

# A Collection of Curricula for the STARLAB® Geologic Time Cylinder



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## Introduction:

The Earth is old. Some stars that rage today were not even clouds of gas when it was born. The Earth has seen the rise and fall of planets and of galaxies. Its history is a long one, stretching back over a time so long that years are almost meaningless. As far as we know, it is the only world capable of supporting complex life, or indeed any kind of life at all. With the discover of hundreds of exoplanets, this may not always be the case. The possibility of extra-terrestrial life, even just bacteria, is one of the greatest concepts in all of science.

By studying the effects of radioactive decay, there is a general consensus among scientists that the Earth is approximately 4.6 billion years old. This makes it not much younger than the sun itself. Some asteroids are older; Mars is almost certainly older, although Venus might not be. Since dealing with billions of years at a time is cumbersome, geologists have invented a scale which is easier for a human mind to visualize. Scientists break down time as follows:

- Supereon: this is the largest unit of geologic time. The only supereon is the Precambrian, which stretches roughly 4 billion years. Most of earth's history falls into this group. However, as you shall see, most interesting events in the time line of life occur later.

- Eon: there are 4 of these. Each is half a billion years or more in duration.
- Eras measure several hundred million years. There are 12 in total.
- Period: no defined length or number.
- Epoch: tens of millions of years.
- Age: millions of years.

Smaller units than these exist, such as a millennium, or one thousand year period. However, these units are too small to define any meaningful length of geologic time. The planet is capable of vast changes, but these changes occur over many years. Usually, smaller units of time are applied to human history where changes occur more rapidly.

Human civilization exists wholly within the Holocene epoch of the Quaternary period. This period began about 12,000 years ago. Civilization itself is probably only 10,000 years old. However, humanity stretches back over two million years.

There are various sub-divisions which can exist within any one unit. For example, the terms early, mid, and late are often used. These terms are capitalized when a formal division is recognized. For example, "Mid-Jurassic" is an officially recognized time period. It is also the time period when Dinosaurs flourished. Due to the enormous amounts of study concerning the Dinosaurs, it helps to have more finely divided time periods. Other times, such as the Pre-Cambrian, are spread out enough where an official breakdown is not necessary.

Please note: all dates are as accurate as possible, but still approximate. GYA means billion years ago, MYA a million years ago, and KYA a thousand years ago.

## In the Beginning

Earth is believed to have formed about 4.6 Billion years ago. After the sun coalesced into a full fledged star, it spun a huge disc of dust and debris around itself. As the massive disc spun, parts were mixed together. Some of this material clumped together and formed the planets. The interior planets, Mercury, Venus, Earth, and Mars, are all made of rocks. The outer planets are composed primarily of gases. Some of this material was left over to form the asteroid belt, Kuiper belt, and Oort cloud. Other material escaped into interstellar space.

Due to the enormous pressures generated by gravity, the early Earth was red hot. In fact, it was too hot for rocks to exist! Some Australian zircons are 4.4 billion years old; these are the oldest rocks found to date. Some of this heat is still present in the core, which is constantly refreshed by the decay of radioactive elements. Without radioactive decay, our core would have cooled by now. This fate befell Mars. The hot mantle and core drives the rock cycle and tectonic movement, which has reshaped the surface of our world many times. This process has also greatly influenced life, by changing climates, seas, and areas suitable for life to take root.

The moon formed shortly after the creation of Earth. The best hypothesis is that a massive proto-planet struck the Earth, knocking some material loose. Some of this material escaped into space, but the rest coalesced and formed the moon. It is believed the moon formed much closer to Earth and has been drifting away. Tidal influences from the moon may have been instrumental in helping life form. This impact hypothesis also postulates that the earth was much smaller in the beginning than it is now, and this impact added greatly to the mass of the earth. In addition, this impact occurred after the Earth began to differentiate, meaning that the ejected material was low in Iron. This helps explain the relatively low density of the moon.

## Hadean Eon, 4.6-3.8 GYA

During the Hadean, the crust begins to form and differentiate.

Heavy elements, like iridium, iron, and uranium, sink down towards the core. Silicon, Aluminum, and oxygen make up most of the crust. The massive iron core spins, producing a strong magnetic field that shields the Earth from the worst of the sun's radiation. Gasses escaped and began to form an atmosphere. This early atmosphere was likely composed of methane, ammonia, hydrogen, and nitrogen.

