# *eras*

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# ***The evolutionary history of our planet is recorded in the eras of the four great eons***

<https://evolution.calpoly.edu/eras>

# ***Hadean Eon volcanic outflows and alien collisions saw hellish conditions from 4.6 – 4 BYA***

## 9.2 BYs of cosmic, galactic, stellar, and global evolution preceded the Hadean Eon

#### **The cosmic web preserved tiny density variations that evolved into stars and galaxies**

The primordial universe was almost perfectly homogeneous other than tiny quantum density fluctuations. Dark matter preserved these variations through gravitational forces at a time when ordinary matter could not form stable dense regions due to absorption of intense electromagnetic radiation. As the universe expanded, it cooled and the energy per photon decreased to the level at which matter could condense into the dense regions formed by dark matter. Without dark matter, structure would not have formed in the universe and there would be no cosmic web, galaxies, stars, planets, or life.

#### **The composition and structure of our galaxy has evolved for billions of years**

Our galaxy consists of two disks of stars, a central bulge, a supermassive black hole, and interstellar medium which is the birthplace of new stars. And one more thing, 95% of its mass is the unseen dark matter which holds everything together gravitationally. Our galaxy formed from the merger of numerous smaller galaxies in a relatively less densely populated region of the universe.

#### **Hot dense stars form in cold dilute molecular clouds in the interstellar medium**

Supernovas are massive stars that synthesize elements up to the iron group. When they explode, they synthesize additional elements and they enrich the interstellar medium with all of these elements. The molecular clouds in the interstellar medium are sites where later generations of stars form with their inheritance of metals.

Some supernovas leave neutron stars behind as remnants and in the case of binary star systems, some of the neutron stars merge by dispersing energy through gravity waves. These mergers synthesize many of the heavier elements that are not synthesized in supernovas. The interior of the Earth has retained much of its initial heat of formation due to the decay of radioactive elements like uranium and thorium. The heat flow drives convection in the opaque rocks of the mantle, producing plate tectonics, earthquakes, volcanoes, and the formation of islands and continents. Without neutron star mergers, the rock formations of the Grand Canyon would not exist. These movements also play a major role in climate and biogeochemical cycles. So neutron stars and the gravity waves that facilitated their mergers had profound effects on Earth and its geobiosphere.

#### **Our solar system – sun, planets, asteroids, comets - fostered the evolution of complex life**

Our solar system has exactly one star which provides a steady output for any orbiting planets. It is small enough to live long enough for life to evolve on adjacent planets. It is not a giant star with excessive ultraviolet radiation, but it is large enough to produce a spectrum that is beneficial to organisms. It is a population I star which means it formed with enough metals to form rocky planets and molecular building blocks of life. It is located in a stable region in the galaxy.

#### **The evolution of Earth and complex life was influenced by internal and external forces**

Earth is located in the Goldilocks zone of our solar system. The interplanetary medium includes gas and dust essential for life. The influence of the moon fostered the evolution of complex life on Earth. The solar system has enough planets and other minor bodies to provide a few rare catastrophes that do not cause total annihilation, but causes enough mass extinction to open up ecological niches for an evolving biosphere.

## the sands of time recorded the 4 BY evolutionary history of life on Earth

The geological history is inseparable from the evolutionary history of life over billions of years and changes in solar brightness, the distance to the moon, formation and movements of continents, heat from the Earth’s interior, oceans, atmosphere, and climate. Even the history of the universe, our galaxy, our solar system, and the occasional asteroid played major roles in what we see today.

Hadean describes the hellish conditions then prevailing on Earth: the planet had just formed and was still very hot owing to its recent accretion, the abundance of short-lived radioactive elements, and frequent collisions with other Solar System bodies. Hadean rocks are very rare, largely consisting of zircons from one locality in Western Australia. Hadean geophysical models remain controversial among geologists: it appears that plate tectonics and the growth of continents may have started in the Hadean. Earth in the early Hadean has a very thick carbon dioxide atmosphere, but eventually oceans of liquid water formed.

Geologists identified a few Hadean rocks from western Greenland, northwestern Canada, and Western Australia. Traces of carbon minerals interpreted as "remains of biotic life" were found in 4.1-billion-year-old rocks in Western Australia. The oldest dated zircon crystals, enclosed in a metamorphosed sandstone conglomerate in Western Australia, date to 4.4 BYA. In many other areas, xenocryst (or relict) Hadean zircons enclosed in older rocks indicate that younger rocks have formed on older terranes and have incorporated some of the older material.

Plate tectonics may have begun as early as 4 BYA. Mantle convection in the Hadean was likely vigorous, due to lower viscosity. The lower viscosity was due to the high levels of radiogenic heat and the fact that water in the mantle had not yet fully outgassed. Whether the vigorous convection led to plate tectonics in the Hadean or was confined under a rigid lid is still a matter of debate. The presence of an ocean during the Hadean is generally accepted, due to zircon evidence. The presence of oceans are thought to trigger plate tectonics. The removal of the CO2-rich early atmosphere also indicates that plate tectonics were active in the Hadean.

If plate tectonics occurred in the Hadean, it would have formed continental crust. Different models predict different amounts of continental crust during the Hadean. The work of Dhiume et al. predicts that by the end of the Hadean, continental crust had only 25% of today's area. The models of Korenaga, et al. predict that the continental crust grew to present-day volume sometime between 4.0-4.2 BYA.

The amount of exposed land in the Hadean is only loosely dependent on the amount of continental crust: it also depends on the ocean level. In models where plate tectonics started in the Archean, Earth has a global ocean in the Hadean. The high heat of the mantle may have made it difficult to support high elevations in the Hadean. If continents did form in the Hadean, their growth competed with outgassing of water from the mantle. Continents may have appeared in the mid-Hadean, and then disappeared under a thick ocean by the end of the Hadean. The limited amount of land has implications for the origin of life.

## Earth’s geospheres evolved through prebiotic geochemical processes

A sizable quantity of water would have been in the material that formed Earth. Water molecules would have escaped Earth's gravity more easily when it was less massive during its formation. Hydrogen and helium are expected to continually escape (even to the present day) due to atmospheric escape.

Part of the ancient planet is theorized to have been disrupted by the impact that created the Moon, which should have caused melting of one or two large regions of Earth. Earth's present composition suggests that there was not complete remelting as it is difficult to completely melt and mix huge rock masses. However, a fair fraction of material should have been vaporized by this impact. The material would have condensed within 2000 years, leaving behind hot volatiles which probably resulted in a heavy CO2 atmosphere with hydrogen and water vapor. Liquid water oceans existed despite the surface temperature of 230 °C because at an atmospheric pressure of above 27 atmospheres, caused by the heavy CO2 atmosphere, water is still liquid. As cooling continued, subduction and dissolving in ocean water removed most CO2 from the atmosphere but levels oscillated wildly as new surface and mantle cycles appeared. Studies of zircons have found that liquid water may have existed between 4.0 and 4.4 billion years ago, very soon after the formation of Earth. For this time interval, meteorite impacts may be been less frequent that previously hypothesized, and Earth may have gone through long periods when liquid oceans and life were possible.

