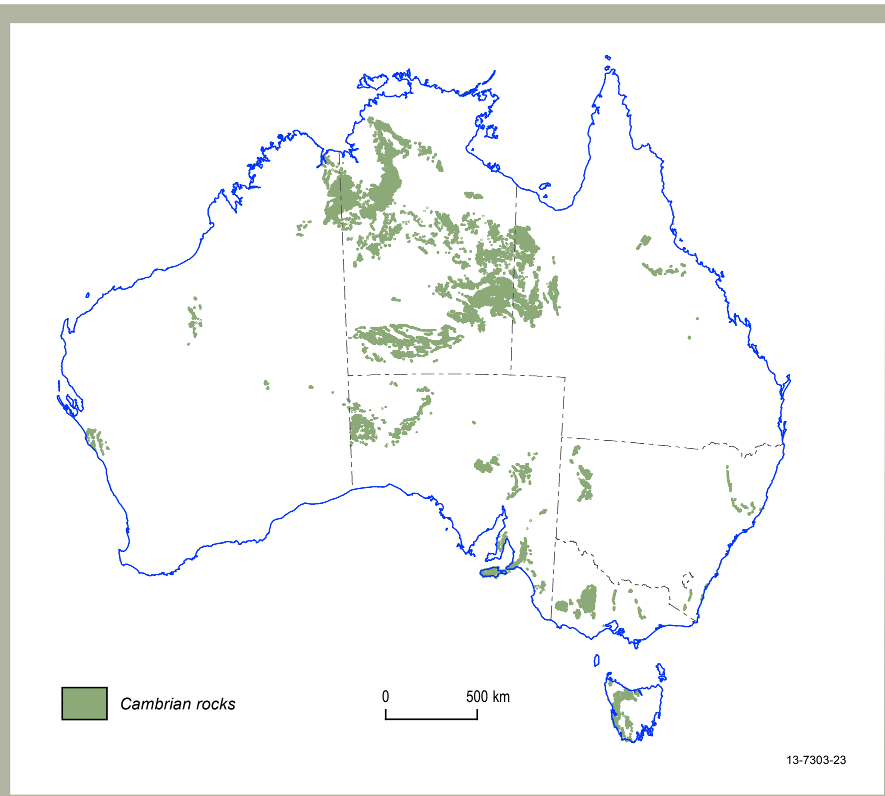
EON: PHANEROZOIC **ERA:** PALEOZOIC

Age (Ma)	Period	Epoch	Stage
485.4–490	Cambrian	Furongian	Stage 10
			Jiangshanian
			Paibian
		Series 3	Guzhangian
			Drumian
			Stage 5
		Series 2	Stage 4
			Stage 3
		Terreneuvian	Stage 2
540			Fortunian

The Cambrian Period was named by Adam Sedgwick in 1835, using the old Roman name for Wales (Cambria), where marine rocks of this age are common.

ULURU

Formerly known as Ayers Rock, this massive sandstone rock covers an area of 3.3 square kilometres, and is 9.4 kilometres around its base. It rises 345 metres above the plain, and is the surface expression of a much larger volume of rock. Now an eroded remnant, the rocks that form Uluru were laid down in an inland sea during the early Cambrian Period.



Redlichia takooensis is an example of a Cambrian trilobite from Kangaroo Island, South Australia.

INTRODUCTION

The Cambrian Period is the first period of the Paleozoic Era. It lasted 55.6 million years, from 541 to 485.4 million years ago. It is subdivided into four epochs.

Early in the Cambrian Period, a major event dramatically changed the face of life on Earth. Known as the 'Cambrian Explosion' it marked a huge increase in animal diversity.

MAJOR EVENTS

- **The 'Cambrian Explosion' occurred.**
- **A major eruption of basalt, around 506 million years ago, covered more than 2.1 million square kilometres of Western Australia, the Northern Territory and western Queensland.**

CLIMATE

Temperature

The Earth's climate was on average 7°C warmer during the Cambrian Period than today's average.

Atmosphere

Oxygen increased to about 12% of the atmosphere, which is still less than two-thirds of current levels. Carbon dioxide was at about 0.45% which is almost 12 times modern day levels.

Sea levels

During the Cambrian Period, sea levels were high and covered large parts of many continents, including Australia.

PALEOGEOGRAPHY

During the Cambrian Period, Australia was part of the supercontinent Gondwana, which included present day Antarctica, South America, Africa, the Indian sub-continent, and numerous other small blocks. At this time, Gondwana lay mostly in the Southern Hemisphere, with the Australian part located near its northern margin just north of the Equator.

Early in the Cambrian Period there were widespread volcanic eruptions in northern Australia, while extensive shallow seas extended from central Australia to Adelaide. By the middle Cambrian Period, these shallow seas extended over northern Australia. In the late Cambrian Period, the shallow seas were replaced with river and coastal environments. The eastern third of Australia was covered by a deep ocean for most of the Cambrian Period and a volcanic chain stretched from western Tasmania to southwestern Queensland.

FAUNA

The Cambrian Explosion led to the evolution of many new species of marine organisms, including numerous trilobites and other arthropods as well as brachiopods, molluscs, echinoderms and vertebrates.

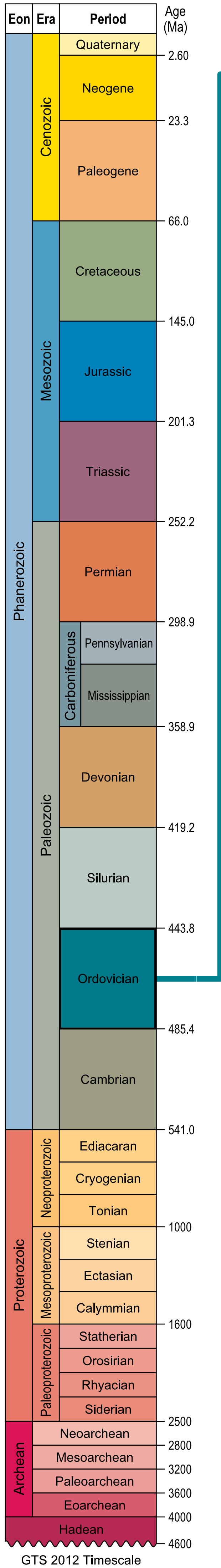
In the first half of the Cambrian Period, the first marine reefs were built by archaeocyaths (sponge-like organisms) and cyanobacteria. A minor extinction event near the end of the early Cambrian Period severely affected archaeocyath populations, but not the cyanobacteria. A minor extinction event at the end of the middle Cambrian Period had a major effect on trilobite populations, whilst a third event at the end of the Cambrian Period affected both trilobite and brachiopod populations.

FLORA

There were no vascular land plants during the Cambrian Period, but there is evidence that a mostly microbial film (with algae, fungi, lichen) covered the land near bodies of water.

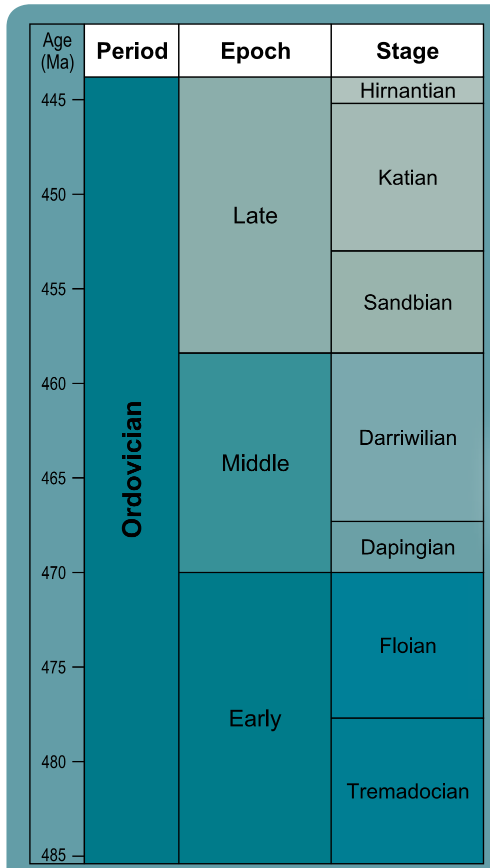
CAMBRIAN RESOURCES IN AUSTRALIA

Mineral resources from Cambrian rocks are in Tasmania and include Rosebery (zinc-lead-copper-silver-gold), Mount Lyell (copper-gold) and Henty (gold).

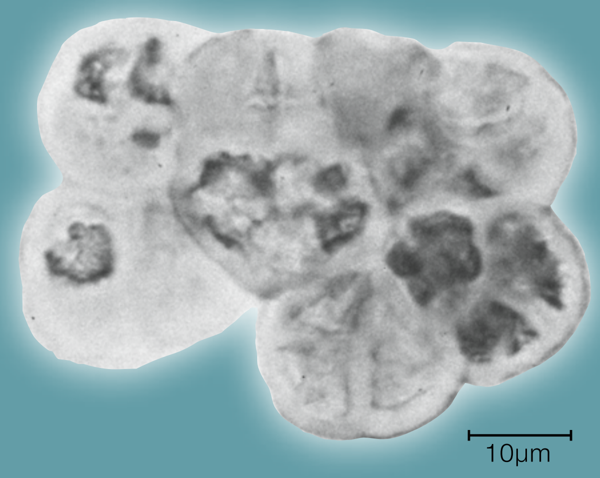


Ordovician Period (485.4–443.8 Ma)

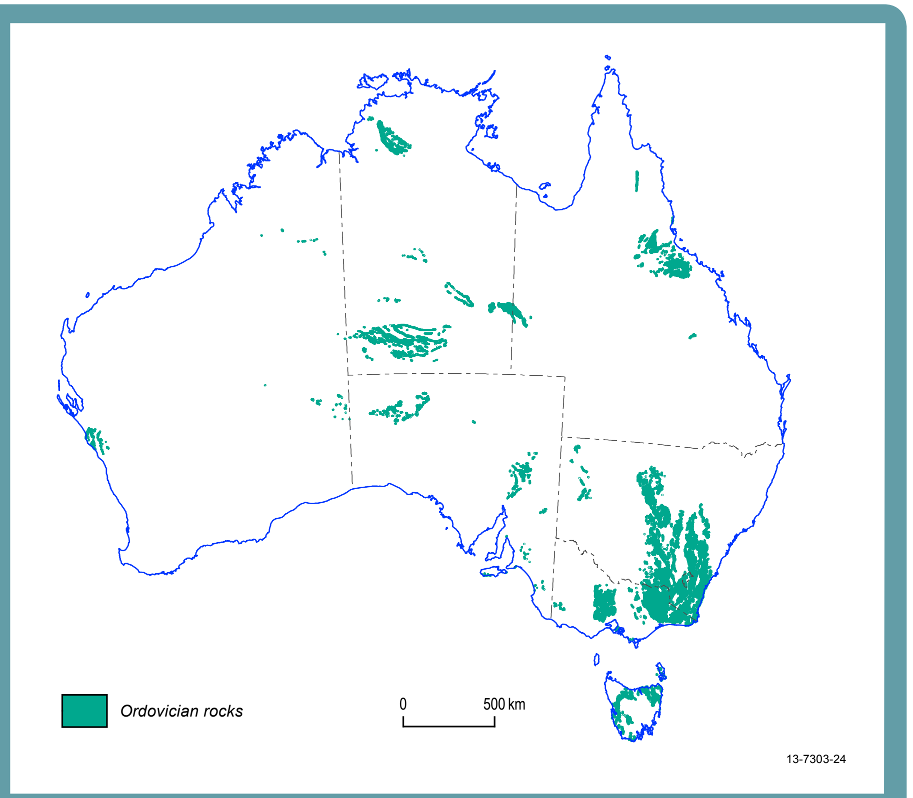
EON: PHANEROZOIC **ERA:** PALEOZOIC



The Ordovician Period was named in 1879 by Charles Lapworth after the Ordovices, a tribe from northern Wales in the British Isles where rocks of this age are common.



Gloeocapsomorpha prisca is a common alga from Ordovician rocks of Western Australia. Most of the world's Ordovician oil is sourced from this alga.



INTRODUCTION

The Ordovician Period is the second period of the Paleozoic Era. It lasted 41.6 million years, from 485.4 to 443.8 million years ago. It is subdivided into three epochs.

The extinction at the end of the Cambrian Period was followed by the 'Ordovician Radiation', early in the period. This 'radiation' was an increase in the diversity of many marine animals and plants. In addition, the first moss-like land plants colonised the shores of lakes and rivers.

MAJOR EVENTS

- **The 'Ordovician radiation' occurred, leading to an explosion in plant and animal species diversity.**
- **Late in the Ordovician Period, global temperatures dropped and the Earth entered an ice age. This ice age lasted into the early Silurian Period.**
- **The 'end-Ordovician mass extinction' event saw about 85% of all species become extinct. This is the first of the Earth's Big 5 extinction events and is thought to be caused by a dramatic decrease in temperature.**

CLIMATE

Temperature

In the early part of the Ordovician Period, the Earth's climate was about 6°C warmer than today's average. However, by the late Ordovician Period, the average temperature had fallen to only 2°C warmer than today.

Atmosphere

Oxygen had increased to about 13% of the atmosphere, which is two-thirds today's level. Carbon dioxide was about 0.42% or approximately 11 times today's level.

Sea levels

Sea levels increased slowly throughout the Ordovician Period, with levels reaching 200 metres higher than today. As the temperature started to decrease towards the end of the period, sea levels dropped dramatically as more and more water froze in the ice caps.

PALEOGEOGRAPHY

During the Ordovician Period, most of the supercontinent Gondwana lay in the Southern Hemisphere, with Australia forming the northern margin just north of the Equator.

Sea levels were very high and most of eastern Australia was covered by ocean. Several small chains of volcanoes extended from New South Wales to north-eastern Queensland. A narrow seaway, the Larapintine Seaway, developed as sea levels rose and extended from south-western Queensland across to the Northern Territory, and possibly to northern Western Australia. As sea levels fell the Larapintine Sea disappeared.

FAUNA

During the Ordovician Period there was an explosion in marine animal diversity. The diversity of trilobites, brachiopods, conodonts, graptolites, molluscs and echinoderms dramatically increased, while other organisms, including tabulate and rugose corals, bryozoans, sea stars and armoured jawless fish, appeared for the first time.