Comet during LHB



Although this atmosphere would not support life today, it contained many useful elements for building life. At that time, the Sun's energy output was about 70% of what it is today. These gasses would have helped retain solar heat, keeping the Earth warm.

The Late Heavy Bombardment (see above) occurs during this time period. A massive swarm of comets attacks the solar system, producing impacts on the moon and inner planets. It is believed that the water for our oceans came from these cometary impacts. Volcanic activity alone is not enough to produce this much water. It is likely that the initial water vaporized, and was held in the atmosphere until the crust had cooled sufficiently to support liquid water. Rain fell, and began to fill the oceans. Imagine a rainstorm lasting a million years, that could fill the oceans with water! Salt from rocks was dissolved by this new water, and made the newborn oceans salty. Water vapor became prevalent in the atmosphere, helping to hold in solar heat, which kept the oceans liquid. These new oceans would be critical for the formation of life.

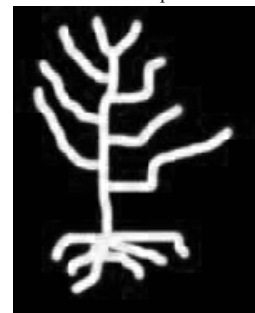
Life probably formed during this period, as early as 3.8 GYA (Billion years ago). A combination of atmospheric elements and molecules from comets formed the building blocks. The exact origin of life is unknown and remains one of the great questions of science. The first life forms were likely primitive prokaryotes. It is possible that viruses and primitive RNA based life forms may have developed first. However, at the writing of this guide, it is generally accepted that prokaryotes were first.

## Archean Eon, 3.8-2.5 GYA

The Archaean eon existed from 3.8 to 2.5 billion years ago. During this period, the Earth was still very hot, resulting in extremely energetic tectonic activity. The continents were made and recycled many times. The Earth's magnetic field protected our fledgling atmosphere from the solar wind, which was much more powerful in those days. Without it, our atmosphere would have been stripped away, and fledgling life forms would have perished by intense radiation poisoning. Even with a protective magnetic shield, ultraviolet light bathes the surface. Primitive life forms are forced to hide underwater to protect themselves. The land is barren, and constantly reshaped by volcanoes.

Life continues to develop. Photosynthesis is evolved; the oxygen liberated initially bonds with iron to create iron oxides. Later, oxygen will build up in the atmosphere, with disastrous results. Photosynthesis replaces

Primitive, single celled algae are the first plants



an older process known as chemosynthesis. The earliest life forms likely fed on chemicals directly, using them for energy. This process works, and is still used by some bacteria today. However, it is inefficient and limits the development of such creatures. Photosynthesis produces far more energy, allowing these bacteria to multiply quickly. Using sunlight, water, and carbon dioxide, these creatures are able to make their own food, and diversify rapidly. However, oxygen is a by-product of photosynthesis, and is toxic to them. It is released as a waste product.

The Last Universal Common Ancestor, or LUCA, exists during the Archean Eon. This organism is the primordial life form, from which all others are descended. Every life form on Earth today is related to this initial bacteria. LUCA may be an individual, or a group of bacteria that shared genes. In either case, it is one of the defining moments in evolution. This particular organism was so successful that its offspring eventually covered the entire globe. You and I are its children.

Prokaryotes and Archea bacteria diverge at this time. Archea are a domain of life that was discovered only recently. In general, they seem to thrive in hostile environments bereft of other life forms. They are quite primitive, and do not share as many genes with other animals as most bacteria. This indicates that the lineage is quite old. Photosynthetic cyanobacteria also develop.

Roughly one billion years after the invention of photosynthesis, the Great Oxygenation Event occurs. Oxygen was a poison to early bacteria, and was released as a waste product. Initially, this oxygen bound to loose iron. When that supply was exhausted, it began to build up in the atmosphere. The Earth was developing an atmosphere of pure poison! Some scientists estimate as much as 99.9% of all life on Earth perished. Some survived by hiding from the oxygen; bacteria in the bottom of lakes are essentially unchanged from early forms. Others were able to use oxygen to produce energy. Instead of photosynthesis, new bacteria emerged that fed on each other. Using oxygen and nutrients consumed from other organisms, they are able to produce enough energy to spread rapidly.

