AUSTRALIA *through* TIME

Eon	Era	Period	Epoch	Ma
PHANEROZOIC	CENOZOIC	NEOGENE	PLEISTOCENE	
			PLIOCENE	
			MIOCENE	23
		PALAEOGENE	OLIGOCENE	
			EOCENE	
			PALEOCENE	65
	MESOZOIC	CRETACEOUS	LATE	
			EARLY	145
		JURASSIC	LATE	
			MIDDLE	
			EARLY	200
		TRIASSIC	LATE	
			MIDDLE	
			EARLY	251
	PALAEOZOIC	PERMIAN	LOPINGIAN	
			GUADALUPIAN	
			CISURALIAN	299
		CARBONIFEROUS – PENNSYLVANIAN	LATE	
			MIDDLE	
			EARLY	
		CARBONIFEROUS – MISSISSIPPIAN	LATE	
			MIDDLE	
			EARLY	359
		DEVONIAN	LATE	
			MIDDLE	
			EARLY	416
		SILURIAN	PRIDOLI	
			LUDLOW	
			WENLOCK	
			LLANDOVERY	444
		ORDOVICIAN	LATE	
			MIDDLE	
			EARLY	488
		CAMBRIAN	FURONGIAN	
			MIDDLE	
			EARLY	542
PROTEROZOIC	NEOPROTEROZOIC		EDIACARAN	542
			CRYOGENIAN	
			TONIAN	1000
	MESOPROTEROZOIC		STENIAN	
			ECTASIAN	
			CALYMMIAN	1600
	PALAEOPROTEROZOIC		STATHERIAN	
			OROSIRIAN	
			RHYACIAN	
			SIDERIAN	2500
ARCHAEAN	NEOARCHAEAN			
				2800
	MESOARCHAEAN			
				3200
	PALAEOARCHAEAN			
				3600
	EOARCHAEAN			

LIFE

EXTINCTION
most of giant Australian megafauna

Common - Molluscs (bivalves and gastropods), crustaceans
Diversification - Mammals and birds
First appearance - Whales, seals, bats, rodents, horses, primates and modern humans

MAJOR EXTINCTION
ammonites, dinosaurs, plesiosaurs, icthyosaurs and pterosaurs

Common - Molluscs (bivalves, ammonites, gastropods), brachiopods and crustaceans
Diversification - Birds, flowering plants (angiosperms) and associated insects
First appearance - Snakes and monotremes

Common - Molluscs, brachiopods, crustaceans, ammonites
Diversification - Dinosaurs, ichthyosaurs and marine reptiles
First appearance - Birds

MAJOR EXTINCTION

Common - Molluscs, brachiopods, crustaceans
Diversification - Ammonites
Spread - *Dicroidium* flora in Gondwana
First appearance -Dinosaurs, pterosaurs, mammals, large marine reptiles and modern (scleractinian) corals

MAJOR EXTINCTION
of >80% known life-forms
rugose and tabulate corals and trilobites

Common - Molluscs, brachiopods and echinoderms
Rare - Trilobites
Spread - *Glossopteris* flora in Gondwana
First appearance - Ammonites, cycads, mammal-like reptiles and beetles

Common - Brachiopods, molluscs, echinoderms and corals
Rare - Trilobites
Widespread - Forests
First appearance - Conifers and dramatic diversification of winged insects

MAJOR EXTINCTION

Common - Brachiopods, molluscs and echinoderms
Widespread - Coral reefs
First appearance - Land vertebrates (amphibians), tree-sized land plants and insects

Common - Trilobites, brachiopods, molluscs, echinoderms, graptolites and corals
First appearance - Land animals (centipedes and arachnids) and vascular land plants

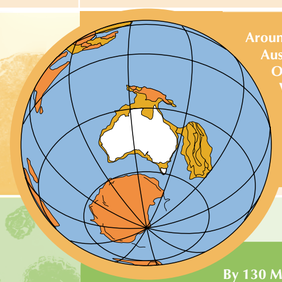
MAJOR EXTINCTION

Common - Trilobites, brachiopods, molluscs and graptolites
First appearance - Coral (rugose and tabulate), bryozoans and land plants (bryophytes)