Asteroid impacts during the Hadean and into the Archean would have periodically disrupted the ocean. The geological record from 3.2 BYA contains evidence of multiple impacts of objects up to 100 kilometers in diameter. Each such impact would have boiled off up to 100 meters of a global ocean, and temporarily raised the atmospheric temperature up to 500 °C.

## the late heavy bombardment may have extinguished any early life forms

The Late Heavy Bombardment (LHB), or lunar cataclysm, is a hypothesized event thought to have occurred approximately 4.1 to 3.8 BYA, at a time corresponding to the Neohadean and Eoarchean eras on Earth. According to the hypothesis, during this interval, a disproportionately large number of asteroids collided with the early terrestrial planets in the inner Solar System, including Mercury, Venus, Earth and Mars. These came from both post-accretion and planetary instability-driven populations of impactors. Although generally accepted, it remains difficult to prove conclusively.

Several hypotheses attempt to explain the apparent spike in the flux of impactors (i.e. asteroids and comets) in the inner Solar System, but no consensus yet exists. The Nice model, popular among planetary scientists, postulates that the giant planets underwent orbital migration and, in doing so, scattered objects in the asteroid belt, Kuiper belt, or both, into eccentric orbits, and into the path of the terrestrial planets.

Geological consequences on Earth

If a cataclysmic cratering event truly occurred on the Moon, Earth would have been affected as well. Extrapolating lunar cratering rates to Earth at this time suggests that the following number of craters would have formed:

    22,000 or more impact craters with diameters >20 km,

    about 40 impact basins with diameters about 1,000 km,

    several impact basins with diameters about 5,000 km,

Before the formulation of the LHB hypothesis, geologists generally assumed that Earth remained molten until about 3.8 BYA. This date could be found in many of the oldest-known rocks from around the world, and appeared to represent a strong "cutoff point" beyond which older rocks could not be found. As no older rocks could be found, it was generally assumed that Earth had remained molten until this date, which defined the boundary between the earlier Hadean and later Archean eons.

Older rocks could be found, however, in the form of asteroid fragments that fall to Earth as meteorites. Like the rocks on Earth, asteroids also show a strong cutoff point, at about 4.6 BYA, which is assumed to be the time when the first solids formed in the protoplanetary disk around the then-young Sun. The Hadean, then, was the period of time between the formation of these early rocks in space, and the eventual solidification of Earth's crust, some 700 million years later. This time would include the accretion of the planets from the disk and the slow cooling of Earth into a solid body as the gravitational potential energy of accretion was released.

Later calculations showed that the rate of collapse and cooling depends on the size of the rocky body. Scaling this rate to an object of Earth mass suggested very rapid cooling, requiring only 100 million years. The difference between measurement and theory presented a conundrum at the time. The LHB offers a potential explanation for this anomaly. Under this model, the rocks dating to 3.8 BYA solidified only after much of the crust was destroyed by the LHB.

Older references generally show that Hadean Earth had a molten surface with prominent volcanos. The name "Hadean" itself refers to the "hellish" conditions assumed on Earth for the time, from the Greek Hades. Zircon dating suggested, albeit controversially, that the Hadean surface was solid, temperate, and covered by acidic oceans. This picture derives from the presence of particular isotopic ratios that suggest the action of water-based chemistry at some time before the formation of the oldest rocks (see Cool early Earth).

Some sedimentary rocks found in Greenland may have been relics of organic matter from about 3.8 to 3.6 BYA, a very short time for abiogenesis to have taken place. The Late Heavy Bombardment and the "re-melting" of the crust that it suggests provides a timeline under which this would be possible: life either formed immediately after the Late Heavy Bombardment, or more likely survived it, having arisen earlier during the Hadean.

Three-dimensional computer models postulate that much of Earth's crust, and the microbes living in it, could have survived the bombardment. Their models suggest that although the surface of Earth would have been sterilized, hydrothermal vents below Earth's surface could have incubated life by providing a sanctuary for thermophile microbes.

***Archean Eon saw surface rocks form, plates move, and microbes evolve 4 – 2.5 BYA***

## Eoarchean era 4 BYA to 3.6 BYA first solid crust on Earth forms

The Eoarchean is the first era of the Archean Eon of the geologic record for which the Earth has a solid crust. The beginnings of life on Earth have been dated to this era and evidence of cyanobacteria date to 3.5 BYA, just outside this era. At that time, the atmosphere was without oxygen and the pressure values ranged from 10 to 100 bar (around 10 to 100 present-time levels).

A characteristic of the Eoarchean is that Earth possessed a firm crust for the first time. However, this crust may have been incomplete at many sites and areas of lava may have existed at the surface. The beginning of the Eoarchean is characterized by heavy asteroid bombardment within the inner solar system: the Late Heavy Bombardment.

The largest Eoarchean rock formation is the Isua Greenstone Belt on the south-west coast of Greenland, which dates from 3.8 billion years. The Acasta Gneiss within the Canadian Shield have been dated to be 4.031 BYA and are therefore the oldest preserved rock formations. The Nuvvuagittuq greenstone belt in northern Québec has been dated to be 4,280 million years ago. The 3,850 million years old Greenland apatite shows evidence of carbon 12 enrichment suggesting photosynthetic life before 3.8 billion years.

## Paleoarchean era 3.6 BYA to 3.2 BYA large continental crust under water

The Paleoarchean is a geologic era within the Archaean Eon. The era is defined chronometrically and is not referenced to a specific level of a rock section on Earth. The earliest confirmed evidence of life comes from this era, and Vaalbara, one of Earth's earliest supercontinents, may have formed during this era.

The geological record from the Paleoarchean era is very limited due to deformation and metamorphism. There are only two locations in the world containing rock formations that are intact enough to preserve evidence of early life: the Kaapvaal Craton in Southern Africa and the Pilbara Craton in Western Australia.

The Dresser Formation, located in the Pilbara Craton, contains samples of sedimentary rock from the Paleoarchean Era. Inside the rocks, there are microbial mats containing the oldest ascertained life form, fossilized bacteria formed 3.48 BYA. The Strelley Pool Chert, also located in the Pilbara Craton, contains stromatolites that may have been created by bacteria 3.4 BYA or may be abiogenic formed through evaporitic precipitation then deposited on the sea floor.