Sea scorpions also appeared for the first time and included the largest arthropods that ever lived, with some species up to 2 metres long.

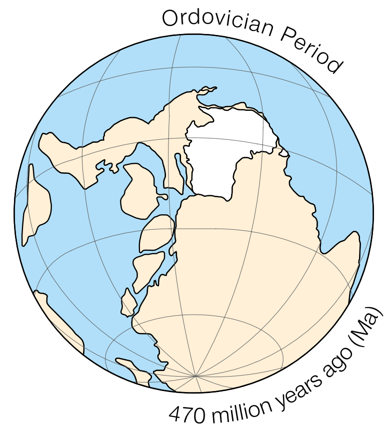
At the end of the period, the 1st of the Earth's Big 5 mass extinction events occurred, seriously affecting trilobites, graptolites, brachiopods, conodonts, bryozoans and echinoderms. It is thought to have been caused by a decrease in temperature.

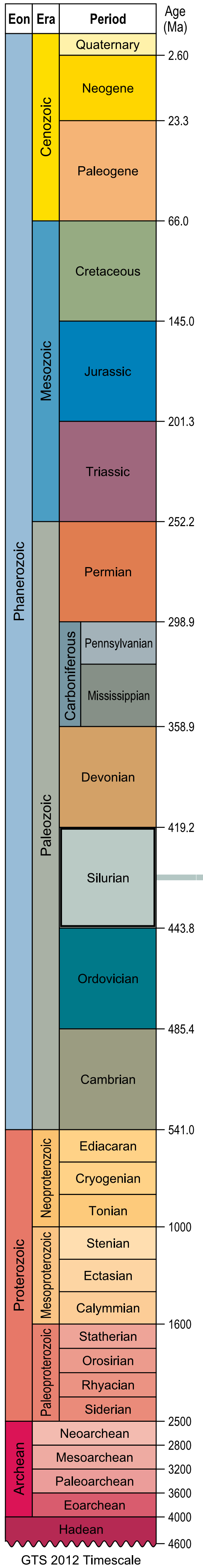
FLORA

Early in the Ordovician Period, fossil records indicate that the first land plants evolved. These plants are thought to be moss or liverwort-like plants which need water to reproduce. The majority of these land plants lived close to rivers and lakes, but marine fungi also were common during this period.

ORDOVICIAN RESOURCES IN AUSTRALIA

Mineral resources in Ordovician rocks include Thalanga and Balcooma (zinc-lead-copper-silver-gold), Queensland. Oil and gas in the Amadeus Basin, Northern Territory, is sourced from Ordovician rocks.





Silurian Period (443.8–419.2 Ma)

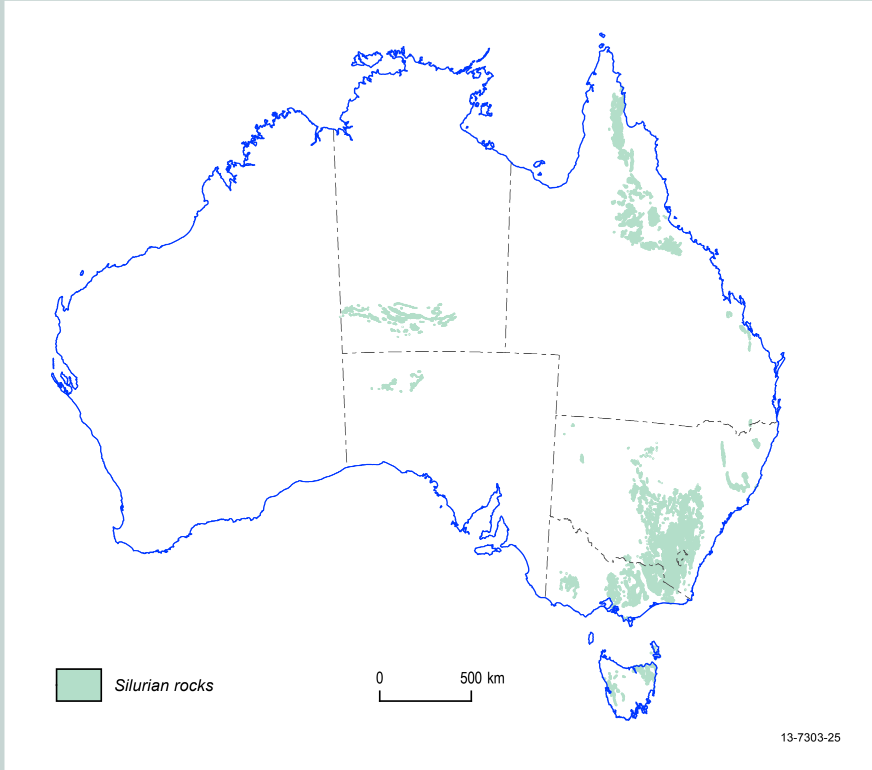
EON: PHANEROZOIC **ERA:** PALEOZOIC

Age (Ma)	Period	Epoch	Stage
420	Silurian	Pridoli	
425		Ludlow	Ludfordian
			Gorstian
430		Wenlock	Homerian
			Sheinwoodian
435		Llandovery	Telychian
440			Aeronian
			Rhuddanian

The Silurian Period was named in 1835 after an ancient Welsh borderland tribe, as many of the early studies on rocks of this age were on outcrops in Wales and western England.

WOOLSHED CREEK, ACT

The Woolshed Creek site in the Australian Capital Territory is of significant scientific value because it was the first place Silurian fossils were found in Australia by the Rev. W.B. Clarke in 1844. The fossils include marine animals such as brachiopods, trilobites and corals, indicating that during the Silurian Period this part of Australia was covered by sea.



Spirigerina mitchelli is an example of a Silurian brachiopod from Yass, New South Wales.

INTRODUCTION

The Silurian Period is the third and shortest period of the Paleozoic Era. It lasted 24.6 million years, from 443.8 to 419.2 million years ago. It is subdivided into four epochs.

The Silurian Period saw the first animals invade the land in the form of small millipedes and centipedes. One metre tall vascular plants evolved and began to spread across the Earth's surface.

MAJOR EVENTS

- **The melting of the Ordovician ice caps early in the period led to a rise in global sea levels.**
- **World-class gold and copper deposits were formed in Victoria and New South Wales.**

CLIMATE

Temperature

The beginning of the Silurian Period was fairly cold, but temperatures increased throughout the remainder of the period. The Earth entered a long warm phase which continued for another 130 million years.

Atmosphere

During the Silurian Period, oxygen levels slowly increased to about 14% of the Earth's atmosphere, whilst carbon dioxide levels had decreased to about 0.3%, which were still around 10 times greater than today's levels.

Sea levels

The rise in temperature early in the Silurian Period had a significant impact on the ice caps that had developed during the late Ordovician ice age. The temperature rise began to melt the ice caps, resulting in sea levels

rising to about 180 metres higher than today's levels.

PALEOGEOGRAPHY

During the Silurian Period, the supercontinent Gondwana drifted further south to cover the South Pole. Australia was located at Gondwana's northern margin, just south of the Equator.

Deep water covered eastern Australia and volcanic island chains emerged from the sea. Coral reefs fringed the continental shelf edges and volcanic islands. The rest of Australia was mostly dry. Central Australia was a desert where wind-blown sand was deposited. In Western Australia, thick salt deposits formed as a result of evaporation under arid conditions.

FAUNA

The Silurian Period saw the first appearance of coral reefs, jawed fish, ammonoids and the oldest known leech. Brachiopods, bryozoans, molluscs, trilobites and graptolites were abundant and diverse.

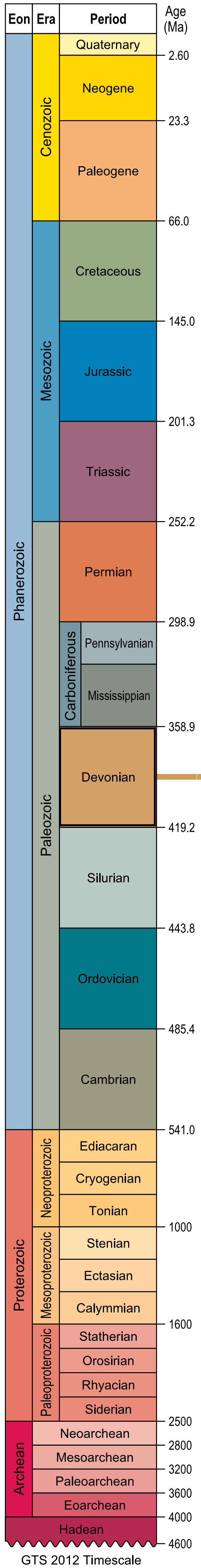
The Silurian Period was the first period during which animals inhabited the land. The first land creatures were millipede-like animals, centipedes and trigonotarbids (extinct spider-like animals).

FLORA

Early in the Silurian Period, only water-dependent plants such as mosses lived on land near streams and lakes. By the end of the period, large (around one metre tall) vascular plants called Lycophytes were widespread. The well preserved Baragwanathia from Victoria is an example of one of the earliest Lycophytes.

SILURIAN RESOURCES IN AUSTRALIA

Mineral resources from Silurian rocks include the world-class Cadia-Ridgeway (copper-gold), New South Wales; and Bendigo and Ballarat (gold), Victoria. Other deposits include Woodlawn and Captains Flat (zinc-lead-copper-silver-gold), New South Wales.

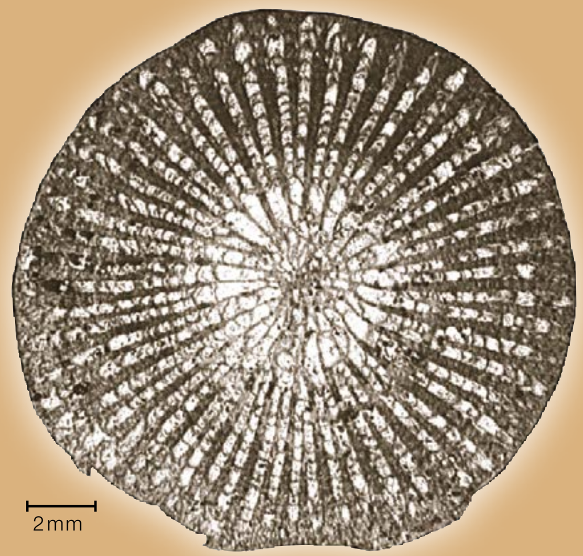


Devonian Period (419.2–358.9 Ma)

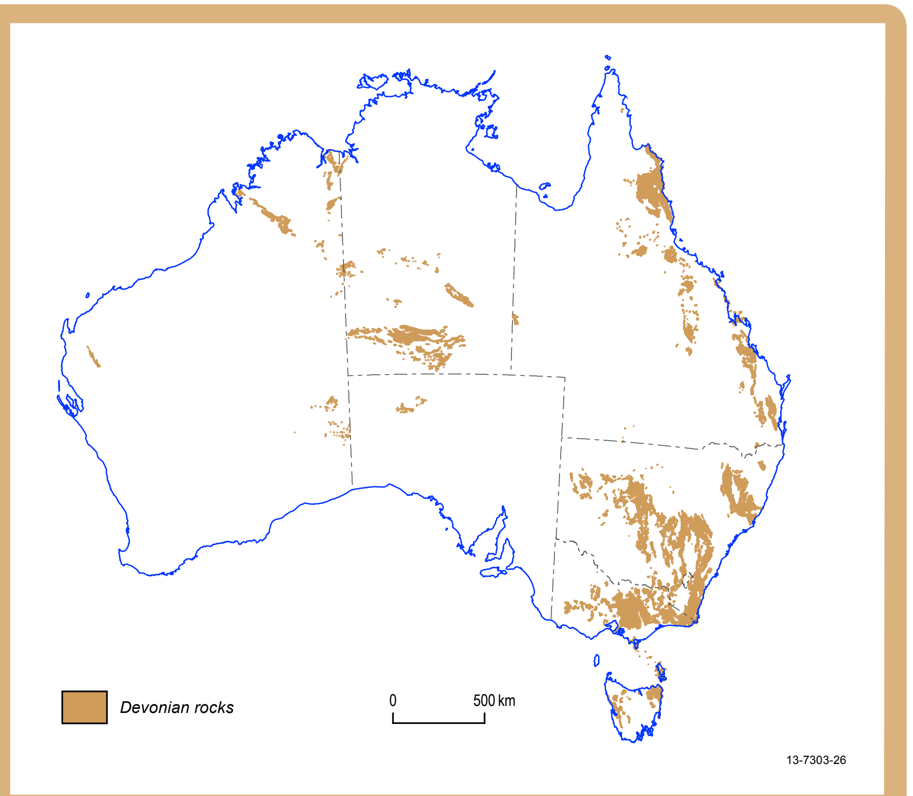
EON: PHANEROZOIC **ERA:** PALEOZOIC

Age (Ma)	Period	Epoch	Stage
360–415	Devonian	Late	Famennian
			Frasnian
		Middle	Givetian
			Eifelian
		Early	Emsian
			Pragian
			Lochkovian

The Devonian Period was named in 1839 after the county of Devon, England, where rocks of this age are fairly common and were studied in detail by early geologists.



Spinophyllum prolatum, a cross section of a solitary coral from the Devonian Period, found in the Kimberley Region, Western Australia.



INTRODUCTION

The Devonian Period is the fourth period of the Paleozoic Era. It lasted 60.3 million years, from 419.2 to 358.9 million years ago. It is subdivided into three epochs.

The Devonian Period was marked by the appearance of many new animals, some of which are still present today, including sharks, amphibians and insects. On land, trees reached up to 30 metres in height and formed the first forests.

MAJOR EVENTS

- **Large trees evolved and formed the first forests.**
- **The second of the Earth's Big 5 mass extinction events occurred near the end of the Devonian Period.**
- **During this extinction event, approximately 70% of all species on the planet became extinct.**

CLIMATE

Temperature

The Earth's climate was on average 6°C warmer in the Devonian Period than today.

Atmosphere

Oxygen slightly increased to about 15% of the atmosphere, which is approximately three-quarters of the today's level. Carbon dioxide continued to drop to about 0.22% which is still six times greater than today's levels.

Sea levels

Actual sea levels had fallen but still were between 50 metres and 150 metres higher than today's levels.