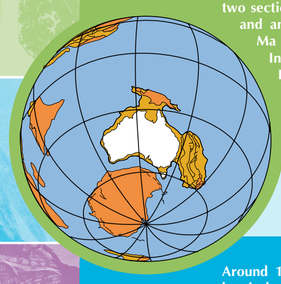
EXTINCTION

Common - Molluscs and sponge (archaeocyath) reefs
Dominant - Trilobites and brachiopods
Diversification - Skeletons and shells
First appearance - Vertebrate fossils as fragmentary plates, trilobites, fish, brachiopods, echinoderms and molluscs

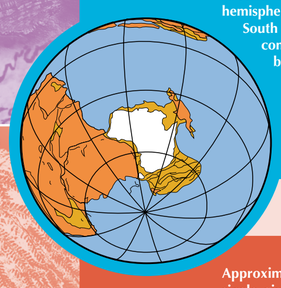
PALAEOGEOGRAPHY



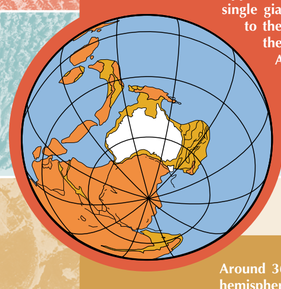
Around *45 million years ago (Ma)*, the deep rift between Australia and Antarctica widened to form the present Southern Ocean. Shallow seas also covered parts of southern Australia. Volcanoes erupted along eastern Australia and Tasmania. Australia's climate was warm and humid. Temperate rainforest was widespread. More recently the Australia plate has moved north and collided with Indonesia and New Guinea.
45Ma



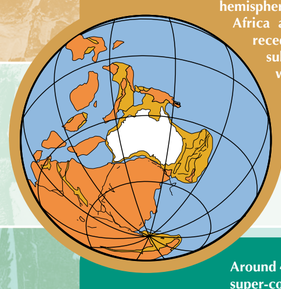
By 130 Ma, Gondwana began to break up, dividing the landmass into two sections, a western half, made up of Africa and South America and an eastern half including Antarctica and Australia. By 70 Ma wide oceans had formed between Antarctica, Africa and India. Australia split from New Zealand and the Lord Howe Rise, forming the Tasman Sea. Rifting between the southern margin of Australia and Antarctica continued and the latter drifted towards the South Pole.
70 Ma



Around 160 Ma Pangaea began to split apart forming a southern hemisphere continent (Gondwana) comprising Antarctica, Australia, South America, Africa and India and a northern hemisphere continent (Laurasia). By 150 Ma, a rift valley began to form between Australia and Antarctica. The sea flooded across the present day coastline in north-west Australia. Attached to eastern Australia were a series of small continental fragments some of which now form the Lord Howe Rise and part of New Zealand. Australia's climate warmed as the continent drifted away from the South Pole.
160 Ma



Approximately 280 Ma all the landmasses of the world united in a single giant super-continent called Pangaea. Australia drifted close to the South Pole with dramatic effects on the climate. Most of the continent was covered by an ice cap, like modern day Antarctica. The Tethys Ocean to the north straddled the equatorial belt. Volcanic activity extended along the eastern seaboard from Sydney to Cairns.
280 Ma



Around 360 Ma the super-continent split in two, with the southern hemisphere continent comprising Antarctica, Australia, South America, Africa and India. In most places around Australia the sea had receded, but parts of eastern Australia and northern WA remained submerged and coral reefs flourished locally. Volcanic activity was widespread along the eastern margin of Australia from central NSW to central Qld.
360 Ma

Around 470 Ma, what is now Australia formed part of a single ancient super-continent. The sea-level was very high and most of eastern Australia was covered by sea, an arm of which extended across the NT to northern WA. Chains of active volcanoes occupied parts of central NSW. Australia was located close to the equator and the climate was relatively warm. Early marine life had existed for many hundreds of millions of years before this.
470 Ma

The Earth is a dynamic Planet. Throughout geological time large-scale forces acting on the Earth's outer crust have reconfigured the arrangement of the continents. Continual continental collision and rifting has affected global ocean circulation and climate, and formed the current continent and ocean arrangement which we are familiar with today.