The Barberton Greenstone Belt, located in the Kaapvaal Craton, also contains evidence of life. It was created 3.26 BYA when a large asteroid, about 37 to 58 kilometers wide, collided with the Earth. The Buck Reef chert and the Josefsdal chert, two rock formations in the Barberton Greenstone Belt, both contain microbial mats with fossilized bacteria from the Paleoarchean era.

Similarities between the Barberton Greenstone Belt in the Kaapvaal Craton and the eastern part of the Pilbara Craton indicate that the two formations were once joined as part of the supercontinent Vaalbara, one of Earth's earliest supercontinents. Both cratons formed at the beginning of the Paleoarchean era. While some paleomagnetic data suggests that they were connected during the Paleoarchean era, it is possible that Vaalbara did not form until the Mesoarchean or Neoarchean eras.

It is also unclear whether there was any exposed land during the Paleoarchean era. Although several Paleoarchean formations such as the Dresser Formation, the Josefsdal Chert, and the Mendon Formation show some evidence of being above the surface, over 90 percent of Archean continental crust has been destroyed, making the existence of exposed land practically impossible to confirm or deny. It is likely that during the Paleoarchean era, there was a large amount of continental crust, but it was still underwater and would not emerge until later in the Archean era. Hotspot islands may have been the only exposed land at the time.

## Mesoarchean era 3.2 BYA to 2.8 BYA plates subduct and atmosphere warms

The Mesoarchean is a geologic era in the Archean Eon, spanning 3,200 to 2,800 million years ago, which contains the first evidence of modern-style plate subduction and expansion of microbial life. The era is defined chronometrically and is not referenced to a specific level in a rock section on Earth.

The Mesoarchean era is thought to be the birthplace of modern-style plate subduction, based on geologic evidence from the Pilbara craton in western Australia. A convergent margin with a modern-style oceanic arc existed at the boundary between West and East Pilbara approximately 3.12 BYA. By 2.97 BYA, the West Pilbara Terrane converged with and accreted onto the East Pilbara Terrane. A supercontinent, Vaalbara, may have existed in the Mesoarchean.

Analysis of oxygen isotopes in Mesoarchean cherts has been helpful in reconstructing Mesoarchean surface temperatures. These cherts led researchers to draw an estimate of an oceanic temperature around 55-85°C while other studies of weathering rates postulate average temperatures below 50°C.

The Mesoarchean atmosphere contained high levels of atmospheric methane and carbon dioxide, which could be an explanation for the high temperatures during this era. Atmospheric dinitrogen content in the Mesoarchean is thought to have been similar to today, suggesting that nitrogen did not play an integral role in the thermal budget of ancient Earth.

The Pongola glaciation occurred around 2.9 BYA, triggered by the evolution of atmospheric photosynthesis.

Microbial life with diverse metabolisms expanded during the Mesoarchean era and produced gases that influenced early Earth's atmospheric composition. Cyanobacteria produced oxygen gas, but oxygen did not begin to accumulate in the atmosphere until later in the Archean.

## Neoarchean era 2.8 BYA to 2.5 BYA supercontinents, atmosphere, and complex life evolve

The Neoarchean is the last geologic era in the Archean eon and is defined chronometrically and not referencing a specific level in a rock section on Earth. The era is marked by major developments in complex life and continental formation.

This era saw the rise of oxygen in the atmosphere after oxygenic photosynthesis evolved as early as the Mesoarchean era. The environmental changes that occurred in the Neoarchean such as its developing atmospheric and soil compositions drastically differentiated the era from others in its encouragement of microbial metabolisms to evolve and diversify. The era could have also seen pre-biotic organic molecules being brought to Earth through meteorites, comets, or through abiotic reactions. The growth of juvenile continental crust as well as the onset of plate tectonics in the Archean allowed for the colonization of a larger variety of niches by microorganisms through increasing the number of rock types present and thereby increasing the surface's chemical diversity. Some noted metabolisms were able to flourish due to changes in the availability of certain metals while others faced famine: an increase in copper present in the environment in the Neoarchean likely favored aerobic metabolisms.

Oxygenic photosynthesis may have been limited earlier in the Archean era from a lack of phosphorus stemming from poor biological recycling in anaerobic conditions. This issue was alleviated in the Neoarchean with the abundance of phosphorus in magmatic rocks, which when combined with other evolving geodynamics such as increasing organic matter burial and higher oxidative states in volcanic sulfur and magmatic iron contributed to a large buildup of oxygen in the atmosphere, leading to the Great Oxidation Event in the Paleoproterozoic era.

During this era, the supercontinent Kenorland is proposed to have formed about 2.7 BYA. Kenorland is of particular interest due to it containing deposits of volcanic-hosted massive sulfide (VHMS), gold, and uranium found in the Canadian shield. With new research, the validity of Kenorland has been questioned in favor of other Neoarchean supercontinent proposals Superia or Vaalbara. Improved geologic knowledge suggests that a part of Kenorland, specifically the Churchill Province, was instead a continental development that formed after the Neoarchean era, Nuna, closer to 1.9 BYA. This challenge to the reconstruction is based on research studying northern Kenorland's Paleoproterozoic cover as well as the suture between the Rae and Hearne cratons.

The supercontinent cycle can be studied through patterns that describe how Earth's crust and its mineral deposits were preserved over time since Pangaea. Plate tectonics, having developed earlier in the Archean eon, produced the force necessary for metamorphism and magmatic activity which greatly contributed to these continental changes. Research on how the supercontinents broke apart and combined into different configurations is involved in linking together deep-interior and surface-level processes as well as the assessment of contrasting models of early Paleoproterozoic geodynamic activity.

# ***Proterozoic Eon saw the endosymbiosis of five kingdoms of eukaryotes 2.5 BYA – 541 MYA***

## oxygenic photosynthesis, endosymbiosis, Eukaryotes, multicellularity, kingdoms

The Proterozoic spans the time from the appearance of oxygen in Earth's atmosphere to just before the proliferation of complex life (such as trilobites or corals) on the Earth. The name Proterozoic combines the two forms of ultimately Greek origin: protero- meaning 'former, earlier', and - zoic, 'of life'. The Proterozoic Eon extended from 2.5 BYA to 541 MYA, and is the most recent part of the Precambrian "supereon". The Proterozoic is the longest eon of the Earth's geologic time scale and it is subdivided into three geologic eras (from oldest to youngest): the Paleoproterozoic, Mesoproterozoic, and Neoproterozoic.