PALEOGEOGRAPHY

During the Devonian Period, the supercontinent Gondwana covered the South Pole and extended north to the Equator. Australia occupied the northern portion of Gondwana and was still just south of the Equator.

Initially hot and dry conditions persisted Salt continued to accumulate in north-western Australia and sand dunes prevailed in central Australia. In northern Western Australia, coral reefs flourished. The eastern coastline was west of its current position and a string of offshore volcanoes stretched between Victoria and Cairns. As sea levels fluctuated, shallow marine environments were replaced by rivers and lakes. Red beds, characteristic of semi-arid conditions, were deposited in eastern and central Australia.

FAUNA

The Devonian Period saw the first appearance of lungfish, sharks, amphibians and insects. In rocks of this age, the first fossil of a fish embryo attached to its mother by an umbilical cord was found in Western Australia. This provides the earliest evidence of vertebrates giving live birth to their young.

The second of the Earth's Big 5 mass extinction events occurred towards the end of the Devonian Period, and affected marine animals such as brachiopods, ammonoids, trilobites and conodonts. In addition, the primary reef-builders such as rugose and tabulate corals were almost wiped out and never really recovered. Extensive reefs only reappeared with the evolution of modern corals during the Triassic Period, more than 100 million years later.

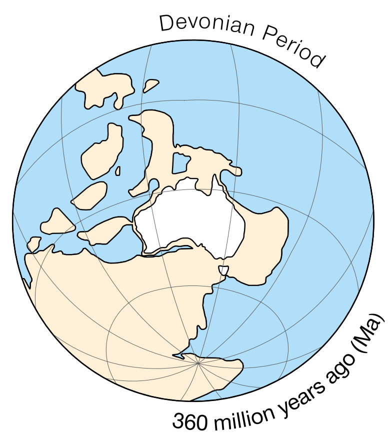
This mass extinction event was probably caused by changes in global weather and erosion patterns resulting from the rapid diversification of land plants. Water runoff into the sea had dramatic effects on the ocean's chemistry and many marine species became extinct.

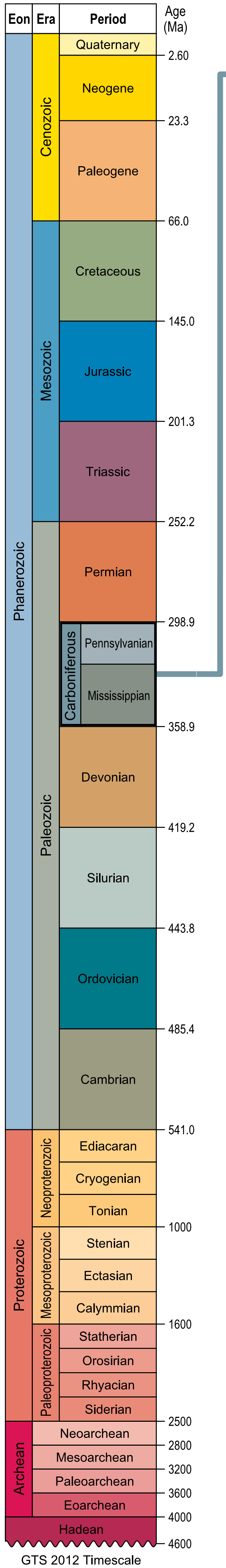
FLORA

Colonisation of the land by plants was well under way. At the beginning of the period, land plants diversified dramatically, but rarely exceeded one metre in height. However, by the end of the Devonian Period, forests abounded, with some lycophytes, progymnosperms and horsetails being the size of modern trees and reaching up to 30 metres high.

DEVONIAN RESOURCES IN AUSTRALIA

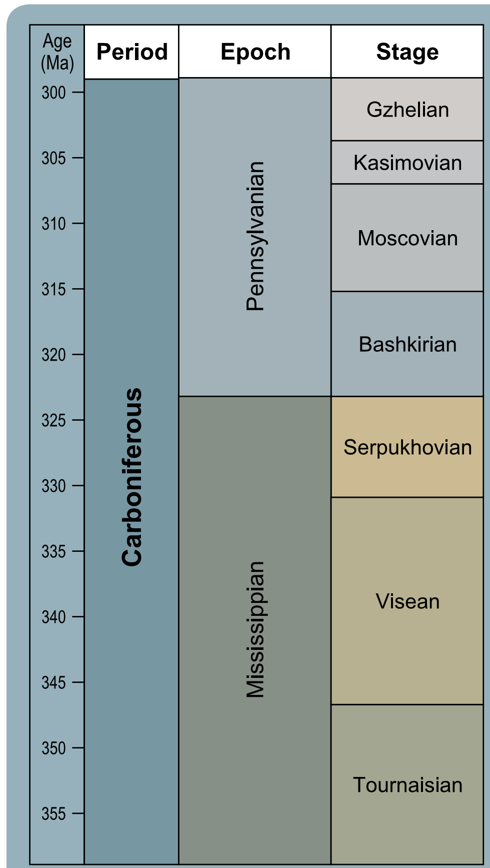
Mineral resources from Devonian rocks include gold at Charters Towers, Queensland and Beaconsfield, Tasmania. Other resources include: Cobar (copper-lead-zinc), New South Wales; Mt Morgan (copper-gold), Queensland; Cadjebut (zinc-lead-silver), Western Australia; and Renison Bell (tin-tungsten), Tasmania. Energy resources sourced from Devonian rocks include gas in the Adavale Basin in Queensland and oil in the Canning Basin, both on and offshore, Western Australia.





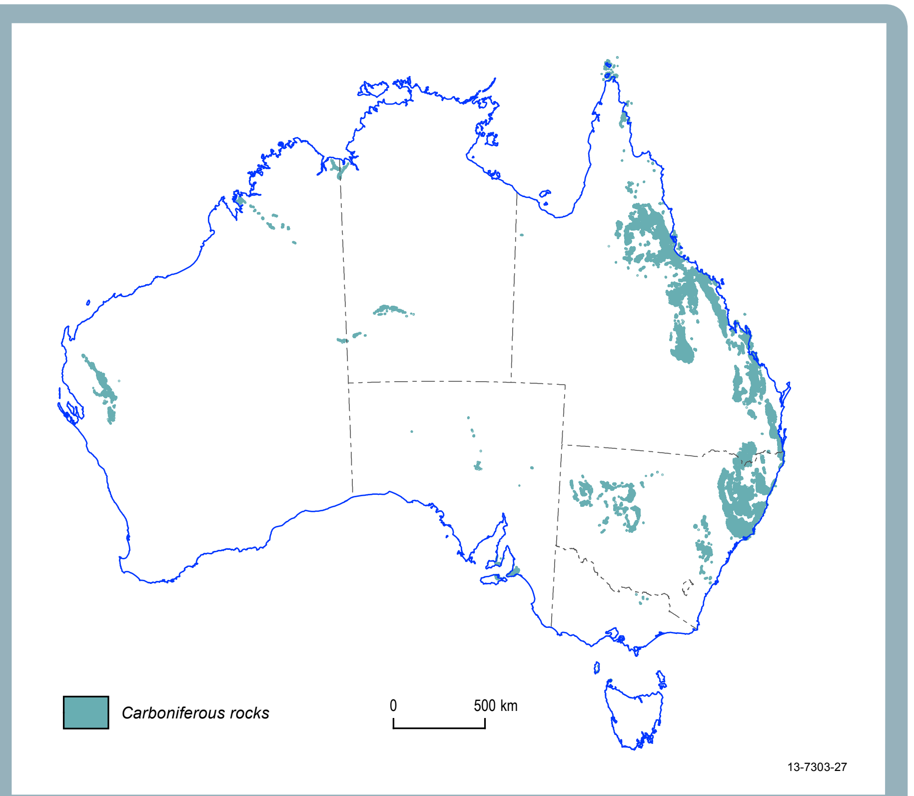
Carboniferous Period (358.9–298.9 Ma)

EON: PHANEROZOIC **ERA:** PALEOZOIC



In 1822, the Carboniferous Period was named by Conybeare & Phillips. It refers to the coal measures and 'mountain limestone' of England. The name is derived from the Latin word 'carbo' meaning coal or charcoal.

Turtle No 2 Oil is derived from rocks containing Carboniferous algae, bacteria and land plants in shallow sea.



INTRODUCTION

The Carboniferous Period is the fifth period of the Paleozoic Era. It lasted 60.0 million years, from 358.9 to 298.9 million years ago. It is subdivided into two epochs.

This period saw the first amniotic egg which allowed the ancestors of birds, mammals and reptiles to lay their eggs safely out of water. During the Carboniferous Period, the supercontinent Gondwana merged with other continents to form the new super-continent Pangaea.

MAJOR EVENTS

- **In the late Carboniferous Period the climate cooled and the Earth entered an ice age which lasted until the early Permian Period. This is known as the Carboniferous-Permian ice age, which was the longest and most severe in the entire Phanerozoic Era.**

CLIMATE

Temperature

At the beginning of the Carboniferous Period the Earth's climate was an average of 4°C warmer than today. By the end of the period it had cooled to about 2°C cooler than today.

Atmosphere

Oxygen levels in the atmosphere began to increase dramatically and rose to levels greater than 30%. Carbon dioxide continued to decrease to about 0.1%, which is still three times the average level of today.

Sea levels

Sea levels fell throughout the early Carboniferous Period, from about 120 metres higher than today to approximately

today's levels. However, they rose again to about 80 metres above today's levels and stabilised later in the period.

PALEOGEOGRAPHY

Early in the Carboniferous Period, the supercontinent Gondwana merged with other continents to form the new supercontinent Pangaea. Throughout the period, Pangaea drifted further south and was located mostly in the Southern Hemisphere. Within Pangaea, Australia was close to the South Pole and was partly covered by ice.

Shallow seas persisted in northwest Western Australia, but the reefs which characterised the Upper Devonian Period had disappeared. Tectonic uplift produced a broad mountain range in central Australia. Warm shallow seas bordering the ocean covered southeast Queensland and northeast New South Wales. Eruptions continued from a volcanic chain along the eastern edge of the continent. Dramatic cooling at the end of the Carboniferous Period led to mountain glaciers and ice caps forming in New South Wales, western Victoria, Tasmania and central Western Australia.

FAUNA

The Carboniferous Period saw the evolution of the amniotic egg. This meant that the ancestors of reptiles, birds and mammals were not dependent on water for reproduction as their eggs could be laid on dry land. This led to the evolution of reptiles.

Land dwelling arthropods increased in diversity during the Carboniferous Period and reached enormous body sizes, larger than at any other time on Earth. The high levels of oxygen at this time promoted this growth by making their respiration more efficient. Fossils have been found of relatives of dragonflies with wingspans of up to 75 centimetres, and millipede-like arthropods as long as 1.5 metres.

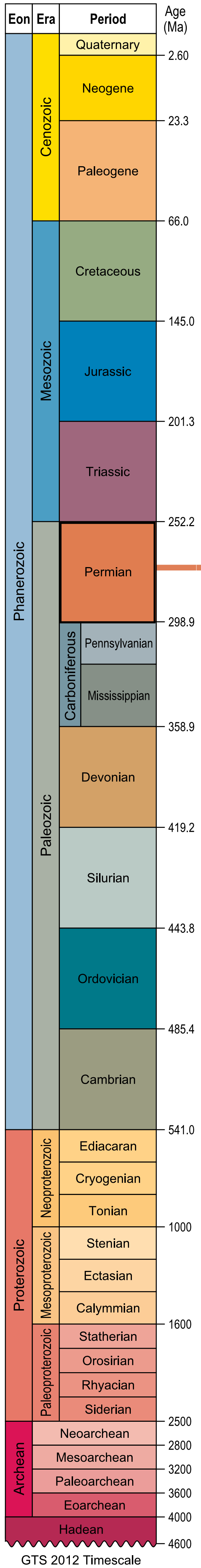
Fish, including sharks, increased in diversity during the Carboniferous Period. Marine environments were dominated by hard shelled marine animals, including brachiopods, bryozoans, molluscs and echinoderms.

FLORA

Land plants such as ferns, seed-ferns and horsetails became prevalent during the Carboniferous Period. Later in the period, the first conifers evolved. The extremely high levels of oxygen combined with the presence of large forests led to the first wildfires.

CARBONIFEROUS RESOURCES IN AUSTRALIA

Mineral resources from Carboniferous rocks include gold at Ravenswood, and Kidston, Queensland and Hill End, New South Wales. Other resources include Pajingo (gold-silver) and Herberton (tin-tungsten), Queensland. Energy resources include oil sourced from Carboniferous rocks in the Canning Basin, both on and offshore, Western Australia and sub-economic oil in the Bonaparte Gulf off Western Australia and the Northern Territory.