MAJOR MINERAL DEPOSITS

Magnesite: Kunwarara (Qld)
Brown Coal: Latrobe Valley (Vic)
Bauxite: Huntly, Mt Saddleback (WA), Gove (NT)
Oil and Gas: Gippsland District, Bass Strait (Vic)
Pisolitic Iron Ore: Yanadicoogina (WA)

Oil: Barrow Island, NW Shelf (WA)
Manganese: Groote Eylandt (NT)
Opal: Andamooka, Cober Pedy (SA)

Oil and Gas: Eromanga Basin (Qld), NW Shelf (WA)
Black Coal: Walloon (Qld)

Black Coal: Ipswich, Callide Basins (Qld)
Gas: NW Shelf, Rankin Trend, Carnarvon Basin (WA)
Oil and Gas: Perth Basin (WA), Timor Sea

Black Coal: Sydney and Gunnedah Basins (NSW), Bowen Basin (Qld), Collie Basin (WA), Arckaringa Basin (SA)
Oil and Gas: Cooper Basin (Qld)
Gold: Gympie, Mt Leyshon (Qld)
Tungsten: Mt Carbine (Qld)

Oil: Canning Basin (WA)
Tin: Herberton Tinfield (Qld)
Gold: Pajingo, Kidston, Ravenswood (Qld)
Lead/Zinc: Cadjebut (WA)

Oil: Canning Basin (WA)
Gas: Adavale Basin (Qld)
Copper/Lead/Zinc/Gold/Silver: Cobar District (NSW)
Tin: Renison Bell, Mt Mischoft (Tas)
Gold: Charters Towers (Qld)
Copper/Gold: Mt Morgan (Qld)
Tungsten: King Island (Tas)

Gold: Ballarat/Bendigo (Vic)
Copper/Lead/Zinc/Silver/Gold: Captains Flat, Woodlawn, Lewis Ponds (NSW)
Tin: Ardlethan (NSW)

Gold/Silver: Gidginbung (NSW)
Copper/Gold: North Parkes, Cadia (NSW)
Oil and Gas: Amadeus Basin (NT)

Copper/Gold/Silver: Mt Lyell (Tas)
Copper/Lead/Zinc/Gold/Silver: Rosebery, Hellyer, Que River (Tas)
Phosphate: Georgina Basin (Qld)

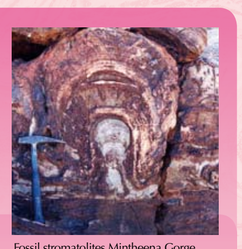
Relative Sea Level

Early Life

The Ediacaran is the first new period-level interval of geological time to be created in the Standard Global Chronostratigraphic Scale for well over 100 years. It takes its name from the Ediacara Hills in the northern Flinders Ranges in South Australia. The Ediacaran Period covers an interval of about 88 million years from the end of the Marinoan glaciation 630 million years ago to the beginning of the Cambrian Period 542 million years ago. The Ediacaran Period is famous for its association with the Ediacara biota, marking the first appearance of large, architecturally complex organisms in Earth history. The marked and rapid increase in abundance, size and diversity of life-forms during the Australian Ediacaran shows that it was a period of major evolutionary change.

