



## Chronology of Earth History

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Millions of Years ago	Eon / Era	Period / Epoch	Events
4,600	Hadean Eon		Origins of Earth-Moon system and other solar system planets
4,500			Oldest rocks dated by radioactivity, a chondrite from Canyon Diablo crater, Arizona.
4,400			Outgassing of volatiles from mantle to atmosphere. Abundant impact cratering.
4,300			Oldest known mineral crystals (Australia). Possible existence of first continents.
4,200			Early Seas. Oldest Moon rocks dated by radioactivity.
4,100			Exuberant volcanism and meteoric cratering continues
4,000	Archean Eon		Beginning of Earth Crust formation and presumed start of tectonic activity. Earliest Earth rocks (zircons from Mount Narryer in Australia) and Acasta gneiss (north-western Canada) dated by radioactivity.
3,900			Origins of life in the form of bacterial cells. Appearance of first kingdom: MONERA. Anaerobic prokaryotes and therefore autopoiesis, metabolism and reproduction have evolved.
3,800			Greenstone Isua Belt (Greenland), indicating possible biologically produced carbonate and reduced carbon.

3,700			First appearance of banded iron formation suggesting local sources of oxygen at sediment-water interfaces.
3,600			Baberton Mountain Land (South Africa) and Pilbara Block (Australia), containing fossil evidence for anoxygenic communities; microfossils, stromatolites, and chemical fossils.
3,500			Onverwacht Group and Warrawoona Group (South Africa), containing abundant reduced carbon in shales, microfossils and stromatolites, imply widespread occurrence of photosynthetic bacterial communities. Earliest known evidence of tectonic activity: granite of the Kaapvaal Craton (South Africa).
3,400			Development of thickest and oldest portions of continents. There is evidence (not absolutely conclusive) for the existence of photosynthesising cyanobacteria in a layer of carbonaceous rock found in the Buck Reef Chert in South Africa.
3,300			Trace amounts of oxygen in atmosphere and sediments.
3,200			Continental tectonic activity, many small plates.
3,100			Formation of Fig Tree Group (South Africa) of rocks that contain fossils of reproducing cells.
3,000			Oldest evidence for life in North America: Steep Rock, Ontario. Widespread stromatolite reefs preserved at Steep Rock and Pongola Belt (South Africa). Diversification of bacteria - probably all major metabolic modes evolved by now (e.g.. chemoautotrophy such as H <sub>2</sub> , H <sub>2</sub> S, NH <sub>3</sub> , and CH <sub>4</sub> oxidation; oxygenic photosynthesis; reduction of iron and manganese oxides to metals.)
2,900			Gold deposited in paleoriver in Witwatersrand, South Africa, indicating bacterial-mediated gold precipitation in ancient estuaries.
2,800			Large continents formed from raised portion of the plates known as the 'pre-Cambrian shields.'
2,700			Stromatolites abundant and cosmopolitan on ancient parts of present day Africa, North & South America, Australia and Asia.
2,600			End of major crust-forming period. The first evidence of life on land. Traces of photosynthetic cyanobacteria have been found in terrestrial sediments at a site in South Africa.

2,500	<b>Proterozoic Eon</b>  <b>Aphebian Era</b>		Geologically modern processes begin: Oxygen gas begins to seasonally accumulate; banded iron formations conspicuous and abundant; extensive huge lakes of oceans; carbonate platforms, indicating biogenic reef-like structures made by bacterial communities in marine settings. First super-continent (prePangea).
2,400			Beginning of worldwide Banded Iron Formations; 90% of Earth's mineable iron deposits formed between 2,400 and 1,800 mya.
2,300			Continued expansion of carbonate reef-like platforms and Banded Iron Formations.
2,200			Widespread occurrence of prokaryotic plankton (bacterioplankton) in world's oceans.
2,100			Increasing UV-absorbing ozone shield accumulating in atmosphere. Oldest abundant fossil bacteria: <i>Gunflintia</i> , <i>Huronospora</i> , <i>Leptoteichus golubicii</i> , etc.
2,000			Free Oxygen abundant in atmosphere, indicating dominance of aerobic organisms. Mitochondria ancestors to most eukaryotes, acquired by symbiosis as purple eubacteria. Gunflint Iron Formation (Ontario Canada) and equivalent fossil biotas in China, Australia and California, containing complex filamentous microfossils and complex communities.
1,900			First appearance of Grypania, identified as the earliest Protocista.
1,800			Replacement of banded iron formations by red beds (oxidised iron sediments), indicating worldwide transition to an atmosphere rich in oxygen.
1,700	<b>Riphean era</b>		Appearance of second kingdom: PROTOCTISTA. Earliest eukaryotes documented in fossil record as acritarchs, indicating cell evolution by symbiosis.
1,600			Diversification of aerobic life. Appearance of planktonic and benthic organisms possibly correlated to symbiotic acquisition of air breathing mitochondria.
1,500			Protocist evolution: origins of mitosis, meiotic sex, gender, and programmed death of individuals in eukaryotic micro-organisms and their descendants.