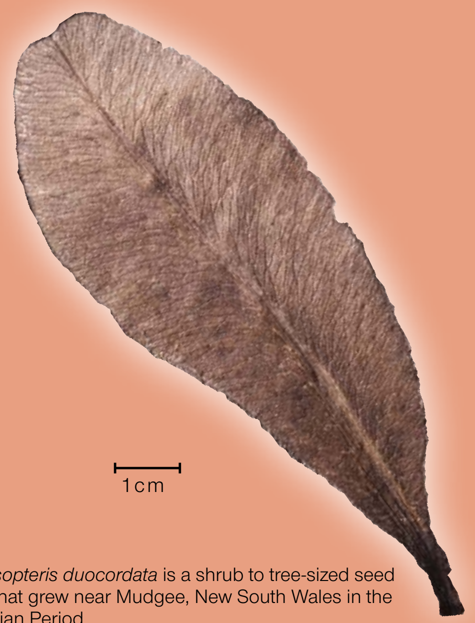
Permian Period (298.9–252.2 Ma)

EON: PHANEROZOIC **ERA:** PALEOZOIC

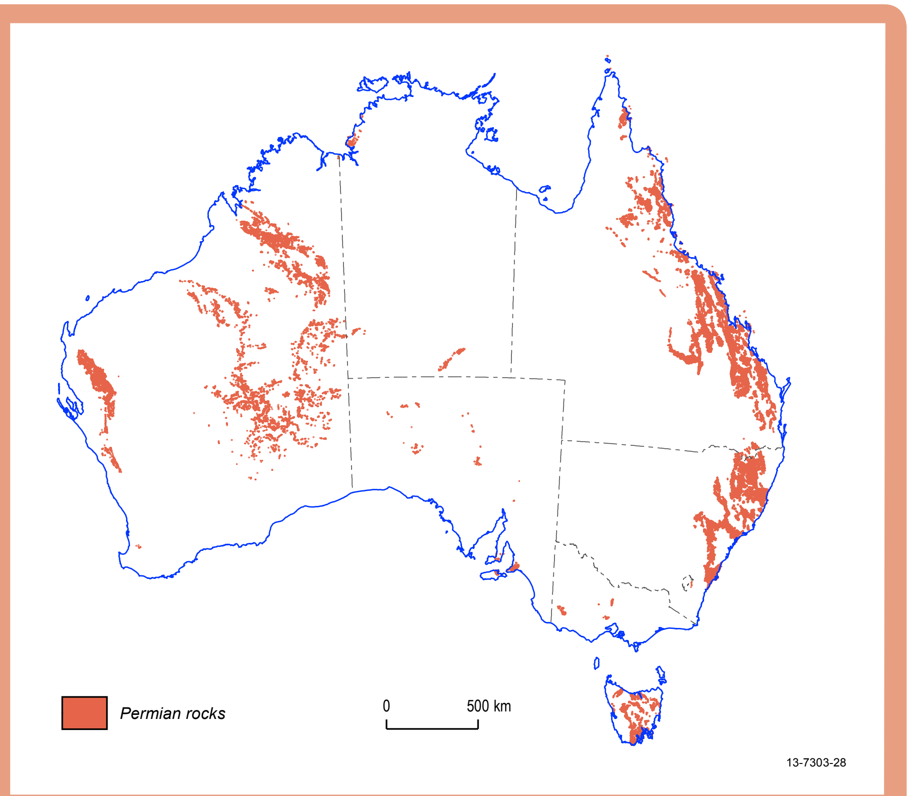
Period	Epoch	Stage
Permian	Lopingian	Changhsingian
		Wuchiapingian
	Guadalupian	Capitanian
		Wordian
		Roadian
	Cisuralian	Kungurian
		Artinskian
		Sakmarian
		Asselian

Age (Ma): 255, 260, 265, 270, 275, 280, 285, 290, 295

The Permian Period was named in 1841 by Roderick Murchison, a Scottish geologist, after the Russian province of Perm where rocks of this age are widespread.



Glossopteris duocordata is a shrub to tree-sized seed fern that grew near Mudgee, New South Wales in the Permian Period.



INTRODUCTION

The Permian Period is the sixth and final period of the Paleozoic Era. It lasted 46.7 million year, from 298.9 to 252.2 million years ago. It is subdivided into three epochs.

The end of the Permian Period saw the third of the Earth's Big 5 mass extinctions in the Earth's history, where 95% of all species were wiped out. This event was the greatest crisis of life on Earth, and fundamentally changed Earth's ecosystems.

MAJOR EVENTS

- **The third and greatest mass extinction event in the Earth's history, referred to as 'the Permo-Triassic Mass Extinction', occurred at the end of the Permian Period, wiping out 95% of all species on Earth. The cause of this event is thought to be the great eruption of flood basalts in the 'Siberian Traps', in current day Russia. This eruption released up to 4 million cubic kilometres of lava and large amounts of toxic gas and ash and is one of the largest known eruptions in Earth's history.**

CLIMATE

Temperature

The Earth was in the middle of an ice age at the beginning of Permian Period, with the average temperature about 2°C cooler than today. By the end of the period, the average temperature had risen to about 5°C above current levels, causing the glaciers and ice caps around the poles to melt.

Atmosphere

During the Permian Period, oxygen levels in the atmosphere peaked at 35%, which is the highest concentration at any time in the Earth's history. By the end of the period, levels had dropped by more than half. Carbon dioxide levels in the early part of the period had dropped to levels similar to today's, but increased to three times present levels by the end of the period.

Sea levels

Sea levels gradually dropped throughout the Permian Period, from about 80 metres above current levels at the beginning, to about 20 metres below current levels by the end of the period.

PALEOGEOGRAPHY

Almost all of today's continents were part of the supercontinent Pangaea. The Gondwanan part of Pangaea covered the South Pole early in the Permian Period and later began to drift northward.

Early in the Permian Period, Australia was covered with large amounts of ice, more ice than it ever would have again. There were three main ice sheets. They included a vast expanse stretching across most of central and Western Australia, with another sheet north of Adelaide and a third over much of Victoria and western Tasmania. A chain of volcanoes extended from Sydney to Cairns. As sea levels dropped, extensive peat bogs formed, which subsequently transformed into coal. Towards the end of the Permian Period, enormous delta complexes formed across Australia.

FAUNA

The Permian Period saw the first appearance of beetles and ammonites, and there was also extraordinary diversification of reptiles and mammal-like reptiles. The first archosaurs (ancestors to the dinosaurs, birds and crocodiles) also appeared later in this period.

In the ocean, hard shelled marine animals including brachiopods, molluscs, echinoderms, bryozoans, ostracods and foraminifera thrived until the end of the period when the third of the Earth's Big 5 mass extinction events occurred, almost entirely wiping out some of these groups. This mass extinction also saw the last of the trilobites, sea scorpions, and tabulate and rugose corals.

On land, insects suffered badly during this event, with major groups becoming extinct, while two-thirds of land-dwelling vertebrate families became extinct.

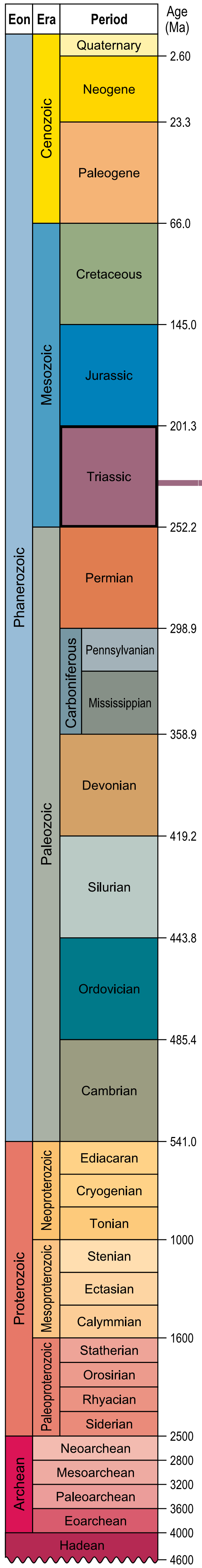
FLORA

During the Permian Period, ginkgoes and cycads first appeared and conifers diversified. On Gondwana, the Glossopteris seed-fern became established in Australia, South America, southern Africa, Madagascar, India and Antarctica. This was one of the earliest pieces of evidence that indicated all of these continents were once combined.

During the mass extinction event, the Glossopteris flora disappeared, while several other major groups of plants were almost wiped out.

PERMIAN RESOURCES IN AUSTRALIA

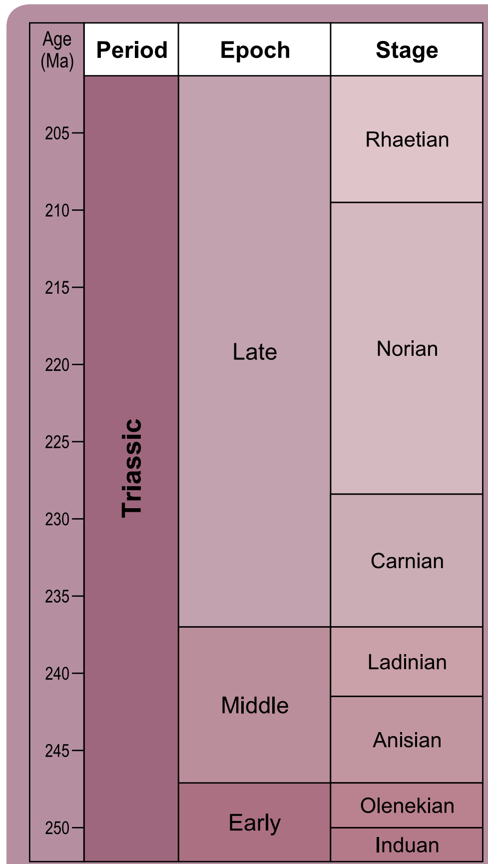
Mineral resources from Permian rocks are mainly in Queensland and include Cracow (gold-silver), Mount Chalmers (gold-copper), Cooktown (tin) and Mount Carbine (tin-tungsten). Energy resources from Permian rocks include Australia's vast coal resources in the Bowen Basin, Queensland; the Sydney and Gunnedah basins, New South Wales; and the Collie Basin, Western Australia. Oil and gas are sourced from Permian rocks across Australia in the Cooper, Bowen, Perth and Bonaparte basins.



GTS 2012 Timescale

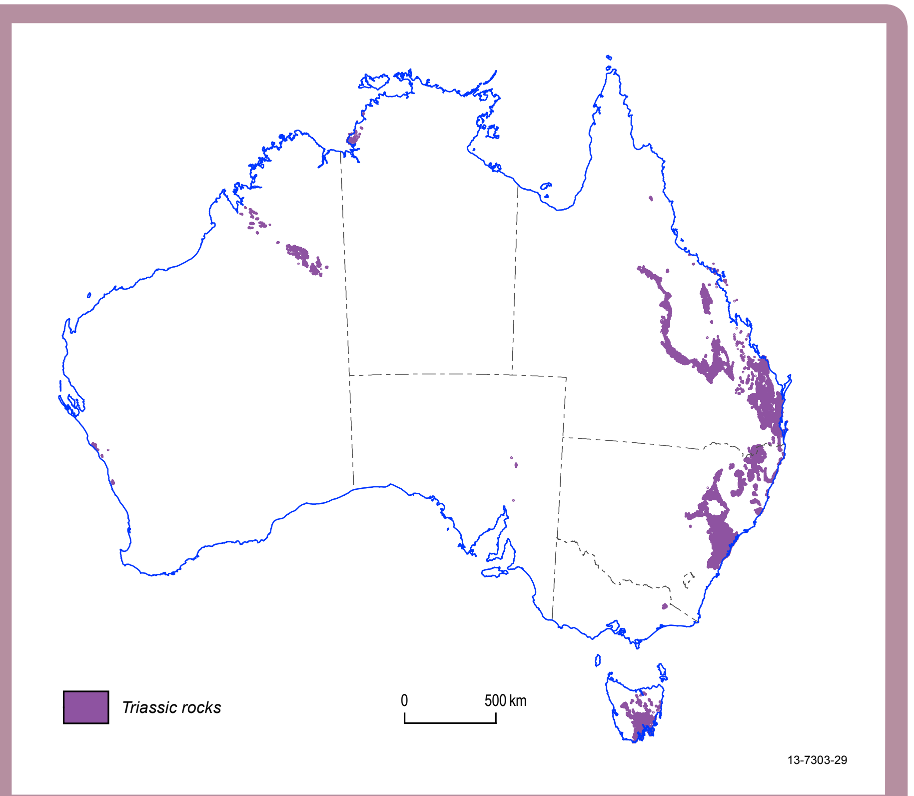
Triassic Period (252.2–201.3 Ma)

EON: PHANEROZOIC **ERA:** MESOZOIC



The period was named in 1834 by Friedrich von Alberti, a German geologist who was the first to recognize the distinct threefold (Latin: trias) subdivision of rocks, red sandstones capped by chalk, followed by black shales, in Germany. Bald Rock, NSW/QLD border

Bald Rock is said to be Australia's largest exposed granite surface. It towers about 200 metres above the surrounding bushland, is 750 metres long, 500 metres wide and rises to 1277 metres above sea level. The granite which forms Bald Rock was emplaced into the surrounding metamorphic and sedimentary rock about 247 million years ago.



FLORA

On land, the *Glossopteris* flora, which had died out during the Permo-Triassic extinction, was replaced by the *Dicroidium* flora. Conifers, cycads and ginkgoes flourished and the *Bennettitales* (cycad-like plant) first appeared. In the ocean, dinoflagellates, a type of algae which bloom to form red tides, evolved.

TRIASSIC RESOURCES IN AUSTRALIA

Mineral resources from Triassic rocks include Gympie (gold-silver) and Ruby Creek (tin-tungsten-molybdenum-copper), Queensland and Timbarra (gold), New South Wales. Energy resources include the giant gas fields of the North West Shelf, Western Australia, and oil from the Perth Basin, Western Australia. Triassic coal is found at Leigh Creek, South Australia and Ipswich Queensland.

INTRODUCTION

The Triassic Period is the first period in the Mesozoic Era. It lasted 50.9 million years, from 252.2 to 201.3 million years ago. It is subdivided into three epochs.

The Mesozoic Era is often referred to as the age of reptiles, and it was during the Triassic Period when the dinosaurs, plesiosaurs, ichthyosaurs, phytosaurs, crocodiles, turtles and mammals first evolved. By the end of the Triassic Period, continental rifting had started in Pangaea.

MAJOR EVENTS

- **The Triassic-Jurassic extinction event, the fourth of the Earth's Big 5 mass extinction events, wiped out half of all species on Earth. It is thought to have been caused by massive volcanic eruptions which covered about 11 million square kilometres of Pangaea (West Africa, the Iberian Peninsula, France and eastern North America).**
- **Major oil and gas deposits were formed in Australia.**

CLIMATE

Temperature

Early in the Triassic Period the Earth's climate was on average about 5°C warmer than today, but by the end of the period it was only about 2°C warmer. The climate was generally arid throughout the Triassic Period.

Atmosphere

After the Permo-Triassic extinction, the oxygen level of the atmosphere had dropped to about 15%, which is about three quarters of today's level. As plants recovered during the Triassic Period, oxygen levels rose to almost 20%. Carbon dioxide levels in the atmosphere increased through most of this period, rising from about 0.12% to 0.22%. This is about six times current levels.

Sea levels

Sea levels rose slowly to peak in the Late Triassic about 50 metres above current levels. They then dropped rapidly to 40 metres below current levels.