## Proterozoic Eon, 2,500-540 MYA

Eukaryotic cells, like the kind that make up humans, appear during this eon. They are able to use the abundant oxygen in the atmosphere to help them produce energy, giving them a huge evolutionary advantage. Some of these early cells combine to form the first multi-cellular creatures. Sexual reproduction also develops, allowing for massive evolutionary advancements. These cells diversify rapidly, and soon begin to crowd out the earlier prokaryotes. Prokaryotes have not 'lost' in any sense of the term; they are still very abundant today. However, there are no known instances of multi-cellular prokaryotic life. They have remained as bacteria.

In addition, the symbiotic relationship of mitochondria and chloroplasts with cells occurs, allowing for the development of plants and animals. These are cellular organelles that seem to have their own DNA. One hypothesis is that they were initially simple bacteria which were absorbed into the new cells. In exchange for protection and nutrients, they helped produce energy. These structures allow plant and animal cells to produce the massive energy required for multi-cellular life.

The Cambrian Explosion occurs. This is one of the most mysterious events in the Earth's history. Within a few tens of millions of years, nearly every phyla around today and several that aren't appeared. This occurred seemingly out of nowhere. In other words, after billions of years of primitive bacteria, the Earth developed a diversity of life that rivals today's. How is this possible? It remains one of the great unanswered questions. The first animals developed during this time, like worms. These primitive animals preyed on bacteria colonies, and later, began to eat each other. This promoted a massive global 'arms race', which likely spurred the incredible diversification that occurred during this time. However, at this point in Earth's history, animals remained relatively primitive. In fact, half a billion years ago the pinnacle of evolution was the worm! Imagine what life will be like a billion years hence.

Oxygen in the atmosphere combines to form ozone, which shields against ultraviolet light. This paves the way for colonization of land. Previously, the Earth had been bathed in ultraviolet light, which forced early organisms to hide in water to protect themselves. Ultraviolet light is especially dangerous to bacteria, who lack shells to protect themselves. Even today, UV light makes a powerful disinfectant. With the development of ozone, the early land was sheltered from this radiation, allowing organisms to start leaving the sea.

Primitive fungi develop. The super continent Rodinia breaks up.

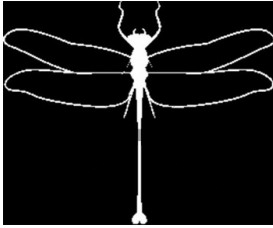
Trilobites are arguably the most famous example of Cambrian life.



## Paleozoic Era, 540-250 MYA

Roughly 450 MYA, plants move out of the seas on to land. They are accompanied by fungi, who may have aided them. This era is sometimes called the age of swamps. Primitive plants quickly spread over the land, covering it with a blanket of decaying organic material. This material later became coal. Some areas were uplifted out of the reach of the sea, like the Appalachian mountains. This means that the coal was never washed away. This is the reason that coal mines are so prevalent in the Appalachian region of North America. In the absence of animal life on land, plants reach their zenith.

Insects begin to develop, but it will be many years before they reach current diversity.



Most of the major landmasses form by this time. The supercontinent Gondwanaland formed, and later joined with other landmasses to form the larger supercontinent Pangea.

Major diversification of marine life forms continues. Trilobites, molluscs, starfish, and chordates develop. Many of these types of creatures are around today. Some, like trilobites and ammonites, flourished for hundreds of millions of years before going extinct. Fishlike invertebrates form.

The first true vertebrates, in the form of jawless fishes, evolve during this era. Lobe Finned Fish develop lungs and crawl onto land. They will develop into tetrapods, which all terrestrial vertebrates are descended from. Amphibians evolve and attain dominance of the land. Later, reptiles, which are less dependent on water, will largely supplant them. Some of these reptiles will survive extinction to become Dinosaurs. Arthropods take to land, eventually becoming insects and arachnids.

The Permian-Triassic extinction event occurs. The exact causes of this extinction are unknown. Up to 96% of marine life and 70% of terrestrial life perished. It took the Earth up to 30 million years to recover its biodiversity. Some probable causes for the event are impact, massive volcanic activity, or a huge release of methane from the sea floor that raised global temperatures. With the possible exception of the GOE (see above), it was the most devastating of all extinctions.

## Mesozoic Era, or “Age of Dinosaurs” 250-65 MYA

The Mesozoic was a golden age of life on earth. This era would see an explosion of insect diversity, the development of dinosaurs, huge increases in marine diversity, the evolution of mammals, the origin of birds, and a massive extinction event.



Triceratops, an impressive specimen of Cretaceous life



The Mesozoic era is divided into three periods: the Triassic, Jurassic, and Cretaceous.