1,400			First evidence of continuous terrestrial cyanobacterial life (desert crust and soil microbial communities).
1,300			Diversification of seaweeds of unknown taxa possibly correlated to symbiotic acquisition of photosynthetic plastids.
1,200			Continued diversification and widespread appearance of monera (iron bacteria, cyanobacteria, and many unknown Protocista - sexual cysts, algae, microscopic and even large fossils.
1,100			Global rifting event.
1,000	<b>Vendian Era</b>		Increase in diversity of algae and other protists.
900			Oldest 'giant' acanthomorph acritarchs, probably algae.
800			Worldwide proliferation of unidentified large 'quilted' organisms, fossilised in sandstone, probably members of diverse Protocista kingdom, the Ediacaran biota.
700			Series of worldwide 'Vendian' ice ages followed by diverse new planktonic and benthic communities, probably of protocists.
600		<b>Ediacaran Period</b>	Appearance of third kingdom: ANIMALS. Inferred origins of egg, sperm, embryo and blastula. Appearance in fossil record of soft-bodied animals (sponges, coelenterates, arthropods and others).
570	<b>Phanerozoic Eon</b>  <b>Paleozoic Era</b>	<b>Cambrian Period</b>	The largest of the Cambrian continents was Gondwana. Composed essentially of modern South America, Africa, southern Europe, a large portion of the Middle East, India, Australia, and much of Antarctica, Gondwana extended from the low northern latitudes to the high southern latitudes.  Fossil remains, which are all marine, include the oldest representatives of most animal phyla. The most abundant were the trilobites, distantly related to the modern horseshoe crab. Other important groups include the graptolites, conodonts, annelids, brachiopods, chordates, ctenophores, echinoderms, molluscs, and sponges. Also foraminifera, dinomastigotes, radiolarians and red algae.

495		Ordovician Period	<p>Gondawana began moving over the South Pole. The Cambrian trilobites were replaced by graptolites (colonial organisms with a skeleton of tough chitinlike material) and brachiopods (lamp shells). Other important marine invertebrates were bryozoans, crinoids, nautiloids and corals. Ostracoderms (jawless armoured fishes) lived in the near-shore tropical waters.</p> <p>The first land plants, related to modern Liverworts, appeared. Spores have been found on rocks dated to 475 million years ago. Definite fossil liverwort sporangia have been dated to 450 million years ago.</p>
443		Silurian Period	<p>The major continental plates begin to move together. Appearance of terrestrial plants, Rhyniophytes with fungi in plant roots. Beginning of widespread life on land. The first jawed fishes appeared.</p>
408		Devonian Period	<p>Major radiation of jawed fish. The first ammonites appeared. On land the first insects appeared and the land extensively covered by forests. First appearance of plants with seeds.</p>
354		Carboniferous Period	<p>Extension of reef building corals (coelenterates) and coralline (rhodophyte) algae. Major radiation of crinoids. On land, widespread large trees in swamps lead to coal forests. The first winged insects. The first amphibia.</p>
290		Permian Period	<p>The super continent Pangea is formed. Appearance of large amphibians; mammal-like reptiles; bird-like reptiles including dinosaurs; and shrew-like mammals. Radiolarians and other protists abound in marine sediments.</p> <p>The end of the Permian is marked by a major mass extinction.</p>
245	Mesozoic Era	Triassic Period	<p>Beginning of break-up of Pangea continent. Major radiation of reptiles. Ferns become abundant. The end of the Triassic is marked by one of the largest mass extinctions of all time.</p>
208		Jurassic Period	<p>Pangea begins to separate into the northern and the southern hemisphere continents.</p> <p>Diversification of phytoplankton. The beginning of the age of the dinosaurs. Gymnosperms become the dominant land flora.</p>

145		Cretaceous Period	Opening of what will become the Atlantic Ocean.  The age of dinosaurs. Appearance of flowering plants (angiosperms) and Primates (plesiadapiforms). Major radiation of boney fish. The end of the Cretaceous is again marked by a mass extinction which ended the age of the dinosaurs on land and the ammonites in the sea.
65	Cenozoic Era	Paleogene Period  <i>Paleocene Epoch</i>	Major radiation of mammals
57		<i>Eocene epoch</i>	Africa and India still separate from but approaching the Eurasian Continent.  Appearance of angiosperm herbs and trees with fruit. Associated with this is a significant increase in diversity of birds and insects. Appearance of earliest Ungulates on land and Whales in the sea.
35		<i>Oligocene epoch</i>	Expansion of grasslands. Appearance of first monkeys.
23		Neogene Period  <i>Miocene epoch</i>	Grasslands become widespread associated with diversification of grazing animals. Radiation of Apes
5		<i>Pliocene epoch</i>	Diversification of Miocene apes (proconsul) including hominids (e.g.. <i>Ramapithecus</i> , australopithecines).
1.65		Quaternary Period  <i>Pleistocene epoch</i>	<i>Homo erectus</i> and <i>Homo neanderthalensis</i> in Middle East, Africa and Europe.
0.01		<i>Holocene epoch</i>	Appearance of agricultural, urban centres.

## Principal Sources

Lynn Margulis & Dorion Sagan. *What is Life?* (Weidenfeld and Nicolson, 1995)Steven Stanley. *Earth System History* (W H Freeman, 1998)

The following graphs illustrate:

1. The major changes in the diversity of animals and plants from the beginning of the Cambrian period to the present.

2. The Estimated extinction rate for the same period.

Both are measured by counting the number of known genera (groups of closely related species) in the fossil record.

The extinction rate shows a number of pronounced peaks representing very significant extinction events.

The mass extinction of 65 million years ago at the end of the Cretaceous period and the subsequent flowering of diversity emerge very clearly from the data.