PALEOGEOGRAPHY

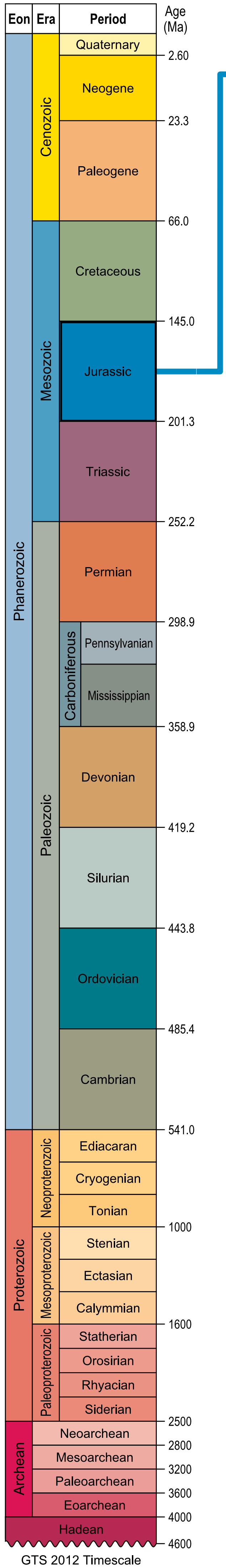
During the Triassic Period, Australia was part of the Gondwanan portion of Pangaea, which still covered the South Pole. Through the period, Australia slowly drifted northward towards the Equator. At the end, rifting had begun in Pangaea but the supercontinent had not yet split apart.

By the middle Triassic Period, Australia was high and dry, but as sea levels fluctuated the North West Shelf was periodically inundated by the sea. As sea levels receded in the later Triassic Period, wide floodplains developed inland. Triassic sediments are commonly coloured red because of highly oxidising weathering conditions.

FAUNA

The beginning of the Triassic Period saw little diversity of fauna as a result of the Permo-Triassic mass extinction, but as organisms recovered, many new groups appeared and diversified. The first dinosaurs, marine reptiles, mammals, turtles, crocodiles and modern corals evolved.

This increase in the number of species was followed by the Triassic-Jurassic mass extinction, the 4th of the Earth's Big 5 mass extinction events, which affected most groups of animals to varying levels. Phytosaurs and conodonts became extinct.



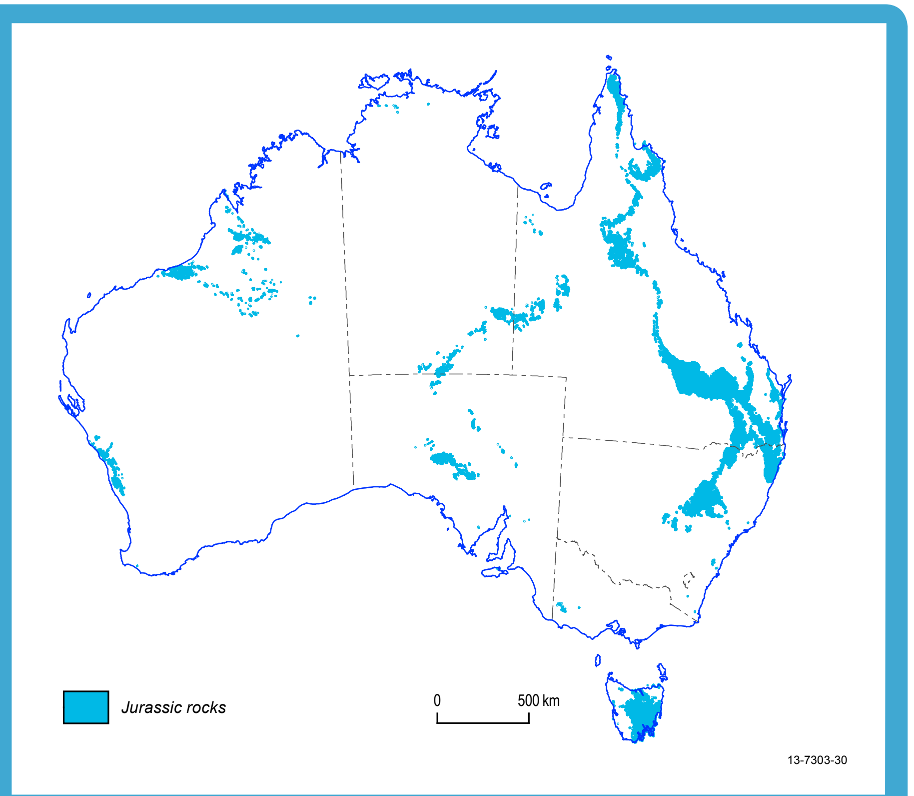
Jurassic Period (201.3–145.0 Ma)

EON: PHANEROZOIC **ERA:** MESOZOIC

Age (Ma)	Period	Epoch	Stage
150–155	Jurassic	Late	Tithonian
			Kimmeridgian
160			Oxfordian
165		Middle	Callovian
			Bathonian
			Bajocian
170			Aalenian
175–180		Early	Toarcian
185–190			Pliensbachian
195			Sinemurian
200			Hettangian

The Jurassic Period was named by Alexandre Brongniart in 1829 after the Jura Mountains in Switzerland where rocks and fossils from this period were first studied.Mt Wellington, Tasmania

Mt Wellington overlooking Hobart is capped with igneous rock which was intruded at very shallow levels in the Earth's crust. As the magma cooled, large joints formed in the rocks. These joints give rise to the characteristic organ pipe structures.



INTRODUCTION

The Jurassic Period is the second period of the Mesozoic Era. It lasted 56.3 million years, from 201.3 to 145.0 million years ago. It is subdivided into three epochs.

Dinosaurs roamed the land, including some of the largest animals to walk the Earth. The oceans were full of fish, squid and reptiles, while the sky was filled with pterosaurs and later, birds.

MAJOR EVENTS

- **The supercontinent Pangaea broke up into the two smaller supercontinents, Laurasia to the north and Gondwana to the south.**
- **Some small dinosaurs developed feathers, probably for insulation, and later some developed the ability to fly and in doing so evolved into birds.**

CLIMATE

Temperature

The Earth was on average 2°C to 3°C warmer in the Jurassic Period than it is today.

Atmosphere

At the beginning of the period, oxygen made up 21% of the Earth's atmosphere or about the same as today. However, by the end of the period oxygen levels had increased to about 26%. Carbon dioxide levels were about 0.2% at the beginning of the Jurassic Period, but by the end of the period had decreased to 0.15% which was about four times today's levels.

Sea levels

Sea levels rose from 40 metres below current levels at the beginning of the period to about 100 metres above current levels by the end.

PALEOGEOGRAPHY

Late in the Jurassic Period, Pangaea had separated into two smaller supercontinents, Laurasia and Gondwana. Laurasia was in the Northern Hemisphere, while Gondwana extended from north of the Equator almost to the South Pole. During the Jurassic Period, Australia drifted south from the Equator.

As sea levels rose, the river systems of eastern Australia linked together to form a drainage network of Amazonian proportions that stretched 2000 kilometres from the central Australian highlands to the east coast. The landscape of eastern Australia was a shifting mosaic of river channels, peat swamps and lakes. During times of high sea level the North West Shelf of Western Australia was inundated. During periods of low sea levels a sandy coast of barrier bars and lagoons stretched from Exmouth in Western Australia to the Northern Territory. On the northwestern margin of the continent there were active volcanoes. In the Late Jurassic Period, a series of fault bounded valleys formed in southern Australia as a lead up to the separation of Australia and Antarctica.

FAUNA

On land, dinosaurs had taken over and some had grown to large sizes, perhaps because of the high levels of oxygen in the atmosphere. The Jurassic Period was the heyday of the large plant eating sauropods, which had small heads, huge bodies and long tails. At the same time predators also increased in size, with the largest being the allosaurs, large two-legged dinosaurs which preceded the tyrannosaurs of the Cretaceous Period.

Feathers first evolved in the Jurassic Period, with many small predatory dinosaurs having feathers. Later in the period some of these small dinosaurs developed the ability to fly and in doing so had become birds.

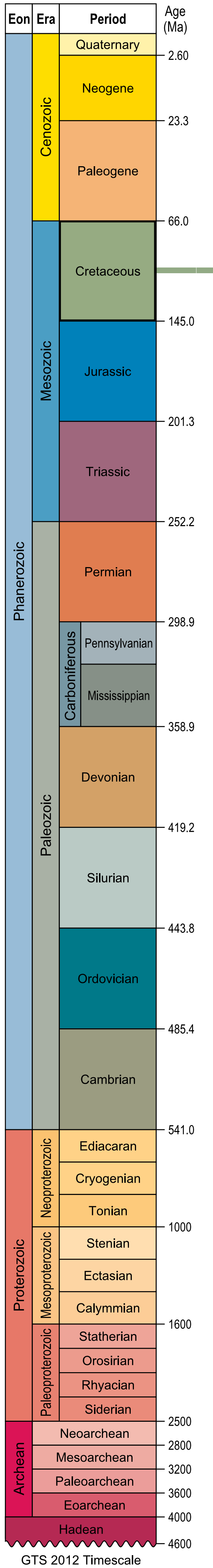
In the ocean, the invertebrate fauna was dominated by molluscs, echinoderms and corals. The marine vertebrate fauna was dominated by fish, marine reptiles and large oceanic crocodiles that grew up to 10 metres in length.

FLORA

In the Jurassic Period, conifers reached their maximum diversity and dominated the forests. Ferns, cycads, *Bennettitales* (cycad-like plants) and ginkgoes persisted, while tree-ferns appeared for the first time.

JURASSIC RESOURCES IN AUSTRALIA

Energy resources from Jurassic age rocks include the giant oil and gas fields of the North West Shelf of Western Australia. This includes Barrow Island, Australia's first commercial oil discovery. The vast coal seam gas resources of southeast Queensland are hosted in Jurassic sediments, as is the Great Artesian Basin, one of the largest groundwater basins in the world.



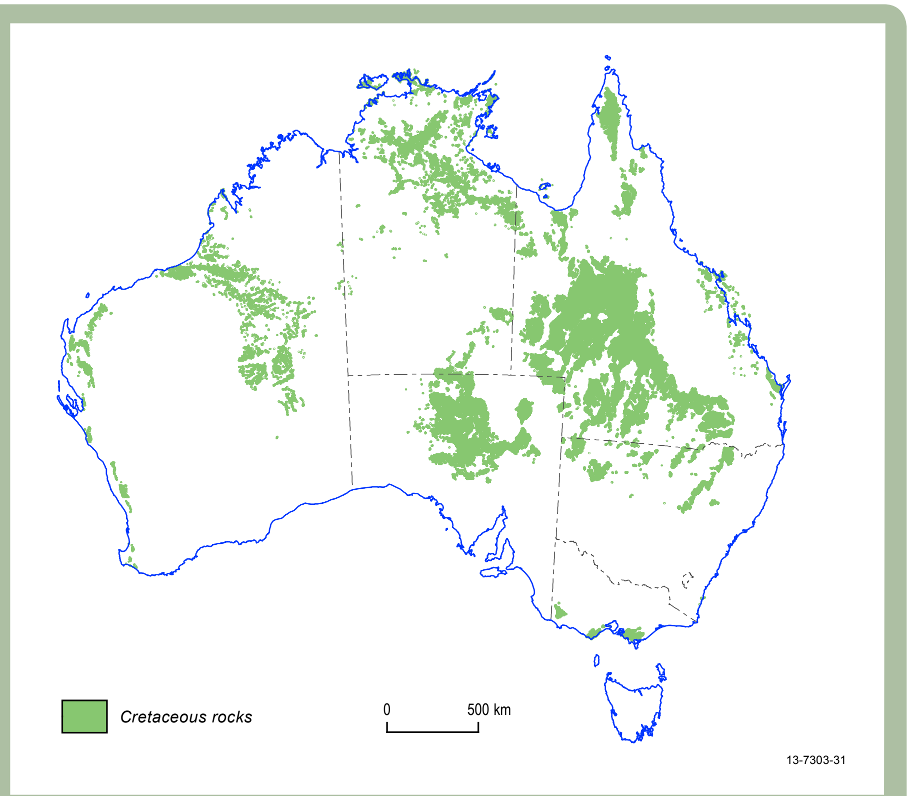
Cretaceous Period (145.0–66.0 Ma)

EON: PHANEROZOIC **ERA:** MESOZOIC

Age (Ma)	Period	Epoch	Stage
70	Cretaceous	Late	Maastrichtian
80			Campanian
			Santonian
			Coniacian
90			Turonian
100			Cenomanian
110		Early	Albian
120			Aptian
130			Barremian
			Hauterivian
			Valanginian
140			Berriasian

The name Cretaceous was derived from the Latin word 'creta' meaning chalk. It was named by the Belgian geologist, Jean d'Omalius d'Halloy in 1822 for the extensive beds of chalk found in Western Europe.

Footprints of the dinosaur stampede that occurred in Winton, Queensland during the Cretaceous Period.



INTRODUCTION

The Cretaceous Period is the third period of the Mesozoic Era. It lasted 79 million years, from 145.0 to 66.0 million years ago. It is subdivided into two epochs.

Dinosaurs initially dominated the landscape but populations began to decline, and at the end of this period, the remaining dinosaurs and several other major animal groups became extinct during the Cretaceous-Paleogene extinction event, the fifth and last of the Earth's Big 5 mass extinctions. Gondwana began to break up during the Early Cretaceous Period.

MAJOR EVENTS

- **The first flowering plants evolved.**
- **Australia began to separate from Antarctica.**
- **The last dinosaurs, marine reptiles, pterosaurs and ammonites died out at the end of the Cretaceous Period. This was the fifth of the Earth's Big 5 mass extinction events.**

CLIMATE

Temperature

The Earth's climate was on average 4°C warmer in the Cretaceous Period than it is today.

Atmosphere

Early in the period, oxygen made up about 27% of the atmosphere but by the end it had increased to 30%. Carbon dioxide was around 0.17% by the middle of the period and peaked at about 0.22%, which is about six times the present day level. This was followed by a rapid decline to about 0.07%.

Sea levels

Sea levels rose and dropped dramatically during the Cretaceous Period. Initially sea levels rose from some 100 metres above current levels to about 220 metres in the Late Cretaceous Period. By the end of the period, levels had dropped but were still 190 metres above those of today.

PALEOGEOGRAPHY

Early in the Cretaceous Period the supercontinent of Gondwana started breaking up. South America, Africa and India/Madagascar separated from Antarctica and Australia. In the Late Cretaceous Period, Australia started to separate from Antarctica and begin its long journey north to its current position. The break up of Pangea allowed ocean currents to flow around the Equator.