The **Triassic period** saw the recovery of life from the devastation of the Permian extinction. Cycads and ginkoes survive the extinction and continue to flourish. Conifers and other seed bearing plants begin to take root as well. Plants survive the extinction much better than animals, and recover much sooner.

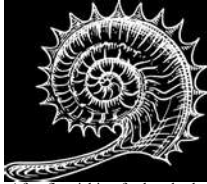
In the oceans, corals spread, and remain little changed even to the present day. Fish fared very badly during the extinction, with very few families surviving. It would be many years until they recovered in diversity. The absence of fish left opportunities for marine reptiles, which became quite diverse.

On land, amphibians fare well, and the first frogs develop. These continue to thrive today. The first mammals develop, as do the first dinosaurs. At the end of the Triassic, an extinction event occurs, which devastates marine life. It is possible that the dinosaurs adapt to this event quicker, thus placing them ahead of mammals for a long time.

The **Jurassic period** marks the middle period of the Mesozoic era. Dinosaurs continue to flourish, diversify, and evolve. The climate is warm and there are no extinctions. This supports very large animals, like Allosaurus and Stegosaurus. The supercontinent Pangea begins to break apart, into Laurasia and Gondwana. Archaeopteryx, a forerunner of birds, evolves. Birds are a direct descendent of dinosaurs, and are the only remnant of that lineage left. If birds are included, dinosaurs can be considered the most successful vertebrates to have ever lived! Their lineage stretches 225 million years, a feat unrivaled by any other group.

The **Cretaceous Period** is the golden age of the dinosaurs. The climate is very warm, even in polar regions. Dinosaur fossils have been found within 15 degrees of the south pole at that time, indicating that global temperatures must have been much higher than they are now.

Incredible vegetation increased the oxygen content of the atmosphere to perhaps as high as 33%. The warmth and high oxygen allowed truly spectacular creatures to develop. Sauropods, like the massive Apatosaurus, reached a hundred feet in length and rivaled whales in weight. Giant herds of triceratops roamed, each animal as large as a family of rhinoceroses. The mighty Tyrannosaurs grew to enormous size and strength in order to prey on these animals. Dinosaurs now dominated the land, the sea, and the skies. Mammals were



After flourishing for hundreds of millions of years, ammonites, and other invertebrates, were utterly annihilated

relegated to the corners of the world. Flowering plants developed, leading to a huge increase in insect diversity.

The dream is shattered in an instant. The K-T extinction event kills roughly half of all species. All terrestrial dinosaurs perish during this time. Most scientists now agree that a massive impact, in this case the Chicxulub event, caused widespread climate change. Dinosaurs were heavily specialized at that time, and could not adapt quickly enough to survive. By contrast, mammals and birds were less dominant and thus less specialized; instead, they eked out an existence using any food source possible. This allowed them to adapt to varying food sources, and warm-bloodedness helped them cope with a sudden decrease in global temperatures. Amongst marine animals, crocodiles, fish, and amphibians were relatively unscathed. However, marine dinosaurs and some invertebrates, such as ammonites, were devastated.

Please see a more concise time line below:

Around 225 MYA, the first dinosaurs develop. They will flourish for 140 million years.

220 MYA: Forests begin to cover the land. Dinosaurs grow to huge sizes in the great abundance of food. Predatory dinosaurs grow proportionally, leading to a massive global 'arms race'.

215 MYA: Primitive mammals develop. However, it will be many millions of years before they attain dominance. Probably, mammals remained small and eked out a living in the shadow of the dinosaurs, and only reached prominence after their demise.

180 MYA: the super-continent Pangea begins to break apart.

170 MYA: Amphibians diversify. Salamanders and newts appear.

155 MYA: Archaeopteryx develops. This curious creature contains many features of both theropod dinosaurs and birds. It is now widely accepted that birds evolved from dinosaurs. Archaeopteryx may be a true transitional fossil, or simply an example of a group of creatures that developed into birds. In either case, the creature remains an immensely important addition to the fossil record. Its discovery in 1861 helped bolster Charles Darwin's theory, which was published only two years before. Archaeopteryx makes a great word for a spelling bee as well.

130 MYA: Angiosperms, or flowering plants, develop. These

highly specialized and successful plants quickly spread throughout the planet, and help animals diversify through coevolution. Bees evolve not long after.

110 MYA: The first true birds develop. Snakes develop about 10 million years later.

80 MYA: Some wasps take to ground and never leave it. They will become the first ants, arguably the most successful animals ever to live.