The well-identified events of this eon were the transition to an oxygenated atmosphere during the Paleoproterozoic; several glaciations, which produced the hypothesized Snowball Earth during the Cryogenian Period in the late Neoproterozoic Era; and the Ediacaran Period (635 to 541 MYA) which is characterized by the evolution of abundant soft-bodied multicellular organisms and provides us with the first obvious fossil evidence of life on earth.

The geologic record of the Proterozoic Eon is more complete than that for the preceding Archean Eon. In contrast to the deep water deposits of the Archean, the Proterozoic features many strata that were laid down in extensive shallow epicontinental seas; furthermore, many of those rocks are less metamorphosed than there are Archean ones, and many are unaltered.

Studies of these rocks have shown that the eon continued the massive continental accretion that had begun late in the Archean Eon. The Proterozoic Eon also featured the first definitive supercontinent cycles and wholly modern mountain building activity (orogeny).

The first known glaciations occurred during the Proterozoic. The first began shortly after the beginning of the Proterozoic Eon, and evidence of at least four during the Neoproterozoic Era at the end of the Proterozoic Eon, possibly climaxing with the hypothesized Snowball Earth of the Sturtian and Marinoan glaciations.

One of the most important events of the Proterozoic was the accumulation of oxygen in the Earth's atmosphere. Though oxygen is believed to have been released by photosynthesis as far back as Archean Eon, it could not build up to any significant degree until mineral sinks of unoxidized sulfur and iron had been exhausted. Until roughly 2.3 billion years ago, oxygen was probably only 1% to 2% of its current level. The Banded iron formations, which provide most of the world's iron ore, are one mark of that mineral sink process. Their accumulation ceased after 1.9 billion years ago, after the iron in the oceans had all been oxidized.

Red beds, which are colored by hematite, indicate an increase in atmospheric oxygen 2 billion years ago. Such massive iron oxide formations are not found in older rocks. The oxygen buildup was probably due to two factors: exhaustion of the chemical sinks, and an increase in carbon burial, which sequestered organic compounds that would have otherwise been oxidized by the atmosphere.

The Proterozoic Eon was a very tectonically active period in the Earth's history. The late Archean Eon to Early Proterozoic Eon corresponds to a period of increasing crustal recycling, suggesting subduction. Evidence for this increased subduction activity comes from the abundance of old granites originating mostly after 2.6 GYA. The occurrence of eclogite (a type of metamorphic rock created by high pressure, > 1 GPa), is explained using a model that incorporates subduction. The lack of eclogites that date to the Archean Eon suggests that conditions at that time did not favor the formation of high grade metamorphism and therefore did not achieve the same levels of subduction as was occurring in the Proterozoic Eon. As a result of remelting of basaltic oceanic crust due to subduction, the cores of the first continents grew large enough to withstand the crustal recycling processes.

The long-term tectonic stability of those cratons is why we find continental crust ranging up to a few billion years in age. It is believed that 43% of modern continental crust was formed in the Proterozoic, 39% formed in the Archean, and only 18% in the Phanerozoic. Studies suggest that crust production happened episodically. By isotopically calculating the ages of Proterozoic granitoids it was determined that there were several episodes of rapid increase in continental crust production. The reason for these pulses is unknown, but they seemed to have decreased in magnitude after every period.

Evidence of collision and rifting between continents raises the question as to what exactly were the movements of the Archean cratons composing Proterozoic continents. Paleomagnetic and geochronological dating mechanisms have allowed the deciphering of Precambrian Supereon tectonics. It is known that tectonic processes of the Proterozoic Eon resemble greatly the evidence of tectonic activity, such as orogenic belts or ophiolite complexes, we see today.

Hence, most geologists would conclude that the Earth was active at that time. It is also commonly accepted that during the Precambrian, the Earth went through several supercontinent breakup and rebuilding cycles (Wilson cycle).

In the late Proterozoic (most recent), the dominant supercontinent was Rodinia (~1000–750 MYA). It consisted of a series of continents attached to a central craton that forms the core of the North American Continent called Laurentia. An example of an orogeny (mountain building processes) associated with the construction of Rodinia is the Grenville orogeny located in Eastern North America. Rodinia formed after the breakup of the supercontinent Columbia and prior to the assemblage of the supercontinent Gondwana (~500 MYA). The defining orogenic event associated with the formation of Gondwana was the collision of Africa, South America, Antarctica and Australia forming the Pan-African orogeny.

Columbia was dominant in the early-mid Proterozoic and not much is known about continental assemblages before then. There are a few plausible models that explain tectonics of the early Earth prior to the formation of Columbia, but the current most plausible hypothesis is that prior to Columbia, there were only a few independent cratons scattered around the Earth (not necessarily a supercontinent, like Rodinia or Columbia).

The first advanced single-celled, eukaryotes and multi-cellular life, preserved as the Francevillian biota, roughly coincides with the start of the accumulation of free oxygen. This may have been due to an increase in the oxidized nitrates that eukaryotes use, as opposed to cyanobacteria. It was also during the Proterozoic that the first symbiotic relationships between mitochondria (found in nearly all eukaryotes) and chloroplasts (found in plants and some protists only) and their hosts evolved.

The blossoming of eukaryotes such as acritarchs did not preclude the expansion of cyanobacteria; in fact, stromatolites reached their greatest abundance and diversity during the Proterozoic, peaking roughly 1.2 BYA.

The earliest fossils possessing features typical of fungi date to the Paleoproterozoic era, some 2.4 BYA; these multicellular benthic organisms had filamentous structures capable of anastomosis.

Classically, the boundary between the Proterozoic and the Phanerozoic eons was set at the base of the Cambrian Period when the first fossils of animals, including trilobites and archeocyathids, as well as the animal-like Caveasphaera, appeared. A number of fossil forms have been found in Proterozoic rocks, but the upper boundary of the Proterozoic has remained fixed at the base of the Cambrian, which is currently placed at 541 MYA.

## Paleoproterozoic era 2.5 BYA to 1.6 BYA photosynthesis frees oxygen from carbon dioxide

The Paleoproterozoic Era, spanning the time period from 2.5 to 1.6 BYA (2.5–1.6 BYA), is the first of the three eras of the Proterozoic Eon. The Paleoproterozoic is also the longest era of the Earth's geological history. It was during this era that the continents first stabilized. The Earth's rotational rate during this era resulted in 20-hour days about 1.8 billion years ago, implying a total of about 450 days per year.

Before the enormous increase in atmospheric oxygen, almost all existing lifeforms were anaerobic organisms, whose metabolism was based upon a form of cellular respiration that did not require oxygen. Free oxygen in large amounts is toxic to most anaerobic organisms. Consequently, the majority of the anaerobic lifeforms on Earth died when the atmospheric free oxygen levels soared in an extinction event called the Great Oxidation Event. The only lifeforms that survived were either those resistant to the oxidizing and poisonous effects of oxygen, or those sequestered in oxygen-free environments. The sudden increase of atmospheric free oxygen and the ensuing extinction of the vulnerable lifeforms is widely considered to be one of the first and most significant mass extinctions in the history of the Earth.