Early in the period continental Australia was a network of river channels, shallow lakes and swamps. As sea levels rose in the middle of the Cretaceous Period, a large inland sea covered central Australia. A long seaway developed along the southern margin of Australia. Sea levels then fell during the rest of the Cretaceous Period and a wide belt of deltas, brackish lagoons and estuaries became established around the margins of the inland sea and on the southern margin. The final retreat of the sea from central Australia left shallow lakes and swamps.

FAUNA

Dinosaurs were at their most diverse and still dominated the landscape during most of the Cretaceous Period, but began to decline later in the period. Small and mainly nocturnal mammals became more common.

During this period insects diversified, with the first ants, bees, butterflies, termites, aphids and grasshoppers appearing. The first snakes also evolved from lizards. The oldest fossils of monotremes and marsupials appear in Cretaceous rocks.

In the oceans, marine reptiles existed, as well as hard shelled ammonites, squid-like belemnites, molluscs, sea lilies and sea-urchins. Rays, sharks and other fish also diversified.

The Cretaceous-Paleogene mass extinction, wiped out about 75% of all species of plants and animals. This was the fifth and last of the Earth's Big 5 mass extinctions. Two possible causes of this mass extinction were a very large meteorite hitting the Yucatan Peninsula in Mexico, creating the 180 kilometres diameter Chicxulub Crater, and the eruption of flood basalts of the 'Deccan Traps', which covered nearly half of India.

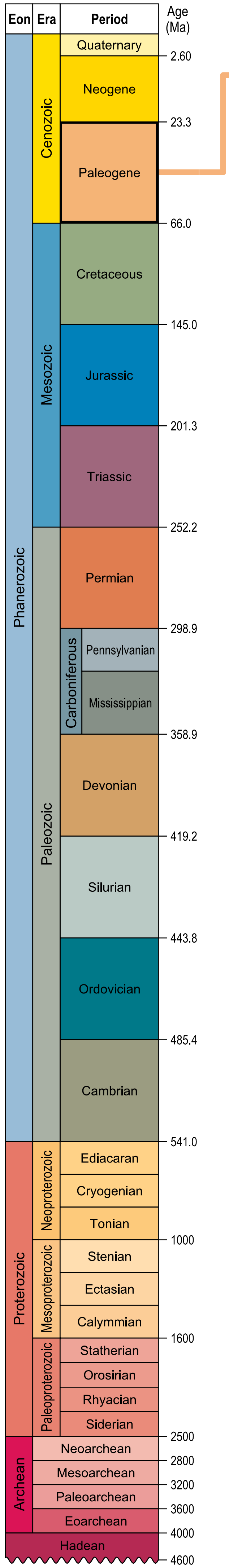
FLORA

Flowering plants appeared for the first time in the Early Cretaceous Epoch and by the end of the period figs, magnolias, plane-trees and grasses had evolved. The evolution of flowering plants is very closely linked with pollinating insects, such as bees. This is one of the best examples of coevolution.

Conifers, cycads and ferns thrived in the Cretaceous Period, whereas Bennettitales died out in the latter half of the period.

CRETACEOUS RESOURCES IN AUSTRALIA

Mineral resources from Cretaceous rocks include Murrin Murrin (nickel-cobalt), Western Australia and opals from Lightning Ridge, New South Wales and Coober Pedy, South Australia. Giant oil and gas fields off the Victorian coast in the Gippsland Basin and smaller fields in the Bass Basin are sourced from Cretaceous to Paleogene rocks. Oil and gas resources are also sourced from Cretaceous rocks in the Otway Basin.



GTS 2012 Timescale

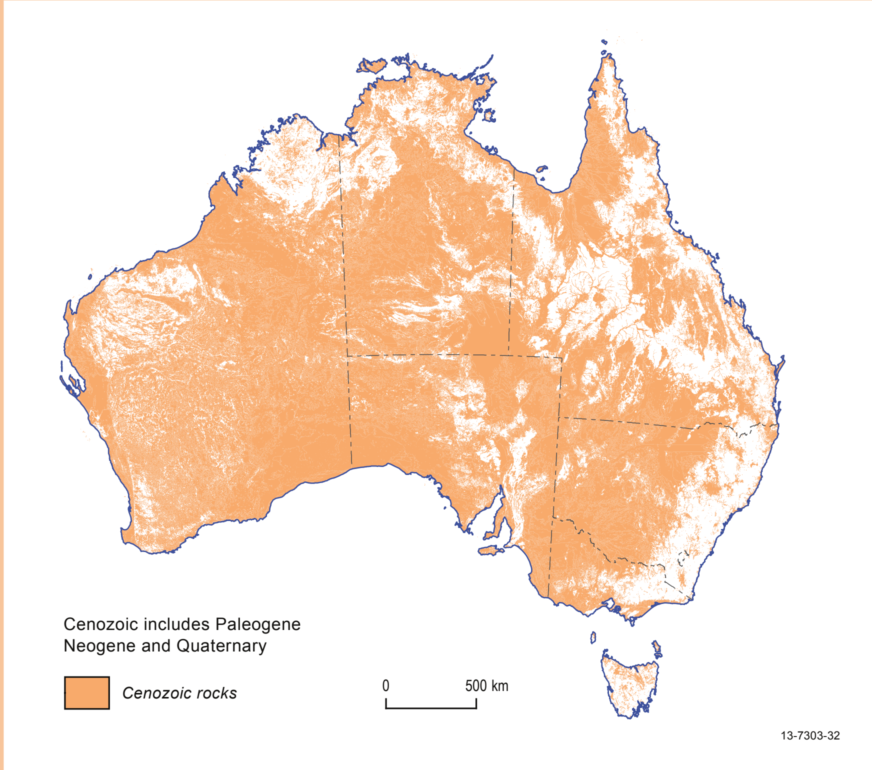
Paleogene Period (66.0–23.3 Ma)

EON: PHANEROZOIC **ERA:** CENOZOIC

Age (Ma)	Period	Epoch	Stage
25	Paleogene	Oligocene	Chattian
30			Rupelian
35		Eocene	Priabonian
40			Bartonian
45			Lutetian
50			Ypresian
55		Paleocene	Thanetian
60			Selandian
65			Danian

The Cenozoic Era was previously divided into two periods, the Tertiary and Quaternary, the first of which came from a system of naming rock successions in Italy (Primary-Secondary-Tertiary) by Giovanni Arduino in 1759. The term 'Tertiary' has now been abandoned and the same interval is now divided into the Paleogene and Neogene.

Australonycteris clarkae, the oldest bat from the Southern Hemisphere, found at a single fossil site in southeastern Queensland.



INTRODUCTION

The Paleogene Period is the first of the three periods of the Cenozoic Era and lasted about 43 million years, from 66.0 to 23.3 million years ago. It is subdivided into three epochs, the Paleocene, Eocene and Oligocene.

The extraordinary diversification of mammals characterises the Paleogene Period. There was also a short-lived dramatic rise of some 6°C in Earth's average temperature during the Paleocene-Eocene Thermal Maximum. This was accompanied by an extinction event. Around 80% of the surface geology of Australia comprises Cenozoic rocks and sediments.

MAJOR EVENTS

- **The 'Paleocene-Eocene Thermal Maximum' was an extreme climatic event which resulted in a dramatic temperature increase over a short period of geological time.**
- **With the progressive break up of Gondwana, seafloor spreading in the Southern Ocean accelerated around 45 million years ago, with separation of Australia and Antarctica occurring around 34 million years ago.**
- **Mammals became the dominant land vertebrates, occupying many niches previously inhabited by dinosaurs and other reptiles.**

CLIMATE

Temperature

Global temperatures rose after the end of the Cretaceous Period to a maximum of about 6°C above present day temperatures. This was interrupted by a short-lived event at the end of the Paleocene Epoch, when average temperatures rose another 6°C in 20 000 years to about 27°C. This event, termed the Paleocene-Eocene Thermal Maximum, was one of the warmest intervals since the Cambrian Period.

By the Oligocene Epoch, temperatures had steadily decreased to levels similar to those of today. At the end of the Oligocene Epoch there was a sudden rise in average temperature to about 3°C above current levels.

Atmosphere

The composition of the atmosphere became more like that of today. Oxygen levels decreased from about 30% to levels approaching the current 21%. Carbon dioxide decreased from levels as high as 0.07% to 0.03%, similar to modern levels.

Sea levels

Sea levels were high throughout the Paleogene Period. Initially at about 190 metres above current levels, by the late Eocene Epoch they had dropped by 90 metres. Early in the Oligocene Epoch, they rose dramatically before plummeting to about 40 metres above current levels.

PALEOGEOGRAPHY

By the end of the Cretaceous Period, Europe had moved away from North America, opening the north Atlantic Ocean. The Indian subcontinent collided with Asia, forming the Himalayas. Australia continued to drift north and began impacting on south eastern Asia. The final separation of Australia and Antarctica occurred around 34 million years ago which allowed the development of the circum-polar ocean current.

Throughout the Paleogene Period, Bass Strait and much of the Coral Sea, including the area now covered by the Great Barrier Reef, was exposed. As the continent moved northward over a mantle hot spot, volcanoes developed along the east coast, with the oldest in north Queensland and the youngest in south-western Victoria.

In the Eocene Epoch, shallow seas encroached on southern Australia, but in the Oligocene Epoch early development of the Antarctic ice cap lowered the global sea level, resulting in a drying of the climate.

FAUNA

After the demise of the dinosaurs, pterosaurs and marine reptiles, mammals diversified in the Paleocene and Eocene epochs. In Australia, marsupials filled many of the habitats previously occupied by reptiles.

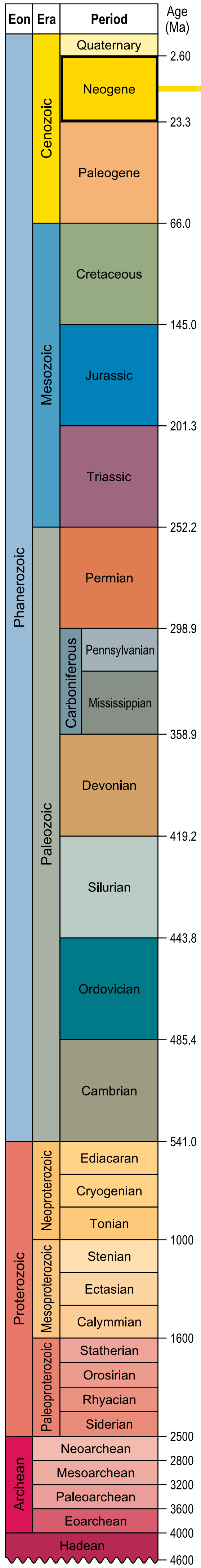
The oldest primate, rodent and elephant fossils are from the Paleocene Epoch. By the Eocene Epoch, pigs, camels, deer, sheep, goats, horses, bats and monkeys had evolved, whilst in the sky, birds diversified greatly. In the ocean, squid became widespread, the variety of sharks increased and the first whales evolved.

FLORA

Immediately after the Cretaceous-Paleogene mass extinction event, ferns colonised what remained of the devastated forests. Many modern groups of plants became established by the Eocene Epoch, with deciduous and conifer forests covering most continents, including Antarctica. Later, grasses diversified and spread across much of the land. In Australia, the first wattle trees evolved in the Oligocene Epoch.

PALEOGENE RESOURCES IN AUSTRALIA

Mineral resources from Paleogene rocks include bauxite from Weipa, Queensland, mineral sands from the Eucla Basin, South Australia, and channel iron ore deposits in the Hamersley Province of Western Australia. Minerals sands, including rutile, zircon, ilmenite and monazite, accumulated on some old shorelines on the southern coastline. Giant oil and gas fields off the Victorian coast in the Gippsland Basin and smaller fields in the Bass Basin are sourced from Cretaceous to Paleogene rocks. Other energy resources include brown coal from the Latrobe Valley, Victoria, and potential oil shale at Rundle, Stuart and McFarlane in Queensland.



GTS 2012 Timescale

Neogene Period (23.3–2.588 Ma)

EON: PHANEROZOIC **ERA:** CENOZOIC

Age (Ma)	Period	Epoch	Stage
	Neogene	Pliocene	Piacenzian
5			Zanclean
		Miocene	Messinian
10			Tortonian
			Serravallian
15			Langhian
20			Burdigalian
			Aquitanian

Spectacular examples of Neogene aged rocks can be found along the Great Ocean Road in Victoria. This part of the Australian coast has been subject to erosion for many millions of years resulting in features like the Twelve Apostles, Loch Ard Gorge and London Bridge. These erosional features are composed of Port Campbell Limestone which was deposited during the Miocene Epoch, and are continually changing. There are now only eight apostles and London Bridge collapsed in 1990.

OIL AND GAS

The early Neogene Period was a time when tectonic activity along the southern continental margin of Australia resulted in the formation of many fold structures in basins such as the Gippsland, Bass and Otway basins of Victoria. These large folds have acted as traps for significant accumulations of oil and gas which have been commercially produced since the mid-1960s.

INTRODUCTION

The Neogene Period is the second period in the Cenozoic Era, which lasted for 20.4 million years and extended from 23.3 to 2.6 million years ago. It is subdivided into two epochs, the Miocene and Pliocene.

During the Neogene Period, landscapes as we know them today began to take shape. The first hominins (the group formerly known as hominids, consisting of modern humans, extinct human species and all our immediate ancestors) appeared.

MAJOR EVENTS

- **After the complete separation of Australia from Antarctica a circum-polar circulation developed in the widened Southern Ocean which drastically affected the climate of Australia.**
- **There was a major global cooling event in the middle of the Miocene Epoch, which continued until the world entered an ice age at the beginning of the following period, the Quaternary.**
- **The first hominins evolved in Africa from the chimpanzee lineage.**

CLIMATE

Temperature

The Neogene Period saw the Earth's climate warm slightly before cooling towards the end of the period when average temperatures were about 0.5°C below current levels. This cooling was the beginning of the ice ages of the Quaternary Period.

Atmosphere

The atmosphere during the Neogene Period was similar to today's, with oxygen levels around 21.5% and carbon dioxide at 0.028%.