65 MYA: The K-T extinction event kills roughly half of all species. This marks an end of the age of reptiles, and the beginning of dominance by mammals.

## Cenozoic Era:

The Cenozoic era is marked by dominance of conifers at high latitudes as the continents drifted away from the equator. Mammals continue their inexorable rise, eventually covering nearly the entire globe. Ants continue to specialize and become enormously successful. Primates will develop and evolve. Towards the end of the era, man will develop. However, that is a story for another class.

During this period, huge ecological niches are left by the extinction of dinosaurs, with mammals and birds racing to fill them. Mammals will attain huge sizes during this period, but nothing like the largest dinosaurs. Grass also evolves, creating savannahs and supporting huge herds of large mammals. Flightless birds are common, but flighted birds are catching up. Flowering plants continue to spread, and uncountable numbers of insects compete to feed off of them. Rodents develop, and snakes diversify in order to become better predators. Changes in ocean currents bring deep, cold polar waters to the surface, resulting in global cooling. This triggers several ice ages during the Pleistocene epoch. In fact, we are currently living in an interglacial period.

60 MYA: flightless birds diversify. The first true primates also develop.

55 MYA: birds continue to diversify, especially flighted birds.

55 MYA: some terrestrial creatures begin to become semi-aquatic. Eventually, they will evolve to become cetaceans. The largest of these become the greatest animals ever to live, with the possible exception of some controversial dinosaur finds.



Whales evolve from land animals

50 MYA: Massive diversification of large mammals, especially primates. Bats appear.

35 MYA: Grasses evolve. These will eventually cover one quarter of the earth's land area, and allow vast numbers of large mammals to be supported. The great herds of the world are only possible due to this event. The Beast of Baluchistan, the largest terrestrial mammal ever to live, developed during this time.



The first rung on the ladder of science

6.5 MYA: First known hominin.

2 MYA: first examples of the genus *homo*.

350 KYA: Neanderthals appear.

200 KYA: modern humans appear in Africa. They will spread, eventually colonizing every continent on the globe.

30 KYA: extinction of Neanderthals.

10 KYA: the Holocene epoch begins. Civilization is born.

35 YA: Starlab is founded.

## Activity 1:

Visualizing vast stretches of time, even with a STARLAB, is hard for most of your students. Trying to convert years to distances is one way of mitigating this difficulty. There are several ways to do this:

- Tell your students to imagine that one foot equals one million years of time. Draw a two foot mark on the blackboard, and explain that all of humanity can be contained within that mark. Using this scale, the entire history of Earth would take 4,600 feet, or 87% of a mile! If possible, take your science class on a nature walk that covers this distance.

- Compress time further. Have 1 foot represent 10 million years. By this scale, human evolution can be represented by 1/5 of a foot, or 2.4 inches. Draw this line on the blackboard. Cut some paper to this length, and give each student or group a piece. Next, take your class out to the athletic field and mark out 460 feet. Have your students walk this distance, with their paper in hand. Have them compare the length of the paper, which again represents all of human evolution.

- Compress time even further. Pass out rulers, and have your

class familiarize themselves with 1/4 inch. Mark a 46 foot line in the corridor. Tell your students that one foot equals 100 million years, and a quarter inch represents all of human evolution. Have your students walk the line a few times, and compare to a quarter inch in size. This should give them an inkling of the immense scale of Earth's History.

## Review Questions:

1. About how many years does Earth's history encompass? How long is human history?
2. True or false: dinosaurs existed for most of Earth's history.
3. What is the longest measurement of geologic time called? How many examples are there?
4. True or false: animals today are descended from many types of creatures. Explain your answer.
5. When did mammals evolve? Did they become dominant quickly?
6. How did the Earth form? Did the moon form at the same time? Explain your answer.
7. True or false: animals developed gradually over hundreds of millions of years.
8. Were the earliest humans around at the same time as the dinosaurs? Explain why or why not.

- 9.** Was Pangea the first and only supercontinent?
- 10.** Why do you think the K-T Extinction was beneficial for mammals?
- 11.** Considering life as a whole, was the extinction caused by the Great Oxygenation Event beneficial or not?
- 12.** True or false: bacteria are more or less unchanged since the beginning? Explain your answer.
- 13.** Has Earth's climate been mostly stable over the eons, or does it fluctuate? Provide examples.
- 14.** Agree or disagree with this statement: insects are a relatively new group of animals. Back up your answer.
- 15.** Write an essay describing, in general terms, the rise of life on earth.