Many crown node eukaryotes (from which modern-day eukaryotic lineages evolved) have been approximately dated to around the time of the Paleoproterozoic era. Eukaryotes evolved somewhere in this era.

During this era, the earliest global-scale continent-continent collision belts developed. The associated continent and mountain building events are represented by the 2.1–2.0 BYA Trans-Amazonian and Eburnean orogens in South America and West Africa; the ~2.0 BYA Limpopo Belt in southern Africa; the 1.9–1.8 BYA Trans-Hudson, Penokean, Taltson–Thelon, Wopmay, Ungava and Torngat orogens in North America, the 1.9–1.8 BYA Nagssugtoqidian Orogen in Greenland; the 1.9–1.8 BYA Kola–Karelia, Svecofennian, Volhyn-Central Russian, and Pachelma orogens in Baltica (Eastern Europe); the 1.9–1.8 BYA Akitkan Orogen in Siberia; the 1.95 BYA Khondalite Belt and 1.85 BYA Trans-North China Orogen in North China.

These continental collision belts are interpreted as having resulted from one or more 2.0–1.8 BYA global-scale collision events that then led to the assembly of a Proterozoic supercontinent named Columbia or Nuna. Felsic volcanism in what is now northern Sweden led to the formation of the Kiruna and Arvidsjaur porphyries. The lithospheric mantle of Patagonia's oldest blocks formed.

Boring Billion

Suavjärvi crater – 2.4 billion years old

Francevillian biota - 2.1-billion-year-old macroscopic organisms

Vredefort crater – 2.0 billion years old

Sudbury Basin – 1.849 billion years old

Instead of being based on stratigraphy, most of these periods are defined chronometrically.

## Mesoproterozoic era 1.6 BYA to 1 BYA complex multicellular organisms invent sex

The Mesoproterozoic Era is a geologic era that occurred from 1.6 to 1.0 BYA. The Mesoproterozoic was the first period of Earth's history of which a fairly definitive geological record survives. Continents existed during the preceding era (the Paleoproterozoic), but little is known about them. The continental masses of the Mesoproterozoic were more or less the same ones that exist today. The major events of this era are the breakup of the Columbia supercontinent, the formation of the Rodinia supercontinent, and the evolution of sexual reproduction.

This era is marked by the further development of continental plates and plate tectonics. The first large-scale mountain building episode, the Grenville Orogeny, for which extensive evidence still survives, happened in this period. This era was the high point of the Stromatolites before they declined in the Neoproterozoic.

The era saw the development of sexual reproduction, which greatly increased the complexity of life to come. It was the start of development of communal living among organisms, the multicellular organisms.

It was an era of apparently critical, but still poorly understood, changes in the chemistry of the sea, the sediments of the earth, and the composition of the air. Oxygen levels had risen to perhaps 1% of today's levels at the beginning of the era and continued rising throughout the Era.

The era did see large quantities of organisms in at least some areas at some periods: The EIA/ARI Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States of June 2013 estimated around 194 trillion cubic feet of gas in place (ca. 44 trillion recoverable) and around 93 billion barrels of oil in place (ca. 4.7 billion recoverable) in the Lower Kyalla and Middle Velkerri formations alone of the Beetaloo Basin in Australia's Northern Territory.

The transition from Calymmian to Ectasian has no meaning beyond calendar time. The usual reason given for the use of a chronometric system is that there is insufficient biological activity or geochemical change to find useful markers. That is a position which is now a little uncertain and is going to become increasingly tenuous over the next few years. For example, there are a number of good potential markers in the rise and decline of "Christmas tree" stromatolites, in the ebb and flow of banded iron formations, the appearance of stable carbon-13 isotope (13C) excursions, and so on. These have real meaning for the geologist and paleontologist.

For that matter, they are not completely without biological markers. There has been considerable progress in studying and identifying fossil bacteria and Eukarya. The cyanobacterium Archaeoellipsoides is one relatively common form, apparently known from several species. It is probably related to the extant Anabaena and indicates the presence of significant free oxygen. Oxygen levels also had significant effects on ocean chemistry; continental weathering rates increased and provided sulfates and nitrates as nutrients. It would be remarkable if this didn't result in new populations of both bacterial and eukaryotic organisms. Since the presence of these cells would be tied directly to important geochemical events, they would make ideal organisms for biostratigraphy.

The time period from 1.78 BYA to 850 MYA is an unofficial period based on stratigraphy rather than chronometry named the Rodinian.

## Neoproterozoic era 1 BYA to 541 MYA complex hard shelled multicellular animals evolve

The Neoproterozoic Era is the unit of geologic time from 1.0 BYA to 541 MYA. It is the last era of the Precambrian Supereon and the Proterozoic Eon; it is subdivided into the Tonian, Cryogenian, and Ediacaran Periods. It is preceded by the Mesoproterozoic era and succeeded by the Paleozoic era of the Phanerozoic eon. The most severe glaciation known in the geologic record occurred during the Cryogenian, when ice sheets may have reached the equator and formed a "Snowball Earth".

The earliest fossils of complex multicellular life are found in the Ediacaran period. These organisms make up the Ediacaran biota, including the oldest definitive animals in the fossil record. The sum of the continental crust formed in the Pan-African orogeny and the Grenville orogeny makes the Neoproterozoic the period of Earth's history that has produced most continental crust.

At the onset of the Neoproterozoic the supercontinent Rodinia, which had assembled during the late Mesoproterozoic, straddled the equator. During the Tonian, rifting commenced which broke Rodinia into a number of individual land masses. Possibly as a consequence of the low-latitude position of most continents, several large-scale glacial events occurred during the Neoproterozoic Era including the Sturtian and Marinoan glaciations of the Cryogenian Period. These glaciations are believed to have been so severe that there were ice sheets at the equator—a state known as the "Snowball Earth".

Neoproterozoic time is subdivided into the Tonian (1 BYA – 720 MYA), Cryogenian (720–635 MYA) and Ediacaran (635–541 MYA) periods. In the regional timescale of Russia, the Tonian and Cryogenian correspond to the Late Riphean; the Ediacaran corresponds to the Early to middle Vendian. Russian geologists divide the Neoproterozoic of Siberia into the Mayanian (from 1000 to 850 MYA) followed by the Baikalian (from 850 to 650 MYA,loosely equivalent to the Cryogenian).