Sea levels

Sea levels fluctuated throughout the Neogene Period, rising during the first half of the Miocene Epoch, before dropping substantially to below current levels. In the Pliocene Epoch, levels initially rose to about 60 metres above those of today before dropping dramatically towards the end as Earth started to enter its most recent major ice age.

PALEOGEOGRAPHY

The continents continued drifting towards their current positions. At the beginning of the period, Australia was well south of the Equator. South America and North America were joined as the Isthmus of Panama formed a land bridge between the two continents, and Arabia collided with Asia. These collisions destroyed the global equatorial ocean current and gave rise to the present day system of ocean currents. A circumpolar current continued to develop in the widening Southern Ocean, separating Antarctica from the warmer waters sourced from the north, causing cooling of the Antarctic continent.

As Australia drifted north it collided with New Guinea about 15 million years ago, causing a rain shadow effect that further changed the weather patterns in Australia, intensifying the drying trend. Shallow seas again flooded the southern margin of Western Australia and South Australia, Spencer Gulf and the Murray Basin. The continent began to tilt down to the north by up to 300 metres as it continued to collide with New Guinea. Volcanoes were active in Victoria, New South Wales and Queensland. Inland, major river systems covered much of the continent and the palaeovalleys subsequently became infilled with sediments.

FAUNA

Australia was still dominated by its marsupial fauna, including early marsupial lions and carnivorous kangaroos. Thunder birds, giant flightless birds, also roamed the land. Many of these animals had grown very large by the end of the Neogene, forming Australia's megafauna which thrived through most of the Quaternary.

However, globally, the vertebrate fauna began to appear essentially modern, with wolves, hyenas, cats, horses, deer, camels and whales evolving. Similarly, crows, ducks, grouse and owls evolved in the Miocene Epoch. As the climate cooled towards the end of the period, animals such as the woolly mammoth, woolly rhinoceros and reindeer developed larger bodies and thick fur.

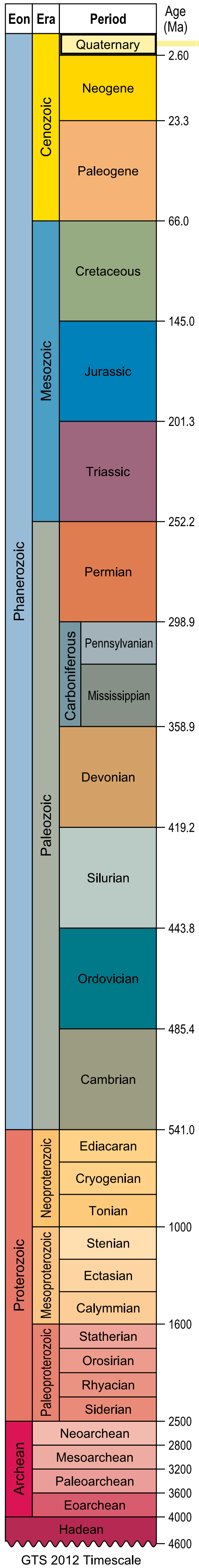
The first hominins evolved in Africa when the human lineage separated from the chimpanzee lineage about the beginning of the Pliocene Epoch. However, they did not leave Africa until early in the next period, the Quaternary.

FLORA

The Pliocene climate was wetter than that of today but the climatic zones now governing Australia had been established. As Earth's climate cooled, areas of previously thick forest were replaced by grasslands and nutrient-poor savannah. Australia's interior dried and became dominated by grasslands, arid plains and open woodlands consisting of eucalypts, she-oaks, banksias, wattles and some legumes. Rainforests persisted in coastal and highland Australia. In the ocean, kelp, a type of large brown algae which attaches to rocks, formed dense shallow marine 'forests' and became one of the most productive ecosystems on the planet.

NEOGENE RESOURCES IN AUSTRALIA

Mineral resources from Neogene rocks include uranium at Beverley, South Australia, and mineral sands from the Eucla Basin, South Australia, and the Murray Basin in both New South Wales and Victoria.



Quaternary Period (2.588–0 Ma)

EON: PHANEROZOIC **ERA:** CENOZOIC

Age (Ma)	Period	Epoch	Stage
0	Quaternary	Holocene	Late Pleistocene
		Pleistocene	Middle Pleistocene
1			Early Pleistocene
2			Gelasian

AUSTRALIA ON THE MOVE

Geoscience Australia monitors tectonic plate movement using Global Positioning Systems (GPS) stations. Highly accurate measurements from stations in Antarctica and Australia indicate that the Indo-Australian plate is moving north-east at an average rate of 7.3 centimetres each year.

INTRODUCTION

The Quaternary Period began 2.6 million years ago and continues to the present day. The Quaternary Period is subdivided into two epochs, the Pleistocene and the Holocene. This period represents the world as we know it today. Although the Quaternary Period saw the continents reach their current positions, they still continue to drift slowly. In the Quaternary Period, hominins left Africa and colonised most continents on Earth.

MAJOR EVENTS

- **Hominins left Africa in two waves and had colonised almost all continents by the beginning of the Holocene Epoch.**
- **The extinction of the megafauna occurred at different times on different continents but all major extinctions occurred late in the Quaternary Period (since about 50 000 years ago).**
- **The Pleistocene Ice Age occurred, with corresponding large sea-level fluctuations, and formation of Australian desert dunefields.**

CLIMATE

Temperature

During the many glacial episodes of the Quaternary Period, temperatures fell dramatically to as low as 9°C below present day levels. Glaciers and ice caps advanced significantly. The last four glacial episodes were the coldest episodes at approximately 100 000 year intervals. Each glacial episode is separated by a warmer interglacial time when temperatures were much the same as today. The last glacial episode was at its maximum around 20 000 years ago and the

current interglacial began around the start of the Holocene Epoch, about 11 700 years ago.

Atmosphere

Oxygen levels in the atmosphere have not changed significantly since the beginning of the Pleistocene Epoch and are about 21%. However, carbon dioxide levels have varied dramatically between glacial and interglacial episodes. During the glacial episodes the carbon dioxide content may have been as low as 0.018%, which is about half today's concentration.

Sea levels

With the increase in the amount of water trapped as glaciers or ice caps, sea levels dropped by as much as 150 metres during the glacial episodes. At the end of a glacial episode, as the glaciers and ice caps receded, the sea rose to roughly current levels. Following the last glacial episode sea levels reached their present position approximately 6000 to 7000 years ago. The transition from glacial to interglacial, and the consequent sea-level rise, has occurred much more rapidly than the original growth of the ice caps when moving from an interglacial to a glacial.

PALEOGEOGRAPHY

Because the Quaternary Period is relatively short, little continental drift has taken place over its duration. However, Australia is currently the fastest moving continent. During the Quaternary Period it has migrated northwards about 180 kilometres and is still moving about 7 centimetres per year.

Sea levels fluctuated markedly during this interval, large areas of the continental shelf were dry land when sea levels were low.

During these episodes it would have been possible to walk from Australia to Papua-New Guinea or from Victoria to Tasmania via land bridges. It may have been during one of these periods of low sea level that humans migrated from south east Asia to Australia though such a journey would always have required an ocean crossing of at least 100 km. Some researchers have pointed out that periods of rising sea level and consequent loss of homelands may have provided a trigger for migrations.

In Victoria and eastern Queensland, there were major volcanic eruptions. Glaciers covered a small area around Mount Kosciuszko and a larger area in the higher parts of Tasmania. Widespread dunefields extended across the desert regions during the glacial periods and dust was blown offshore beyond both the eastern and western coasts. Perennial lakes changed to ephemeral playas and then to salt lakes in response to dessication. Aeolian sand dunes and sand plains now cover about 40% of the Australian arid to semi-arid zone.

FAUNA

The Pleistocene Epoch in Australia was the heyday of the megafauna, which were animals characterised by large body size. Many of these animals became extinct about 40 000 to 50 000 years ago, around the time humans first arrived in Australia. The megafauna included marsupial herbivores weighing up to 2000 kilograms (Diprotodon), 3 metre tall kangaroos (Procoptodon), 3 metre tall flightless birds (Genyornis) related to ducks, a giant goanna (Megalania) 5 to 6 metres long, sheep-sized echidnas and the leopard-sized marsupial lion (Thylacoleo). Not all of the megafauna became extinct: animals such as the Red Kangaroo, Eastern Grey Kangaroo, Perentie, Cassowary and Emu survived. The reason for the extinction of the Australian megafauna is hotly debated, as is the extinction of megafauna on other landmasses. Human hunting, climate change, human impact on the environment or some combination of these factors are the most commonly listed causes.

EVOLUTION OF HUMANS

At the beginning of the Quaternary Period, there were several species of hominins, but all were restricted to Africa. It was not until about 1.8 million years ago that hominins (the species *Homo erectus*) left Africa and moved to central Asia and by about 1 million years ago had reached Europe, Java, Vietnam and China. In Europe, the powerfully built *Homo neanderthalensis* evolved from *Homo erectus* and adapted to the colder climate of Europe. In Indonesia, it is likely that the tiny *Homo floresiensis* evolved from *Homo erectus* or from earlier hominims.

Meanwhile in Africa, *Homo sapiens sapiens* (modern humans) evolved from *Homo erectus* and by 70 000 years ago a small group had left Africa. They reached India soon after, and by 50 000 years ago had spread widely across Australia. It was not until 40 000 years ago that *Homo sapiens sapiens* reached Europe and possibly drove *Homo neanderthalensis* to extinction. *Homo sapiens sapiens* reached North America and South America via the Bering Land Bridge between Siberia and Alaska after about 12 000 years ago. *Homo sapiens sapiens* only reached Madagascar about 2000 years ago and New Zealand about 800 years ago.

Quaternary Period (2.588–0 Ma)

EON: PHANEROZOIC **ERA:** CENOZOIC

FLORA

In southeastern Australia, diverse temperate rainforests survived from the Neogene Period, but there was a slow transition to modern eucalypt-acacia-grevillea woodland. The development of this modern flora was driven by the change from a mostly summer to a mostly winter rainfall pattern about 1 million years ago. Temperate rainforests survive only in the highlands of New South Wales, Victoria and in western Tasmania. Northern Australia retained a summer rainfall pattern. Changes to the modern woodland type vegetataion were driven by increased climatic variability resulting from more intense El Niño events. Significant modification to some ecosystems is a result of changed fire regimes since the first humans arrived. For instance, some ecologists believe that much of the widespread distribution and dominance of Spinifex grassland in central and northern Australia is a result of human burning of the landscape.

QUATERNARY RESOURCES IN AUSTRALIA

Mineral resources of Quaternary age include mineral sands in coastal Western Australia, New South Wales and Queensland, uranium at Yeelirrie, Western Australia, and manganese at Groote Eylandt in the Gulf of Carpentaria. Many industrial and construction minerals such as salt, gypsum, sand and gravel are mostly or wholly Quaternary deposits, as is calcrete and other unsealed road construction materials. Similarly, much of the groundwater vital for communities, pastoral and mining activities in arid-zone areas is Quaternary in age, even if often hosted in older geological sequences such as the Great Artesian Basin.

Glossary

Aeolian:
Describes the transport and deposition of sediment due to wind action.

Amoeba:
A single-celled aquatic marine animal that has the ability to change shape.

Ammonite/Ammonoid:
An extinct marine mollusc with a chambered shell which was usually spirally coiled.

Aquifer:
A body of permeable rock or unconsolidated sediment that is capable of storing significant quantities of water, underlain by impermeable material, and through which groundwater moves. The area where water fills the aquifer is called the saturated zone; the top of this zone is called the water table.

Archaea:
Along with bacteria and eukaryotes, archaea are one of the three domains of life. Like bacteria, they do not have a cellular nucleus, but in other respects they are more similar to eukaryotes. Archaea can often survive in very extreme conditions of heat, cold, salinity and acidity.

Archaeocyath:
An extinct reef-building, sponge-like marine animal with a conical or cup-like appearance.

Arthropod:
An invertebrate characterised by an exoskeleton and jointed legs.

Bacteria:
Along with archaea and eukaryotes, bacteria are one of the three domains of life. Bacteria do not contain a cellular nucleus.

Basalt:
A dark coloured mafic igneous rock commonly extruded as lava from volcanoes.

Basin:
Subsided part of the Earth's crust in which sediment accumulates from surrounding higher areas.

Belemnite:
An extinct marine mollusc related to modern cuttlefish.

Bennettitale:
An extinct non-flowering seed plant similar in appearance to cycads.

Brachiopod:
A marine invertebrate that had a two- valved shell.

Bryozoan:
A small coral-like marine animal that lives in fan or mat-like colonies.

Calcrete:
Calcium carbonate ($CaCO_3$) formed in soil or sediments in a semiarid region under conditions of sparse rainfall and warm temperatures, normally by precipitation of carbonate (HCO_3) carried in solution. The two main types are pedogenic (or vadose) calcrete and groundwater (or non-pedogenic or phreatic) calcrete. Calcareous refers to rock or sediments that contain calcium carbonate.

Carbonate:
A sedimentary rock formed by the precipitation of carbonate, either of calcium, magnesium or iron e.g. limestone is calcium carbonate.

Conglomerate:
A sedimentary rock containing relatively large, rounded to subangular rock fragments (pebbles, cobbles or boulders), set in a fine-grained matrix of sand or silt.

Conifer:
A non-flowering plant, commonly with needle-like or scale-like leaves which develop their seeds in cones. Conifers include pines, firs and spruces.

Conodont:
A small extinct eel-like chordate with cone-shaped teeth-like structures.

Craton:
Old, stable and strong continental core onto which younger rocks have accumulated.

Cycad:
A plant that looks similar to a palm, which is non-flowering and often develops its seeds in cones.

Cyanobacteria:
A type of bacteria characterised by the presence of chlorophyll and can produce free oxygen during photosynthesis. They can occur singularly or in colonies and can live in very inhospitable environments. They were previously known as blue-green algae.

Dessication:
Drying out. Long term loss of water associated with regional climatic change.

Dicroidium:
An extinct warm, dry climate seed fern from the Triassic of Australia.

Dinoflagellate:
A single-celled microorganism, chiefly marine, which exhibits features of both plants and animals. Populations sometimes reproduce rapidly, causing 'red tides'.

Echinoderm:
A solitary marine animal which often has radial symmetry. Starfish, sea urchins and sea cucumbers are all echinoderms.