Dickinsonia costata (length 1.5cm) and *Tribrachidium heraldicum* (holotype) (diameter 2.5cm) © Jim Gehling, South Australian Museum

Living stromatolites Shark Bay WA © Amy Prendergast



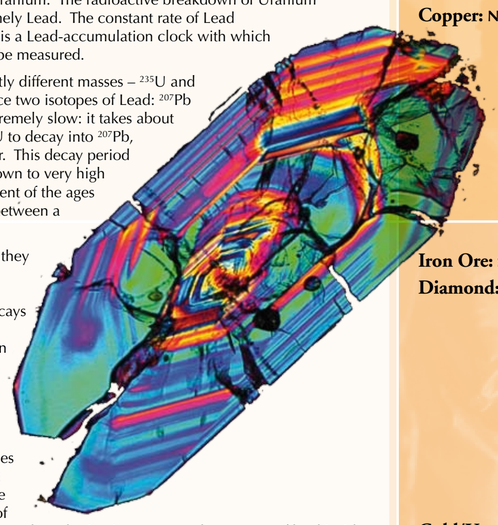
Fossil stromatolites Mintheena Gorge Pilbara © Mary Gee

First Life – living rocks, living fossils

Stromatolites first appeared in the fossil record between 2.7 billion years and 3.465 billion years ago. Stromatolites are laminated mound-like sedimentary structures which form over time as single-celled filamentous cyanobacteria bind layers of sediment grains together. Fossil stromatolites from the Pilbara in Western Australia are some of the earliest evidence of cellular life on Earth. Stromatolites were the Earth's first reef-building organisms and still exist today in places such as Hamelin Pool - Shark Bay, Western Australia.

A clock to measure the age of the Earth

The breakthrough in dating rocks came in 1896 with Becquerel's discovery that radiation is emitted by minerals containing Uranium. The radioactive breakdown of Uranium produces a stable end-product, namely Lead. The constant rate of Lead accumulation from Uranium decay is a Lead-accumulation clock with which the ages of rocks and minerals can be measured.



Two isotopes of Uranium with slightly different masses – ^{235}U and ^{238}U – decay radioactively to produce two isotopes of Lead: ^{207}Pb and ^{206}Pb. Their rate of decay is extremely slow: it takes about 700 million years for half of the ^{235}U to decay into ^{207}Pb, and the decay of ^{238}U is even slower. This decay period is known as the 'half-life' and is known to very high precision, which permits measurement of the ages of geological events that occurred between a few million to billions of years ago.

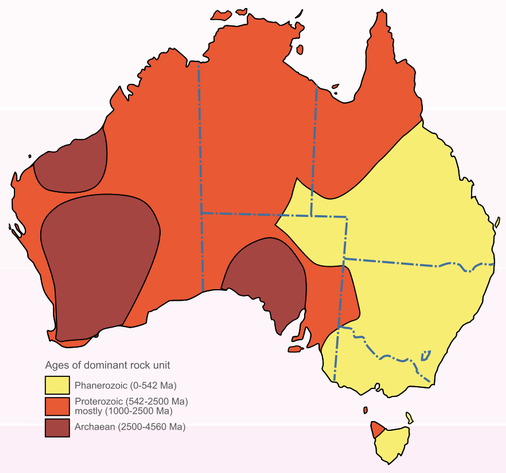
Other elements are radioactive and they all have different rates of decay and accumulation useful in geological dating. For example, Rubidium decays to form Strontium, and Potassium decay causes accumulation of Argon gas locked in certain minerals. The Lead-accumulation clock is the most widely used because tiny, but measurable, amounts of Uranium and Lead are found in most rocks. Zircon is a mineral which locks traces of Uranium within its crystals and it is found in many types of rocks. The Lead that accumulates from decay of the Uranium is trapped within the crystals and scientists measure the amount of lead inside zircon crystals to measure the time since the crystal formed.

The science of dating rocks is called 'geochronology'. 'Mineral chronometers' like zircon reveal the ages of magmatic events, metamorphism (when rocks are altered by extreme heat) and the deposition of sedimentary rocks many millions of years ago.

How old is the Earth?