The idea of the Neoproterozoic Era was introduced in the 1960s. Nineteenth-century paleontologists set the start of multicellular life at the first appearance of hard-shelled arthropods called trilobites and archeocyathid sponges at the beginning of the Cambrian Period. In the early 20th century, paleontologists started finding fossils of multicellular animals that predated the Cambrian. A complex fauna was found in South West Africa in the 1920s but was inaccurately dated. Another fauna was found in South Australia in the 1940s, but it was not thoroughly examined until the late 1950s. Other possible early animal fossils were found in Russia, England, Canada, and elsewhere (see Ediacaran biota). Some were determined to be pseudo-fossils, but others were revealed to be members of rather complex biotas that remain poorly understood. At least 25 regions worldwide have yielded metazoan fossils older than the classical Precambrian–Cambrian boundary (which is currently dated at 541 MYA).

A few of the early animals appear possibly to be ancestors of modern animals. Most fall into ambiguous groups of frond-like organisms; discoids that might be holdfasts for stalked organisms ("medusoids"); mattress-like forms; small calcareous tubes; and armored animals of unknown provenance. These were most commonly known as Vendian biota until the formal naming of the Period, and are currently known as Ediacaran Period biota. Most were soft bodied. The relationships, if any, to modern forms are obscure. Some paleontologists relate many or most of these forms to modern animals. Others acknowledge a few possible or even likely relationships but feel that most of the Ediacaran forms are representatives of unknown animal types.

# ***Phanerozoic Eon began with the Cambrian explosion of animals 541 MYA - now***

## Paleozoic era 541 MYA to 250 MYA plants and insects radiate onto land

The Phanerozoic Eon is the current geologic eon in the geologic time scale, and the one during which abundant animal and plant life has existed. It covers 541 MYA to the present, and it began with the Cambrian Period when animals first developed hard shells preserved in the fossil record. The time before the Phanerozoic, called the Precambrian, is now divided into the Hadean, Archaean and Proterozoic eons.

The time span of the Phanerozoic starts with the sudden appearance of fossilized evidence of a number of animal phyla; the evolution of those phyla into diverse forms; the emergence and development of complex plants; the evolution of fish; the emergence of insects and tetrapods; and the development of modern fauna. Plant life on land appeared in the early Phanerozoic eon. During this time span, tectonic forces which move the continents had collected them into a single landmass known as Pangaea (the most recent supercontinent), which then separated into the current continental landmasses.

Its name derives from the Ancient Greek, meaning visible and life; since it was once believed that life began in the Cambrian, the first period of this eon. The Proterozoic-Phanerozoic boundary is at 541 MYA. The boundary was set at time of appearance of the first abundant animal (metazoan) fossils but several hundred groups (taxa) of metazoa of the earlier Proterozoic eon have been identified since the systematic study of those forms started.

The Phanerozoic is divided into three eras: the Paleozoic, Mesozoic, and Cenozoic, which are further subdivided into 12 periods. The Paleozoic features the evolution of fish, amphibians and reptiles. The Mesozoic features the evolution of lizards, crocodiles, snakes, turtles, mammals, and dinosaurs (including birds). The Cenozoic begins with the extinction of the non-avian dinosaurs, and feature evolution of great diversity in birds and mammals. Humans evolved at the end of the Cenozoic.

The Paleozoic is a time in Earth's history when complex life forms evolved, took their first breath of oxygen on dry land, and when the forerunners of all multicelular life on Earth began to diversify. There are six periods in the Paleozoic era: Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian. The Cambrian is the first period of the Paleozoic Era and ran from 541 to 485 MYA. The Cambrian sparked a rapid expansion in the diversity of animals, in an event known as the Cambrian explosion, during which the greatest number of animal body plans evolved in a single period in the history of Earth. Complex algae evolved, and the fauna was dominated by armored arthropods, such as trilobites. Almost all phyla of marine animals evolved in this period. During this time, the super-continent Pannotia began to break up, most of which later recombined into the super-continent Gondwana.

The Ordovician spans from 485 to 444 MYA. The Ordovician was a time in Earth's history in which many species still prevalent today evolved or diversified, such as primitive fish, cephalopods, and coral. This process is known as the Great Ordovician Biodiversification Event, or GOBE. Trilobites began to be replaced by articulate brachiopods, and crinoids also became an increasingly important part of the fauna.

The first arthropods crept ashore to colonize Gondwana, a continent empty of animal life. By the end of the Ordovician, Gondwana had moved from the equator to the South Pole, and Laurentia had collided with Baltica, closing the Iapetus Ocean. The glaciation of Gondwana resulted in a major drop in sea level, killing off all life that had established along its coast. Glaciation caused an icehouse Earth, leading to the Ordovician–Silurian extinction, during which 60% of marine invertebrates and 25% of families became extinct. Though one of the deadliest mass extinctions in earth's history, the O-S extinction did not cause profound ecological changes between the periods.

The Silurian spans from 444 to 419 MYA, which saw a warming from an icehouse Earth. This period saw the mass evolution of fish, as jawless fish became more numerous, and early jawed and freshwater fish appeared in the fossil record. Arthropods remained abundant, and some groups, such as eurypterids, became apex predators. Fully terrestrial life established itself on land, including early arachnids, fungi, and myriapods (many-legged arthropods). The evolution of vascular plants such as Cooksonia allowed plants to gain a foothold on land as well. These early terrestrial plants are the forerunners of all plant life on land. During this time, there were four continents: Gondwana (Africa, South America, Australia, Antarctica, India), Laurentia (North America with parts of Europe), Baltica (the rest of Europe), and Siberia (Northern Asia).

The Devonian spans from 419 to 359 MYA. Also informally known as the "Age of the Fish", the Devonian features a huge diversification in fish. Armored fish included jawless "agnathans", as well as jawed placoderms such as Dunkleosteus. The Devonian also saw a diversification of modern fish groups such as chondricthyans (sharks and kin), osteichthyans (ray-finned fish), and sarcopterygians (lobe-finned fish). One lineage of sarcopterygians evolved into the first four-limbed vertebrates, which would eventually become tetrapods. On land, plant groups diversified; the first trees and seeds evolved during this period. By the Middle Devonian, shrub-like forests of early plants existed: lycophytes, horsetails, ferns, and progymnosperm. This event also allowed the diversification of arthropod life as they took advantage of the new habitat. Near the end of the Devonian, 70% of all species became extinct in a sequence of mass extinction events, collectively known as the Late Devonian extinction.