Eukaryotes:
Along with archaea and bacteria, eukaryotes are one of the three domains of life. Eukaryotes are organisms in which the cell contains a nucleus. All plants, animals and fungi are eukaryotes.

Foraminifera:
A single-celled marine organism which produces a shell of calcium carbonate or other cemented material.

Glacial:
Dominated by glacial ice, or formed or deposited by a large ice mass and/or its movement. Proterozoic, Permian and Quaternary glacial deposits and rocks occur in Australia.

Ginkgo:
A non-flowering plant represented by the modern Chinese Maidenhair Tree.

Glossopteris:
An extinct cold climate deciduous seed fern found in the continents which formerly were part of Gondwana.

Gneiss:
A metamorphic rock, commonly rich in quartz and feldspar, with a banded and foliated texture, formed at temperatures above about 550°C.

Gondwana:
An ancient supercontinent comprising Antarctica, Australia, New Zealand, Africa, Madagascar, Arabia, South America and the Indian subcontinent which had formed the southern half of Pangaea.

Granite:
A light coloured intrusive igneous rock composed mainly of quartz and feldspar.

Glossary

Graptolite:
An extinct tiny marine animal characterised by a cup- or tube-shaped highly resistant exoskeleton, arranged with other individuals along one or more branches to form a colony.

Great Artesian Basin:
Australia's largest artesian groundwater basin, underlying an area of approximately 1.7 million square km, extending beneath the arid zones of Queensland, New South Wales, South Australia and the Northern Territory to depths of up to 3000 metres. The Great Artesian Basin (GAB) comprises the Eromanga, Surat and Carpentaria sedimentary basins and parts of the Bowen and Galilee Basins, and consists of Triassic, Jurassic and Cretaceous sediments (252-66million years ago).

Greenhouse gases:
Gases which absorb infrared radiation reflected from the Earth's surface, thereby warming the Earth's surface and lower atmosphere. Greenhouse gases include water vapour, carbon dioxide, methane and nitrous oxide.

Groundwater:
All water contained in the void spaces of rocks and sediments. It originates as rainfall or surface water that has infiltrated into the ground in recharge zones. Groundwater is stored in—and moves slowly through—permeable layers of rocks, sand and soil, called aquifers, and eventually discharges to rivers, streams, lakes or the ocean.

Hominid:
A hominid is any member of the biological family Hominidae (the "great apes"), including the extinct and living humans, chimpanzees, gorillas, and orangutans.

Hominin:
Modern humans, extinct human species and all our immediate ancestors (including members of the genera Homo, and Australopithecus, among others); the term replaces the former term, hominid which refers to all Great Apes and their ancestors.

Ice age:
A cold period marked by episodes of extensive glaciation.

Ichthyosaur:
A large extinct marine reptile which resembled a dolphin.

Igneous:
One of the three principal classes of rocks; along with metamorphic and sedimentary rocks. Igneous rocks are those which solidified from molten or partly molten material, i.e. from a magma. Intrusive igneous rocks form underground and extrusive igneous rocks (volcanic) form at the surface.

Interglacial:
A warm period between two (cold) glacial periods, typically associated with vegetation change.

Invertebrate:
Any animal that lacks a backbone.

Kimberlite:
A dark coloured intrusive igneous rock, containing at least 35% olivine. The name comes from the Kimberley district in South Africa, where kimberlites are the host for diamonds.

Komatiite:
A very dark coloured high temperature extrusive igneous rock that is common in Archean rocks but do not form today as the Earth is no longer as hot inside. These rocks are often characterised by needle-like crystals forming a criss-cross pattern (spinifex texture).

Lamproite:
A dark coloured intrusive or extrusive rock which is derived from the Earth's mantle. It is an important host for diamonds in Australia.

Land bridge:
In the past when sea levels were significantly lower than today, land was exposed between islands and continents allowing migration of flora, fauna and humans across regions that were formerly isolated by seawater. The converse, seaways, formed when sea levels were high and inundated continental land masses.

Laurasia:
An ancient supercontinent which formed the northern half of Pangaea.

Lycophytes:
A primitive vascular plant that reproduced by spores. Also known as club-mosses, fossils of these are some of the oldest vascular land plants.

Mafic igneous rocks:
A dark coloured igneous rock with very little quartz.

Megafauna:
Large land animals considered typical of the last ice age. In Australia these included the Diprotodon, Megalania, Dromornis and Thylacoleo, among others.

Metamorphic:
One of the three principal classes of rocks; along with igneous and sedimentary rocks. Metamorphic rocks are modified from pre-existing rocks at depth in the Earth's crust by heat and/or pressure.

Mineral sands:
Also termed 'heavy mineral sands' these are placer deposits, accumulated in alluvium by gravity separation of quartz and heavier mineral sand grains on beaches or palaeoshoreline settings. Typical mineral sands contain a mixture of black oxides, dominantly magnetite, with variable amounts of ilmenite, monazite, rutile, zircon, cassiterite and wolframite.

Mollusc:
An invertebrate usually with a shell of calcium carbonate. Molluscs include squid, octopus, clams, scallops, pipis, snails, slugs and chitons.

Monotreme:
A mammal that lays eggs instead of giving birth to live young. The echidna and platypus are both monotremes.

Multicellular:
An adjective referring to organisms which are made of many cells.

Ostracod:
A small crustacean, about 1 mm in size, that is protected by two calcium carbonate valves or 'shells'. Often referred to as 'seed-shrimps'.

Palaeoshoreline:
Ancient ocean or lake shoreline formed during different water level regimes, commonly used with respect to sea level changes during glacial and interglacial periods.

Palaeovalley:
Geologically ancient, non-functional valleys, formed by palaeorivers. Palaeochannel, on the other hand, refers to infilled channels of ancient palaeorivers and are typically small and represent only a part of palaeovalley sedimentary infill.

Pangaea:
An ancient supercontinent which contained almost all the Earth's landmass and existed from about 350 to 150 million years ago.

Photosynthesis:
The process used by plants, algae and cyanobacteria to convert carbon dioxide into organic compounds, especially sugars, using the energy from sunlight. Oxygen is a waste product of photosynthesis.

Placoderm:
The fish-like vertebrates that had bony plates on their heads and upper body which were dominant in seas and rivers during the Devonian Period. They are considered the earliest vertebrates with jaws.

Playa:
Also referred to as a pan or dry lake, is a flat-bottomed depression found in interior desert basins or palaeovalleys within arid and semi arid regions, periodically covered with water that infiltrates into the groundwater system or evaporates, causing a deposit of salt, mud and sand.

Plesiosaur:
A large extinct marine reptile with a barrel-like body, a long neck, a long tail and four flippers.

Progymnosperm:
An extinct group of woody, spore-bearing plants that had fern-like leaves.

Primate:
A mammal group including lemurs, tarsiers, monkeys, apes and humans.

Pterosaur:
A group of now extinct flying reptiles, the first vertebrates to evolve the ability to fly.

Phytosaur:
A large extinct crocodile like reptile with a long thin snout and their nostrils above their eyes.

Radiometric dating:
A process used to determine the age of rocks, using the radioactive decay of atoms in a mineral.

Rain shadow:
An area having relatively little precipitation due to the effect of a topographic barrier, such as a mountain range, in the path of rain-bearing winds that causes the prevailing winds to lose their moisture on the windward side before reaching the leeward side of the high ground.

Rare earth elements:
A series of 15 metallic elements with closely similar chemical properties. These elements are not especially rare in the Earth's crust but their concentrations are: they are only found in trace amounts.

Rodinia:
An ancient supercontinent which formed in the late Proterozoic and contained most of the Earth's landmass.

Rudist:
An extinct marine mollusc usually with a conical shell which became a major reef building organism during the Cretaceous Period.

Rugose coral:
An extinct type of coral that often lived solitary lives in a horn-shaped exoskeleton.

Salt lakes (also known as saline lakes):
Formed where there is no external outlet from a lake and where evaporation causes the concentration of solutes in surface water or in discharging groundwater so that evaporite minerals and underlying brines accumulate. Typical salts are gypsum (calcium sulphate) and halite (sodium chloride). In Australia, salt lakes can be groundwater dominated and highly evolved geomorphologically, characterised by irregular shapes with numerous islands and lunettes (lake-shore dunes) composed of aeolian gypsum sands. Also termed saline lakes; salinity relates to the measure of the total quantity of dissolved solids in water.

Savanna (Savannah):
A flat grassland of tropical or subtropical regions, either treeless or having a mix of widely spaced trees and shrubs and an open canopy. Savannas have distinct wet and dry seasons and they are prone to bushfire. Savannas cover approximately 20% of the Earth's land area.

Seafloor spreading:
Relating to plate tectonics with seafloors spreading along divergent plate margins, resulting in formation of new oceanic crust/lithosphere. Seafloor spreading accommodates the loss of crustal material at convergent/subduction zones such that the total surface of the globe remains constant. The lateral relative movement of plates typically varies from zero to 100 mm annually.

Sedimentary:
One of the three principal classes of rocks; along with igneous and metamorphic rocks. A rock formed by the consolidation of sediments or accumulated by chemical precipitation or secretions from organisms. It is deposited as layers on the Earth's surface, above or below sea level.

Silica:
An oxide of silicon (SiO_2). Silica is the most abundant compound in the crust, making up 60.6% of the crust by mass. Its most common form is the mineral quartz.

Southern Ocean:
Encircling Antarctica and lying immediately south of Australia, although some classifications regard the 60°S latitude as the northern boundary of the Southern Ocean, with the Pacific, Indian and Atlantic oceans extending south to 60°S. The Southern Ocean includes the Antarctic Circumpolar Current (a 20 000 km long, 100–200 km wide and 4 km deep current path around Antarctica), north of which is the Antarctic Convergence, where cold, northward flowing waters from the Antarctic mix with warmer subantarctic waters.

Spore:
A reproductive structure in fungi, some more primitive plants and some bacteria.

Stromatolite:
Stromatolites are laminated mound-like sedimentary structures which form over time as single-celled filamentous cyanobacteria and other bacteria bind layers of sediment grains together.

Supercontinent:
A large continent formed when smaller continental blocks collide and amalgamate.

Tabulate coral:
An extinct form of coral that lived in colonies which commonly have an exoskeleton of hexagonal tubes, similar in appearance to honeycomb.

Trilobite:
An extinct marine arthropod which had an exoskeleton of numerous segments, each of which consisted of three lobes.

Vascular plant:
A plant with tissue that transports water and nutrients.

Vertebrate:
An animal with a backbone.

Zircon:
An accessory mineral found in many rocks which is often used for radiometric dating.

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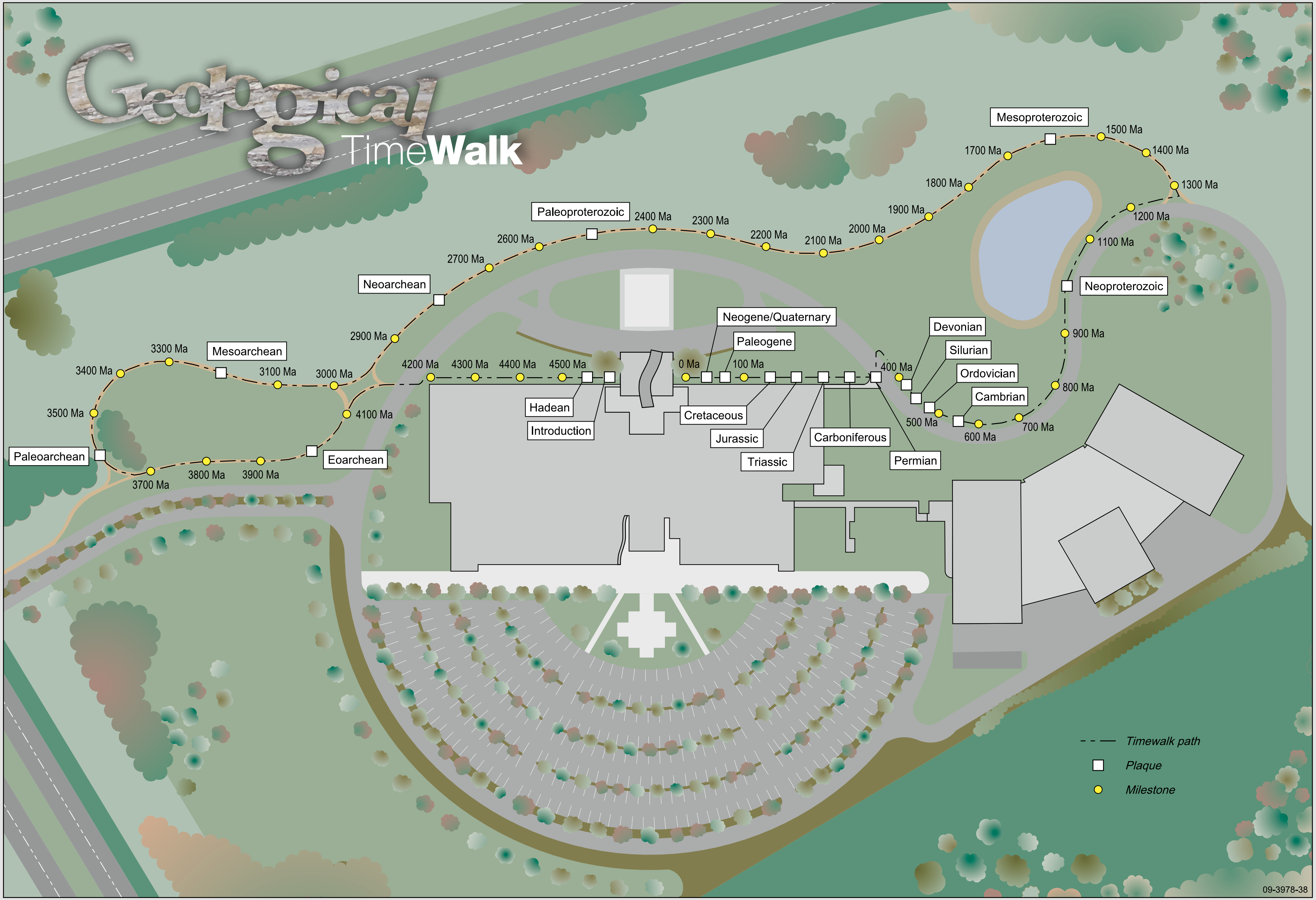
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2300 Ma
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