Using the Lead-accumulation clock, it has been discovered that some rocks in Alaska are 4,000 million years old. Rare sand grains found in some sandstones in Western Australia are even older, at 4,250 million years. 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. With the Earth, the Sun and the other planets, meteorites are a product of the event which created the Solar System and started the Lead-accumulation clock. Several meteorites preserving remnants of the original matter have been dated at 4,560 million years old. This is the formation age of our Solar System and of the Earth.



Evolution of Australia

Australia has grown from west to east. The Pilbara (north) and Yilgarn (south) Blocks, in WA and the Gawler Block in SA, are Archaean. Proterozoic basement extends eastwards from these and this is bounded by Phanerozoic rocks, which form most of the eastern states. Much of the older basement in the western half of the continent is covered by younger Phanerozoic sediments and recent regolith, which are not shown.

MAJOR MINERAL DEPOSITS

Gold: Telfer (WA)
Copper: Nifty, Maroochydore (WA)

Gold pour WA © Jon Claoué - Long

Iron Ore: Savage River (Tas)
Diamond: Argyle (WA)

Gold mine Kalgoorlie WA © Jon Claoué - Long

Gold/Uranium/Copper/Rare Earth Elements: Olympic Dam (SA)

By this time crustal growth had progressed far enough to support the formation of large sedimentary basins, which host
Lead/Zinc: McArthur River (NT), Mt Isa & Century (Qld), Broken Hill (NSW)
Gold: Tanami region(NT)
Gold/Tin/Base Metals (Lead/Zinc/Copper): Pine Creek region (NT)
Uranium/Gold/Platinum/Palladium: Pine Creek (NT)
Uranium/Rare Earth Elements: Mary Kathleen (Qld)
Gold/Copper/Bismuth: Tennant Creek (NT)
Iron: Hammersley (WA), existing formations underwent hydrothermal upgrading

MAJOR MINERAL DEPOSITS (2500-3000 Ma)

Gold: Yilgarn Block (WA)
Banded Iron Formations: Hammersley Ranges, Shay Gap, numerous small formations in the Pilbara and Yilgarn (WA)
Tin/tantalum/lithium: Greenbushes, SW Yilgarn; Wodgina, Pilbara (WA)
Nickel sulphide: Kambalda, Yilgarn Block (WA)
Nickel/Copper: Ruth Well (WA)
Copper: Mons cupri/Whims Creek (WA)
Platinum horizons: Munni Munni (WA)

OLDEST KNOWN MINERAL DEPOSITS (older than 3000 MA)

Gold deposits: 2900 and 3400 Ma, Pilbara (WA)
Barite-rich Lead/Zinc: Big Stubby, 3470Ma; Panorama, 3240 Ma, Pilbara (WA)
Molybdenum/Copper: Spinifex Ridge, Gobbos, 3324 Ma, Pilbara (WA)

(the age of many of these deposits are uncertain; the oldest age considered possible has been used)

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Geoscience Australia
Education **Tel** (02) 6249 9571
Email education@ga.gov.au
Sales Centre **Tel** 1800 800 173
Email sales@ga.gov.au

Cnr Jerrabomberra Ave & Hindmarsh Dr
Symonston ACT 2609
GPO Box 378 Canberra ACT 2601
www.ga.gov.au

Geological Society of Australia
Tel (02) 9290 2194
Fax (02) 9290 2198
Email info@gsa.org.au

Suite 706, 301 George Street
Sydney NSW 2000
www.gsa.org.au

Source: Gradstein, Ogg & Smith, A Geological Time Scale 2004

Watermark images courtesy Australian Museum, Museum Victoria & Geoscience Australia. Sealevel Curve: **Mesozoic:** Haq, B.U., Hardenbol, J. & Vail, P.R., 1987. Chronology of Fluctuating Sea-Levels since the Triassic. *Science 235*, 1156-1167 **Palaeozoic:** Schutter, S.R. & Laurie, J.R., 1997. Palaeozoic sealevel. In AGSO Phanerozoic Timescale Calibration and Development Team (eds), *Australian Phanerozoic Timescale and Biozonation Chart 1997, Version 1997-1*

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