The Carboniferous spans from 359 to 299 MYA. Tropical swamps dominated the Earth, and the large amounts of trees created much of the carbon that became coal deposits (hence the name Carboniferous). About 90% of all coal beds were deposited in the Carboniferous and Permian periods, which represent just 2% of the Earth's geologic history. The high oxygen levels caused by these swamps allowed massive arthropods, normally limited in size by their respiratory systems, to proliferate. Tetrapods diversified during the Carboniferous, and one lineage acquired an amniotic egg which could survive outside of the water. These tetrapods, the amniotes, included the first reptiles and synapsids (mammal relatives). Throughout the Carboniferous, there was a cooling pattern, which eventually led to the glaciation of Gondwana as much of it was situated around the south pole. This event was known as the Permo-Carboniferous glaciation and resulted in a major loss of area for coal forests, the Carboniferous rainforest collapse.

The Permian spans from 298 to 251 MYA and was the last period of the Paleozoic era. At its beginning, all continents came together to form the super-continent Pangaea, surrounded by one ocean called Panthalassa. The Earth was relatively dry compared to the Carboniferous, with harsh seasons, as the climate of the interior of Pangaea was not moderated by large bodies of water. Amniotes flourished and diversified in the new dry climate, particularly synapsids such as Dimetrodon, Edaphosaurus, and the ancestors of modern mammals. The first conifers evolved during this period, then dominated the terrestrial landscape. The Permian ended with at least one mass extinction, the Permian-Triassic mass extinction, an event sometimes known as "the Great Dying".

### This extinction was the largest in earth's history and led to the loss of 95% of all species of life.

## Mesozoic era 250 MYA to 66 MYA reptiles and dinosaurs rule Pangaea

The Mesozoic ranges from 252 to 66 MYA. Colloquially known as "the age of the dinosaurs", the Mesozoic features the appearance of many modern tetrapods, as reptiles ascend to ecological dominance over synapsids. There are three periods in the Mesozoic: Triassic, Jurassic, and Cretaceous.

The Triassic ranges from 252 to 201 MYA. The Triassic is a transitional time in Earth's history between the Permian Extinction and the lush Jurassic Period. It has three major epochs: Early Triassic, Middle Triassic. and Late Triassic.

The Early Triassic lasted between 252 million to 247 million years ago, and was a hot and arid epoch in the aftermath of the Permian Extinction. Many tetrapods during this epoch represented a disaster fauna, a group of animals with low diversity and cosmopolitanism (wide geographic ranges). Temnospondyli recovered and rediversified into large aquatic predators during the Triassic. Reptiles also diversified rapidly, with aquatic reptiles such as ichthyosaurs and sauropterygians proliferating in the seas. On land, the first true archosaurs appeared, including pseudosuchians (crocodile relatives) and avemetatarsalians (bird/dinosaur relatives).

The Middle Triassic spans from 247 million to 237 million years ago. The Middle Triassic featured the beginnings of the breakup of Pangaea as rifting commenced in north Pangaea. The northern part of the Tethys Ocean, the Paleotethys Ocean, had become a passive basin, but a spreading center was active in the southern part of the Tethys Ocean, the Neotethys Ocean. Phytoplankton, coral, crustaceans, and many other invertebrates recovered from the Permian extinction by the end of the Middle Triassic. Meanwhile, on land, reptiles continued to diversify, conifer forests flourished, as well as the first flies.

The Late Triassic spans from 237 million to 201 million years ago. Following the bloom of the Middle Triassic, the Late Triassic was warm and arid, with a strong monsoon climate and with most precipitation limited to coastal regions and high latitudes. The first true dinosaurs appeared early in the Late Triassic, and pterosaurs evolved a bit later. Other large reptilian competitors to the dinosaurs were wiped out by the Triassic–Jurassic extinction event, in which most archosaurs (excluding crocodylomorphs, pterosaurs, and dinosaurs), many synapsids, and almost all large amphibians became extinct, as well as 34% of marine life in the fourth mass extinction event. The cause of the extinction cause is debated, but likely resulted from eruptions of the CAMP large igneous province.

The Jurassic ranges from 201 million to 145 million years ago, and features three major epochs: Early Jurassic, Middle Jurassic, and Late Jurassic. The Early Jurassic Epoch spans from 201 million to 174 million years ago. The climate was much more humid than the Triassic, and as a result, the world was warm and partially tropical,[39][40] though possibly with short colder intervals. In the oceans, plesiosaurs, ichthyosaurs and ammonites dominated the seas. On land, dinosaurs and other reptiles dominated the land, with species such as Dilophosaurus at the apex. Crocodylomorphs evolved into aquatic forms, pushing the large amphibians to near extinction. True mammals were present during the Jurassic but remained small, with average body masses of less than 20 pounds until the end of the Cretaceous.

The Middle and Late Jurassic Epochs span from 174 million to 145 million years ago. Conifer savannahs made up a large portion of the world's forests. In the oceans, plesiosaurs were quite common, and ichthyosaurs were flourishing. The Late Jurassic Epoch spans from 163 million to 145 million years ago. The Late Jurassic featured a severe extinction of sauropods in northern continents, alongside many ichthyosaurs. However, the Jurassic-Cretaceous boundary did not strongly impact most forms of life.

The Cretaceous is the Phanerozoic's longest period, and the last period of the Mesozoic. It spans from 145 million to 66 million years ago, and is divided into two epochs: Early Cretaceous, and Late Cretaceous. The Early Cretaceous Epoch spans from 145 million to 100 million years ago. Dinosaurs continued to be abundant, with groups such as tyrannosauroids, avialans (birds), marginocephalians, and ornithopods seeing early glimpses of later success. Other tetrapods, such as stegosaurs and ichthyosaurs, declined significantly, and sauropods were restricted to southern continents. The Late Cretaceous Epoch spans from 100 million to 66 million years ago. The Late Cretaceous featured a cooling trend that would continue into the Cenozoic Era.

Eventually, the tropical climate was restricted to the equator and areas beyond the tropic lines featured more seasonal climates. Dinosaurs still thrived as new species such as Tyrannosaurus, Ankylosaurus, Triceratops and hadrosaurs dominated the food web. Whether or not pterosaurs went into a decline as birds radiated is debated; however, many families survived until the end of the Cretaceous, alongside new forms such as the gigantic Quetzalcoatlus. Mammals diversified despite their small sizes, with metatherians (marsupials and kin) and eutherians (placentals and kin) coming into their own. In the oceans, Mosasaurs diversified to fill the role of the now-extinct ichthyosaurs, alongside huge plesiosaurs such as Elasmosaurus. Also, the first flowering plants evolved. At the end of the Cretaceous, the Deccan Traps and other volcanic eruptions were poisoning the atmosphere. As this was continued, it is thought that a large meteor smashed into Earth, creating the Chicxulub Crater creating the event known as the K–Pg extinction, the fifth and most recent mass extinction event, during which 75% of life on Earth became extinct, including all non-avian dinosaurs. Every living thing with a body mass over 10 kilograms became extinct, and the age of the dinosaurs came to an end.

## Cenozoic era 66 MYA to today flowering plants fill many vacated ecological niches

The Cenozoic featured the rise of mammals as the dominant class of animals, as the end of the age of the dinosaurs left significant open niches. There are three divisions of the Cenozoic: Paleogene, Neogene and Quaternary. The Paleogene spans from the extinction of the non-avian dinosaurs, some 66 million years ago, to the dawn of the Neogene 23 million years ago. It features three epochs: Paleocene, Eocene and Oligocene.

The Paleocene Epoch began with the K–Pg extinction event, and the early part of the Paleocene saw the recovery of the Earth from that event. The continents began to take their modern shape, but many continents (and India) remained separated from each other: Africa and Eurasia were separated by the Tethys Sea, and the Americas were separated by the strait of Panama, as the Isthmus of Panama had not yet formed. This epoch featured a general warming trend, and the earliest modern jungles expanded, eventually reaching the poles. The oceans were dominated by sharks, as the large reptiles that had once ruled became extinct. Mammals diversified rapidly, but most remained small. The largest tetrapod carnivores during the Paleocene were reptiles, including crocodyliforms, choristoderans, and snakes. Titanoboa, the largest known snake, lived in South America during the Paleocene.

The Eocene Epoch ranged from 56 million to 34 million years ago. In the early Eocene, most land mammals were small and living in cramped jungles, much like the Paleocene. Among them were early primates, whales and horses along with many other early forms of mammals. The climate was warm and humid, with little temperature gradient from pole to pole.

In the Middle Eocene Epoch, the circum-Antarctic current between Australia and Antarctica formed, disrupting ocean currents worldwide, resulting in global cooling, and caused the jungles to shrink. More modern forms of mammals continued to diversify with the cooling climate even as more archaic forms died out. By the end of the Eocene, whales such as Basilosaurus had become fully aquatic.

The late Eocene Epoch saw the rebirth of seasons, which caused the expansion of savanna-like areas with the earliest substantial grasslands.[56][57] At the transition between the Eocene and Oligocene epochs there was a significant extinction event, the cause of which is debated.

The Oligocene Epoch spans from 34 million to 23 million years ago. The Oligocene was an important transitional period between the tropical world of the Eocene and more modern ecosystems. This period featured a global expansion of grass which had led to many new species to take advantage, including the first elephants, cats, dogs, marsupials and many other species still prevalent today. Many other species of plants evolved during this epoch also, such as the evergreen trees. The long term cooling continued and seasonal rains patterns established. Mammals continued to grow larger. Paraceratherium, one of the largest land mammal to ever live, evolved during this epoch, along with many other perissodactyls.

The Neogene spans from 23.03 million to 2.58 million years ago. It features two epochs: the Miocene and the Pliocene. The Miocene spans from 23.03 million to 5.333 million years ago and is a period in which grass spread further across, effectively dominating a large portion of the world, diminishing forests in the process. Kelp forests evolved, leading to the evolution of new species, such as sea otters. During this time, perissodactyls thrived, and evolved into many different varieties. Alongside them were the apes, which evolved into 30 species.

Overall, arid and mountainous land dominated most of the world, as did grazers. The Tethys Sea finally closed with the creation of the Arabian Peninsula and in its wake left the Black, Red, Mediterranean and Caspian Seas. This only increased aridity. Many new plants evolved, and 95% of modern seed plants evolved in the mid-Miocene.

The Pliocene lasted from 5.333 million to 2.58 million years ago. The Pliocene featured dramatic climactic changes, which ultimately led to modern species and plants. The Mediterranean Sea dried up for several thousand years in the Messinian salinity crisis.

Along with these major geological events, Africa saw the appearance of Australopithecus, the ancestor of Homo. The isthmus of Panama formed, and animals migrated between North and South America, wreaking havoc on the local ecology. Climatic changes brought savannas that are still continuing to spread across the world, Indian monsoons, deserts in East Asia, and the beginnings of the Sahara desert. The Earth's continents and seas moved into their present shapes. The world map has not changed much since, save for changes brought about by the glaciations of the Quaternary, such as the Great Lakes.

The Quaternary spans from 2.58 million years ago to present day, and is the shortest geological period in the Phanerozoic Eon. It features modern animals, and dramatic changes in the climate. It is divided into two epochs: the Pleistocene and the Holocene.

## Cenozoic era mammals and birds fill many vacated ecological niches

The Pleistocene lasted from 2.58 million to 11,700 years ago. This epoch was marked by a series of glacial periods (ice ages) as a result of the cooling trend that started in the Mid-Eocene. There were numerous separate glaciation periods marked by the advance of ice caps as far south as 40 degrees N latitude in mountainous areas.

Meanwhile, Africa experienced a trend of desiccation which resulted in the creation of the Sahara, Namib, and Kalahari deserts. Mammoths, giant ground sloths, dire wolves, sabertoothed cats, and humans were common and widespread during the Pleistocene.

As the Pleistocene drew to a close, a major extinction wiped out much of the world's megafauna, including non-Homo sapiens human species such as Homo neanderthalensis. All the continents were affected, but Africa was impacted to a lesser extent. That continent retained many large animals, such as elephants, rhinos, and hippos. The extent to which Homo Sapiens were involved in this extinction is debated.

The Holocene began 11,700 years ago and lasts until the present day. All recorded history and "Human history" lies within the boundaries of the Holocene epoch. Human activity is blamed for an ongoing mass extinction that began roughly 10,000 years ago, though the species becoming extinct have only been recorded since the Industrial Revolution. This is sometimes referred to as the "Sixth Extinction". Hundreds of species have become extinct due to human activity since the Industrial Revolution.

It has been demonstrated that changes in biodiversity through the Phanerozoic correlate much better with the hyperbolic model (widely used in demography and macrosociology) than with exponential and logistic models (traditionally used in population biology and extensively applied to fossil biodiversity as well). The latter models imply that changes in diversity are guided by a first-order positive feedback (more ancestors, more descendants) or a negative feedback that arises from resource limitation, or both.

The hyperbolic model implies a second-order positive feedback. The hyperbolic pattern of the human population growth arises from quadratic positive feedback, caused by the interaction of the population size and the rate of technological growth. The character of biodiversity growth in the Phanerozoic Eon can be similarly accounted for by a feedback between the diversity and community structure complexity. It is suggested that the similarity between the curves of biodiversity and human population probably comes from the fact that both are derived from the superposition on the hyperbolic trend of cyclical and random dynamics.

# ***additional information***

<https://evolution.calpoly.edu/eras>